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ABSTRACT BOOK



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Oral Presentation Abstracts

Friday, October 4th

Session I Valuation and Value System

The construction of value: How subjective preferences for visual art are computed from elementary stimulus features.

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Humans are capable of exhibiting strongly varied preferences for visual stimuli whether art in a museum or pictures on social media. Understanding how such subjective preferences are computed in the first place remains an open question. Are subjective value judgments for art inscrutable, idiosyncratic and irreducible? Or can we develop a mechanistic understanding? Here, we suggest a computational mechanism of value construction whereby a visual stimulus is first deconstructed into low-level visual attributes such as color and contrasts, and higher-level cognitive attributes, such as concreteness and dynamics. These attributes are then combined together using specific weights in order to produce a final value judgement about the stimulus as a whole. We tested this hypothesis in three steps. First, we collected behavioral preference ratings about unfamiliar paintings and pictures (on-line (n=1936) and in-lab (n=7)). Consistent with our attribute-based theory, we found that a small and specific set of attributes can reliably predict subjective preferences for images across all participants even without tuning weights for each individual. Second, we tested if attribute-based computations can arise spontaneously in a neuron-like substrate. We trained a deep convolutional network on the behavioral preference data, without explicitly teaching the model about the attributes. The deep-network successfully predicted human subjective ratings, and various relevant attributes spontaneously emerged in the hidden layers in a distributed manner: low-level attributes (e.g. color) in earlier layers and high-level attributes (e.g. concreteness) in later layers. Finally, 6 participants were scanned with fMRI for 4 hours each while reporting their preferences for visual art. Preliminary findings suggest that subjective preference is represented in medial prefrontal cortex, while low- and high- level attributes are hierarchically encoded: low-level features in early visual cortex and high-level features in higher-order visual areas and prefrontal cortex. Connectivity analyses support the dynamic integration of these various attribute representations to compute an overall subjective value. Deep network representations were also differentially correlated with fMRI activity across cortical regions supporting similar organizational principles between the network model and the brain. Overall our findings support an attribute-based theory of subjective value computation whereby a complex object is reduced to elementary attributes and these attributes are then dynamically combined to produce an integrated value judgement.

A dynamic utility maximization model explains rats' willingness to work for water

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An animal must continually invest time and energy to obtain sufficient food and water, and to meet other immediate and long-term survival needs. Because time and energy are limited, considerable selection pressure would exist for animals to efficiently allocate their efforts, such that the effort directed toward each goal is sufficiently but not excessively energized. In the laboratory, rats will perform

tasks to earn food or water rewards. Given an alternative, we know that rats choose options with larger rewards, and are willing to work harder for them. But little is known about the effect of average reward size on the total amount of work a rat is willing to do per day (the analog of labor supply), or the total amount of water the rat will consume per day (the analog of the market demand) at equilibrium. We tested this in N=14 rats, which performed work to obtain water in a long-term closed economy (no other hydration source). The task was freely available 24 hours/day for months, over which the time of every unit of labor (trial) and quantity of every unit of earned water (reward) were recorded to ms and ul precision. The task difficulty was fixed, but the wage rate in ml/trial was varied. At any given time, only one reward size was offered, and the size of that reward was stable for weeks. We show that when wage rates were stably low, rats would do more total work per day - even though this required investing more effort for smaller rewards. The simplest explanation of this would be that rats' demand for water is inelastic, such that they consume the same quantity of water per day regardless of its price in effort. But we find that rats' demand for water is surprisingly elastic: when the cost (trials/ml) is very high, rats consume enough for long-term health maintenance. But when the cost of water is low, rats will consume twice that amount or more. Utility maximization theory can account for both the back-bending labor supply curves and price elasticity of demand for water we observe in rats. We suggest an analytical form which fits all our steady state behavioral data, and which makes testable quantitative predictions for how labor supply and water demand would be affected by a fixed endowment (free water allocation). We interpret the net marginal utility of a trial as a time-varying signal in the brain driving moment-to-moment behavioral engagement. We suggest that this dynamic variable is represented in circumventricular hypothalamic neurons. We propose a Markov model that switches between work and rest states depending on instantaneous marginal net utility, and show that this replicates stochastic temporal dynamics of the rat behavior.

Dopamine modulates the richness of the environment in human economic foraging

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Objectives: Dopamine has long been linked to value-based decision-making through its role in the processing of rewarding outcomes. However, research examining dopamine's role in reward processing has typically used paradigms that may not reflect real-world decision-making problems. A better understanding of dopamine's contribution to value-based decision-making may therefore come from studying problems that our species has evolved to solve. Ecological theories point to one such real-world problem: patch-leaving. To maximise rewards, an individual has to make accurate decisions about when is the best time to stop collecting rewards in one's current location, and travel to somewhere else to start collecting rewards again. Such decisions are common problems both for animal foraging and human economic decisions alike. Theoretically, such decisions depend on (i) the current (foreground) rate at which rewards are being obtained in a location (patch), which will naturally deplete as resources are consumed, (ii) how long it will take to get to a new location where rewards can be harvested, and (iii) the environmental richness, or average (background) rate of rewards available in all patches in the environment. When the foreground rate falls to the level of the background rate, that is the optimal time to leave. Although dopamine has a known role in reward processing, it is unclear what information it might signal in this ecological decision problem. Does dopamine code for foreground or background reward rates? **Methods:** Here, we used a novel economic game where people make patch-leaving decisions in which foreground and background reward rates varied. We performed a double-blind

placebo controlled study with the dopamine D2 agonist cabergoline in healthy people (n=29), and tested Parkinson's Disease (PD) patients on and off their typical dopaminergic medications (n=35). Results: Increasing dopamine availability modulates the effect of background reward rates on patch leaving. Increased dopamine made healthy participants treat the poor environment as if it were richer. Moreover, we found a dopamine-dependent effect of the background environment on patch-leaving in PD. However, in neither study did changing dopamine availability modulate the effect of foreground rewards on patch-leaving. Conclusion: These results highlight a key role for dopamine in signalling how plentiful the environment is, in terms of how rewarding other options may be. Moreover, they show the utility of ecologically based paradigms for understanding value-based decisions, the neuromodulatory mechanisms underlying them, and the effects of pathological impairments.

Forecasting the social media impact of nature imagery with neural data

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A recent United Nations report places over one million species at risk for extinction, with global diversity declining at a rate unprecedented in the last ten million years. It is crucial to find new ways to motivate people to engage with the natural world and take positive steps to protect and restore it. In an incentive-compatible fMRI task, we aimed to understand the neural mechanisms that motivated liking of nature imagery on social media and subsequent conservation philanthropy to protect species and their habitats. We then assessed whether this neural data could forecast engagement with the nature imagery on social media, measured as the percentage of followers of National Geographic (NG)'s Instagram account who liked and/or shared the images. During the fMRI task, subjects (n=37, 20 female, 24.7 ± 6.8 yrs old) chose in 56 trials whether to like the pictured nature imagery on Instagram, and whether to donate to protect the depicted species. Image stimuli were selected from 3 months of NG's posted Instagram photos, divided into quartiles based on the engagement score. Images were selected based on presence of animal species and absence of humans and urban environments. One trial was randomly chosen for each decision type (liking and donating) as a binding choice. If subjects had liked the image, they liked the photo online via their Instagram account. If subjects decided to donate on the binding trial, the requested amount (from \$2-\$28 of a \$30 endowment) was deducted from their study payment and donated to an organization that aided the depicted species and/or its habitat. Subjects also completed a survey providing demographic information and environmental attitudes, and rating their affective response to, and subjective perceptions of, the depicted species. Hierarchical logistic regression analyses using volume of interest fMRI activity revealed that increased Nucleus Accumbens (NAcc) activity ($Z=4.18$, $p<0.001$) and decreased Anterior Insula (AIns) activity ($Z=-3.04$, $p<0.001$) predicted likes, whereas only increased NAcc activity predicted donations ($Z=3.22$, $p<0.010$) in scanned individuals. Activity in NAcc and AIns also predicted out-of-sample global engagement with the photos on National Geographic's Instagram feed (NAcc: $Z=1.96$, $p<0.05$; anterior insula: $Z=-2.15$, $p<0.05$). This study adds to a growing neuroeconomic literature suggesting that brain activity from a small sample of individuals can forecast the preferences of national or global populations. These findings provide a first step in deconstructing which motivational elements of nature imagery resonate deeply, and thus may encourage pro-environmental actions related to conservation.

Saturday October 5th

Session II Learning

Planning activities in monkey OFC-RSC circuit in a 3D virtual reality foraging task

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During natural foraging, animals exhibit goal-directed behavior to learn the structure of the environment and obtain reward. Prospective goal state representation and navigational planning are essential to this process. Although neural activities for route planning have been shown in hippocampus, the neural underpinnings for the learning and use of goal state encoding, which potentially informs hippocampal route-planning activities, is still unknown. We hypothesized that reward simulation, i.e. reactivation of reward state in neural populations, is the key to prospective goal state representation. We developed a 3D virtual reality foraging task to test this hypothesis. In this task, a jackpot reward is hidden at a random location in the virtual maze (goal location) for each session, while other maze configurations stay the same across all sessions. On each trial, the subject is teleported to another random location (start location) during the inter-trial interval. The subject then navigates through the virtual maze with a joystick to forage for the hidden jackpot reward. Subjects took significantly longer search time (from start to goal location) and less efficient travelled paths during pre-learning than during post-learning trials. We simultaneously recorded around 40 single-units in each of orbitofrontal (OFC) and retrosplenial (RSC) cortices across a minimum of 50 trials for each session. We defined goal state as population activity pattern containing averaged firing rates from each neuron across 1500 ms at goal locations during jackpot reward receipt. Representational similarity and state-space analyses reveal that: (1) goal state representation was prospectively reactivated at start of the navigation; (2) it was reactivated during navigation, after but not before, the learning of hidden jackpot location; (3) goal state representation across trials was stable in OFC but correlated with learning in RSC. We further investigated: (1) the correspondence between decision points during navigation and goal state reactivation; (2) the correlations among the behavioral indications of learning, the population dynamics in OFC, and the population dynamics in RSC.

Model-free or muddled models in the two-stage task?

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Two-stage decision tasks are used frequently to determine if behavior is driven by model-free, model-based learning, or a combination of both. The consistent finding is that people use a hybrid mixture of both learning types. In contrast to the typical results, we accidentally found that elaborate story-based instructions, which explain every event in the task, lead participants (n = 45) to make choices that reveal little, if any, model-free influence. In other words, behavior was almost exclusively model-based despite the fact that being model-based did not yield more reward. To explain this finding, we ran simulations and determined that purely model-based agents who misunderstand the task, even slightly, can be mistaken for hybrid agents. Thus, the agent must model the task correctly in order for logistic regression or hybrid model fitting analyses of the two-stage task to accurately distinguish between learning types. It is difficult to say how much of the assumed model-free influence in previous work is really confusion about the task model. However, we found that a substantial fraction of participants in our own and some previously published data sets appear to misunderstand the standard two-stage task in some way. Thus,

the degree of model-free influence in the standard two-stage task may often be over-estimated. We also conducted an fMRI experiment to test for different neural activity when playing the two-stage task after receiving elaborate story-based instructions (ES group; $n = 46$) or the instructions used in previous studies (Daw et al. 2011; PI group; $n = 49$). In a logistic regression analysis, evidence of model-based learning was 1.9 times larger (95% CI [1.6, 2.3]) and evidence of model-free learning was 4.6 times smaller (95% CI [1.20, 7.40]) for the ES group compared to the PI group. Next, we used regions of interest reported in Donoso et al. 2014 as templates for brain activity patterns during the exploitation and rejection of task models. We reasoned that, if the ES group more accurately models the task, then their brain activity should be more related to exploiting the best strategy. Similarly, if the PI group fails to form correct task models, then they should have more activity across regions related to searching through and rejecting inaccurate mental models. Indeed, we found that the ES group showed more activity in the exploitation template relative to the PI group ($p = 0.0103$), and the PI group had greater activity in the model rejection template than the ES group ($p = 0.0021$). Overall, our results suggest that apparent model-free influences in the two-stage task may instead be the result of incorrect mental models.

Neurocomputational mechanisms of learning on social networks

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OBJECTIVE: Many social species are embedded in social networks, including our own. The structure of networks plays an important modulatory role in decision-making, ranging from foraging to finding a partner. However, it remains largely unknown how social network structures are represented in the brain and integrated with other information to guide decisions. Here, we combine model-based fMRI with a lab experiment on a variety of small, static, and stylized social networks to investigate the neurocognitive mechanisms by which subjects learn from observing actions of others embedded on the same network. **METHODS:** A total of 217 subjects (31 fMRI participants) played a guessing game on connected, undirected networks in groups of 7 (1 inside scanner). In each round, participants were randomly assigned to different nodes on a network, and received noisy signals based on which they needed to infer the underlying state of the world that determined the distribution of signals. Importantly, subjects could revise their inferences after observing guesses of their neighbors, allowing us to investigate network-dependent integrations of external information. Inspired by the well-established DeGroot learning model in economics, we formulated a DeGroot reinforcement learning model, where individuals learn through the weighted average of neighbor actions. Critically, the model posits that the learning rate is modulated by a neighbor's degree, one of the most fundamental measures quantifying the centrality of a node on a network. **RESULTS:** The model-derived prediction error for neighbor actions correlated with activity in an inferior frontal gyrus cluster. Importantly, when observing a neighbor decision, the degree of the neighbor was represented in areas within the frontal-parietal network, regions previously implicated in attention modulation. Finally, signals reflecting the integration of action prediction error and the corresponding neighbor's degree were found in the dorsal anterior cingulate cortex. **CONCLUSIONS:** These results suggest that learning in complex, interrelated social environments can be realized by means similar to the well-established RL mechanism. Such learning is constrained to decisions of well-connected individuals who have richer sources of information, likely through signals in the frontoparietal control network. More broadly, by connecting tools and ideas from social network literature and those of neuroeconomics, our study opens a new avenue for incorporating formal

descriptions of complex interpersonal relationships into the investigation of neural substrates of a range of behaviors constrained by or interacting with social environment.

Plasticity of human strategic sophistication

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When two or more agents interact strategically, the outcomes of one's decisions are affected by the decisions of the others. Strategic interactions are particularly challenging, as agents typically do not know what action the others will choose at the moment of making their own decisions, and thus cannot plan based on their counterparts' actual actions. At best, one can try to anticipate the other agents' actions based on the analysis of their incentives and past behavior, and select the action (or course of actions) that yields the largest payoff given such prediction. This strategic reasoning can be more or less deliberate and accurate, reflecting the agents' degree of strategic sophistication. Although it is intuitively plausible to assume that one's strategic skills are distinctively shaped by the features of the interactive decisions previously faced, little is known about how experience affects human strategic sophistication. In this paper, we show that the level of strategic sophistication can be enhanced by manipulating the structure of the decision environment in which experience is gained. We collect and jointly analyze choice and eye-tracking data from an experiment in which participants' strategic sophistication was assessed before and after a training phase. In the training phase, participants played repeatedly games of low and high strategic complexity with immediate feedback, in a between-subject design. This design allows us to study how the initial level of strategic sophistication of an individual is shaped by experience gained in a specific decision environment. The main contribution of our study is threefold. We show that: 1) training with low-complexity games is not sufficient to improve strategic sophistication, and the Patterns of information acquisition (henceforth PIAs) are substantially not modified by such training 2) training with complex games leads to a substantial change in the PIAs that corresponds to an increased level of strategic sophistication, and triggers learning that is generalized to other decision situations. 3) feedback plays a crucial role in the development of strategic learning, as eliminating feedback from the training phase, exposure to neither high- nor low-complexity games affects participants' performance or their PIAs. Thus, feedback appears a necessary condition for plasticity of strategic sophistication.

Session III Social Reward and Social Preferences

Neurocomputational mechanisms at play when weighing concerns for extrinsic rewards, moral values and social image

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Humans not only value extrinsic monetary rewards, but also their own morality and their image in the eyes of others. Yet, violating moral norms is frequent, especially when people know that they are not under scrutiny. When moral values and monetary payoffs are at odds, how does the brain weigh the benefits and costs of moral and monetary payoffs? I will present recent fMRI and TMS findings allowing us to identify how the brain processes three sources of motivation: concerns for self-image, moral values

and extrinsic rewards. Using a neurocomputational model of decision value and fMRI, we investigated whether different brain systems are engaged when deciding whether to earn money by contributing to a 'bad cause' and when deciding whether to sacrifice money to contribute to a 'good cause', both when such choices were made privately or in public. Although similar principles of decision value computations were used to solve these dilemmas, they engaged two distinct valuation systems. When weighing monetary benefits and moral costs, people were willing to trade their moral values in exchange for money, an effect accompanied by decision value computation engaging the anterior insula and the lateral prefrontal cortex. In contrast, weighing monetary costs against compliance with one's moral values engaged the ventral putamen. Moreover, regardless of the type of dilemma, a brain network including anterior cingulate cortex, anterior insula and the right temporo-parietal junction was more engaged in public than in private settings. In a TMS study using the same paradigm, we found that disrupting the right temporo-parietal junction (rTPJ) did not change the general motivation to give or to react to social reputation cues, but specifically reduced the behavioral impact of moral-material conflicts. These findings reveal that signaling moral-material conflict is a core rTPJ mechanism that may contribute to a variety of human moral behaviors. Together, these studies pinpoint the specific neural mechanisms engaged in weighing concerns for extrinsic rewards, moral values and social image.

Size Matters: Social preferences are reflected in the cortical thickness of the temporoparietal junction

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Objective: Recent research has attempted to uncover the biological mechanisms that underlie individual differences in social preferences. Behavioral tendencies in social decision-making have been consistently linked to differences in Theory of Mind (ToM), as well as to differences in cognitive control. While much of the literature suggests that variations in social preferences between individuals are related to temporary differences in neural activity, notable exceptions give reason to suspect that structural differences of the frontal and temporal cortices predict social preferences. This study continues this line of thinking by examining whether chronic other-regarding preferences are related to anatomical variations in the human brain. **Methods:** Structural brain images were acquired at the University of Amsterdam. Social Value Orientation (SVO) was measured outside of the scanner using the Ring Measure technique (Liebrand, 1984). Each participant (n = 194) made 24 incentivized choices between pairs of own-other monetary outcomes. These allocation choices were also used to calculate each participants' weight to self (Wself) and weight to other (Wother). We ran independent regressions of each of the 74 cortical parcellations of the Destrieux Atlas on Wself and Wother, correcting for age, gender, and intracranial volume. Results for the regression coefficients of Wself and Wother were corrected for multiple comparisons by using the Freedman and Lane (1983) procedure. **Results:** No regions in the occipital lobe were correlated with Wself or Wother. Two areas in the orbitofrontal cortex, a region associated with ToM, showed a relationship to SVO but did not survive permutation testing. Finally, as predicted, four areas in the parietal lobe linked to Theory of Mind are correlated with SVO. Permutation testing within lobes reveals a small but robust negative relationship between the left Jensen sulcus and Wself. **Conclusions:** With a well-powered study of 194 participants, we find no relationship between other-regarding preferences and anatomical differences in prefrontal cognitive control areas. This suggests that the structural differences in prefrontal brain anatomy do not contribute to understanding whether and how cognitive control modulates inter-individual differences in prosociality. At the same time, our results also suggest that structural differences in the left Jensen sulcus - an area implicated in

ToM - contributes to inter-individual differences in the extent to which decision-makers value personal rewards when choices affect both oneself and others.

Model-free learning is prioritised when avoiding harm to others

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A fundamental aspect of human morality is prohibition against harming others. In order to be moral, we must learn associations between our actions and their outcomes for others. However, despite extensive theorizing about the nature of morality by philosophers, psychologists, neuroscientists and economists for centuries, the core mechanisms that underpin moral learning are unknown. Existing work has suggested two different systems drive learning between actions and outcomes: a computationally expensive 'model-based' system that builds an internal model of the environment, and a computationally efficient 'model-free' system that assigns values to actions through trial-and-error and selects actions retrospectively. This division has been hugely influential for understanding learning and decision-making across species. Researchers from several different disciplines have theorized that the model-based/model-free distinction might illuminate puzzles of human morality but until now, there has been no data to support this theory. We designed a novel paradigm to reliably distinguish between these model-free and model-based learning strategies in a setting where participants (n=36) learned to avoid receiving painful electric shocks for themselves or a stranger. Using computational fMRI, we found that model-free learning was prioritized when avoiding harm to others compared to oneself. Model-free prediction errors for others relative to self were tracked in the thalamus/caudate at the time of the outcome. At the time of choice, a signature of model-free moral learning was associated with responses in subgenual anterior cingulate cortex (sgACC), and resisting this model-free influence was predicted by stronger connectivity between sgACC and dorsolateral prefrontal cortex. Finally, multiple behavioural and neural correlates of model-free moral learning varied with individual differences in moral judgment. Specifically, utilitarian moral judgments were negatively correlated with model-free behavior and positively correlated with dlPFC-sgACC connectivity when resisting model-free influence. Moreover, the sensitivity of moral judgments to harm severity was positively correlated with model-free behavior, the strength of model-free prediction error in thalamus/caudate, and the strength of model-free influence in sgACC. Our findings suggest moral learning favours efficiency over flexibility and has unique behavioural and neural signatures.

MDMA increases cooperation and recruitment of social brain areas when playing trustworthy players in an iterated prisoner's dilemma

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Objective: Social decision-making is fundamental for successful functioning and can be affected in psychiatric illness and by serotonergic modulation. The Prisoner's Dilemma is an archetypal paradigm to model cooperation and trust. However, the effect of serotonergic enhancement is poorly characterized, and its influence on the effect of variations in opponent behaviour unknown. To address this, we conducted a study investigating how the serotonergic enhancer 3,4-methylenedioxy-methamphetamine (MDMA) modulates behaviour and its neural correlates during an iterated Prisoner's Dilemma with both trustworthy and untrustworthy opponents. Methods: We administered 100 mg

MDMA or placebo to 20 male participants in a double-blind, placebo-controlled, crossover study. While being scanned, participants played repeated rounds with opponents who differed in levels of cooperation. On each round, participants chose to compete or cooperate and were asked to rate their trust in the other player. Results: Cooperation with trustworthy, but not untrustworthy, opponents was enhanced following MDMA but not placebo (respectively: odds ratio = 2.01; 95% CI, 1.42-2.84, $p < 0.001$; odds ratio = 1.37; 95% CI, 0.78-2.30, not significant). Specifically, MDMA enhanced recovery from, but not the impact of, breaches in cooperation. During trial outcome, MDMA increased activation of four clusters incorporating precentral and supramarginal gyri, superior temporal cortex, central operculum/posterior insula, and supplementary motor area. There was a treatment \times opponent interaction in right anterior insula and dorsal caudate. Trust ratings did not change across treatment sessions. Conclusions: MDMA increased cooperative behaviour when playing trustworthy opponents. This was driven by the recovery of cooperation rather than the initial impact of breaches in trust, suggesting that MDMA did not impair the ability to recognise untrustworthy behaviour. Furthermore, that behaviour with untrustworthy opponents was unchanged suggests that MDMA did not cause participants to naively cooperate when it was not in their interest to do so. Underlying these behavioural effects were changes in brain activity in regions linked to social cognition. That these changes were seen only when receiving feedback of others' decisions suggests that different aspects of social interactive behaviour (decision/feedback) can be modulated separately. While MDMA altered activity in some areas during feedback from all opponents the right anterior insula showed differential changes depending on opponent-type. Together, these findings highlight the context-specific nature of MDMA's effect on social decision-making.

Sunday, October 6th

Session IV Risk, Effort, and Delay

How executive fatigue arises and affects decision making

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Executive control is a critical ability for educational and professional success, because it enables tolerating delay and effort in the pursuit of important goals. In a previous fMRI study (Blain et al., 2016, PNAS), we showed that executive control is susceptible to fatigue: after one day of hard cognitive work, left lateral PFC activity was reduced during economic choice, which led to more impulsive decisions favoring immediate rewards. Here, we report three studies that bring biological, behavioral and computational evidence that casts light on both the origins and consequences of executive fatigue. First, we tested whether executive fatigue could be induced by real-life activities. Students in medical school ($n=26$) were invited to a 7-hour revision day divided into 4 sessions between which they performed inter-temporal choices and a mock exam with multiple-choice questions. Choices became significantly more impulsive with the number of revision sessions, but scores at the medical exam remained stable. This suggests that control ability is not lost with hard cognitive work, but only recruited when it matters most, as if control cost was increased. Second, we looked for metabolic changes that could explain the increase in control cost, using magnetic resonance spectroscopy (MRS). Participants were divided into two groups, one ($n=16$) performing an easy version and one ($n=24$) performing a hard version of the same cognitive tasks (N-back and N-switch), for about 6 hours divided in 5 sessions. Executive fatigue was

accompanied by an increase in glutamate level within the left lateral PFC, but not in the visual cortex, with a significant interaction between group and session. Thus, the increase in control cost could be the result of a regulation process whose purpose would be to limit glutamate accumulation beyond clearance capacity. Third, we specified the effects of executive fatigue on decision making by including effort and risk discounting tasks in addition to delay discounting tasks, and by using computational models to capture the cost/benefit trade-off in all tasks. Executive fatigue only affected choices when options were involving executive control (delay and effort, but not risk). These effects were dissociated from those of time pressure, which were tested in a separate group (n=27). While time pressure increased global choice stochasticity, executive fatigue effects were best captured by an additive bonus for low-cost options. This double dissociation suggests that executive fatigue does not affect the decision-making process itself, but increases the preference for low-cost options.

NoThe neuroimaging analysis replication and prediction study results: Variability of neuroimaging results across analysis teams and over optimism in prediction markets

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Background. The "replication crisis" in many scientific fields has raised concerns regarding the reliability of published results. One reason for the high rate of false positive results is the large number of "researcher degrees of freedom", where the process of data analysis can be performed in multiple ways. This is specifically apparent in neuroimaging with a thriving "garden of forking analysis paths". Aims and methods. In the Neuroimaging Analysis Replication and Prediction Study (NARPS: www.narps.info/), we provide the first scientific evidence on the variability of neuroimaging results across analysis teams. We collected fMRI data from 108 participants performing two versions of the mixed gambles task, often used to study decision-making under risk. Seventy independent analysis teams received this dataset, including raw and preprocessed data. They freely analyzed it to test nine ex-ante hypotheses regarding activations in specific contrasts and brain regions based on previous studies with this task. The main outcome variable was measured as the fraction of teams reporting a significant result, based on their own criteria, for each hypothesis. We measured peer beliefs about the main outcome variable with two independent prediction markets (PMs): one for members from the analysis teams ("teams PM", n=83) and one for expert scientists that did not participate in the analysis ("non-teams PM", n=65). Results. The fraction of teams reporting significant results of the nine hypotheses varied from 6% to 84% (mean 28%). Between 6% and 37% (mean 20%) of teams disagreed with the majority result. Thus, the coherence of results varied across hypotheses and variability across teams was high for most of the hypotheses. The rank correlation between the predictions and the main outcome variable was high for "teams PM" (Spearman correlation, $r=0.962$, $p<0.001$) and moderate for "non-teams PM" ($r=0.553$, $p=0.122$), but both groups substantially overestimated the support for the nine hypotheses (Wilcoxon signed-rank test: "teams PM" $p=0.008$; "non-teams PM" $p=0.011$). Conclusions. Based on the results of 70 independent analysis teams comprising 180 worldwide researchers, different choices of analysis pipelines affect neuroimaging results. Furthermore, we found that experts from the field are over-optimistic in predicting the support for neuroimaging hypotheses, even if they analyzed the data themselves. Our findings provide the first ecological scientific evidence on the variability of

neuroimaging results across analysis methods in the wild and raise challenges on how to address variability of results.

Translational neuroeconomics in addiction: Species-specific similarities and differences in dysfunction between wanting vs liking among humans and mice.

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Valuations involved in the process of obtaining a reward are fundamentally distinct from those involved in its hedonic appreciation. These processes, mediated via separable decision-making circuits, can be dissociated by measuring behaviors before vs. after reward consumption. It remains unclear how each might uniquely malfunction in addiction and to what extent such dysfunctions might be conserved across species. We used a translational neuroeconomic task to dissociate reward-seeking vs. post-consumption valuation algorithms via behavioral analyses equally applicable to rodents and humans. Mice trained on the Restaurant Row task spent time from a limited budget (60 min) foraging for food of four different flavors (indicated by visual cues) whose delays (ranging 1-30s) were cued by the pitch of a tone that, if accepted, descended in pitch. Thus, mice were tasked to accept or reject serial offers. Separate hedonic behaviors were measured as time spent lingering at feeding sites after consuming rewards. Mice were then exposed to 12 daily injections of saline (n=10), cocaine (n=7), or morphine (n=10) and tested for two weeks after final drug exposures. When encountering preferred flavors with a delay above one's willingness to wait, cocaine-exposed mice were less likely to appropriately reject economically disadvantageous offers. Furthermore, these mice did so despite spending more time deliberating. Morphine-exposed mice demonstrated distinct impairments when given the opportunity to correct previous mistakes. All mice lingered longer at feeding sites in more preferred restaurants. This relationship was exaggerated in cocaine-exposed mice, and while intact, was down-shifted in morphine-exposed mice. Next, we recruited 12 human non-treatment seeking cocaine users and 9 controls to perform the translated computer-based Web-Surf task. Humans similarly spent time from a limited budget (20 min) to earn natural rewards, i.e., entertaining video clips of different genres (four unique video galleries cued by an icon), available after varying delays (ranging 1-30s, cued by a download bar) and then were asked to rate the hedonic value of videos on a scale of 1-4 stars. Like cocaine-exposed mice, human cocaine users displayed impairments in the ability to reject economically disadvantageous offers despite deliberating. Interestingly, human cocaine users inverted the relationship between genre preference and post-consumption hedonic valuations compared to controls, rating consumed videos of more preferred genres fewer stars. These data elucidate the neuroeconomic facets of addiction that are both shared and different between humans and non-human animals.

Large-scale evidence for neuroanatomical and genetic associations with risky behaviors

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From speeding to drinking and smoking, humans vary in their tendencies to engage in risky behaviors. Although the disposition to take risks is partially heritable and stable across the lifespan, little is known about how it is embodied in anatomical features of the brain, and how these features translate genetic dispositions into behavioral phenotypes. We report the results of a large-scale (N=12,675) pre-registered study in a general population sample from the UK, that investigated the associations between (1) MRI-

derived phenotypes of grey matter volumes and white-matter microstructure (obtained from T1 and DTI images), (2) individuals' self-reported tendencies to engage in risky behaviors in the smoking, drinking, driving and sexual domains, and (3) individuals' genetic disposition to take risks, proxied via polygenic risk scores (PRS) derived from a genome-wide association study (GWAS) performed in an independent sample (N=297,025). Our analyses controlled for sex, age, height, SES and genetic population structure. We find robust negative associations between risky behaviours and grey matter volume in several structures, including Amygdala (bilateral), Hippocampus (posterior division), Putamen (bilateral), Ventral Striatum (bilateral), Posterior Middle Temporal Gyrus (bilateral), Dorsolateral Prefrontal Cortex (bilateral), and Ventromedial Prefrontal Cortex (all $P_s < 1.2 \times 10^{-4}$). Risky behaviour was also negatively associated with white-matter microstructure (e.g. fractional anisotropy and intra-cellular volume fraction) in fornix, stria terminalis and genu of corpus callosum and anterior and superior corona radiata ($P_s < 1.7 \times 10^{-5}$). Thus, the tendency to engage in risky behaviours is associated with the structural connectivity of reward structures within the striatum and their projections to and from the prefrontal cortex. Our analyses using GWAS-derived PRS revealed that individuals' genetic dispositions to engage in risky behaviors were associated with reduced grey matter volume in dlPFC (BA 46), Putamen, and Hypothalamus ($P < 9.3 \times 10^{-7}$). Grey matter volume in these structures partly mediated ($\sim 2.4\%$) the associations between the PRS and individual differences in behavior, as did the fractional anisotropy of fiber tracts connecting the Midbrain to the Thalamus (i.e. the left cerebral peduncle, $\sim 1\%$, $P < 8.8 \times 10^{-4}$). Our results shed light on the neuroanatomical and genetic underpinnings of risky behaviours, that are related to long-term socioeconomic and health outcomes, suggesting that the translation from a genetic propensity to behavior involves the neuroanatomical structure and connectivity of subcortical and prefrontal brain areas.

Session V Choice and Choice Mechanisms

Towards a space of behavioral interventions

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A large body of research in the social and behavioral sciences studies the impact of behavioral interventions (or "nudges") on decisions; factors such as option presentation format, preference-elicitation procedures, as well as incidental affect, social belief, and cognitive capacity. Although this work has been extremely influential, we currently lack an overarching theoretical framework for behavioral interventions that provides a systematic account of their behavioral consequences, cognitive mechanisms, and statistical interpretations. In this paper, we propose such a theoretical framework using the drift diffusion model (DDM), a quantitative theory of decision making whose parameters offer a theoretically compelling characterization of the neurocognitive underpinnings of choice behavior. The DDM decomposes choice processes into three components: choice preparation (the starting point parameter), information accumulation (the drift rate parameter) and choice caution (the decision boundary parameter). Through the lens of the DDM, we can break down any behavioral intervention into changes on the model's three parameters, or equivalently, into three sub-effects. In our framework, we consider each parameter-based sub-effect as one dimension of a multidimensional space, and subsequently place behavioral interventions in this space based on their impact on the three DDM components. To illustrate the power of our theoretical framework, we perform two very large-scale choice experiments, involving fifteen distinct behavioral interventions, and construct a space spanning all the tested interventions. Our space describes these interventions in terms of their sub-effects on three

DDM components, permitting not only a deeper understanding of mechanistic and statistical interpretations for each of the interventions, but also theoretical connections among them. Within the three-dimensional space, the distance between a pair of behavioral interventions corresponds to their dissimilarity, which we subsequently use to uncover intervention clusters. Furthermore, the constructed space provides an intuitive approach to measure "cognitive effect size" of an intervention. This effect size is captured by the distance between a given behavioral intervention and the origin point (which represents a null effect on all three DDM components). Our space of behavioral interventions is theoretically grounded in a well-established neurocomputational model, empirically constructed through large-scale experiments, and constitutes a step towards a more integrative and cohesive study of behavioral interventions, along with their behavioral, neurocognitive and statistical implications.

A novel circuit architecture for choice: Local disinhibition generates normalized value coding, persistent activity, and winner-take-all dynamics in value-guided decision making

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Objective: Computational models of decision making today utilize two different circuit motifs. One motif focusses on implementing choice dynamics, including recurrent excitation and competitive inhibition (Wang, 2002; Wong & Wang, 2006). The other motif focusses on the nature of value representation. These networks employ a form of global divisive inhibition embedded as a gain control element to successfully capture divisive normalization in value representation (Louie et al. 2014). Until now, little has been known about how both value normalization and competitive decision networks could be implemented in a single circuit architecture. Here we examine how these two processes can be combined in a single network that respects known cortical physiology. **Methods:** We examined dynamic firing rate models that expand on existing normalization circuits (Louie et al. 2014; LoFaro et al., 2014) by incorporating different biophysical implementations of recurrent excitation and inter-neuronal competition. Each model was implemented as a system of differential equations capturing response to input, recurrent excitation, divisive inhibition, and inter-neuronal competition. In addition to the qualitative behavior of the different models, we tested model performance in fitting reaction time and choice data in standard monkey perceptual decision-making datasets (Roitman & Shadlen, 2002). **Results:** Here, we show that networks with recurrent excitation, global divisive inhibition of gain control, and a local inhibitory regulation of the gain control circuit to induce competition, i.e., local disinhibition, produce normalized value coding, persistent activity, and winner-take-all dynamics. Furthermore, this local disinhibition normalization model accurately captures reaction time and choice data in existing perceptual choice datasets. **Conclusion:** We find that a biologically-plausible decision network architecture with recurrent excitation, global inhibition, and local disinhibition generates key properties of decision circuits including normalized value coding, persistent activity, and WTA dynamics. This model captures empirical psychometric and chronometric data in monkey perceptual choice, suggesting a neural circuit mechanism for data commonly described with more abstract drift diffusion models. These results suggest that local disinhibition may play a particularly important role in biological value representation and decision making.

Multiple memory traces of choice and reward in macaque frontal cortex

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Prefrontal cortex signals relate to different aspects of the choices we are about to pursue. Rewards increase the value of the choices with which they are associated, but the way rewards and choices influence decision making can be multifaceted. Choices are sometimes simply repeated regardless of whether they have been linked to reward receipt and rewards can reinforce choices to which they are not causally linked. We investigate the brain networks underlying linked and unlinked choice and reward representations using reinforcement learning models and functional magnetic resonance imaging in macaque monkeys (25 sessions, 4 monkeys). The history of reward paired with a choice guided decision making, but in addition, unlinked effects of choice and reward drove behaviour. In particular, animals were more likely to repeat choices during phases of high average reward rates. We implemented memory traces of choice and reward in an RL model in addition to contingent learning. This improved model fit. Reward traces led to asymmetric and dynamic value updates consistent with the influence of the average reward rate on stay/switch choices. Behavioural analyses and modelling suggest that choices are driven by an integration of different types of evidence. We found that, similarly, ventromedial prefrontal cortex (vmPFC) activity is better described by both value signals and choice memories and not value difference alone. Based on the modelling, we identified unlinked memories of choice and reward in frontal cortex. Medial orbitofrontal cortex (mOFC) represented whether animals stayed with their previous choice stimulus or switched, while dorsal anterior cingulate (dACC) and agranular insula (AI) tracked the reward trace. Time course analyses of AI demonstrate a gradual change in coding the reward trace to coding of the current outcome, suggesting that this brain region integrates new reward into the reward trace. Behavioural and RL modelling analyses suggest that memory traces of choice and reward persist to some degree independently and influence decision making. MOFC, as well as dACC and AI, carried such unlinked memory traces of choice and reward, respectively. Ventromedial prefrontal cortex signals reflected the general integration of choice evidence.

Session VI Attention

Visual attention modulates the accumulation of goal-relevant evidence and not value

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People tend to choose the option they have spent longer looking at. The dominant interpretation of this gaze-boosting effect is that visual attention increases value. Using sequential sampling models, such as the attentional drift diffusion model (aDDM), resulted in an elegant mechanistic explanation of the gaze-boosting effect in which visual attention directly enhances the drift rate of a stochastic value accumulation process. However, because all previous studies invariably asked participants to choose their preferred item, we cannot discern whether visual attention was actually modulating value, as typically interpreted, or goal-relevant information. In this study, we use a simple task-framing manipulation to answer this question, decoupling value from goal-relevant information. At the beginning of the experiment participants reported the value of several food snacks. Then, in the main experiment, participants were asked to choose between two snacks, using two task-frames. In the 'like-frame' (identical to previous studies) they indicate which snack they wanted to consume. In the 'dislike-frame', they were required to indicate the snack that they would prefer not to eat. In the like frame, we

replicate typical gaze-boosting effect: participants look more at the item they like and choose. In the dislike frame, however, contrary to the prediction from most current theories, participants look more (and thus allocate more attention) to the least valuable item, which they then chose to eliminate. Thus, attention modulates goal-relevant information and not mere value. We then fitted different dynamic accumulation models. We show that visual attention boosted the accumulation of goal-relevant evidence that guides choice in each task-frame, instead of absolute value. To test the generality of these findings we conducted a second perceptual decision-making experiment. Participants were now asked to choose between two circles filled with dots. In some blocks they had to indicate the circle with more dots ("most" frame); while in others, the circle with fewer ("fewest" frame). We replicated all the effects of the first value study, corroborating the hypothesis of a domain general role for attention in modulating goal-relevant information that drives choice. We finally developed a decision-theory model that predicts these findings as adaptation of optimal information gathering. This work questions the dominant view in neuroeconomics about the relationship between attention and value, showing that attention does not boost value per se, but instead modulates the evidence that is accumulated to achieve a given goal.

The role of attention in opportunity cost neglect

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Choices necessitate opportunity costs: choosing one option means foregoing another. However, consumers often neglect opportunity costs (Frederick et al. 2009). Making opportunity costs salient can increase the likelihood that they are considered (Spiller, 2011) and thus, change the considered evidence in favor of not buying. A potential mechanism for this evidence shift is attention. Past research has demonstrated a causal role of attention in choices (Armell et al., 2008; Gwinn et al., 2019; Pärnamets et al, 2015). Specifically, attention amplifies evidence from the looked-at option (Smith & Krajbich, 2019). Thus, we predict the lower purchase rate (with explicit opportunity costs) is driven by (1) a larger amount of attention to the opportunity cost and/or (2) a larger impact of attention to the opportunity cost. Subjects (N = 50) made 200 incentivized choices (two blocks of 100 trials; order counterbalanced across subjects) about whether to buy various food items while undergoing eye-tracking. On each trial, subjects chose between a "buy" option and a "no buy" option. In one block, the "no buy" option was labeled "Do Not Buy Food for \$X" (implicit condition); in the other, it was labeled "Keep \$X" (explicit condition). Crucially, the two "no buy" options led to identical outcomes: the subject not buying the food. However, the results indicate that subjects did not treat them identically. As expected, subjects purchased less often in the explicit condition ($p < .001$). Moreover, they spent relatively more time looking at "Keep" than "Do Not Buy" ($p = .017$). There was a significant indirect effect of condition on purchase through relative attention ($b = -0.034$, 95% CI: $[-0.067, -0.007]$) indicating that the amount of attention partially accounted for the purchase effect. Moreover, a significant moderated indirect effect ($b = -0.003$, 95% CI: $[-0.007, -0.0002]$) indicates that the indirect effect due to relative attention was stronger in the explicit condition than the implicit condition. Computational modeling (i.e. the Attentional Drift Diffusion Model) provides more evidence for this finding; the two conditions' attentional discounting parameters have non-overlapping confidence intervals (Smith et al., 2019). Together with the mediation results, this suggests that consumers not only pay more attention to the "Keep" option, but attention to "Keep" also has a greater impact. Overall, we provide substantial evidence for the role of attention in opportunity cost considerations. Two attentional factors (amount

and impact of attention) help to explain the difference in purchase rates observed in choices with implicit vs. explicit opportunity costs.

Distinct mechanisms underlie mean reward and reward variance in risky decision making: Evidence from behavior, eye-tracking and fMRI

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Value-based choices are influenced by both the mean and variance of potential outcomes. How our brain represents expected value and potential risks and how these representations lead to subjective decisions are still not clear. Using a new incentivized reaction time (RT) task in which mean reward (expected value) and reward variance (risk) of two values were parametrically manipulated and orthogonalized, we examined the neural correlates of reward and risk encoding. Behavioral results (n = 90) showed that RTs varied as a function of mean reward but not reward variance, suggesting that expected utility is the main driver of reward motivation. Moreover, eye movement data (n = 68) revealed that gaze transitions tracked mean reward but not reward variance, indicating that participants shifted gaze more towards higher expected average utility. Pupil size tracked the variability of RTs, possibly reflecting the emotional arousal induced by subjective risk preference with integrating both mean reward and reward variance. Neuronally (n = 22), the striatum tracked mean reward, and its functional connectivity with amygdala and superior frontal gyrus (SFG) was associated with average utility. The insula tracked reward variance, and its functional connectivity with vmPFC and dACC was correlated with risk representation. Lastly, using computational modelling, we further show that the putamen was involved in subjective risk preference by integrating both expected value and risks. This is the first study to characterize subjective risk preference at behavioral, attentional, and neural levels, and we first consistently show that the expected value and risks are encoded differently. Taken together, our results show that the expected value was linked with faster RT, more gaze shifts, and enhanced activity in the striatal-cortical limbic motivational network; objective risk was involved in the cingulo-opercular/insular reflective and salience network; and subjective risk was associated with the pupil-linked arousal system and represented by striatum activity. Our results provide new insights into developing effective tools to investigate subjective risk preference, and lay the foundation for a better understanding of pathological gambling in real life.

How contextually irrelevant values influence choice and vmPFC activity in humans

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Nearly all objects we decide between have multiple attributes. Previous research has shown that during decision-making the brain's attentional control network enhances the processing of attributes that are relevant in the current context, while ventromedial prefrontal cortex (vmPFC) represents the expected value associated with these attributes. Yet, if this selective value retrieval is less than perfect, then values of contextually irrelevant attributes will influence neural value representations as well as choice. Here, we investigated this question by utilizing a context-dependent random dot motion paradigm. Forty human subjects were asked to decide between two clouds of moving dots. Each cloud had two attributes (motion direction and dot color) that were associated with specific reward values. The reward-attribute mapping were learned previous to the choice task. During choice trials, participants were cued to focus

only on one attribute type (color or motion) and received the reward associated with the chosen cloud's cued attribute. The cued dimension changed (pseudo)randomly between trials. Thus, only one attribute-type was relevant for the decision outcomes in a given trial, but attribute types were not more or less relevant overall. We hypothesized that values associated with the outcome-irrelevant attributes will have an impact on participants' choice behavior (reaction time) as well as expected value signals in vmPFC. In line with our hypothesis, we found that the value of the attributes that were irrelevant in a given context impacted behavior and neural responses. Specifically, RTs were faster when the values of the irrelevant attributes indicated the same choice compared to indicating a different choice ($t = 4.5737$, $p < 0.001$). This effect was parametric, i.e. RTs were linearly affected by the magnitude of value difference associated with "irrelevant" attributes (mixed effects model: $\chi^2(1) = 11.623$, $p < 0.001$). Furthermore, fMRI analyses showed a parametric modulation of the signal in the vmPFC by the value of the relevant as well as the value difference of the irrelevant attributes. ($p < 0.001$, uncorrected). These results indicate that contextually-irrelevant attributes can influence expected value representation in the vmPFC and elucidate the potential neural mechanisms underlying choices made based on attributes that are known to be irrelevant for the outcome. Next we plan to investigate the relations between these effects and attentional mechanisms using multivariate analysis, and whether relevant and irrelevant values are processed in parallel or are integrated in vmPFC representations during choices.

Poster Spotlight Abstracts

Spotlight I Friday, October 4th

Decomposing neurocognitive bases of indebtedness in grateful situations: A dual-motivational account

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Humans commonly repay others' favors even when these favors are unsolicited and disliked. This compliance to the norm of reciprocity affects everyday decisions and is closely associated with the negative feeling of indebtedness. However, little is known about the neurocognitive mechanisms underlying the role of indebtedness in reciprocity. Here, by combining diverse approaches including interactive game, computational modeling and fMRI, we identified dual components of indebtedness, i.e., guilt and the sense of obligation, at behavioral and neurobiological levels. These components served as dual motivations underpinning the beneficiary's behaviors. In each round of the interactive game, an anonymous co-player decided how much endowment to spend to reduce the participant's pain. In half of the trials, participants could decide whether to accept help; in the remaining trials, participants had to accept help and could reciprocate by allocating monetary points to the co-player. We manipulated benefactor's intention by providing information about whether the co-player knew the participant could (Can condition) or could not (Cannot condition) reciprocate after receiving help. Results demonstrated two principal components of participants' emotional responses to others' help: participants reported increased guilt as well as gratitude when they perceived more benevolence from a benefactor in Cannot

condition; in contrast, participants reported increased sense of obligation when they believed that the benefactor expected a repayment in Can condition. We developed a computational model to capture how participants make trade-off between these two emotional motivations to decide whether to accept help and how much to reciprocate. This dual motivational model accurately predicted participants' behaviors and revealed individual differences in weights on the two motivations during decision-making. While some participants were more motivated by guilt and gratitude and consequently repay more to benevolent help, others were more motivated by obligation and consequently repay more when the benefactor expected a repay. fMRI results revealed differential neural bases underlying the two components of indebtedness. While processing of guilt involved the activation of insula, processing of obligation involved activation of dorsomedial prefrontal cortex (dmPFC) and its connectivity with dorsal anterior cingulate. The stronger the neural coupling between dmPFC and reciprocity related areas (i.e., dorsolateral prefrontal cortex), the larger the relative weight on obligation during reciprocity. This work shed light on understanding related social phenomena, such as bribe-taking.

Delay discounting and anhedonia: a transdiagnostic approach

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Anhedonia, or diminished ability to experience pleasure, is a prominent symptom in mood and psychotic disorders. More specifically, anticipatory pleasure is impaired in these psychiatric conditions, and this impairment may be reflected in blunted activity in the fronto-striatal circuitry underlying reward processing. To examine the neural correlates of anhedonia and anticipation of future reward, we collected functional magnetic resonance imaging data in a delay discounting paradigm designed to assess the subjective value of future rewards in a group of healthy individuals (n = 23), and individuals with major depressive disorder (n = 18), bipolar disorder (n = 21), and schizophrenia (n = 26). Although behavioral performance did not distinguish the primary diagnosis or varying levels of anhedonia, activity in the vmPFC correlated with the subjective value of future rewards was blunted in anhedonia, such that increasing symptoms of anhedonia were correlated with dampened value-related signals. Moreover, the effect of anhedonia remained significant after statistically accounting for the effects of primary diagnoses and multiple potential confounds, including cognitive functioning, smoking, depression severity, and positive and negative symptoms of schizophrenia. These findings provide evidence for hypofunction in the vmPFC across mood and psychotic disorders that is specifically linked to anticipatory anhedonia, rather than a general feature of major psychopathology.

Violations of economic rationality in reinforcement learning are driven by a saliency-dependent reward-prediction-error signal in the ventral striatum

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When choosing among more than two options, humans and other animals frequently violate the independence principle of rational choice theory. According to this principle, relative choice probabilities between options should not be affected by the composition of the choice set. Recently, Spektor et al. (2019, Psychological Review) have demonstrated that such violations can also occur in reinforcement-learning (RL) tasks. They proposed the accentuation-of-differences (AOD) model, a novel RL model

according to which outcome saliency distorts feedback processing and therefore leads to violations of the independence principle. More specifically, the reward-prediction error (RPE) of options with particularly distinct outcomes is assumed to be biased in the positive direction. In the present study, we tested this proposal on the neural level by investigating the fMRI-BOLD signal of the RPE in the ventral striatum. A total of 40 participants completed two sessions of an RL task comprising three choice options each (A, B, C; B, C, D). Reward contingencies for two of the three choice options (B and C) were equal across sessions, which allowed us to test for violations of the independence principle. The third option (A in session 1 and D in session 2) was specified such that the AOD model would predict a relative preference for C over B in session 1 and vice versa in session 2. fMRI data was acquired on a 3T MR scanner. Analysis of the choice behavior provided very strong evidence for the predicted independence violation: The relative choice share of the target option (C in session 1, B in session 2) was .71, which was significantly larger than the .50 that would satisfy the independence principle, $t(39) = 6.28$, $p < .001$, $d = 0.99$. Additionally, the AOD model provided a better account of the choice data compared to a standard RL model and a risk-sensitive RL model. Model-based fMRI data analysis revealed a significant AOD-based RPE signal in the ventral striatum, even after controlling for the reward signal itself, $Z = 5.42$, whole-brain-corrected $p = .005$. Critically, a Bayesian model comparison of the brain data showed that the AOD model provided a better account of the RPE signal in the ventral striatum than the competing RL models. In conclusion, our study provides further evidence for violations of the independence principle in RL decisions and elucidates the underlying neural mechanism. Feedback processing in the reward system of the brain is influenced by the distinctiveness of outcomes such that particularly salient options are preferred.

Early Childhood Trauma negatively affects real-life outcomes via detrimental effects on neurodevelopment: Large-scale evidence from the UK biobank

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Early childhood trauma (ECT) is associated with negative financial, social, and health outcomes during adulthood. Do these negative long-term consequences of trauma reflect detrimental effects on brain development? Here we report the results of a large-scale pre-registered study conducted in a general population sample from the UK Biobank ($N = 13,554$). We investigated how ECT is associated with MRI-derived neuroanatomical phenotypes of macrostructure (grey matter volumes obtained from T1 images) and white-matter microstructure (obtained from DTI and NODDI analyses), and how these neural phenotypes translate into behavioral phenotypes. All our analyses controlled for the effects of sex, age, height, socioeconomic status, and genetic setup (first 40 principal components of PCA on genetic variation in the population, derived in an independent sample with $N \sim 500,000$), ruling out the influence of these confounding factors. A whole-brain analysis revealed that early childhood traumatic events (ECT) was associated with grey matter volume decreases in distinct prefrontal areas (vlPFC, dlPFC, and vmPFC) as well as areas in the cerebellum. Interestingly, ECT was not only associated with anatomical macrostructure of the prefrontal areas mentioned above but also with white-matter microstructure of afferent and efferent fiber pathways connecting these areas. Specifically, such associations were found for fractional anisotropy and intra-cellular volume fraction of the anterior corona radiata, the genu of the corpus callosum, and the superior longitudinal fasciculus (all P s $< 2 \times 10^{-4}$). To further examine brain-behaviour associations, we found that ECT was negatively associated with fluidic IQ (Structural

Equation Modeling, $\beta = -.08$, $P < 1.3 \times 10^{-19}$) and that this effect was mediated (7.8%, $P < 2.27 \times 10^{-5}$) by whole brain volume differences. Congruent with this, we also found that ECT correlated with lower long-term economic success (Structural Equation Modeling, $\beta = -.21$, $P < 1.8 \times 10^{-120}$); this effect was again mediated (3.5%, $P < 3.6 \times 10^{-6}$) by overall brain volume. Our results inform psychological theories and mechanistic models of how negative childhood events may impact on brain development, and may help to monitor and mitigate adverse consequences of childhood trauma.

Over- and underreaction in detecting regime shifts and the neurocomputational substrates for estimating probability of change

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In dynamic environments where technology, markets, competitors and even narratives change regularly, many decisions are tightly associated with our ability to estimate and detect changes. Previous studies on judgment and decision making had established that people exhibit systematic biases in their estimation of change: we can overreact -- believing that a change has occurred such as a regime has shifted while in fact it has not -- or underreact depending on the stability of the environment and reliability of the information we receive. The goal of this study was to investigate these systematic biases and their neurocomputational substrates. In a probability estimation task, subjects were instructed that there were two regimes, represented by two urns -- a red urn and a blue urn. Each urn consisted of red and blue balls; the red urn had more red balls and the blue urn had more blue balls (same relative ratio). In each trial, ten samples were drawn sequentially from one of two urns. The regime can shift from one urn to another at most one time in a trial. After observing each sample, subjects had to estimate the probability that regime has shifted. We manipulated the stability of the environment by varying the transition probability between the regimes and the reliability of information by varying the relative ratio of red to blue balls, which we referred to as signal diagnosticity. We replicated the systematic biases shown in previous studies: compared with the ideal Bayesian solution, subjects ($n=30$) tended to overreact to a new sample by giving larger estimates on the probability of regime-shift in noisy (low signal diagnosticity) but stable environments (small transition probability). By contrast, subjects tended to underreact in precise (high signal diagnosticity) but unstable (large transition probability) environments. Further, we fit a quasi-Bayesian model that incorporate free parameters to separately estimate sensitivity to transition probability and signal diagnosticity under different environmental conditions. We found that sensitivity to both transition probability and signal diagnosticity are a decreasing function of their respective dimensions, consistent with a "system-neglect" model in which people respond primarily to the signal and secondarily to the system that generates the signal. Preliminary fMRI results showed that activity in the posterior parietal cortex (PPC) represents probability estimate on regime shift, while the ventromedial prefrontal cortex (VMPFC) tracks the amount of information collected. Together, these results indicate the possibility that PPC and VMPFC dynamically interact when estimating changes in environments.

Spotlight II Saturday, October 5th

Testosterone administration increases social discounting in healthy males

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Although testosterone is thought to induce antisocial and aggressive behavior, research on social economic interactions has associated it with prosocial and affiliative behavior. Most of the findings are based on social economic games in which the distinction between prosocial motives and other social motives, such as reputation building, strategic responding, and status management, is convoluted. Testing the effects of testosterone using paradigms that less ambiguously target prosocial motives is necessary to more accurately understand the effect of testosterone on prosocial behavior. In the present study, we aimed at investigating the role of testosterone in human generosity by combining testosterone administration with a social discounting task, where prosociality in the form of generosity was not confounded with other social motives. In each trial, healthy male participants were asked to choose between a selfish and a generous alternative. The generous alternative involved sharing money with either a close or a distant other, whereas the selfish alternative yielded a payoff only for the participant. We combined this task with testosterone administration in a double-blind, placebo-controlled, between-subjects design to test whether and how testosterone modulates generosity. Across two studies (total $n = 174$), we showed that a single dose of testosterone reduced model-free generosity, as indicated by smaller AUC of the amount forgone and steeper discounting in the testosterone group compared to the placebo group. Reduced generosity was particularly evident for interactions with distant others. We also found that testosterone increased perception of social distance; however, perception of social distance did not mediate the effect of testosterone on generosity. Our findings provide causal evidence that testosterone reduces generosity in human economic decision-making. Moreover, they suggest that the valuation and the perception of social distance are independently affected by testosterone.

Individual differences in dopamine predict self-control of everyday desires

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Humans experience a multitude of natural desires in their day-to-day lives. Practicing self-control to avoid giving in to these desires has both immediate and long-term consequences on financial stability, health outcomes, and general wellbeing. What, then, makes some people better at self-control than others? The neurotransmitter dopamine (DA) is believed to underlie individual differences in self-control abilities. Specifically, DA D2 receptors regulate decisions to inhibit impulsive actions in controlled laboratory studies. However, no study to date has examined whether such associations between dopamine and self-control measured in behavioral experiments also explain self-control for desires that are spontaneously experienced in the real-world. Using ecological monetary assessment (EMA), we repeatedly sampled 74 healthy adults' desires over the course of ten days. Participants used smartphone-based surveys to indicate desires they experienced, attempted to resist, and enacted in their daily lives. They also rated the degree to which the desires conflicted with personal goals--a previously identified predictor of self-control. These participants underwent a positron emission tomography (PET) scan with the high-affinity D2 radiotracer [18F]fallypride. Using mixed-effects logistic regression, we identified novel associations between EMA and PET measures. Within EMA measures,

degree of conflict with personal goals strongly predicted attempts to resist desires (OR = 3.36, $p < .001$) and failed attempts to resist desires (OR = .70, $p < .001$), corroborating prior reports. The association between degree of conflict with personal goals and predicted attempts to resist desires was moderated by D2 receptors in the ventral striatum (+1 SD OR = 5.18, -1 SD OR = 2.70, $p < .001$) and midbrain (+1 SD OR = 5.02, -1 SD OR = 2.65, $p = .001$). Individuals with lower D2 receptor availability in these regions were less likely to attempt to resist desires in spite of conflict with personal goals. However, the association between degree of conflict with personal goals and predicted failed attempts to resist desires was moderated by D2 receptors in the amygdala (+1 SD OR = .820, -1 SD OR = 6.40, $p = .050$). Individuals with higher amygdala D2 receptor availability were more likely to fail in their attempts to resist desires in spite of conflict with personal goals. These results are the first to demonstrate that dopamine impacts self-control in everyday life and suggest that individual differences in this system moderate the impact of conflict with personal goals on resistance of everyday desires.

The bounded rationality of probability distortion

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In decision under risk, participants act as if their choices were based on probability values systematically different from those that are objectively correct. Similar systematic distortion is found in tasks involving relative frequency judgments and confidence ratings. For simplicity, we will use the term probability for all these forms of uncertainty. Observed distortions are highly patterned and conform to a simple two-parameter model. They are also dynamic: the same participant can have markedly different distortions in different tasks (Zhang & Maloney, 2012, *Frontiers*). Why do we choose the particular probability distortions that we do choose? **MODEL.** We propose a Bounded Log-Odds (BLO) model of probability that allows us to predict the distortion actually observed in decision tasks and tasks involving judgments of relative frequency. The model is based on four assumptions. First, probability is represented as log-odds. Second, the actual internal representation of probability is on a bounded Thurstone scale with any value on the scale subject to perturbation by Gaussian error. As a consequence, the resolution with which probability values can be stored is limited. Third, the Thurstone scale is adaptive: it can represent any interval of the abstract log-odds scale by an adaptive mapping. It can represent a small range of log-odds at high resolution or a larger range at lower resolution. The fourth assumption is technical: objective probabilities can themselves be random variables (e.g. when based on binomial samples). We assume that the adaptive mapping stabilizes variance in probability estimates. **Experiments.** We test the model in four experiments, two involving judgments of relative frequency (JRF), one concerning decision under risk (DMR), and a fourth involving both. The last experiment allows us to compare probability distortion in two different kinds of task in a single participant. **RESULTS.** We demonstrate that BLO accounts for human performance in all of these experiments. We are able to predict individual choices of probability distortion function across tasks and conditions. We use factorial model comparison to separately test each of the assumptions of the model against alternatives. All are necessary. We show that BLO better accounts for data than any other model in the literature. Finally, we demonstrate that people, in choosing their probability distortions, come close to maximizing mutual information between the objective probabilities in a task and their internal representations (Shannon & Weaver, 1949), a form of bounded rationality (Simon, 1957).

Agreement with the group majority vote prevents consideration of past outcomes

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Past research on collective decisions focused on their accuracy benefits when compared to individual ones, but there is a lack in empirical studies addressing the individual motivations to engage or not in group decisions (El Zein et al., 2019). We argue that being a member of a group can protect individuals from negative consequences of decisions due to shared responsibility. To empirically test this claim, here we investigated how experienced outcomes triggering emotions of loss and regret impacted people's tendency to make decisions alone or in a group. In an online experiment on Amazon's Mechanical Turk, 125 participants (aged 19-57, mean age=31.72±7.31, 88 males) first selected whether to play alone or in a group with majority rule. Then they chose between two gambles with different probabilities of winning and losing, and both factual and counterfactual outcomes were shown to elicit regret (Coricelli et al., 2005). Expected value and anticipated regret both influenced decision-making about gambles replicating previous results (Coricelli et al., 2005). Interestingly here, individual choices were more strongly driven by loss and regret than choices that were factored into collective decisions. Using computational modelling, we investigated how outcome magnitude and valence (from a combination of factual and counterfactual outcomes) changed individuals' propensity to play alone or in group. Experienced outcomes affected participants' propensity to join a group both when participants were fully responsible (i.e., acting alone) or not at all responsible (i.e., in group minority) for decision outcomes: The higher the negative outcome, the more participants switched their status from deciding alone to deciding in a group or vice versa. However, participants did not consider past outcomes when they shared responsibility with others. When a participant's vote was consistent with the group majority, experienced outcome ceased to have any impact on their propensity to play alone or in a group. These results reveal an alarming consequence of consensual decisions: When bad choices made by majority vote lead to unpalatable outcomes, the protective shield of the collective may render the majority unwilling to make critical changes. To conclude, our study provides a mechanistic explanation of the motivations to join, stay in, or leave groups. It also offers some important insight into questions such as whether belonging to a ruling political party renders its members unresponsive to the party's failure and successes, or whether there is more variance in the decision to stay or leave a group when disagreements arise within a group.

The construction and deconstruction of suboptimal preferences through reinforcement learning

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Introduction. Wealth of evidence in behavioral economics and affective neuroscience suggests that option values are highly dependent of the context in which the options are presented. Building on an analogy with perceptual psychophysics and neuroscience, option valuation seems to be affected by both the spatial and temporal contexts. In a series of recent papers, we demonstrated that contextual adjustments also occur in reinforcement learning. However, the exact algorithmic implementation of context-dependence and how this process is affected by modulating feedback information, still remain unclear. To fill these gaps, we implemented 8 new variants of an instrumental learning task where we orthogonally manipulated outcome magnitude and feedback information, resulting in variations in reward ranges. Methods. In a first phase of the task (learning test), participants had to determine by trial-and-error the most favorable option in 4 fixed pairs of options. In a second phase (transfer test), the

original pairs were remodeled to investigate the choice preference between options extrapolated from their original context. Results. In 8 experiments, subjects learned above chance level. We replicate previous studies indicating partial range adaptation in the learning test and context-induced suboptimal preferences in the transfer test. We found that increasing feedback information (complete feedback) in the learning test increases the context-induced suboptimal preferences compared to the partial feedback case. Further analysis of trial-by-trial dynamics during the transfer test showed that, while complete feedback redresses suboptimal preferences, partial feedback has no effect. In complement to choice rate analysis, we developed a computational model that implements normalization by tracking the range of each decision context and adapting the perceived reward accordingly. Model simulations show that this model best explains subjects' behavior, capturing both the partial adaptation during the learning test and the context-induced suboptimal preferences in the transfer test. Model comparison indicates that the new model performs better compared to a simple Q-learning model and a previously proposed descriptive model, featuring normalization as a weighted average of absolute and relative outcomes. Conclusions. We provide definitive evidence of context-dependent reinforcement learning in humans and concomitantly propose a more satisfactory computational model to explain these processes. Between-task comparison indicates that increasing feedback information shows counter-intuitive results, since it decreases maximization in the transfer test.

Spotlight III Sunday, October 6th

Increasing honesty with "smart drugs": The effects of methylphenidate and atomoxetine on cheating behavior

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Objective: Dishonest behavior such as accepting bribes and tax evasion causes substantial societal damage across the globe. And trust in honest behaviour is needed to sustain the functioning of companies, industries and societies. Research on the neural mechanisms of honesty implicates a frontostriatal circuitry that receives modulatory input from dopaminergic and noradrenergic neurons. However, the neuromodulation of honesty has yet to be investigated. To examine the role of neurotransmitters in honesty, we examined the effects of methylphenidate (increases striatal dopamine (DA), frontal DA and norepinephrine (NE)) and atomoxetine (increases frontal DA and NE) on cheating behaviour. Both of these substances are used off-label as "smart drugs" to enhance attention and memory in educational and workplace settings. **Methods:** In a double-blind, placebo-controlled design, participants (N = 154) in our study were randomly assigned to receive either placebo (n = 52), methylphenidate (n = 50), or atomoxetine (n = 52). Participants then played a die rolling task that incentivized cheating and allowed us to distinguish different levels of cheating, from minor to severe. The die rolling task was embedded in a series of other incentivized tasks that measured self-interest, patience, and risk preferences. **Results:** We found substantial levels of cheating in the placebo condition. Relative to placebo, methylphenidate reduced cheating by 72% in total, and significantly reduced cheating at all levels, from minor to severe. In fact, participants who received methylphenidate showed no evidence of any cheating. Atomoxetine, by contrast, did not reduce cheating overall relative to placebo. However, we do find evidence that atomoxetine reduced cheating in those who felt a conflict between their honesty norms and their self-interest. **Discussion:** Our results suggest that striatal DA

plays an important role in increasing the value of honesty. In particular, we find that methylphenidate, which increases striatal DA, dramatically decreased cheating. Atomoxetine, which does not increase striatal DA, only modulated cheating in those who perceived cheating as wrong before the experiment. Given the high prevalence of "smart drug" use, with 14% of people world-wide reporting use in the last 12 months, our results also have important practical implications, suggesting that at least some smart drugs not only increase attention and memory, but also honesty.

Medial forebrain bundle structure is associated with impulsivity in humans

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Comparative studies implicate dopaminergic projections from the ventral tegmental area (VTA) to the nucleus accumbens (NAcc) in motivated behaviors. However, quantification of the structural qualities of these white-matter tracts in humans has proven difficult. Using diffusion-weighted imaging and probabilistic tractography, we aimed to identify white matter tracts connecting VTA and NAcc. We then tested whether structural properties of the tracts were related to individual differences in trait impulsivity, as assessed with the Barratt Impulsiveness Scale (BIS). Tractography was successfully performed in every subject from two independent samples (sample 1: n=40, 17 female, 32.7±11.8 years old; sample 2: n=31, 14 female, 51.7±19.5 years old). This revealed two distinct fiber trajectories between VTA and NAcc: an inferior trajectory that coursed from VTA through the lateral hypothalamus (LH) and entered NAcc from below the anterior commissure (AC), and a more superior tract that coursed above the AC and entered the internal capsule before reaching NAcc. Tract coherence metrics of fractional anisotropy (FA) and inverse mean diffusivity (1-MD) in the inferior VTA-NAcc tract were negatively associated with impulsivity (BIS-inverse MD correlation: $r=-0.49$, $p=.002$; BIS-FA correlation: $r=-.37$, $p=.02$). This was not the case with the superior VTA-NAcc tract (BIS-inverse MD correlation: $r=.05$, $p=.77$; BIS-FA correlation: $r=-.08$, $p=.63$), suggesting that the observed relationship was specific to the inferior VTA-NAcc tract. This relationship was strongest in a portion of the left inferior tract where it coursed through the LH ($r=.50$, $p=.001$; mean MNI coordinates: X=-5 to -7, Y=-8 to -2, Z=-10 to -9). To test the replicability of this association, we characterized the inferior VTA/SN-NAcc tract in a second sample. Calculating the correlation between BIS and inverse MD for the portion of the tract where the correlation was strongest in the first sample revealed a remarkably similar relationship (BIS-inverse MD correlation: $r=0.45$, $p=.014$). Discount rates (based on Kirby delay-discounting) were also correlated with inverse MD, and partial correlation analysis revealed that shared variance with trait impulsivity accounted for this relationship. Conventional DWI analyses which spatially normalized subjects' data from individual to standard space did not reveal the association. Collectively, the findings suggest that decreased coherence of the inferior VTA-NAcc tract is associated with increased impulsivity, and highlight a novel structural target for assessment in individuals with disorders marked by low impulse control.

Efficient noisy sampling and decision behavior

Joseph Heng¹, Michael Woodford², Rafael Polania¹

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Given the overwhelming evidence that decisions emerge via information sampling, what are the sources of noise, variability and "irrational" biases in the system's percepts guiding decision behavior? Can these observations be explained within a single, unifying and biologically plausible framework while accounting for the organism's goals? From the theoretical point of view, we clarify for the first time that

optimal decision behavior in capacity-limited systems can be parsimoniously achieved via discrete information sampling where, crucially, noise serves to optimize decision behavior while accounting for the organism's goals and environment statistics. This result makes it clear, why decisions must be noisy, given that: 1) one's nervous system relies on collecting discrete samples of information (e.g., high/low readings from neuron's action potentials), 2) is limited in its capacity to collect and represent information, and 3) we show that these noisy codes must be adaptive as they depend on the current goal of the organism (e.g., representing the world accurately or maximizing fitness). Crucially, this unifying theory is derived from first principles and with a parsimonious biological implementation. We test this theory on numerosity perception, as to the best of our knowledge, it has not been formally tested whether humans have evolved their number sense to maximize discrimination accuracy or to maximize fitness. Therefore, we implemented a set of numerosity decision experiments, where the goal of the decision maker is either to maximize fitness or accuracy (across four days of psychophysical testing for each participant (n=13, 2400 trials per participant) in a within subjects design), while carefully controlling for the environment statistics. Surprisingly, the results show that humans do not directly follow the normative efficient-coding recipes, but rather appear to rely on suboptimal but efficient proxy mechanisms of sampling from memory irrespective of the goals of the task. That is, while suboptimal, this sampling from memory strategy efficiently considers the environment statistics which is in turn the optimal strategy if neural systems are constrained to rely on comparing past experiences. Crucially, this model can explain the data better than other competing models including the well-established logarithmic model of number perception. These theoretical and empirical findings provide a novel mechanistic framework for understanding decision behavior while accounting for biological restrictions of noisy information coding and organism's goals, which could be extended to any other decision-making domain in humans, other species, and machines.

Investigation of the role of the ventro-medial prefrontal cortex local morphology in its functional organization

Alizee Lopez-Persem¹, Lennart Verhagen¹, Celine Amiez², Michael Petrides³, Jerome Sallet¹

¹University of Oxford, ²University of Lyon, ³McGill University

In humans, the ventro-medial prefrontal cortex (vmPFC) is, on one hand, assumed to be a key region for supporting decision-making processes. It is in particular associated with the ability to assign values to options that we are facing in our everyday life choices. On the other hand, the vmPFC is also one of the main hub of the Default Mode Network, a network classically activated during resting state and mind wandering. However, the term "vmPFC" does not refer to a specific anatomical delineated brain area. Functional neuroimaging studies that are classically based on statistical inferences established on the average brain activity of a group of subjects showed that "vmPFC" is used to label a large portion of the prefrontal cortex. It comprises various cytoarchitectonic subdivisions such as Brodmann area 10, 14, 25 and 32 and vmPFC boundaries are debated. Moreover, the fact that the classic neuroimaging approach is to average results across subjects in the MNI referential induces a glossing over of the interindividual variability of the morphological sulcal patterns of the vmPFC. In our study, using a dataset of 57 subjects from the Human Connectome Project for which anatomical MRI, resting-state MRI and functional reward-related task MRI data are available, we provide a precise description of the vmPFC sulcal patterns. First, we showed that sulcal patterns could vary either in terms of presence/absence of sulci but also in terms of shape or relative position to one from another. Importantly, we showed that the position of the main sulci influences the localization of the vmPFC peak of functional MRI studies. Those

results are critical for the investigation of the function of the vmPFC. First, they show that the brain area that we label "vmPFC" in two different contexts might be two distinct functional areas. In conclusion, we show that taking into account the variability in sulcal patterns might be essential to guide the interpretation of neuroimaging studies of the vmPFC.

Enhancement of the reward prediction error signal of midbrain dopamine neuron by the cost of obtaining the reward

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The midbrain dopamine neuron plays a central role in reward processing and represents the reward prediction error (RPE) to update the value of options. Here, we examined whether the RPE signals coded by the midbrain dopamine neuron are modulated by the cost paid to obtain the reward. Two macaque monkeys performed a saccade task. After fixation on a fixation point, the subjects were required to make a saccade to a condition cue and then a target appeared. In the high cost condition, long fixation to the target was required. In the low-cost condition, only a short fixation was required. After fixation on the target, the subjects made a saccade to the reward cue. Choice trials between condition cues and between reward cues were inserted randomly to test if the subjects showed a preference. Free reward and free air-puff trials were also inserted randomly to determine whether each dopamine neuron was of a salience or motivation subtype. Dopamine neurons were found to respond less when a cue was presented signaling that the monkey would have to perform a costly action compared to a cue signaling a less costly action, but dopamine neuron responses to cues predicting reward and to the delivery of rewards were found to be enhanced after the monkey had performed a costly action compared to a less costly action. These findings suggest that dopamine neurons incorporate the cost of performing an action into the prediction error signal, and specifically that reward prediction errors are enhanced following the performance of a costly action. The finding of an enhanced prediction error signal by cost generated a hypothesis about a novel behavioral effect: that monkeys would be faster to learn stimulus-reward associations after performing a costly action compared to a less costly action. This hypothesis was confirmed in a subsequent behavioral experiment. Thus, information about action cost is processed in the dopamine reward system in a manner that amplifies the dopamine RPE signal, thereby producing more rapid learning under situations of high cost.

Poster Abstracts

Poster Session 1 Friday, October 4th

A. Attention

1-A-1 Prolonged attention to probability reduces probability weighting in risky choice

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To determine the value of a risky monetary lottery, one must locate and integrate two kinds of information: reward magnitude and probability. The role that selective attention plays in this process is not well understood. Here, we tested the following hypotheses: visual attention to distinct features of the lottery (magnitude and probability) depends on the choice set, and differences in attention to the features of the lottery impact choice. 50 adults made 210 choices between a certain gain of \$5 and a lottery whose magnitude and probability of payout varied from trial to trial. On each trial, eye-tracking confirmed fixation on a centrally-located cross, and participants were presented with \$ and %, one on each side of fixation, indicating where magnitude and probability information for that trial's lottery could be found. Before choosing, participants viewed both features for as long as they wished. The display was gaze-contingent and eye movements to each periphery were required to reveal the information, so only one feature was ever displayed at a time. Thus, we recorded choice and the amount of overt attention that had been allocated to each lottery feature. Participants were randomly assigned to one of two choice sets: the value-diverse choice set paired 21 lottery magnitudes (\$5-\$80) with 5 lottery probabilities (0.2-0.8), whereas the probability-diverse choice set paired 21 lottery probabilities (0.2-0.8) with 5 lottery magnitudes (\$5-\$80). Each lottery was presented twice, counterbalancing the location of the magnitude and probability information; a subset of 50 lotteries were in both choice sets. One trial was randomly selected and the outcome was realized. We calculated a Feature Bias Index, FBI=prop. of attention to magnitude minus prop. of attention to probability. To model risk preferences and probability weighting, we used maximum likelihood to fit data with a two-parameter subjective utility model and a logistic choice function. Choice sets influenced attention and probability weighting. FBI scores in the probability-diverse environment were significantly lower than in the value-diverse environment, indicating increased attention to probability. Estimates of probability weighting in the probability-diverse choice set were significantly higher than in the value-diverse environment, indicating that the probability-diverse choice set also led to reduced probability weighting. In short, the ratio of distinct magnitudes and probabilities in the choice set influenced trial to trial attentional strategies, which co-occurred with changes in subjective probability estimates. Study supported by an NSF Research Opportunity Award to MG and IL.

1-A-2 Out of sight, out of mind: Visual attention and loss aversion

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While economic theory can generally account for individual differences across subjects, it has largely failed to explain choice inconsistencies within individuals. Random Utility models (RUM) are commonly employed to account for such within-subject differences, as these incorporate noise into the modelling of choices. While this approach might enable empirical estimations, it models as noise potentially important choice-related processes that might account for such choice inconsistencies. Here we hypothesize that attention provides a mechanistic explanation underlying previously observed choice inconsistencies. As a proxy for attention we use eye-tracking to investigate visual fixation patterns (saccades and dwell times) while participants made risky decisions over mixed gambles. In two experiments, (N1=41, N2=51), we independently vary the amounts of potential gains and losses (offered with equal probability) on each trial. Importantly, we spatially separate the presentation of the gain and loss amounts of lotteries in the visual display to improve recordings of visual fixation patterns using eye-tracking. Each participant completed a total of 160 trials without feedback. Using a RUM framework, we

estimate logistic regressions with random effects within which we directly account for the effects of attention on decisions. Thereby we directly model an important cognitive process that supports decision-making, which also reduces potential sources of noise in our models. Our results show that longer dwell times on gains, reflecting more attention, are associated with a greater likelihood of accepting the gamble, while longer dwell times on losses reduce the chance of accepting a gamble. The attentional effect of losses occurs both directly and through the relative increase in the weighting of losses over gains (i.e. Loss aversion). Additionally, dwell times on the different attributes are influenced by their values, with larger stake sizes attracting more attention (but not strongly). To test attentional effects on beliefs, we also elicit participants' level of confidence in the correctness of their choice in the second experiment. Jointly, our results indicate that attention plays an important role in risky decision-making involving gains and losses. Importantly, greater loss aversion is associated with greater deployment of attention to losses (relative to gains), supporting the notion that cognitive mechanisms involved in the initial processing of choice-relevant information can have an important impact on subsequent valuation processes.

1-A-3 Is the decoy effect an attention-driven phenomenon?

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The decoy effect is a well documented example of a preference reversal in which individuals seem to change their subjective valuation of two options (A vs B) when a third, irrelevant, alternative (C) is introduced in the choice-set. However, the mechanisms underlying the decoy effect are still imperfectly understood. Why should an irrelevant change in the choice-set affect decision-making? Here, we examine the hypothesis that introducing a third alternative in the choice-set causes changes in the allocation of visual-attention to the options, and in turns visual-attention changes give rise to changes in the decision process. We investigate and replicate the attraction effect in a lottery task, i.e., individuals change their risk attitude as a function of whether the decoy relates to option A or B. Although the decoy is basically never chosen it has a considerable effect on the relative allocation of attention to the two relevant options. If the decoy similar to option A it induces frequent comparisons between the decoy and this option and thus strongly increases the relative attention to option A. We then ask how and by which mechanisms these shifts in visual-attention allocation could influence choices. Based on an evidence accumulation process (race model and aDDM), we test different modeling hypothesis that could explain the decoy effect through a reallocation of visual-attention without changing the valuation of the options in the choice set.

1-A-4 Combining choices and response times in the field: A drift-diffusion model of mobile advertisements

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We study how choice and response time data can be combined to estimate the effectiveness of manipulating attention to advertisements. We utilize the class of drift-diffusion models -- originally developed in psychology and neuroeconomics to jointly explain laboratory subjects' choices and response times -- to model users' responses to video advertisements on mobile devices. To

accommodate important features of this setting, we propose a "two-stage" extension of the drift-diffusion model. In the first stage, the user is exposed to the ad and cannot make any decision while the video ad is being played (it is "non-skippable"). We call this the ad exposure stage. In the second stage, users are prompted to either click-through or click-back. This is the decision stage. By combining response times with choice data, we can separately identify the parameters of the diffusion processes during both the ad exposure stage as well as the decision stage. We apply our drift-diffusion model to responses to advertisements on mobile devices, a decision scenario which in recent years has become the dominant component of internet advertising. We observe $N = 194,607$ ad "impressions" from a mobile ad network for mobile games, as well as user demographics. We find that the diffusion process changes strikingly between the two stages. In the initial ad exposure stage, the diffusion process drifts toward the advertised app. But once the ad finishes, the diffusion process shifts course and drifts back towards the originating app. This change likely reflects the difference in information attended to by users in the two stages: while users initially see new information contained in the video ad, once the ad finishes, users compare this new information to their previous gameplay experience in the originating app. The incorporation of response times is crucial for identifying these effects: the change in drift of the diffusion process leads to longer response times. Without the change in drift, response times would be quicker and more instantaneous than what we observe in the data. Using our estimates, we address the counterfactual of whether users should be permitted to skip part or all of a video advertisement before making a choice. Overall, we find that allowing users to skip the ad after ten seconds yields the same revenue as forcing them to view the entire thirty-second ad, thus rationalizing the practice of some platforms (e.g. YouTube) where users can skip an ad after 5 or 10 seconds. However, the effects are very heterogeneous across users. Ad revenue can be higher if the "skip-ability" of the ad could be targeted and individualized according to users' demographics.

B. Choice & Choice Mechanisms

1-B-5 Choice framing effects arising from non-choice items

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Imagine a decision about whether or not to buy a particular item. How might other items on display in your field of vision impact your choice? Prior work suggests that the mere presence of non-choice items can elicit decision-related evaluations (Lebreton et al. 2009; Tusche, Bode & Haynes 2010 etc.) and that even explicitly unavailable "phantom" options may still influence choice (e.g. Pratkanis & Fahrquhar, 1992.) If non-choice items on display are evaluated as valid choice set options, most models would predict the qualitative nature of their influence would depend on their relative subjective value compared to the choice target. Recent findings argue against this, and instead show that display items' influence is dependent on their congruency with the target's category (Karmarkar, 2015; Friedman, Savary & Dhar, 2018.) Specifically, purchase intent for a target item is increased when display and target items come from the same category, and decreased when display and target items' categories are mismatched. One possible mechanism governing the distinct role of display items may be that mismatched items distract from the target (while matched items reinforce the target category's value.) To explore this, forty-nine participants in an eyetracking study made incentive compatible purchase decisions about target items shown with neutral landscapes, category-matched items, and category mismatched items. Landscapes were chosen to reflect additional visual information that could not be interpreted as part of the choice. Mixed-effect logistic regressions showed that participants were significantly more likely to purchase target items in the matched and mismatched conditions compared

to those shown with landscapes. Post-hoc comparisons confirmed that purchase rates were higher in the matched condition compared to the mismatched one regardless of the display items' subjective value. On average, participants had similar total fixation durations for target items across matched and mismatched trials. However, fixation times for the display items were longer in the mismatched trials compared to the matched ones. Thus mismatched display items do not necessarily divert attention away from the target, but do capture more attention themselves. This could raise the salience of opportunity costs and/or a broader range of options as valid alternate considerations in the decision. We integrate these findings with additional studies testing item memory and price salience to propose a model in which display items define the category scope considered in a choice, serving as choice frames rather than choice options.

1-B-6 Sources of confidence in value-based choice

Jeroen Brus¹, Marcus Grueschow¹, Rafael Polania¹

¹ETH

The evaluation of confidence in value-based decisions is essential to guide goal-directed behaviour, learning and group decisions. Despite its importance, it remains unclear what confidence judgments really reflect. This has been a difficult question to answer given that behavioural paradigms and mechanistic models attempting to capture the underlying sources of confidence do not allow to formally tease apart key aspects of the decision process. For instance, whether confidence reflects the reliability of subjective valuations of the choice alternatives, or downstream noise due to comparison processes, or both. Additionally, previous studies have ignored the role of endogenous attention in confidence judgments, which is an essential component of value-based decisions. Here, we address these issues in a unifying framework that takes into consideration capacity limitations of biological systems during value-based decisions. This allows dissociating sources of noise due to imprecisions of subjective valuation from downstream noise in the comparison process, and crucially, we extend this framework by incorporating the influence of attention. We designed a value-based choice paradigm that allowed us to mechanistically disentangle the sources of confidence emerging from value-based decisions. Surprisingly, we find that confidence does not reflect imprecisions in the representation of subjective values, but rather downstream noise due to comparison processes. Additionally, we uncover a novel dynamical signature of endogenous attention in value-based choice, which participants appear to track via metacognitive processes, playing a fundamental role in confidence judgments irrespective of gaze dynamics and other sources of noise. These findings reveal a new mechanistic interplay of endogenous attentional states and noise for guiding decisions and metacognitive awareness of choice certainty.

1-B-7 Classifying individuals into "Info-Types" based on information-seeking motives

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Objective: As massive amounts of information are becoming available, people must decide whether they want to receive personalized information about their health, genetic make-up, social standing etc. Deciding whether to seek personal information (i.e. 'should I undergo recommended diagnostic testing for disease?') can be difficult, because while information can inform action (i.e. 'I may be able to treat the disease if I learn I am a carrier') it can at times induce negative affect (i.e. 'I will feel bad if I learn I am a carrier'). Here, we test the hypothesis that people can be classified into different "info-types" based on

the relative importance they place on the instrumental utility and hedonic utility of information. We hypothesize these classifications are meaningful as they provide clues about people's mental health. Methods: Participants (N=200) indicated whether they wanted to receive 80 different pieces of information relating to their health and personal characteristics. They also rated their expectations regarding how useful each piece of information will be and its likely impact on their affective state. Results: Cluster analysis revealed two well-defined "info-types". Approximately half the participants made information-seeking decisions based predominately on whether information was useful in guiding action (the "Dogmatic Action group"). The other half of participants also took into account the expected influence of information on their affect (the "Affect-Action group"). Those who integrated affect and action considerations were generally more likely to avoid information. They were also less likely to sign up for a follow up study in which they would learn what others thought of them, when we highlighted the information could induce negative emotions. Interestingly, it was also this group that exhibited less depression and anxiety symptoms. This suggests information avoidance is an emotional regulation strategy that is impaired in individuals with affective disorders. Conclusion: In deciding whether to seek knowledge people differ in the extent to which they weight the usefulness of information and its impact on affect. Our study highlights two possible applications of classifying individuals into "info-types". First, information can be framed according to an individual's information seeking type in order to increase the likelihood that knowledge will be consumed. Second, we have shown that information-seeking patterns are related to psychopathology symptoms. Thus, our research could inform the development of new screening tools, which are based on information-seeking behavior.

1-B-8 Associations of loss aversion with feedback-related negativity during free and restricted choices.

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Losses tend to be overvalued compared to gains of the same amount, a phenomenon known as loss aversion (Kahneman and Tversky, 1979). Previous studies have investigated the neural mechanisms related to loss aversion in conditions where participants had freedom of choice, and loss aversion has been shown to be associated with the feedback-related negativity (FRN) potential component (Kokmotou et al., 2017). However, real life decisions are often constrained by external factors that are outside the decision maker's control and which can change the range of available outcomes. Whether loss aversion is also associated with neural responses to outcomes if those outcomes are arbitrarily inflicted upon an individual rather than freely chosen remains to be explored. The present study investigated the associations between loss aversion and neural responses to monetary outcomes resulting from free and imposed choices using electroencephalographic (EEG) recordings. Participants (n = 24) completed a monetary gambling task which required them to choose between a 50% chance of winning or losing variable amounts of money versus a sure outcome. Similar to previous studies (Sokol-Hessner et al., 2009; Stancak et al., 2015), parametric modelling of participants' choices was employed to estimate individual differences in loss aversion. A subsequent gambling task was used to evaluate neural responses to monetary outcomes resulting either from participants' own choices or irrespective of their choices. Event-related potentials (ERPs) time-locked to outcome presentation were analysed separately for free and imposed choices. FRN was evaluated as the difference between loss and gain

ERPs following each choice condition and was correlated with loss aversion. Losses led to more negative ERP amplitudes following free compared to forced choices, while there were no statistically significant differences for gain outcomes. Importantly, loss aversion was associated with FRN only following free choices. Furthermore, the above findings pertained only to those participants who exhibited strong neural responses to the switching of their original choice for an arbitrarily imposed choice. Results suggest that loss aversion is associated with the neural processing of outcomes only when outcomes are contingent upon one's free choices and only for those displaying sensitivity towards having the freedom of choice. Thus, loss aversion appears to depend on a component of perceived ownership of the decision.

1-B-9 Decomposing preferences with the drift diffusion model

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Decision making is complex because there are often many factors that can influence choices. For example, you might choose an item of Type A over an item of Type B because A's are generally better than B's, because A's come with a bonus that B's do not, because you get more of A than you do of B, or simply because A is better than B in this particular instance. It is important to be able to distinguish between these cases, since they make different predictions about what people will choose in new scenarios. In the perceptual domain, at least two types of biases have been identified: response bias and stimulus bias. Response bias occurs before the options are presented, whereas stimulus bias occurs while evaluating the options. We also introduce a third "magnitude" bias, which is a stimulus bias that increases with magnitude. These biases affect the decision process in distinct ways, leading to different patterns of choices and response times. We use the drift-diffusion model (DDM) to detect these patterns. We ran two experiments, each with conditions designed to elicit different biases. Subjects (n=93, 67) first rated how much they would like to eat various snack foods, then made binary choices between those foods. We randomly designated options on one side of the screen as the targets. Our conditions were as follows: (1)Demand - we told subjects that we were testing if people favor options on one side. (2)Quarter - the target side came with a bonus of 25 cents. (3)Double - the target side came with double the amount of food or two foods of the same value. (4)Proportion - the target side had higher value foods a majority/minority of the time. We hypothesized that participants would exhibit a response bias in the Demand and Proportion conditions, a stimulus bias in the Quarter condition, and a magnitude bias in the Double condition. Our results reveal that while there was no overall starting point bias in the Demand condition, there was one in the Proportion condition. Both the Quarter and Double conditions displayed stimulus biases but the bias was larger in the Quarter condition. Finally, in the Double condition, we observed a magnitude bias. We also investigated how starting point biases can change over time. In the Quarter and Double conditions, starting points increased with trial number as subjects learned that one side was consistently better. But in the Demand condition, starting points decreased with trial number as subjects learned that one side was no better than the other. Our findings indicate that in value-based decision making, different components of preferences can indeed be differentiated with DDM.

1-B-10 Early Childhood Trauma negatively affects real-life outcomes via detrimental effects on neurodevelopment: Large-scale evidence from the UK biobank

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Early childhood trauma (ECT) is associated with negative financial, social, and health outcomes during adulthood. Do these negative long-term consequences of trauma reflect detrimental effects on brain development? Here we report the results of a large-scale pre-registered study conducted in a general population sample from the UK Biobank (N = 13,554). We investigated how ECT is associated with MRI-derived neuroanatomical phenotypes of macrostructure (grey matter volumes obtained from T1 images) and white-matter microstructure (obtained from DTI and NODDI analyses), and how these neural phenotypes translate into behavioral phenotypes. All our analyses controlled for the effects of sex, age, height, socioeconomic status, and genetic setup (first 40 principal components of PCA on genetic variation in the population, derived in an independent sample with N ~ 500,000), ruling out the influence of these confounding factors. A whole-brain analysis revealed that early childhood traumatic events (ECT) was associated with grey matter volume decreases in distinct prefrontal areas (vIPFC, dIPFC, and vmPFC) as well as areas in the cerebellum. Interestingly, ECT was not only associated with anatomical macrostructure of the prefrontal areas mentioned above but also with white-matter microstructure of afferent and efferent fiber pathways connecting these areas. Specifically, such associations were found for fractional anisotropy and intra-cellular volume fraction of the anterior corona radiata, the genu of the corpus callosum, and the superior longitudinal fasciculus (all P s < 2×10^{-4}). To further examine brain-behaviour associations, we found that ECT was negatively associated with fluidic IQ (Structural Equation Modeling, $\beta = -.08$, $P < 1.3 \times 10^{-19}$) and that this effect was mediated (7.8%, $P < 2.27 \times 10^{-5}$) by whole brain volume differences. Congruent with this, we also found that ECT correlated with lower long-term economic success (Structural Equation Modeling, $\beta = -.21$, $P < 1.8 \times 10^{-120}$); this effect was again mediated (3.5%, $P < 3.6 \times 10^{-6}$) by overall brain volume. Our results inform psychological theories and mechanistic models of how negative childhood events may impact on brain development, and may help to monitor and mitigate adverse consequences of childhood trauma.

1-B-11 Commonalities between the attraction effect and the Gestalt law of proximity

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Objective: Since we live in a noisy world with endless sensory information around us, we aim to perceive reality as efficient and effective as possible, but under constraints of limited resources and capacity of the nervous system. This limitation is demonstrated in the sensory domain through perceptual heuristics and illusions. Previous studies demonstrated that there are analogies and similarities between sensory and value processes. This notion led us to examine the mechanisms underlying choice biases such as the attraction effect using a well-defined perceptual mechanism: proximity grouping according to the Gestalt theory. Methods: We performed two identical experiments with 119 subjects in total. Each experiment consisted of two tasks: 1) A Gestalt task, which estimated for each subject the threshold for differentiating between two stimuli of 12 dots arranged in a row, while the distance of the dots in one of the stimuli was systematically varied across trials. 2) A decoy task, which measured for each subject her tendency to be affected by the introduction of a decoy option to the choice set. In the basic condition, participants made choices between two gambles. In the decoy condition, we systematically varied the value distance between the Decoy and the Target gambles. We then, related for each subject their sensitivity threshold to the Gestalt law of proximity and their tendency to be affected by the attraction

effect. Results: We found that the further away (in terms of value) the Decoy was from the Target, the less the subject chose the Target, and hence, demonstrated a weaker attraction effect. Moreover, we found that the lower the Gestalt sensitivity threshold of a given subject (more sensitive to the proximity low), the more the subject tended to choose the Target option (displayed a stronger attraction effect). Importantly, we replicated these preregistered results in a second identical experiment and analyses. Conclusions: Based on our results, we suggest that the variation across subjects in their susceptibility to the Gestalt law of proximity might account for some of the variation observed in the attraction effect. We have demonstrated a within-subject link between the sensitivity to a perceptual heuristic (proximity law of Gestalt theory) and the sensitivity to a value-based bias (attraction effect), which may indicate that a common mechanism of the brain is involved in perceiving both sensory and value information. These findings support the notion that sensory and choice biases are the consequence of a small number of canonical computations and patterns in the brain, which we use to represent our environment efficiently.

1-B-12 Testing the DDM: A behavioral Experiment to measure evidence accumulation during decision making

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OBJECTIVE: Drift-diffusion models (DDM) have had empirical success in fitting choice and reaction time behavior as well as electrophysiological recordings during binary choice. The standard assumption is that evidence accumulates according to an (unobserved) underlying stochastic process with a drift that depends on the stimulus, but usually neither on the state of the accumulator nor on time. Here, we present a behavioral experiment designed to directly visualize the "drifting particle" of the DDM by measuring how choice accuracy evolves with time. This permits more direct inference on the form of the underlying stochastic process than do traditional approaches, allowing us to better differentiate between competing models of evidence accumulation. **METHODS:** In each of 360 trials, our 159 subjects were briefly shown (simultaneously) 100 small circles (some red, some blue), and were asked whether the majority of these were red or blue. After their response, we elicited subjects' probabilistic beliefs (or confidence) that their preceding choice was correct. We systematically varied the duration for which the circles were visible prior to onset of a visual mask. Three treatments are examined: unpredictable-time-of-offset, unpredictable-time-of-onset, and free-response (which corresponds to a standard reaction time experiment). Finally, separate blocks of trials also manipulated the prior probability of "red" being the correct response. **RESULTS:** As expected and previously demonstrated, choice accuracy increases as a function of the time during which the circles are displayed. Increasing signal strength scales these curves, while changes in prior probability shift them in their early stages. The influence of the prior on the decision variable decays over time. The rate at which evidence accumulates over time is revealed as a function of signal strength and prior, allowing us to quantitatively compare this process with the predictions of the DDM. One striking feature we observed was that evidence against the prior accumulates at a faster rate than evidence in favor of the prior. Reported confidence is linearly correlated with the accuracy of the decisions, and provides further empirical restrictions on the model. **CONCLUSIONS:** Visualizing the "drifting particle" using this experimental methodology allows us to infer the form of the stochastic process according to which evidence accumulates. While the DDM approximates key features of this process quite well, preliminary analysis of our data suggests that it can

be improved upon by considering more general stochastic processes, for example one with a drift rate that depends on the state of the accumulator.

1-B-13 Language and recall regions of the brain track evidence of guilt in mock criminal scenarios.

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Criminal trial verdicts often elicit controversies that undermine public confidence in the justice system. Maximizing the benefits of the justice system requires an understanding of the juror decision-making process. Here, we seek to understand how different factors influence the decision-making process by identifying the neural substrates active as different aspects of the criminal scenario is presented. We performed fMRI scanning on 32 participants (29 analyzed) while details of mock criminal cases were revealed to them sequentially in random order. Information provided to participants included the type of crime and three categories of evidence (physical evidence, prior criminal history, and the presence of a witness). Each of these pieces of evidence differentially contributed to likelihood of guilt, as measured by subjects' ratings of the strength of the case against the accused. We focused on the effects of two aspects of the crime scenarios presented: available evidence and the type of crime described. First, we consider deliberative accumulation of evidence. For each piece of information revealed, the accumulation of evidence in each scenario was modeled as a sum of the weight of each factor, with model weights determined by previous large-scale behavioral studies. Whole-brain corrected univariate analyses found a network of brain regions whose activation increased linearly with the accumulation of evidence, including: posterior parietal; anterior cingulate; visual; parahippocampal; temporal pole; and lateral frontal cortices. These regions are typically associated with working memory, reading comprehension, and fact recall. Evidence accumulation within this network could then be interpreted as a process of matching patterns in the crime narrative to weigh its veracity, but not as moral culpability as is typically emphasized. Second, we tested for the less deliberative effects of crime type, which could be viewed as biasing. In previous behavioral work, crime context contributed both to perceived case strength and to desire to punish; different crimes were found to vary in the strength of bias they evoked. The neural response to crime type encompassed a network of regions including lateral frontal cortex and temporal parietal junction which correspond more closely to moral decision making than to the evaluation of narrative cohesion. These findings support a complex view of juror decision making that integrates narrative pattern matching and a moralistic calculation.

1-B-14 Conjoint measurement of quality and quantity of sensory data in evidence-based decision-making

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Many decisions we make rely on how we evaluate sensory evidence associated with the options under consideration. Critically, the reliability of sensory evidence depends on two important attributes - the quality of each single datum and the quantity (sample size) of sensory data. Despite great progress in understanding how decision makers accumulate evidence over time in decision making, it remains unclear how people evaluate and combine the quality and quantity of sensory data in evidence-based

decision making. To address these questions, in this study, we designed a novel decision task that requires the subjects to take into account both attributes in order to maximize payoffs. We employed a particular method - conjoint measurement - that simultaneously estimates the subjective scaling of these attributes and their interaction during decision making. In a lottery decision task subjects chose between options that differed in both the quality and quantity of sensory data. Once an option was chosen, the subjects had to perform a guessing task on the selected option. An option consisted of red and green dots shown on a computer screen. The subjects were told that these dots were randomly drawn from a box consisting of 100 red and green balls and his or her task was to guess whether there are more green or red balls in the box based on the available information. Subjects would receive a reward if making a correct guess and otherwise nothing. To produce different qualities of sensory data, we manipulated the gray scale of the red and green dots so as to change the discriminability between these two colors. Quantity of data was manipulated by changing the number of dots presented on the screen. In three behavioral experiments (n=70 subjects), we found that subjects in general chose the option that led to greater likelihood of making a correct guess. We fit 5 different conjoint models and found that an additive model that assigns equal weights to quantity and quality and that linearly combines them best described subjects' choice. Notably, we consistently observed across the experiments a small but statistically significant bias that can be attributed to a preference for the quality of sensory data. This bias is captured by the additive model in which the decision maker ignores the interaction between quantity and quality at the medium to high level on performance in their corresponding subjective scales. Together, these results provide key insights into evidence-based decision making and demonstrate conjoint measurement as a powerful method for measuring subjective scaling of evidence attributes and their interactions with minimum parametric assumptions.

1-B-15 The neuroeconomics of narratives and asset-price bubbles: Persuasive bubble-driving narratives may favor valuation- over control-network activation

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Objective: Narratives (e.g., "housing prices will keep rising" and "dot-com stocks are a great investment") may drive asset-price bubbles by persuading investors to focus attention on supposedly positive aspects of assets (Shiller, 2017). Furthermore, narratives may elicit bubble-related herding (Baddeley, 2010; Stiglitz, 2011) by activating an evolutionary predisposition to group behavior seen also in non-human species (Haracz, 2013). Therefore, this review seeks neuroeconomic mechanisms potentially mediating the spread of bubble-related narratives. Methods: A systematic literature review focused on neuroimaging studies of herding (i.e., social conformity), persuasion, and narrative-influenced attention. Results: Valuation-network components (i.e., nucleus accumbens [NA] and ventromedial prefrontal cortex [vmPFC] or orbitofrontal cortex) were activated in subjects showing a herding-like change in opinion or behavior (Zaki et al., 2011; Wei et al., 2019). Exposure to persuasive health-related messages was associated with increased connectivity between the NA and vmPFC (Cooper et al., 2017; Falk and Scholz, 2018), as well as less connectivity in the frontoparietal control network (Cooper et al., 2018). This connectivity pattern, increased in the valuation network and decreased in the control network, was found relative to healthy controls in individuals with heroin addiction (Xie et al., 2014; Zhai et al., 2015; Zou et al., 2015) or internet gaming disorder (Dong et al., 2015), suggesting a tendency for these networks to function alternatively or in opposition. Suggesting an opposing functional relationship, lab-market bubbles were driven by asset buying based on NA activity, whereas crashes were triggered by

selling related to anterior insula (AI) activity (Smith et al. 2014). The AI may signal the need for deliberation and frontoparietal activity (Chang et al., 2013; Hinault et al., 2018). NA- or AI-mediated asset-buying or -selling, respectively (Smith et al., 2014), may reflect roles of these areas in attention focusing. The NA or AI was activated when subjects were instructed to focus, respectively, on positive or negative aspects of stimuli (Kruschwitz et al., 2018). Conclusions: Persuasive bubble-driving narratives may favor valuation- over control-network activation. This proposed bubble-driving role for the valuation network, which includes neocortical areas, represents a refined neuroeconomic theory of bubbles (Haracz, 2013) that now emphasizes relatively, rather than absolutely, predominant control over decision making by evolutionarily ancient or new brain structures during, respectively, bubble or non-bubble periods of market activity.

1-B-16 Arousal and neural signals during deliberation to exert physical effort

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Pupil diameter increases during physical effort, in a way that is proportional to the intensity of the exerted effort. These pupillary changes are associated with effort-related noradrenergic activity. However, it remains unclear whether such pupillary responses can also be observed during choice deliberation about effort to be exerted in the future. Here, we show that pupil dilations reflect an anticipatory energisation process during choice. We measured pupil responses while healthy participants (N = 50, 27 females, mean age = 22.4 (3) years) made decisions about whether to accept or reject monetary reward offers that required effort, without executing the effort immediately. Rate of acceptance increased with larger rewards and decreased with larger effort associated with the choice option. Pupillary dilation showed a significant choice-by-effort interaction that was driven by a faster rate of dilation (ROD) when participants were choosing to accept (vs. reject) high-effort options. This suggests that pupil-linked arousal systems participate in an energisation process when participants choose to 'go for' a big challenge; namely accepting (vs. rejecting) offers associated with high effort. Using fMRI, we found a similar choice-by-effort interaction for activity in the supplementary motor area (SMA) / anterior cingulate cortex (ACC) and bilateral anterior insula (whole brain, FWE-corrected $p < 0.05$). Extracted activity within these SMA/ACC and insula clusters showed a correlation with the 'go for it' response in the pupil data: Individuals with faster pupil ROD when accepting (versus rejecting) high-effort offers had larger SMA/ACC and insula signal changes for this contrast. This effect remains robust even in cases for which RT differences are controlled. Thus, our results pinpoint a brain process instantiating anticipatory arousal to prepare for a physical challenge, in the absence of actual exertion, potentially reflecting simulated energisation.

C. Consumer Behavior & Marketing

1-C-17 The N400 study of price perception

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Inspired by the success in the neuroeconomics of purchasing decisions, neuromarketing specialists strive to identify an objective and affordable approach to apply to real-life campaigns--this method seems to be electroencephalographic (EEG) neuroimaging. One such EEG candidate is the N400 component of event-related potentials (ERP). The N400 of semantic processing appeared promising in marketing communications in general and branding in particular. Recently, we found that N400 could be sensitive to

the strength of brand associations (Gorin et al., submitted for publication). We showed that incongruent brand associations elicited the N400 brain response in humans, similar to the response, which occurs when processing linguistic information. We hypothesized that N400 would be elicited by the mere incongruence of a product and its price. We tested if inflated or low prices would evoke more significant N400 responses than evoked by market prices. We modified the price fairness task proposed by Herbes et al. (2015) to assess if inflated or low prices would evoke the N400 response. Each trial employed an identical structure: subjects first saw one of two products (mobile phones), then a randomly chosen price (low, accurate or high). Following the presentation of the price, the price was replaced by a context-defining word—either 'cheap' or 'expensive'. For example, the presentation of Nokia (with an accurate price of 1000-2000 roubles or 15-30 USD) with 30,000 rubles (or 450 USD) and 'cheap' denoted an incongruent condition, whereas the combination of Apple iPhone X (with an appropriate price of 70,000-110,000 Russian rubles, or 1,000-1,650 USD) with 110,000 rubles, and 'expensive' denoted a congruent condition. Trials ended when subjects indicated whether they agreed or disagreed with the correctness of the expression. We analyzed the brain activity associated with the beginning of the final condition-defining words. This experiment was replicated once more using another set of stimuli. In both experiments, the excessive and the low prices evoked N400-like responses 300-400 ms after the presentation of the condition-defining word. This activity had centro-parietal distribution. For each of the four products, the polarity of the N400 response to the incongruence of the price and the condition-word was affected by the degree to which the presented price conflicted with the fair price; this, in turn, accurately corresponds with the average market price. This work was supported by the NeuroTrend company in the framework of the research project №NB/I-1-01.01/2017 to develop neurotechnology which monitors customer behavior in various contexts.

1-C-18 Hierarchical Recurrent CNN for Decoding Valuations from Neural Activity to Predict Consumer Preferences

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There is increasing demand within consumer-neuroscience (or neuromarketing) for objective neural measures, such as may be obtained from Electroencephalography (EEG), to quantify consumers' preferences and predict responses to marketing campaigns within individuals and the general population. However, the properties of EEG datasets raise various difficulties when performing predictions on them, such as small data sets, very high dimensionality, the need for elaborate and exploratory feature extraction, intrinsic noise and obscurity, and unpredictable between-subject variations. Our aim is to try and overcome these limitations using a Deep Learning Network, a methodology that has revolutionized many research fields, and by combining several state-of-the-art techniques to address these drawbacks while providing interpretable results for neuroscientific and decision-making insight. In our study, we developed a DLN model to predict subject-specific preferences based on their EEG data. In each trial, 120 subjects were presented with a local product's image (out of 72 possible products) together with its short description, followed by a standard BDM task to elicit how much they were willing to pay (WTP) for the product. The DLN uses EEG recordings from product observation to predict the corresponding reported WTP values. Our novel DLN architecture considers the unique characteristics of the EEG signal by including depth-wise separable convolution for spectral and spatial filtering, and Hierarchical LSTMs for time-dependencies (within and between trials). Our interim results show 75.7% accuracy in predicting high vs low WTP, while network visualizations provide the

predictive frequencies of neural activity and their scalp distributions, shedding light on the neural mechanism involved. In conclusion, DLNs may be the superior method to perform EEG-based predictions, due to ability to consider multiple dependencies, improve SNR, and eliminate manual feature extraction by automatically identifying optimal value-related information, to the benefit of decision-making researchers and marketing practitioners alike.

1-C-19 Reward type matters for probing behavioral similarity across species: A comparative study on rat and human consumers

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Here we propose a novel human consuming paradigm translated from a rat effort-budget task to investigate the behavioral similarities in cross-species economic decision-making. In our previous animal study, rats were trained to trade effort (i.e. nose-pokes, NP) for milk rewards (i.e. chocolate and vanilla soymilk) and we also manipulated the price (i.e. number of NP required to get a reward) of the two rewards, as well as the size of individual budget (i.e. total number of NP available per session). In this study, we recruited heterosexual male subjects (n= 64), aged between 18 to 32, to participate in two tasks: Picture task and Food task. In the Picture task, subjects were instructed to trade a certain number of button-presses (BP) to obtain two types of sexual reward (i.e. a picture of sexual female body or a beautiful female face). In the Food task, subjects were asked to stay fasted for 4 hours prior to the experiment, and during the experiment, they could spend their budget of BP to purchase two types of food reward (i.e. chocolate and vanilla soymilk), same as we used in the animal study. Both tasks have the same A-B-A block design as the animal paradigm that A refers to the Baseline session in which two rewards were equally priced and B refers to the budget session when preferred reward in the previous baseline became more expensive and individual budget either maintained unchanged (i.e. Uncompensated budget) or got compensated for the price increase (i.e. Compensated budget). The order of the two tasks was counterbalanced among subjects, as well as the two budget sessions within each task. Firstly, we found a similar price and budget effect on human consuming behavior in both tasks as we observed on our rat consumers that demand for preferred reward decreased as its price increased. And, when the individual budget was extended to compensate the price increase, subjects tended to maintain their baseline consumption as shown by a smaller demand elasticity relative to the Uncompensated budget session. Furthermore, we found significant differences in reward consumption and budget expenditure between the two tasks. When consuming the milk rewards with a limited individual budget, human subjects exhibited more negatively elastic demand than the picture rewards, which led to a much more proximation in the consumption pattern to the rational performance of our rat consumers. Our data demonstrate that although sexual stimuli and food reward are both commonly considered as primary reward, the application of a certain reward type could matter for comparing the behavior rationality across species in an economic trade-off scenario.

1-C-20 Variations of choice behavior and eye fixation according to rating level, category homogeneity, and choice difficulty

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People often agonize over choosing one item among all others they like, even without putting disliked-

items in options. If items belong to a single category, this biased choice becomes more solid by navigating only within favorite items (e.g. brand loyalty). Few studies, however, have taken into account this bias in understanding choice behavior. This study aims to investigate how choice behavior changes according to rating level (low-value / mixed / high-value), category homogeneity (multiple/single) and choice difficulty (easy/difficult), and to observe how these value-based decisions are reflected in eye movements using the attentional drift diffusion model (aDDM) with two parameters: the speed of integration (d) and the fixation bias (θ). Participants were asked to answer whether they knew 51 food items (i.e. multiple categories) and 51 beer items (i.e. single category). Then, they rated how much they would like to eat or drink each item in 9-scale (1: not at all - 9: very much). Finally, they performed a choice task between two items randomly presented in 12 conditions (3 rating level X 2 category homogeneity X 2 choice difficulty) based on individuals' rating results. The items presented in the low-value condition received ratings in a range of 1~4, 5~8 in the high-value condition, and one low-value and one high-value items in the mixed condition. The choice difficulty was determined by a rating difference between two items, 2~3 for easy and 0~1 for difficult. Eye movements were recorded during the choice task. We found that participants chose a higher-rated item more likely and more rapidly in the high-value condition than in other conditions, and that they did so in the easy than difficult condition. Also in the easy condition, they tended to compare items less often, shown by less eye transitions between them. The search for the aDDM parameters, d and θ , that were fitted best to the eye movement data revealed that participants were less biased toward what they were looking at in the high-value condition than other conditions. This phenomenon became more pronounced in the single category condition than multiple one. Based on the results, more fixation biases when choosing between low-rated items imply that the formation of preference due to visual presence of an item could partially affect decision makings, which could elucidate why participants more likely choose lower-rated items in the low-value condition. Our results also demonstrate that the rating level is one of the key factors in driving value-based decision making, and that the fixation bias could illuminate choice variations.

1-C-21 Misattributing incidental affect on individuals' consumption utility

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Consumer research has well established that one's affective states, triggered by incidental events or marketing contexts, could influence consumers' seemingly unrelated decision utility. Most of this research has vaguely theorized a "misattribution" process without providing in-depth explanations of how exactly affect is carried over to subsequent consumer behavior. Integrating knowledge in decision neuroscience, we propose a novel arousal transport hypothesis (ATH) that arousal of affect, which acts as a carrier, transports the valence of affect, representing positivity or negativity of affective value, to influence consumers' experienced utility (more than decision utility). ATH has been tested and supported by four studies in the lab and in the field using behavioral and neurophysiological methods and has been generalized in visual, gustatory and auditory domains. In S1 (N=20) and S2 (N=47), participants' affect was altered by receiving incidental monetary payoffs from a lottery on a trial-to-trial basis and they were asked to evaluate how much they liked tasting wines (S1) or enjoyed viewing images (S2). fMRI was used to measure their brain activity in S1, and their skin conductance and facial expressions were measured in S2. In S3 (N=387; mturk sample), participants' affect was manipulated by viewing different affect-laden images varying systematically on valence and arousal dimensions before participants listened to music and reported their enjoyment. In S4 (N=86), participants' affect was altered by terror-related stressor

and their skin conductance and facial expressions were measured while they were performing the same task of S2. By dissociating valence and arousal in the brain activity (S1) and on psychophysiological responses (S2), S1 and S2 supported ATH by showing that positive valence mediated (enhanced) participants' reported enjoyment of wines and images, and such mediation was moderated by arousal such that higher arousal led to better consumption experiences. S3 found that reported enjoyment of music was highest after exposure to positive high arousal images than positive low arousal images and neutral images. These results are in line with ATH suggesting that arousal facilitates transfer of valence that influences consumption utility. S4 found that terror-related stressor selectively dampened participants' arousal while their facial valence was intact. In turn, the blunted arousal impeded the misattribution of valence. ATH unpacks the misattribution theory by delineating its underlying mechanism and provides new insights about when incidental affect is more (or less) effective to alter consumers' consumption experiences.

E. Game Theory & Strategic Interactions

1-E-22 Acute tryptophan depletion in healthy subjects leads to greater preferences for negative reciprocity.

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Objective Often our decisions involve a conflict between self-interests and the interests of others. In these situations, reciprocity may occur, mirrored by the decision-makers willingness to reward those who are kind (=positive reciprocity) and punish those who are unkind (=negative reciprocity). Serotonin (5-HT) is a neurotransmitter frequently implicated to modulate human behavior in various social situations. Using game-theoretical approaches, several studies could demonstrate that lowering brain 5-HT levels in healthy subjects can promote retaliation to perceived unfairness, leading to a decrease in cooperative behavior. Based on these findings, we hypothesized that 5-HT depletion would lead to an increase in preferences for negative reciprocity in the Hawk-Dove game. The Hawk-Dove game represents a conflict situation between two persons with two strategies: the aggressive 'Hawk' strategy and the peaceful/cooperative 'Dove' strategy. Strategy choices were labeled as negative reciprocity when 'Hawk' was chosen in response to an expected 'Hawk'. **Methods** 49 healthy young males (treatment: n=25; control: n=24) participated. We induced a temporary reduction of brain serotonin availability using acute tryptophan depletion (ATD) and asked participants to play several versions of the Hawk-Dove game, differing in the incentive for mutual cooperation (Dove, Dove). Afterwards, we assessed subjects' expectations (=beliefs) regarding the opponent's strategy choices and risk preferences using the Holt and Laury (2002) lottery choice procedure. Mood was assessed (MDMQ) before the agents were given ATD/placebo drinks and again before the start of the experimental game. Different generalized estimating equations with a logit link for binary responses and marginal effects of ATD over beliefs were calculated. **Results** No sig. differences in beliefs, mood, and risk attitudes between the experimental groups were observed. A moderating effect of ATD on beliefs and strategic choice was obtained (z-Value 4.52, $p < 0.001$). The assessment of the marginal effects of ATD over beliefs suggests that ATD statistically significantly increased the tendency for negative reciprocity, whereas positive reciprocity (Dove' choice when believing in a 'Dove' choice of the opponent) was unaffected. **Conclusions** Our study suggests, that 5-HT depletion increases the tendency for negative reciprocity, whereas positive reciprocity is unaffected, shaping our understanding of 5-HT in social interactions. Since beliefs, risk attitudes, and mood remained unaffected by ATD, we can rule out these variables as an explanation for the group differences in game behavior.

1-E-23 Enhancing cooperation through the selective provision of social information to reinforcement-learning agents

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In the Iterated Prisoner's Dilemma (IPD), each player can choose between two options: to cooperate or to defect. Defection is a dominant individual strategy but mutual cooperation is better than mutual defection. In most IPD experiments, participants are provided with full information about their payoffs and choices. The proportion of cooperative choices, however, grows with the amount of information provided about the interdependent relationship. This study explores how information impacts cooperation using computational simulations with reinforcement-learning (RL) algorithms, which are frequently used for modeling neural responses in the process of associative learning. When confronted with an IPD, RL agents tend to defect at very high levels, whereas humans tend to be much more cooperative. Thus, we explored possible extensions of RL algorithms that may cooperate more often with more social information. Five conditions with varying levels of information were evaluated - from no information at all to the provision of information about outcomes to information about both the choices and/or outcomes of others. In each condition, we simulated 200 games (200 trials each) with agents differing in the values of key RL parameters. In all conditions, agents using the Q-learning algorithm were compared (with varying step sizes and decision noise). When providing information about opponent's choices, we also extended the number of states considered by agents. When information about the outcomes of others was provided, we extended Q-learning to include the sum of payoffs obtained by both players (termed E-learning). In the model, the values learned by standard Q-learning and the summed E-learning were combined through a single weight that could change through the simulation. Our results indicated that the provision of outcome information to these RL agents significantly enhanced cooperation. When only outcome information appeared, the proportion of cooperation was higher than when both information types or only the choice information were present. Moreover, information about the other agent's choice had a negligible effect on cooperation as opposed to no information. We confirmed these findings by evaluating our model in both a sequential IPD and Ultimatum Game and again found increased cooperation with the provision of outcome, but not choice, information. Thus, targeted learning about others' outcomes may be important for enhancing cooperation for RL algorithms. Supported by the Ministry of Science and Higher Education of Poland Diamond Grant, decision number: 0135/DIA/2017/46.

1-E-24 Your pupils betray you - lie detection through cross-participant pupil synchrony

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Deception has been examined extensively in psychology, neuroscience, and economics. By contrast, the neurobiological mechanisms of lie detection are poorly understood. Prior studies suggest lying increases pupil size, possibly due to an increased cognitive load, internal moral conflict, and/or arousal. Yet other studies indicate that enlarged pupils promote trust. To address this apparent paradox, we developed a novel behavioral paradigm featuring pair-wise, turn-based, face-to-face interactions to study the relationship between pupil dilation, lying, and lie detection. Two participants sat face-to-face, with direct visual access to each other's eyes, and received separate instructions through headphones. In half of trials ("message trials"), one participant (A, the "sender") was informed of two options, one self-

benefiting and one other-benefiting, and he/she chose to recommend one for the other participant (B, the "recipient") to choose. In turn, the recipient decided whether to trust the sender's recommendation. In the other half of trials ("choice trials"), A (the "chooser") simply chose one of the two options (as in a dictator game) and B (the guesser) judged whether A had made a self-serving choice. This design not only afforded us the opportunity to study realistic and naturalistic social interactions, it also facilitated precise measurements of within-participant pupil dynamics and cross-participant pupil synchrony during both truthful and deceptive communications. Comparing message and choice trials allowed us to isolate pupil changes specifically due to deception and disentangle these from changes elicited by reward anticipation. Overall, we found that selfish participants showed greater pupil dilation when choosing to reward themselves, whereas altruistic participants showed greater pupil dilation when choosing to reward others. Selfish participants also engaged in more deception, and their pupils were further enlarged during deception. This was not true for altruistic participants. Cross-participant pupil synchrony was widely observed during participant A's stimulus presentation and choice period. The relationship between pupil synchrony and trust, however, varied greatly across pairs of participants. Together these findings indicate that pupil dynamics and pupil synchrony vary with social communication in a context-dependent fashion. More specifically, a selfish person's pupils dilate when lying, and an implicit detection of such dilation (through synchrony) will benefit lie detection. By contrast, a prosocial person's pupils dilate when engaged in altruistic behavior, and pupil synchrony in this case will promote mutual trust.

1-E-25 Capturing choice processes during strategic interactions with the drift-diffusion model

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Objective: Decisions in many economic choice domains - such as food choice, risky and intertemporal choice, social allocations, and reinforcement learning - have been successfully described with the drift-diffusion model (DDM). This suggests overlapping choice mechanisms between these domains. However, it is so far unclear whether this overlap also extends to more complex cases such as strategic choices. Here we sought to identify whether the DDM can explain subjects' choices and response times (RTs) in a competitive game with a repeated interaction, where the value of each choice depends on the previous history of play. **Methods:** Pairs of subjects (N = 80) played the standard mixed-strategy "inspection" game [1] in which the players' incentives are misaligned and there is no pure strategy equilibrium. Here the game was framed in an abstract way to prevent any cultural biases: on each trial, both subjects chose between letters H and T (restricted to 3 s). If the choices matched, one of the subjects received a reward, whereas in the case of mismatch, the other subject was rewarded. Each subject played the game for 400 trials with the same anonymous opponent. We presented the task and recorded RTs with Psychtoolbox. **Results:** The behavioral data (individual choice and RT distributions) were best explained by a computational model that combined the influence learning model [2] with the 3-parameter DDM with fixed decision boundaries. The values of the options were updated using a fictitious play component (first-order beliefs based on the opponent's history of play) and the influence component (second-order beliefs based on the player's own history). The difference in the values of the two options produced the drift rate in the DDM. **Conclusions:** Our results suggest that even choices in complex social situations might involve mechanisms that are well captured by the DDM. Thus, these types of choices may draw on choice mechanisms that partially overlap with those involved in simpler types of choices. Moreover, the DDM can be used to predict individual subjects' RT and choice distributions in such settings.

Acknowledgements: This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 725355 BRAINC0DES). References: 1. Hill, C. A. et al. A causal account of the brain network computations underlying strategic social behavior. *Nat. Neurosci.* 20, 1142-1149 (2017). 2. Hampton, A. N., Bossaerts, P. & O'Doherty, J. P. Neural correlates of mentalizing-related computations during strategic interactions in humans. *PNAS* 105, 6741-6746 (2008).

1-E-26 Robust prediction of individual differences in trust propensity from intrinsic brain morphology and functional connectivity

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Trust is an essential component of human relationships, which is indispensable in friendships, organizations, and societies. The past decades have witnessed a surge of interest in studying interpersonal trust across many disciplines, including psychology, economics, and recently neuroscience. However, the driving neuropsychological signatures behind individual differences in trust propensity remain poorly understood. Here, we applied a prediction-analytics framework via machine learning in two independent samples of healthy participants to examine the relationship between individual differences in trust propensity (as measured by two different types of trust games) and task-independent, multimodal brain measures (as gained from structural MRI and resting-state fMRI). As trustors in a one-shot trust game, the first sample (n=89, 18-27 years old) played the standard version, whereas the second sample (n=86, 18-30 years old) played the binary version with different anonymous partners. Our multivariate prediction analyses revealed that individual differences in trust propensity (as measured with the standard trust game) were predicted by gray matter volume (as an anatomical measure based on structural MRI) and node strength (as a graph-theoretical measure of the centrality of a brain region based on task-free fMRI) across multiple brain regions, including frontoinsula areas, dorsomedial prefrontal cortex, temporoparietal junction, dorsolateral prefrontal cortex, and inferior parietal cortex. Further, the gray matter volume of these regions further enabled classification of individuals from an independent sample with the propensity to trust or distrust as measured with the binary trust game. The predicted brain regions have been previously implicated as being part of domain-general large-scale brain networks, supporting affective, cognitive, and social processes, that determine an individual's propensity to trust-- as the willingness to be vulnerable to the risk of betrayal by others. In summary, based on internal and external validation our results identified novel and critical evidence for intrinsic structural and functional features of multiple brain systems that are predictive of trust propensity at the individual level, supporting previous evidence from task-based fMRI and coordinate-based meta-analysis studies investigating the neurobiological underpinnings of trust. In conclusion, our findings do not only deepen our neuropsychological understanding of individual differences in interpersonal trust but also provide potential biomarkers in predicting individual differences of trust impairment in patients with neurological and psychiatric disorders.

G. Intertemporal Decision

1-G-27 Delay discounting and anhedonia: a transdiagnostic approach

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Anhedonia, or diminished ability to experience pleasure, is a prominent symptom in mood and psychotic disorders. More specifically, anticipatory pleasure is impaired in these psychiatric conditions, and this impairment may be reflected in blunted activity in the fronto-striatal circuitry underlying reward processing. To examine the neural correlates of anhedonia and anticipation of future reward, we collected functional magnetic resonance imaging data in a delay discounting paradigm designed to assess the subjective value of future rewards in a group of healthy individuals ($n = 23$), and individuals with major depressive disorder ($n = 18$), bipolar disorder ($n = 21$), and schizophrenia ($n = 26$). Although behavioral performance did not distinguish the primary diagnosis or varying levels of anhedonia, activity in the vmPFC correlated with the subjective value of future rewards was blunted in anhedonia, such that increasing symptoms of anhedonia were correlated with dampened value-related signals. Moreover, the effect of anhedonia remained significant after statistically accounting for the effects of primary diagnoses and multiple potential confounds, including cognitive functioning, smoking, depression severity, and positive and negative symptoms of schizophrenia. These findings provide evidence for hypofunction in the vmPFC across mood and psychotic disorders that is specifically linked to anticipatory anhedonia, rather than a general feature of major psychopathology.

1-G-28 The cortical oscillatory patterns during varying levels of cognitive effort: Effects of reward and value of effort

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Objective Cognitive effort is 'the degree of engagement with a cognitively demanding task', this is often viewed as a cost and is associated with fatigue. Previous research has investigated the effect of reward on cognitive effort (Massar, Lim, Sasmita, & Chee, 2016), showing that rewards can be used to elicit faster reaction times. Recently, evaluation of cognitive effort has been conceptualised as a value discounting factor in economic decision making (Westbrook, Kester, & Braver, 2013). The purpose of this study was to analyse the amplitude changes of cortical oscillations during an effortful vigilance task and investigate their associations with values of effort and levels of reward. The cortical oscillatory changes in alpha (8-12 Hz) and beta (16-24 Hz) were evaluated using the event-related desynchronization (ERD) method (Pfurtscheller & Aranibar, 1977). Methods A sustained vigilance task, was utilised to investigate the effect of reward on cognitive effort. 17 participants were required to respond as quickly as possible whenever they were presented with a target stimulus and were given a performance based reward (0p, 1p or 10p). Following the vigilance task, participants were required to complete a discounting task in which the subjective value of effort was evaluated using a staircase procedure, where the relative difference between the amounts of money offered for high and low effort options was manipulated based on participant choice. Results Mean reaction-times decreased significantly as a higher performance-based reward was offered, this was significant only in slow trials. The amplitudes of alpha-ERD before the speeded reaction-time response significantly increased over frontal and occipital electrodes as reward increased and as reaction-times decreased. The amplitude of beta-ERD increased over the contralateral sensorimotor hand area as reaction-times increased and over the ipsilateral sensorimotor hand area as reward increased. In the discounting task, decreases in subjective value were observed as effort increased, however, no significant correlations were observed between subjective value and reaction times or ERD patterns. Conclusions Incentive related to cognitive effort increases cortical activation in the ipsilateral sensorimotor area prior to a speeded motor response. This may show

the spread of activation over a large part of the sensorimotor cortex during increasing monetary rewards. Cortical oscillations related to reward show no associations with the value of effort, this suggests that the instantaneous investment of effort during a cognitive task is not determined by the economic value of effort itself.

1-G-29 Across space, time, and country lines: A cross-cultural examination of time perception and its influence on economic decision-making.

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Time is the phenomenon that we perceive as the existence of continuous, unidirectional change. Time is represented in three temporal frames: the past, present, and future, and one's perception of time is strongly influenced by one's culture and language. American-English speakers' conceptualize time using horizontal spatial metaphors, making use of front/back references, like "put the past behind us" and "I am looking forward to next week." Chinese-Mandarin speakers utilize horizontal spatial metaphors, employing words like qian (front, before) and hou (back, after) to reference time. However, vertical spatial metaphors are more widely used in Mandarin than in English, whereby shang (up) refers to events earlier in time and xia (down) events later in time. Moreover, American-English speakers are heavily present and future focused, and view the past and future as distant temporal frames relative to the present. Chinese-Mandarin speakers alternatively, are more past-focused; and perceive the past and future as closer to the present. Though the effect of language on one's mental representation of time has been examined, the relationship between time perception and decision-making remains understudied. To address this gap we developed a novel paradigm to delineate the influence of language and culture on one's spatial representation of time and explored the effect of time perception on economic decision-making. Native speakers (age =18-30) in the United States (n=40) and China (n=32) organized a series of past and future events on a grid, placing events according to their subjective perception of the event's temporal position relative to themselves. Participants further completed an economic delay-discounting task, indicating their willingness to wait for a future monetary reward. We found that American-English speakers adopted a strongly horizontal, linear view of time, while Chinese-Mandarin speakers adopted a more circular representation. We quantified the spread of events along the y-axis of the grid as a measure of the horizontality and verticality of event placements and found that Chinese-Mandarin speakers more widely distributed events in the y-direction ($p=0.003$). Individuals in both cultures who viewed the past and future as further from themselves, measured by the mean distance of event placements from the participant on the grid, chose more immediate rewards and avoided delayed rewards (Pearson's $r = -0.35$, $p=0.003$). Altogether, this work highlights the distinct perspectives adopted by American-English and Chinese-Mandarin speakers and suggests that individual variability in one's perception of time may underlie differences in economic choice.

1-G-30 Role of locus coeruleus noradrenergic arousal in choice conflict adjustments

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A crucial aspect of human adaptive behaviour and decision-making is the resolution of choice conflict. Choice conflict arises when a prepotent habitual response is suppressed for the choice of an alternative option that better fits present behavioral goals. The detection and resolution of choice conflict is

associated with processing costs that manifest as increased reaction times. Humans vary substantially in the ability to resolve choice conflict, but the neural origins of this heterogeneity are currently not well understood. Neuroimaging studies point to activity in the dorsomedial prefrontal cortex (dmPFC) and dorsolateral prefrontal cortex (dlPFC), which are generally increased during choice conflict. Moreover, recent theoretical frameworks also implicate noradrenergic arousal in this process. In particular, the locus coeruleus noradrenergic system (LC-NE), which innervates the entire neo-cortex and has strong connections with the dmPFC. However, there is no evidence until now that individual functioning of these systems determines the ability to resolve choice conflict. Here we provide such evidence. Participants (N=48) completed a classic behavioural response conflict task during fMRI and concurrent pupil dilation measures, a well-established proxy for LC-NE firing. Our analyses of activation and functional connectivity (Psychophysiological Interactions; PPI) reveal a decisive role of the LC-NE in the individual ability to resolve choice conflict. More specifically, we show that the level of individual behavioural adjustment in choice conflict (reaction time differences between conflict trials and no-conflict trials) is strongly related to the level of functional coupling between the dmPFC (seed) and (1) LC-NE as well as (2) dlPFC: The more effective the behavioural adjustment, the stronger these indices of functional coupling (dlPFC: $p=0.038$, LC-NE: $p=0.11$, SVC). Moreover, we show that pupil dilation tracks neural markers of conflict adjustment. That is, the individual differences between neural activity in the dmPFC between conflict vs. no-conflict trials correlate with the individual differences in pupil dilation of the same contrast ($p=0.002$). Our data provide novel insights into the role of arousal systems for determining the individual ability to deal with choice conflict. Moreover, our results establish pupil dilation as a valuable external marker for endogenous neural processes involved in adjusting and optimizing behaviour. These findings may be clinically relevant for a variety of pathologies with impairments of cognitive control, such as anxiety, depression, addiction and PTSD.

1-G-31 Task-switching in social contexts

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Whilst previous studies have investigated the brain correlates of cognitive control mechanisms involved in task-switching, no studies have investigated whether the same brain regions are involved in task-switching between social and non-social cognition. We conducted an fMRI study and an EEG study investigating the brain regions and psychological mechanisms involved in mediating the switch between social and non-social cognition. A task-switching paradigm was used for both studies, consisting of a social task-set and a non-social (financial) task-set. Unlike previous task-switching studies, these tasks were based on inferences from behaviour rather than visual cues. Specifically, 40 images of individuals were paired with sentences denoting social or financial behaviour, and participants studied this information before scanning. During scanning, participants decided whether they would approach or avoid an individual whilst in the social context or financial context. fMRI results indicated greater activity in the ACC during switch trials but no DLPFC activity, and a behavioural switch cost for the financial but not the social task. Results suggest that whilst the ACC may be involved in task-switching in the social context, the DLPFC is not. Different mechanisms may mediate task-switching in the social context compared to what has been found in previous task-switching literature. EEG analysis is ongoing. We predict a replication of fMRI response time results. In the brain, we predict differential face sensitive N170 response between social and financial conditions, indicating reduced social cognition in the financial context, and a P3 response indicating cognitive control in switch versus stay trials. These results

suggest that switching cognitive states beyond visual cues may recruit overlapping but different brain structures compared to traditional cognitive control tasks.

1-G-32 Preferences and temporal patterns of intertemporal decision making in marijuana users versus never and former users

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Individuals dependent on substances, such as nicotine, cocaine, and methamphetamine, devalue delayed rewards to a higher degree than those who do not (delayed reward discounting). This is well-documented for all drugs of abuse, except marijuana, for which results have been mixed. One possibility is that the effect size for differences in discounting between marijuana users and nonusers is small compared to that reported for other substances. Another possibility is that concurrent cigarette smoking has made it more difficult to reveal group differences. The current study investigated these possibilities. Data were combined from six studies to create a database containing the demographic characteristics and the performance on a delayed reward discounting task for 259 healthy adults. By self-report, subjects were classified as recent marijuana users (used in last 30 days; RECENT), past marijuana users (not last 30 days but used in lifetime; PAST), and never marijuana users (NEVER). Performance measures included 137 trials assessing preference between an immediate monetary reward (\$0-\$10.50) and \$10 available after a delay (0, 7, 30, 90, 180, 365 days), and the time taken by the subject to register that preference (decision time). The decision time was fractionated so that temporal patterns of computer cursor movements and clicks during the trial could be examined. Analysis of the demographic characteristics indicated that the age of the RECENT users was lower, so age was used as a covariate throughout. RECENT users discounted delayed monetary rewards significantly more than NEVER or PAST users. In each trial of the delay discounting task, RECENT users switched between the immediate and delayed alternatives more often before registering their preference. When there was 0-day delay, the decision time was shorter than other durations of delay. The decision time was longer for trials at the indifference point, where the subject had equal preference for the immediate and delayed alternatives, compared to other trials. These relationships did not differ amongst the three marijuana user groups. Additional analyses indicated that being a cigarette smoker moderated the user group effects on the preferences. However, the discrete temporal components were not affected by cigarette use. This study demonstrates a disassociation between the revealed preference and the decision time components. It also demonstrates the importance of considering a concurrent recreational drug use in the delay discounting preference and temporal components of decision making.

1-G-33 At the heart of conflict: Physiological markers of attack and defense during competition

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Interpersonal conflict often involves a clash between a revisionist attacker seeking to change the status quo and increase its gains through victory, and a non-revisionist defender who seeks to protect itself against loss and defeat (De Dreu & Gross, forthcoming). Recent work in social psychology and experimental economics highlighted the behavioral dynamics that emerge during such attacker-defender conflicts, yet remained silent about the physiological adaptations underlying decisions to invest in attack and defense. Here we used an incentivized economic predator-prey contest game and continuously

measured electrocardiography (ECG), impedance-cardiography (ICG), and blood pressure to get cardiovascular markers (pre-ejection period [PEP], mean arterial pressure [MAP], heart rate [HT], cardiac output [CO], total systemic peripheral vascular resistance [TPR]). With these measures we established the underlying physiological mechanisms of interpersonal conflict in terms of the biopsychosocial (BPS) model of challenge and threat (Blascovich, 2008). We organized $n = 108$ (79.5% female; age: $M = 21$ years, range = 18 - 35) participants in 59 attacker-defender dyads. Participants made 90 incentivized investment decisions with full feedback and reset after each round. We replicate previous behavioral results. Individuals invest less during attack than defense ($B = -0.92$, 95%CI = -1.27, -0.57, $p = 0.001$, $M \pm SE = 4.40 \pm 0.11$ versus $M \pm SE = 5.39 \pm 0.09$), and attacks disproportionately often fail (success attack rate: 30.73%, $SE = 1.74$). Physiologically, participants were especially engaged at the initial 25 rounds, as reflected in PEP-scores < 0 ($t = -4.54$ $p < 0.001$) and their $HR > 0$ ($t = 5.95$ $p < 0.001$); attackers had higher physiological threat than their defenders ($B = -0.78$, 95%CI = -1.64, -0.07; $p = 0.075$, marginal), and in particular had higher TPR ($B = 236.05$, 95%CI = 39.24, 432.86; $p = 0.020$) and MAP ($B = 6.32$, 95%CI = 3.88, 8.76; $p < 0.001$). Combined, these findings suggest that investing in attack is physiologically more demanding than investing in defense, fitting earlier findings that during attack rather than defense, participants are more susceptible to manipulations of cognitive load (De Dreu et al., 2018). However, such physiological stress is present early in the contest and role differences fade-out over time, suggesting habituation is possible.

I. Risk & Uncertainty

1-I-34 Risk aversion: Attention, arousal and incentive effects

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Objective: We investigate the relationship between incentives, physiological arousal, and attention in risky choice. Empirical and experimental research on risky choice documents an increase in risk aversion with stake size. Our goal is to acquire physiological and gaze fixation data in conjunction with large changes in monetary incentives in risky choices in order to investigate the physiological mechanisms underlying the effect of increased incentives on risk aversion. **Methods:** We collected eye-tracking and biometric data while 20 participants made a series of incentivized choices between two lotteries, each with two possible non-zero outcomes. Our within-subject design involved low real, high real, and hypothetical stakes as treatment conditions. The high real stakes condition involved stake sizes that were 50 times greater than in the low real stakes condition. Each condition was presented in a separate block and participants were informed of the incentives before making choices in that block. In each block, participants made decisions involving the paired lottery-choice decisions of Holt & Laury (2002). While participants made decisions, we collected reaction time, pupil dilation, and gaze fixation data. We also recorded pulse photo-plethysmogram and electrodermal activity. **Results:** We observed significantly more safe choices in the high real stakes condition relative to the low real stakes and hypothetical choice conditions, consistent with the behavioral results of Holt & Laury (2002). Attention and arousal patterns demonstrate clear differences between high real and low real or hypothetical stakes. When participants display increased risk aversion, we find greater arousal levels as measured by skin conductance, heart rate, and pupil dilation. In particular the high real stakes treatment involved the highest degree of risk aversion and the highest levels of physiological arousal. We also find differential attention patterns under high real stakes, where participants fixated significantly less on the higher payoff of the risky option and significantly more on both payoffs of the safe option compared to the hypothetical stakes treatment. **Conclusion:** We find that physiological measures differ significantly when the payoffs are large and real compared to small or hypothetical stakes. Moreover, by comparing physiological measures under

hypothetical, low, and high real payoffs, our study provides a methodological insight into the role of incentives in experiments. These results lay the groundwork for developing a choice process model of risky decision making that incorporates physiological states and attention.

1-I-35 Disruption of frontal activity asymmetry using tACS to modulate risk-taking behavior

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Risk-taking behavior is defined as a (consciously or unconsciously) controlled behavior with uncertain outcomes, costs or rewards (Trimpop, 1994). Abnormal risk-taking is characteristic of several psychiatric and neurological disorders, such as ADHD and substances abuse. Therefore, being able to properly take risks is one of the most important abilities to define one's behavioral appropriateness (Brand et al., 2007), making this a relevant topic for cognitive neurosciences. Studies have shown that participants that engaged in more risk-taking showed higher prevalence of theta frequency (4-8 Hz) oscillations in the right prefrontal cortex (PFC), compared to the left PFC (Gianotti et al., 2009). Therefore, it is expected that this is the electrophysiological mechanism that underlies the risk-taking regulation. However, this causal relationship is still not clear since most of these studies use correlational methods (EEG) or lack proper controls. To investigate if the theta-band asymmetry has a causal role in the regulatory control of risk-taking behavior, we used tACS in theta frequency during an economic risk task designed exclusively to isolate the effects of risk and reduce impulsivity and loss aversion effects that were found to occur in similar tasks used by previous studies. We also used gamma band stimulation and sham as control conditions (Feurra, Galli, & Rossi, 2012; Sela, Kilim, & Lavidor, 2012). As expected, the theta-band entrainment significantly affected the risk-taking behavior in the economic risk task. These results were driven by the participants' increase in preference for higher bet values. This effect was not present in either control conditions. Moreover, the increase in theta power in the area stimulated was significant, confirming the effects of the entrainment. These findings support the hypothesis that the theta-band asymmetry has a causal role in the risk-taking behavior regulation. Keywords: Risk-taking, risk Human behavior, EEG, human electrophysiology, tACS, frontal theta asymmetry, theta-band entrainment.

1-I-36 Measuring ambiguity attitude efficiently

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Objective Uncertainty affects many aspects of human behavior, particularly decision making. Risky decisions are made when the probability of the outcome is known, while ambiguous decisions are made when the exact probability cannot be estimated. Existing tasks assessing risk and ambiguity preferences typically show that people are ambiguity averse and that ambiguity aversion increases with degree of ambiguity. However, these tasks are lengthy and therefore not suitable for pharmacological studies or patient studies. As we ultimately aim to investigate the pharmacological basis of ambiguity aversion, we investigated whether a modified multiple price list task can measure ambiguity aversion in a short period of time. Methods So far, twenty-four healthy participants have completed the task; the data collection is currently ongoing. We used multiple price lists where participants chose between safe and ambiguous alternatives using Ellsberg Urns with 26%, 50% and 100% ambiguity levels for both gains and losses. To determine ambiguity aversion we also measured risk preferences. We defined risk attitude (aversion or

proneness) as the difference between the expected value of a lottery and its certainty equivalent (safe amount at which the participant crossed over from choosing the lottery to choosing the safe alternative). Ambiguity aversion corresponded to the strength of preference for risky options over ambiguous options, calculated as difference between the certainty equivalents of the risky and the ambiguous options. We performed a repeated measures ANOVA with ambiguity aversion as dependent variable and ambiguity level (26%, 50% and 100%) and gains/losses as independent variables. Post-hoc tests served to interrogate significant effects. Results We found a significant main effect for gains/losses on ambiguity aversion ($F_{1,23} = 5.80, p = 0.025$). Ambiguity aversion was stronger for gains than for losses for every ambiguity level (26% ambiguity: $t_{71} = 2.67, p = 0.015$; 50%: $t_{71} = 2.60, p = 0.016$; 100% ambiguity $t_{71} = 4.51, p = 0.001$). Moreover, further analyses reveal a significant effect of ambiguity level on ambiguity aversion within the gain trials, with 100 % ambiguity resulting in higher ambiguity version than 26% (ambiguity $t_{71} = -3.10, p = 0.009$). Conclusion Our task showed ambiguity aversion, converging with the findings of studies using lengthier tasks in healthy participants. Future research will apply our task in a pharmacological study but may also use it to study ambiguity aversion in individuals with psychiatric disorders.

1-I-37 Associations between white matter connectivity and individual differences in risky and social choices

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Each day we must consider the possible risks of an array of outcomes to make both mundane and critical decisions. Empirical behavioral economics studies evince sizable inter-individual variability in how closely a person's risk preferences match economically normative behavior predicted by economic models such as Expected Utility Theory. Such variability in risk preferences is thought to partially depend on relatively-stable differences in reward processing, cognitive control, memory, and affect. In the brain, a constellation of brain regions have been implicated in risk preferences including the striatum, hippocampus, amygdala, insula, and several areas of the prefrontal cortex. Although each of these regions has been shown to functionally respond to risk independently, almost nothing is known about how white matter connectivity among these key brain regions might account for the substantial individual differences in risk preferences observed behaviorally. To address this gap, we leverage diffusion imaging, a method that has already shed considerable light on individual differences in realms such as intertemporal choice and in predicting clinical outcomes including smoking, alcoholism, and gambling disorder. Here we draw on a large ($n=152$) sample of healthy adults, and utilize validated behavioral assays (Dynamic Experiments for Estimating Preferences) to elicit measures of risk preferences including λ (loss aversion), σ (curvature of the value function), and (α) probability weighting function. Using probabilistic tractography, we estimated the connective strength between the array of brain regions previously implicated in risk preferences and related constructs. Broadly, ventral striatal and hippocampal white matter tracts most consistently predict risk preferences. Specifically, higher loss aversion associated with higher of ventral striatal-amygdala and hippocampal connectivity; lower distortion of probabilities was associated lower hippocampal connectivity to orbitofrontal cortex and insula; and lower value function curvature was associated with higher fornix connectivity and ventral striatum-insula connectivity. These associations were also robust when controlling for age, gender, and fluid intelligence. Our findings demonstrate that human deviation from economic risk preferences is

structurally reflected in differential white matter connectivity, particularly of reward- and memory-related neural regions.

1-I-38 Excitotoxic lesions of the lateral orbitofrontal cortex, but not medial prefrontal cortex, altered risk-dependent choice in the rat

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Prefrontal cortex (PFC) is known to be critical in decision making under uncertainty, but the specific contribution of PFC subregions to risk-based decision making remains elusive. This study thus evaluated the lesion effects of lateral orbitofrontal cortex (IOFC) and medial PFC (mPFC) on risk choice in the rat. In a T-maze risk choice task, the subject would choose to enter either a small and certain reward arm of the maze or a large but uncertain reward arm of the maze during the free-choice test sessions. One sweeten pellet was given each time for the former choice being made. By contrasts, the latter option, when chosen, resulted in provision of 2, 4, or 8 sweeten pellets with a probability of 0.5, 0.25, or 0.125, respectively. This task was specifically set up to run with the expected value being equal (i.e., $EV = 1$) between the binary choice options which tests were carried out with three reward ratios of 1:2, 1:4, and 1:8 as correspondingly representing low-, medium-, and high-level risk conditions. With the between-subject design on both factors of reward ratio and lesion area, the rats were randomly assigned to the experimental groups receiving excitotoxic lesion of IOFC or mPFC, or to the correspondingly sham control groups, prior to behavioral testing. From the free-choice test conducted over seven days, the results showed that the rats in both sham control groups significantly acquired risk choice which patterns were dissociable and depended on different reward ratios or risk levels. While risk-prone and risk-averse patterns, respectively, appeared in low-risk and high-risk conditions, an intermediate pattern of choice acquired in between risk-prone and risk-averse ones was shown in the medium-risk condition. The IOFC lesion significantly interfered with the risk choice behavior by apparently shifting the choice toward a risk-prone style. In contrast, as compared to sham control, the mPFC lesion did not alter choice behavior in any of three reward ratios. The behavioral alterations observed in rats with IOFC lesion rats were not the result of motor deficit, anxiety-like response, or incapability to discriminate reward magnitudes, as no lesion effect revealed by the test of locomotor activity, elevated T-maze, or a discrimination task for a small vs. large reward. Together, these results indicate differential involvements of IOFC and mPFC in risk-based decision making and further suggest that the IOFC contributes to the acquisition of risk-dependent choice given at a particular level of risk based on reward magnitude and probability.

1-I-39 Influence of volatility on matching behavior in mice

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How reward shapes behavior has been a long-lasting question in behavioral psychology and neuroscience and extensively studied using choice between two or more options that provide reward probabilistically while these probabilities change between blocks of trials or sessions. A general finding based on studies across multiple species is the matching law which states animals distribute their choices between a set of options proportional to reward obtained from those options. Most of these studies, however, use reward schedules with fixed block lengths. In contrast, reward contingencies can change on multiple timescales corresponding to different levels of volatility in the reward environment,

and such volatility should influence learning and choice behavior. Here, we trained mice on a foraging task with a dynamic reward schedule (variable block length) in order to study how choice and learning from reward feedback and the ensuing matching behavior are influenced by volatility of the environment. In these experiments, mice chose between licking the left or right tubes that deliver water with changing probabilities. Reward probabilities associated with the two actions changed at random time points without any signal to the animals. We first quantified matching by the difference between choice and reward fractions toward the better action in each block and observed significant undermatching (choice fractions were smaller than reward fractions) found in most previous studies. To identify choice- and reward-dependent strategies that contribute to undermatching, we examined multiple quantities related to the tendency to repeat an action on two successive trials and changes in action selection in response to reward or no reward. Using a stepwise-regression model, we found the strongest predictors of undermatching to be: 1) information entropy of reward-dependent strategies (ERDS) that measures uncertainty associated with response to reward feedback in terms of Win-Stay and Lose-Switch strategies; and 2) repetition index (RI), measuring the tendency to repeat an action beyond what is expected by chance. We then used changes in block length across a set of neighboring blocks to group those blocks into less and more volatile environments. We found that although undermatching increased with ERDS, this correlation was stronger in the less compared with more volatile environment. In contrast, undermatching more strongly increased with RI in the more volatile environment. These results suggest that volatility weakens the link between reward-dependent strategies and matching behavior whereas it strengthens the link between choice-dependent strategies and matching.

1-I-40 High gamma activity in the human prefrontal and insular cortices represent monetary gains and losses during decision making

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Many decisions we face involve choosing between options that carry potential gains and losses. Decades of research from psychology show that people are loss averse -- the agony incurred by a loss outweighs the pleasure of the same-sized gain. Human fMRI studies showed that many brain regions, including the ventromedial prefrontal cortex (VMPFC), orbitofrontal cortex (OFC) and ventral striatum, represent information about monetary gains and losses during decision making. It remains controversial, however, whether these regions simultaneously represent both gains and losses. In this study, we attempted to address this issue using human intracranial electrophysiology. **Method.** In a mixed-gamble task, human subjects (n=13) on each trial faced a 50/50 lottery of a potential monetary gain or loss and had to decide whether to play the lottery. As part of a treatment plan attempting to identify epileptogenic zone, multi-contact depth electrodes were implanted in different brain regions including the OFC, dorsal-to-mid cingulate cortex, amygdala and insula. These four brain regions, with a total of 141 contacts across subjects, were the focus of this study. **Results.** We replicated previous findings on loss aversion. Lambda, the ratio of sensitivity to changes in losses to gains inferred from choice behavior was 1.93 (median), close to previous studies (lambda=2). Overall, high-gamma activity in 90% of the contacts in these regions showed gain-only, loss-only, or gain-and-loss representations. However, there were more contacts representing either gain or loss than representing both gain and loss. The proportion of contacts representing only gains was identical to that representing only losses (~ 40%), while a significantly smaller proportion (15%) represented both gains and losses. When examining each region separately, these two statements remain true in amygdala and insula. Dorsal-to-mid cingulate cortex,

compared with OFC, amygdala and insula, showed less response to both gains and losses: the ratio of gain-representing contacts in dorsal-to-mid cingulate to all gain-representing contacts was significantly smaller than the ratio of contacts in dorsal- to-mid cingulate to all contacts. The same is true for losses. Together, these results provide more support to the separate encoding hypothesis -- that gains and losses are represented by different populations of neurons in these regions than by the same neurons.

J. Social Rewards & Social Preferences

1-J-41 Exploration of uncertainty with trust decisions in social networks

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In our modern society, we live in an increasingly connected environment. We encounter and communicate with people who we previously are not familiar with. Major theories of social interaction have proposed mechanisms of reducing uncertainties in such situations. However, most of the real social situations involve an active increase of uncertainty. For example, a social encounter starts with a decision whether to have some social interaction with the stranger. In other words, it is the decision to explore the new social world through that social partner or not. Such explorative aspect of social interaction has not attracted much attention in the previous studies. Here, we addressed this issue with the specially designed paradigm to examine the act of trust. Specifically, we developed the variant of the task called network prisoner's dilemma (Network PD) in which subjects decided whether to cooperate or defect with a social partner in each trial. The social partner was not fixed and in each trial is chosen from the existing network of players connected to the subject. The network itself was variable: in some trials, subjects were presented a new comer who wished to join the network of the subject and the subject decided whether to continue to play the game with the current partner or not. We examined cognitive mechanisms of trust in the behavior of subjects performing the network PD task. We found that an act of trusting the other (cooperation) does not mean simple bias toward trusting decisions. In a sequence of trials involving interactions with a same social partner, initial trusting decision (cooperation) kept the flexibility of behavioral strategy so that the subject can easily adjust their responses to both cooperating and non-cooperating partners. In other words, the trusting decision made the subject's mind open to the different possibilities of the relationship in subsequent interactions. Finally, we investigated the neural mechanisms underlying such trusting decisions. Network-based fMRI experiment was conducted by socially connecting the subject within a scanner with the other subjects outside the scanner. In the brains of scanned subjects performing the network PD task, "reward-related" brain areas were active. Specifically, cooperate/defect decision involved dorsal anterior cingulate cortex, which has been previously associated with uncertainty and long-term prospect of the environment. In sum, the most basic action of a social network, a decision of trusting another individual is based on basic cognitive and neural mechanisms of decision making, which regulate processing of inherent uncertainty in social interactions.

1-J-42 Behavioral and neural predictors of the effectiveness of mobile digital health message framing

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The goal of this project is to better understand how the brain responds to health communication and motivates behavior change, in order to produce more successful health interventions. Clinical trials have attempted to identify optimal messages that could be delivered in health interventions with mixed success. The small number of studies that have used neural responses to predict behavior change have largely described brain-behavior relationships that are agnostic to message characteristics, making it difficult to identify why some messages are most effective in driving brain responses that relate to later behavior. The goal of this project is to use a neuromarketing approach to identify neural predictors of health behavior change and ultimately produce more successful health interventions. Motivation ratings for positively-framed (highlighting benefits of activity) and negatively-framed (highlighting costs of sedentary behavior) health messages were collected in a preliminary sample (Study 1, N =119, ages 30-80) who did not complete an intervention and then the same ratings were collected in a separate sample of adults while undergoing fMRI (Study 2, N = 14, ages 30-80) who received the same 80 health messages (one message per day) during a mobile digital health intervention while wearing an activity tracker. In Study 1, participants rated positively benefit messages ($m = 5.31$, $sd = 1.40$) as more motivating than negative cost messages ($m = 5.10$, $sd = 1.43$), $t = 2.945$, $p = 0.004$. In Study 2, participants rated positive messages ($m = 7.62$, $se = 0.14$) as more motivating than negative messages ($m = 5.50$, $se = 0.14$), $t = 10.86$, $p < .001$, replicating Study 1. We also examined whether the positive messages that participants self-reported as most motivating increased physical activity in daily life. There were no significant effects of valence (positive/benefits, negative/costs) on daily steps, $t = 0.12$, $p = .90$. However, ignoring message framing, participants' motivation ratings were weakly related to daily steps, $r = .13$. Participants walked more steps on days that they received a message via text that they rated as more motivating during fMRI several weeks earlier. This effect was very small, $r^2 = .016$, such that the majority of the variance in daily activity was unexplained by self-reported ratings. Initial analyses of the neuroimaging data revealed positive parametric effects of self-reported motivation ratings in the medial prefrontal cortex (MPFC) and posterior cingulate cortex (PCC). Future analyses will examine whether functional neural responses to health messages explain significant additional variance, beyond self-reported motivation ratings alone

1-J-43 A neurocomputational account of moral hypocrisy

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Objective: Moral hypocrisy occurs when people hold themselves to different moral standards than others - for example, blaming someone else for committing the same moral transgression that they themselves committed. The neurocomputational processes that give rise to moral hypocrisy are unknown. **Methods:** We used functional neuroimaging and computational modeling to develop a mechanistic account of moral hypocrisy. Participants (N=79) completed a moral decision task in the fMRI scanner where they traded off profits for themselves against pain for an anonymous receiver. At least one week after scanning, participants returned to the lab and completed a blame task in which they judged the blameworthiness of another person's decisions to trade off profits and pain. Crucially, the decisions that participants judged others for making in the blame task were identical to those they had previously faced in the scanner themselves. We defined moral hypocrisy as blaming another person for making the same harmful decisions that oneself had made previously. For each participant, we computed a 'hypocrisy index' by summing the amount of blame assigned across the full set of judged decisions, weighted by their own likelihoods of making the same harmful decisions. To examine the

neural computations associated with moral hypocrisy, we investigated the relationship between each participant's hypocrisy index and their neural representations of benefits to oneself, harm to others, and blame during moral decision-making. Results: Strikingly, 97% of our participants displayed at least a minimal level of moral hypocrisy. However, there was considerable variation in the degree of hypocrisy. Participants with stronger moral preferences (i.e., those who were less willing to harm others for personal gain) were less hypocritical. Regardless of their moral preferences, participants who reported feeling more morally conflicted about their decisions were more hypocritical. Neurally, individual differences in hypocrisy were associated with stronger representations of blame in the insula, hippocampus and DLPFC at the time of decision-making. Conclusions: We show here that one manifestation of moral hypocrisy - blaming another person for making the same decisions oneself has made previously - is associated with an enhanced neural encoding of blame during moral decision-making, accompanied by stronger feelings of moral conflict. This suggests that moral hypocrisy, rather than arising from a lack of moral principles, may instead result from a stronger representation of those principles that are then applied asymmetrically to oneself versus others.

1-J-44 Decomposing neurocognitive bases of indebtedness in grateful situations: A dual-motivational account

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Humans commonly repay others' favors even when these favors are unsolicited and disliked. This compliance to the norm of reciprocity affects everyday decisions and is closely associated with the negative feeling of indebtedness. However, little is known about the neurocognitive mechanisms underlying the role of indebtedness in reciprocity. Here, by combining diverse approaches including interactive game, computational modeling and fMRI, we identified dual components of indebtedness, i.e., guilt and the sense of obligation, at behavioral and neurobiological levels. These components served as dual motivations underpinning the beneficiary's behaviors. In each round of the interactive game, an anonymous co-player decided how much endowment to spend to reduce the participant's pain. In half of the trials, participants could decide whether to accept help; in the remaining trials, participants had to accept help and could reciprocate by allocating monetary points to the co-player. We manipulated benefactor's intention by providing information about whether the co-player knew the participant could (Can condition) or could not (Cannot condition) reciprocate after receiving help. Results demonstrated two principal components of participants' emotional responses to others' help: participants reported increased guilt as well as gratitude when they perceived more benevolence from a benefactor in Cannot condition; in contrast, participants reported increased sense of obligation when they believed that the benefactor expected a repayment in Can condition. We developed a computational model to capture how participants make trade-off between these two emotional motivations to decide whether to accept help and how much to reciprocate. This dual motivational model accurately predicted participants' behaviors and revealed individual differences in weights on the two motivations during decision-making. While some participants were more motivated by guilt and gratitude and consequently repay more to benevolent help, others were more motivated by obligation and consequently repay more when the benefactor expected a repayment. fMRI results revealed differential neural bases underlying the two components of indebtedness. While processing of guilt involved the activation of insula, processing of obligation involved activation of dorsomedial prefrontal cortex (dmPFC) and its connectivity with dorsal anterior cingulate. The stronger the neural coupling between dmPFC and reciprocity related areas (i.e.,

dorsolateral prefrontal cortex), the larger the relative weight on obligation during reciprocity. This work shed light on understanding related social phenomena, such as bribe-taking.

1-J-45 Neural correlates of expected wealth, competitive success, and risk in economic contests

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Introduction Competitions are part of daily life and require people to invest time and energy to gain advantage over others, and to avoid (the risk of) falling behind. Whereas standard economic theory assumes investment in competitions to be rooted in selfish pay-off maximization, psychological science adds that people may be driven also by the prospect of being victorious (or preventing defeat) and by risk-aversion. To unravel these "desires," we used a neurocomputational approach that integrated neuroimaging with decision making in a competitive contest. **Method** Subjects (n=25) underwent fMRI while making investments that could increase their wealth at their counterpart's expense ("attack"), or avoid losing wealth to their counterpart ("defense"). To examine whether and to what extent the desire for payoff maximization, competitive success, and risk of losing account for investments and track targeted neural circuitries in the human brain, we computed from investment history the reward individuals should expect given their investment (henceforth expected payoff), the probability of success (attacker victory and defender survival; henceforth expected success), and outcome uncertainty, or risk, immanent in their decision (henceforth expected risk). We then related these expected values to neural activation, with better prediction assumed to be indicative of the specific desire underpinning investment in attack and defense. **Results** Our study showed that expected payoff, expected success, and expected risk all correlated with investment behavior and, accordingly, account for the often observed behavioral deviations from game-theoretic predictions. We furthermore observed that these subjective desires were meaningfully related to neural activity in distinct brain regions. Expected competitive success tracked activity in the Ventral Striatum, and expected risk was related to neural activity in an expansive fronto-parietal cluster that included the temporal-parietal junction along with the dorsolateral prefrontal cortex. Interestingly, the neural correlations of competitive success and risk were observed only during investments aimed at winning from the antagonist (attacks), and when defending against possible antagonist attacks, respectively. This suggests that specific roles during competitions - to attack versus to defend - make certain desires more prominent and others less salient. **Conclusion** Our results suggest that expected success and risk are at least as important "desires" during competitive decision-making as is wealth maximization, and that these desires correlate with activity in the ventral striatum and a fronto-parietal network, respectively.

1-J-46 Differential roles of MPFC subregions in self-serving prosocial dishonesty

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Recent neuroimaging research have reported neural processes associated with prosocial goals on dishonesty (Cui et al., 2017; Yin et al., 2017; Pornpattananagnkul, Zhen & Yu, 2018). However, less is reported regarding another type of socially motivated dishonesty which exists in situations where dishonesty benefits both self and others. The present research aimed to devise an experimental paradigm that allows for classifying dishonest as opposed to honest choices on a trial-by-trial basis. The reward magnitude and the beneficiary of the dishonest decision were experimentally manipulated and

varied across trials. Participants (N=37) were instructed to report the side of the screen where more dots appeared. The screen was shown for a short duration of time but was calibrated individually to be long enough for the participant to be aware of the difference in the number of dots, and points could only be obtained through misreporting. Dishonest reports could benefit the participant (self), another participant (other), or both, and the magnitude of the benefit ranged from 0 to 2 points. The participants were told that the points obtained during the task would be used to reduce the length of the stressful task that will follow. Behavioral data analysis revealed that the proportion of dishonest report differed depending on the point to be obtained and the beneficiary, showing a significant 2-way interaction effect. People made significantly more dishonest reports when there were points to be obtained, and when the points would benefit self or both. A generalized linear mixed effects logistic regression was applied to model the effects of points, self-interest motivation and prosocial motivation on dishonest choices. Latent class analysis on the effects obtained from the model revealed that participants could be grouped into two sub-groups based on self-interest and prosocial motivations. Preliminary fMRI data analyses revealed that the dorsomedial prefrontal cortex activity varied with increasing points in all beneficiary conditions. In addition, the beneficiary of dishonesty modulated the activity in the rostromedial prefrontal cortex, which was significant only in those who showed overall lower self-interest motivation. In sum, the present preliminary findings suggest that distinctive subregions in the medial prefrontal cortex may contribute differentially to self-serving prosocial dishonesty.

1-J-47 Mentalising with the future? Electrical stimulation of the right TPJ increases sustainable decision-making

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With the omnipresence of reports on environmental problems, many people around the globe agree that immediate action and a drastic change in consumption patterns is needed if we want to avoid a global climate change with catastrophic consequences for future generations. Most people, however, fail to live a sustainable lifestyle, especially in the global north. Based on recent developments in the environmental sciences, we hypothesised that a lack of sustainable behaviour often stems from a failure to mentalise with the future. In other words, we believe that people today do not take the harm their decisions now are causing to people in the future into account. To test this hypothesis, we applied HD-tDCS to the right TPJ. During stimulation, participants engaged in a behavioural economic paradigm, measuring their sustainable behaviour if being sustainable meant that they had to forego a monetary reward for the sake of strangers in the future. All participants were tested two times, once with the stimulation of interest at the right TPJ, once with stimulation at the vertex as active control. Indeed, excitatory anodal HD-tDCS at the TPJ led to more sustainable decisions compared to vertex stimulation. Importantly, the behavioural change towards more sustainability was neither caused by changes in participants' fairness norms, nor by their estimation on how other people would behave, indicating that participants did not merely expect their fellow participants to behave differently and follow their lead, but changed their behaviour towards more sustainable decisions on their own accord. Our findings grant insight into the neural underpinnings of sustainable behaviour as well as its connection to socio-cognitive processes. Our findings could inspire targeted interventions to change the functioning of the TPJ to improve sustainable decision-making. From a more applied point of view, our results give neuroscientific support to theories on how to effectively communicate climate change information in a way that promotes intergenerational mentalising.

1-J-48 A new behavior change model compatible with expected utility theory

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It is often difficult for clinicians, trainers, or teachers to change people's undesirable habitual or addictive behaviors, such as overeating, excessive drinking, lack of exercise, and smoking. How can we help them change people's behavior for the better? The problem of "behavior change" has long been studied in various research fields such as psychology, pedagogy, nursing, public health, medicine, and health promotion (Fishbein and Ajzen, 2010). Several models for behavior change have converged to the hypothesis that attitudes, norms, and self-efficacy are the important determinants of intentions and behavior (Sheeran et al., 2016). However, existing models for behavior change, such as "Social Cognitive Theory" and "Theory of Planned Behavior (TPB)" cannot sufficiently predict the occurrence probabilities of a considered behavior or its change through interventions (Sniehotta et al., 2014). To improve the accuracy of predictive models for behavior change, some researchers have started to try to combine behavioral economics models with existing models for behavior change (Roberto and Kawachi, 2015). Because behavioral economics models consider various behavioral biases that affect the occurrence of a target behavior and/or its change through interventions, this combination was expected to be useful. However, existing models of behavior change are not consistent with Expected Utility Theory (EUT), which underlies a variety of behavioral economics models (Kahneman and Tversky, 1979; Schoemaker, 1982), and, therefore, this combination of models has been challenging. By clarifying the corresponding components between TPB and EUT, we propose a new model, Decision-Theoretic Model of behavior change (DTM), which is consistent with EUT. Specifically, perceived self-efficacy is MULTIPLIED by the weighted sum of attitude toward the behavior and subjective norm in DTM, in contrast to TPB in which it is ADDED to these factors. The superiority of DTM to TPB will be discussed.

1-J-49 Reciprocal fairness and human justice. A brain stimulation study

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We investigate the brain mechanisms associated with norm enforcement in social interactions. Using continuous theta burst stimulation (cTBS) we disrupt the activity of dlPFC and mPFC to establish a causal link between these brain regions and norm enforcement. This allows us to disentangle between different theories regarding the roots of human justice and to better inform theoretical models of norm implementation. Participants face different monetary allocations and have the opportunity to either reward or punish the individual who proposed the allocation (i.e., the proposer). Rewarding means to increase the earnings of the proposer and punishing means to decrease the earnings of the proposer. We implement a 2x2 within-subject design where we vary the target of the allocation (2nd party vs. 3rd party conditions). Further, we vary the cost involved in punishing and rewarding (no cost vs. cost conditions). H1. If the dlPFC is involved in overriding economic selfish impulses to facilitate the implementation of social norms, after downregulating the right dlPFC we expect a decrease in punishment and reward when it is costly. This holds in both the 2nd and 3rd party condition. Such an effect should not be observed when norm enforcement is costless. H2. The dlPFC has been suggested to be more generally involved in determining the appropriate norm enforcement through integrating notions of harm and intentionality, independently of a cost-benefit calculation. Downregulating the right dlPFC should result in decreased punishment and reward across all conditions compared to sham

stimulation. H3. Concerning the mPFC, it has been proposed that this region is important in fairness considerations only when unfair actions damage the self. Downregulation of the mPFC should result in a decrease in punishment and reward in 2nd party conditions compared to sham stimulation, regardless of the cost of punishing/rewarding. H4. If the mPFC is involved in cost-benefit calculations related to norm enforcement, downregulating the mPFC should lead to reduced punishment and reward in conditions where it is costly (regardless of personal involvement). Conclusion. Our results confirm H1 and H4, suggesting that both the right dIPFC and the mPFC have a specific role associated with overriding economic selfish impulses to facilitate the enforcement of social norms. Personal involvement in the situation to assess does not seem to be particularly linked to these two areas in our setting. Both the fairness evaluation and the social appropriateness judgment of allocations were not affected by brain stimulation.

1-J-50 Mood dynamics during altruistic decision making

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Although research in the fields of psychology and economics suggest that a possible motive for generosity is happiness that results from altruistic acts, one possibility is that this is the case only in individuals that value altruistic behavior. We developed a social decision-making task in which subjects made choices between generous and selfish probabilistic alternatives and rated their current happiness after few trials. In some trials, subjects did not have a choice about which option was selected. Using computational modeling, we show that momentary happiness depends on (1) the history of rewards, (2) agency (i.e., the ability to choose whether to make an altruistic decision), and (3) deviations from individual preferred allocations. Preferred allocations estimated from happiness predicted a participant's generosity in a separate dictator game. Our results constitute a step towards understanding the computational basis of the relationship between momentary happiness and altruism.

1-J-51 Spreading news: The multimodal factors of information sharing behaviors

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Introduction. Sharing is the central feature of social behaviors that modern social media have amplified in the form of information sharing. Previous work has shown that false information spreads more rapidly than true information, and that information shared on the Internet is predictive of psychological traits. Moreover, metabolic factors (e.g., plasma tyrosine, a brain dopamine precursor) have been associated with behaviors that enforce fairness in sharing of resources. However, despite the importance of sharing in human interactions, the specific dynamics of sharing behaviors are yet unexplored. Methods. Here, we investigated the contextual, psychological and metabolic factors influencing how people share information with others. Thirty-nine participants (18 males) came to the lab and gave blood samples before undergoing a novel, interactive, information-sharing task with other participants. At the end of the experiment, questionnaires on psychological traits were filled out. Results. We demonstrate that participants share more information in a competitive context and that this information is of poorer quality. On the contrary, less information was shared in a cooperative context, but this information was

of higher quality. Moreover, during cooperation, higher confidence about the information's quality was required for sharing, suggesting that participants were filtering the quality of their information. Across contexts, more extrovert individuals shared more information of higher quality. Finally, higher plasma tyrosine levels predicted more high-quality information sharing in a cooperative context. Conclusions. These results suggest that during cooperation, individuals care more about the quality of their information, applying a quality filter to share only what may most benefit the group. On the contrary, during competition, information may be used to win out over the competitors, for instance, spreading low-quality information to dumbfound and sidetrack them. Further, sharing behavior hinged on individual psychological traits and individual metabolic states. In particular, the positive relationship between high-quality information sharing and plasma tyrosine may indicate a role of brain dopamine in sharing of qualitative information. These results are of pivotal interest not only to psychologists, economists and neuroscientists but also to politicians and policy-makers. For instance, given recent attempts to reduce the spread of fake news on the Internet, creating more cooperative online environments may help foster the spread of high-quality information, concomitantly reducing the sharing of fake news.

1-J-52 When the grass is greener on the other side of the border: How the wealth of foreign countries affects our own life-satisfaction.

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Objective: Life satisfaction is greatly influenced by relative wealth. An individual earning \$100K tends to be happier if their neighbors earn \$80K than \$120K. At the same time, however, a person's identity is tied to their group. Is life satisfaction therefore also influenced by the relative wealth of a person's group? One group that is closely tied to a person's identity is their country. Here, we test whether the relative wealth of an individual's country, in comparison to neighboring countries, influences personal life satisfaction. That is, would citizens of a country where the average income is \$100K be happier if the average income in neighboring countries is \$80K than \$120K (controlling for all the obvious confounds)? Further, we examine whether inequality between neighboring countries also influences life satisfaction. **Methods:** We used a dataset that included the reported life-satisfaction of a representative sample of 2.08 million individuals from 154 countries (this is over 95% of countries in the world). We then examined whether the relative wealth of a country in comparison to neighboring countries, as well as inequality between neighboring countries, affects people's life satisfaction. **Results:** The greater the relative wealth of a country relative to neighboring countries (defined as the country's rank within a geographical region) the greater the life satisfaction of its citizens ($\beta = 0.20$, $p < 0.0001$) (controlling for absolute wealth of the country and of the individual, as well as a host of other factors). Moreover, the higher the inequality between neighboring countries, the lower the life satisfaction of the citizens within those countries ($\beta = -0.58$, $p < 0.0001$). Models that included these two factors predicted life satisfaction better than a broad range of other models. The effects were even larger in countries that are more interconnected with other countries on an economic, political and social level. **Conclusion:** Between-group comparisons significantly impact life-satisfaction. Citizens' well-being is affected by the relative wealth of their country as well as the level of inequality between countries in a region. We followed up this study with an experiment in which a person's group's wealth was manipulated and found the same results. Our findings highlight one mechanism by which globalization may impact happiness.

K. Valuation & Value Systems

1-K-53 Resting-state connectivity correlates of gain and loss valuation in a mixed-gambles task

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Background and aim. Prospect theory describes risky decision-making as subjective valuation of potential gains and losses. Previous studies have demonstrated, using functional magnetic resonance imaging (fMRI), that activity in the amygdala, ventromedial prefrontal cortex (vmPFC) and ventral striatum (VS) represent potential gain and loss magnitudes. In addition to task related fMRI, functional connectivity at rest has been demonstrated to predict individual differences in multiple cognitive tasks. Therefore, the aim of our study was to examine the correlation between functional connectivity at rest and valuation in a mixed gambles decision-making task. Methods. We collected data from 100 participants from two experimental groups. On each trial, participants were asked to decide whether or not they would like to accept a mixed gamble entailing an equal 50% chance of gaining one amount of money or losing another amount. In one group gains and losses had an equal range ('equal range', n=50), where in the second group the gains' range was twice the range of the losses ('equal indifference', n=50). Each participant performed four runs (256 trials) of a mixed gambles task while inside the MRI. In addition to task related data, we collected resting-state fMRI data. For each participant we calculated pairwise Pearson Correlation Coefficients of the time series among six predefined ROIs (amygdala, vmPFC and VS; right and left). We correlated the connectivity between each pair of ROIs with the behavioral measures of gain and loss valuation from the mixed gambles task across participants. Results. We found that within the 'equal indifference' group the connectivity of the right amygdala with all other ROIs correlated with the measures of loss valuation (r range = 0.29-0.35, $p < 0.05$). For gain valuation, there was only correlation with the connectivity of the right and left amygdalae ($r = 0.37$, $p < 0.01$). No such correlation was found in the 'equal range' group. Conclusions. The amygdala, vmPFC and VS were previously found to be linked with gain and loss valuation in task fMRI. Our results demonstrate for the first time that connectivity at rest between these areas are also predictive of these behavioral measures. Our results are in line with the accumulating evidence of the relationship between task related brain activity and connectivity at rest.

1-K-54 The geometry of flexible goal-dependent representations for value-based choice

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Throughout their lives, humans must compare the value of different options. The neural circuits underpinning these value based decisions have been object of intense investigation over the past two decades, which led to a consensus about the central role of the ventromedial prefrontal cortex (vmPFC). In most previous studies, however, the value of options or actions was not explicitly manipulated, as options were usually evaluated in terms of monetary value or subjective pleasantness. Therefore, this line of enquiry has overlooked a central aspect of value computation: value is inherently goal dependent. For someone stranded in a desert, for instance, a glass of water is more valuable than a diamond. In this study, we sought to investigate how preferences between behavioural options, and their underlying neural activity, are affected by changing goals. To this end, we acquired behavioural and imaging data while volunteers made decisions in order to achieve two different goals. Specifically, in some trials participant had to imagine using a series of everyday items to achieve either goal; in other trials, they choose the most useful amongst two items. We found that choices, as well as vmPFC activity, were driven by the value that items acquired under the current goal but were insensitive to the value for the

alternative goal. This finding implies a specific goal dependent neural mapping between the sensory input and the behavioural output. We then used representational similarity analysis to test how such new goal dependent geometries emerged. In other words, we looked for regions in which similarity between items was decoupled from the items' sensorial appearance and was instead determined by its usefulness in the context of a specific goal. This analysis revealed evidence of value representations (even in absence of evaluation or choice) in a brain network including the vmPFC and the orbitofrontal cortex (OFC). Critically, the OFC activity supported an integrative code of value and confidence. Finally, since estimations of the goal dependent usefulness were idiosyncratic and depended on participants' individual past experience, we tested the role of the hippocampus in triggering this remapping. We found that, during valuation, the hippocampus represented value; moreover, during binary choice, the hippocampus preferentially reinstated the representation of the item that was later chosen. In summary, with this study we broad the classical role of the "value network" in value based decision making, and at the same time we provide new evidence of a flexible reorganization of the neural representational geometry that is shaped by behavioural goals.

1-K-55 Stable value-based choices relate to structural connectivity between hippocampus and parietal cortex

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Objective: Decisions based on subjective values are essential for survival, for instance when deciding what we should (not) eat. Recent studies using EEG and transcranial alternating current stimulation (tACS) suggest that disruptions of fronto-parietal gamma phase-coupling reduce preference-consistency of value-based choices (Polania et al. 2014, 2015). We recently revealed neural circuit mechanisms that underlie these tACS-induced behavioral effects by concurrent tACS-fMRI (Moisa et al., SNE, 2018). This study showed that tACS effects on choice consistency were accompanied by changed value representations in hippocampus and caudate; moreover, the strength of the behavioral tACS effects correlated with the size of tACS-induced changes in functional connectivity between hippocampus/caudate and the tACS targeted areas. Here, we test the hypothesis that the tACS-induced changes in value-based choices relate to measures of structural connectivity between these areas. We hypothesize that the perpendicular diffusivity through myelin sheath (PD) and the fractional anisotropy (FA) will inversely correlate with the tACS-induced changes in preference-consistency of choice. **Methods:** We acquired high-angular-resolution diffusion-imaging (HARDI) for 28 participants who participated in the initial tACS-fMRI study. We performed probabilistic tractography to identify two tracts between areas identified as functionally connected, namely hippocampus and parietal cortex and caudate and frontal cortex. To test the hypothesized role of these tracts for value-based choices, we correlated the mean PD/FA values across participants with the tACS-induced changes in preference-consistency of choice. **Results:** Both indices of structural connectivity between hippocampus and parietal cortex correlated with the tACS-induced change in value-based behavior (mean PD in hippocampus-parietal tract: $r(27) = -0.40$, $p < 0.05$; mean FA in hippocampus-parietal tract: $r(27) = 0.43$, $p < 0.05$). The same correlation effects for the caudate-frontal tract were not statistically significant. **Conclusions:** The present results reveal that structural connectivity between the hippocampus and parietal cortex correlates with the strength of tACS effects on the stability of value-based choices. Thus, our results show that anatomical pathways between the hippocampus and the parietal cortex are involved in the construction of stable choice values guiding behavior. Furthermore, we show that combining tACS, fMRI and HARDI data can

comprehensively characterize the interplay between behavior and structural/functional connectivity underlying value-based decisions. Funding: ERC grant No 725355 BRAINCOCODES.

1-K-56 Normalized value coding adapts choice performance to prevalent rewards

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Objective: Neural systems can encode wide ranges of information despite limited coding capacity. Efficient coding theory suggests that neurons accomplish this by adapting to statistical regularities in the environment. Adaptive coding is well-described in sensory systems, and recent work implicates similar mechanisms in decision-related brain areas. However, the computational and behavioral consequences of adaptive value coding are largely unknown. Here, we use computational modeling and empirical choice behavior to show how an adaptive coding algorithm, divisive normalization, mediates recent reward effects on choice performance. **Methods:** Computational simulations were performed to quantify the predictions of different forms of normalized value coding with: no context-dependence, temporal context-dependence (adaptation), and temporal and spatial context-dependence (choice set normalization). To test these predictions, monkeys were trained in a saccadic decision task for options of differing reward volume. In each session, subjects first learned the values associated with distinct visual stimuli. Subjects then performed multiple blocks of 250 trials. ~50% of trials presented a binary choice between learned stimulus-reward pairs; the other ~50% of trials presented single-choice trials with a learned adaptor value. Adaptor value was constant within a block; in different blocks, the adaptor value was either low or high. Low and high adaptor blocks were alternated, with 2-9 blocks per session. **Results:** Simulation results predicted a strong and specific effect of normalized adaptation on choice performance, with better discrimination between low value pairs in low adaptation contexts and high value pairs in high adaptation contexts. Furthermore, models with strong spatial normalization showed diminished adaptation-driven effects. Preliminary data from one monkey (28 sessions; 13,964 trials) showed improved discrimination between low value pairs and high value pairs in low and high adaptation blocks, respectively. As predicted by model results, we observed relatively minor spatial normalization effects on overall choice behavior. Finally, consistent with an adaptive effect, magnitude-specific improvements in discrimination increased with progress through a block. **Conclusions:** Our results show that the reward environment affects choice behavior in a manner consistent with adaptive normalization, with improvements in choice performance specific to decisions between likely rewards. These findings suggest that a canonical gain control computation, normalization, may operate in decision circuits to optimize choice behavior despite biological constraints.

1-K-57 Examining valuation decisions during product purchases: a combined mobile EEG and eye tracking investigation

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Little is known about the neural temporal dynamics of value based decisions. Previous electroencephalographic (EEG) studies in humans (Harris et al., 2011) and animals have shown that valuation decisions can be computed within hundreds of milliseconds. However, it is unclear how valuation decisions evolve in realistic scenarios. The current study aimed to extend the results presented

in our recent paper (Roberts et al., 2018) by examining the spatio-temporal brain dynamics that accompany valuation decisions for products in realistic environments using mobile EEG and eye tracking. Twenty participants viewed and rated 216 images of household products (£0.50 - £12.00) in a product gallery whilst EEG and eye tracking was recorded. A Becker-DeGroot-Marschak (BDM) auction task was used to obtain willingness to pay (WTP) ratings for products, which were used to split stimuli into subjective value conditions (low, low medium, high medium and high value). Eye movement related potentials (EMRPs) were examined and an independent component analysis (ICA) decomposed sources of activation from the grand averaged EEG. A K-means clustering solution was applied to decomposed grand averaged EMRP data for 20 subjects using the principle component analysis (PCA) method in EEGLAB. Each cluster's mean activation was statistically compared across subjective value conditions between -200 and 600 ms. Four clusters displayed significant differences in amplitude for subjective value between 50 and 230 ms. Cluster 3 showed enhanced amplitude for low compared to high (116-127 ms) and for high compared to medium (193-204 ms). Cluster 5 showed enhanced amplitude for low compared to low medium (50-63ms) and high (132-148 ms), then low compared to both medium conditions (170-183 ms). Cluster 6 showed enhanced amplitude for low versus the highest value products (56-58 ms), followed by enhanced amplitude for all value conditions versus high medium (225-230 ms). Cluster 9 showed enhanced amplitude for high medium versus all (158-185). Results suggest that low value products receive a prioritization of attention by the brain in real world scenarios. Lower value products are quickly isolated and compared across multiple clusters. High medium value products appear to receive enhanced attention slightly later as these products may require more deliberation. The early prioritization of attention toward low value products may represent an aversive mechanism that exists to maximize economic resources (by avoiding loss). The results demonstrate that the brain does not allocate attention for products in a linear manner, rather, multiple ICs detect differently valued products in parallel.

1-K-58 Violations of economic rationality in reinforcement learning are driven by a saliency-dependent reward-prediction-error signal in the ventral striatum

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When choosing among more than two options, humans and other animals frequently violate the independence principle of rational choice theory. According to this principle, relative choice probabilities between options should not be affected by the composition of the choice set. Recently, Spektor et al. (2019, Psychological Review) have demonstrated that such violations can also occur in reinforcement-learning (RL) tasks. They proposed the accentuation-of-differences (AOD) model, a novel RL model according to which outcome saliency distorts feedback processing and therefore leads to violations of the independence principle. More specifically, the reward-prediction error (RPE) of options with particularly distinct outcomes is assumed to be biased in the positive direction. In the present study, we tested this proposal on the neural level by investigating the fMRI-BOLD signal of the RPE in the ventral striatum. A total of 40 participants completed two sessions of an RL task comprising three choice options each (A, B, C; B, C, D). Reward contingencies for two of the three choice options (B and C) were equal across sessions, which allowed us to test for violations of the independence principle. The third option (A in session 1 and D in session 2) was specified such that the AOD model would predict a relative preference for C over B in session 1 and vice versa in session 2. fMRI data was acquired on a 3T MR scanner. Analysis of the choice behavior provided very strong evidence for the predicted independence

violation: The relative choice share of the target option (C in session 1, B in session 2) was .71, which was significantly larger than the .50 that would satisfy the independence principle, $t(39) = 6.28$, $p < .001$, $d = 0.99$. Additionally, the AOD model provided a better account of the choice data compared to a standard RL model and a risk-sensitive RL model. Model-based fMRI data analysis revealed a significant AOD-based RPE signal in the ventral striatum, even after controlling for the reward signal itself, $Z = 5.42$, whole-brain-corrected $p = .005$. Critically, a Bayesian model comparison of the brain data showed that the AOD model provided a better account of the RPE signal in the ventral striatum than the competing RL models. In conclusion, our study provides further evidence for violations of the independence principle in RL decisions and elucidates the underlying neural mechanism. Feedback processing in the reward system of the brain is influenced by the distinctiveness of outcomes such that particularly salient options are preferred.

1-K-59 Over- and underreaction in detecting regime shifts and the neurocomputational substrates for estimating probability of change

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In dynamic environments where technology, markets, competitors and even narratives change regularly, many decisions are tightly associated with our ability to estimate and detect changes. Previous studies on judgment and decision making had established that people exhibit systematic biases in their estimation of change: we can overreact -- believing that a change has occurred such as a regime has shifted while in fact it has not -- or underreact depending on the stability of the environment and reliability of the information we receive. The goal of this study was to investigate these systematic biases and their neurocomputational substrates. In a probability estimation task, subjects were instructed that there were two regimes, represented by two urns -- a red urn and a blue urn. Each urn consisted of red and blue balls; the red urn had more red balls and the blue urn had more blue balls (same relative ratio). In each trial, ten samples were drawn sequentially from one of two urns. The regime can shift from one urn to another at most one time in a trial. After observing each sample, subjects had to estimate the probability that regime has shifted. We manipulated the stability of the environment by varying the transition probability between the regimes and the reliability of information by varying the relative ratio of red to blue balls, which we referred to as signal diagnosticity. We replicated the systematic biases shown in previous studies: compared with the ideal Bayesian solution, subjects ($n=30$) tended to overreact to a new sample by giving larger estimates on the probability of regime-shift in noisy (low signal diagnosticity) but stable environments (small transition probability). By contrast, subjects tended to underreact in precise (high signal diagnosticity) but unstable (large transition probability) environments. Further, we fit a quasi-Bayesian model that incorporate free parameters to separately estimate sensitivity to transition probability and signal diagnosticity under different environmental conditions. We found that sensitivity to both transition probability and signal diagnosticity are a decreasing function of their respective dimensions, consistent with a "system-neglect" model in which people respond primarily to the signal and secondarily to the system that generates the signal. Preliminary fMRI results showed that activity in the posterior parietal cortex (PPC) represents probability estimate on regime shift, while the ventromedial prefrontal cortex (VMPFC) tracks the amount of information collected. Together, these results indicate the possibility that PPC and VMPFC dynamically interact when estimating changes in environments.

Poster Session 2 Saturday, October 5th

B. Choice & Choice Mechanisms

2-B-1 Exploring value-computation elements and motor-execution elements as sources of choice inconsistency

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Objective: A fundamental axiom in neoclassical theories of choice is that the decision-maker is consistent in her choices, though several studies showed subjects violate this axiom. However, studies have yet to examine the ongoing dynamics leading up to an inconsistent choice by exploring the moment-by-moment process of choice itself. By looking into the dynamics of inconsistent choice behavior, we aim to explore some of the sources of choice inconsistencies such as motor execution elements originating in motor-related brain regions ("trembling hand" errors), and value computation elements originating in value-related brain areas. To do so, we use mouse tracking tools, which have been extensively used in the literature, to investigate cognitive processes underlying subjects' choices. **Methods:** 91 subjects completed a task aimed to measure their level of inconsistency on a given trial. Subjects were presented with budget sets, where each bundle on the budget set represented a 50-50 lottery between the amount of x and y. On each trial, subjects had to choose their most-desired bundle lottery. We recorded the mouse trajectories during each trial. In addition, subjects completed two similar supplementary tasks, but without the need to compute the values of the bundles, aiming to solely capture trajectory features related to motor execution and numerical cognition. Our design presents subjects with infinite number of choice options due to the continuum of the budget line. We therefore, developed novel algorithms to characterize mouse features extracted from our data set, using advanced machine learning and image processing techniques. We clustered the different mouse features, and looked into the relationship between each cluster and the severity of inconsistent choice. Importantly, we compared features across the main task and the two supplementary tasks in order to identify differences in mouse features on a trial-by-trial basis. **Results:** Subjects exhibit higher inconsistency levels compared with previous studies due to the high number of trials subjects encountered. We extracted a total of 37 different mouse features, classified features into 5 clusters, and characterized each cluster ex-post. We found that 3 clusters related to velocity, entropy and "movement fixations" (movement layovers) affect choice inconsistency. **Conclusions:** These findings imply that certain elements in choice-dynamics can predict inconsistency levels. Using the trial-by-trial comparison, we aim to indicate which elements can be regarded as malfunctions in motor execution, and which elements are related to noisy value computations.

2-B-2 Dorsolateral prefrontal cortex plays dual role for mental effort

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Mental work increases performance but is subjectively perceived as aversive. Models of mental effort disagree on how the aversiveness of mental effort arises through reduced availability of cognitive resources (capacity hypothesis) or inherent toll of cognitive control (cost hypothesis). Here, we pitted these competing hypotheses against each other. Specifically, we disrupted functioning of dorsolateral

prefrontal cortex (DLPFC) with continuous theta burst stimulation (cTBS) before 60 participants decided whether to exert mental effort for monetary rewards in a demanding working memory task (N-back task). In support of the cost but not the capacity hypothesis, we observed that participants were less sensitive to effort costs during decision making and felt less exhausted after working memory performance in the DLPFC compared with the control stimulation group. Moreover, prefrontal downregulation impaired performance in the working memory task, suggesting that effort costs are represented by the same DLPFC subregion that is also causally involved in mental effort exertion. Together, our findings suggest that motivation and performance are linked at the neural level and support theoretical notions on the inherent costs of cognitive control.

2-B-3 Forecasting the US primary elections from convenience samples using behavioural science tools

Joseph Marks¹, Tali Sharot¹

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Objective: Forecasting the outcome of elections is hard. Traditionally, such forecasts have been based on the voting intent of a representative sample. This approach has two critical limitations: (i) it requires a large, inconvenient, sample; and (ii) it has failed in recent years to predict important election results. Thus, new approaches are needed. Here we test whether models, based on a large range of theories in social psychology, cognitive psychology and behavioural economics, can accurately forecast the 2020 US Democratic primaries from small convenience samples. We further test whether this method provides similar forecasts to those generated from large, expensive, representative samples. Methods: Fifty U.S. citizens completed surveys that elicit a range of measures, including responders' (i) familiarity and recollection of the candidates; (ii) evaluations of the candidates' characteristics (e.g., warmth, competence, etc.); (iii) forecasts of the outcome; (iv) beliefs about others' forecasts and their voting intentions. These measures were used to build models to predict the 2020 Democratic Party primary election outcomes. Results: As outcomes are not yet available, it is impossible to assess absolute accuracy of our models at this time. Instead, we compare our models' predictions to available forecasts generated from large, expensive, representative samples. Our results show that the best performing model includes a measure assessing participants' beliefs about other people's forecasts (Adjusted $R^2 = .96$). Adding a memory-based measure to this model increased the fit to $R^2 > .99$. In contrast, simply asking responders of this convenient sample about their voting intention did not provide a close fit to the forecasts generated from large representative samples ($R^2 = .51$). Conclusion: A small, non-representative, sample provided forecasts of the 2020 Democratic Party primaries that fit exceptionally well to the national poll average, which combines data from many large representative samples. This was not accomplished by asking subjects about their voting intentions, rather by probing their beliefs about others' beliefs (as well as their recollection of candidates). This is the first step of an on-going project that aims to predict the 2020 Democratic Party primaries.

2-B-4 Predicting decision regret in vaccination: Does the decision matter?

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Regret is one of the most commonly investigated, yet not fully understood, emotion in the decision-making literature, and it holds significant implications for both individual and public welfare. To date, still

little is known on the antecedents of a certain form of regret--decision regret--, and on its time-sensitive nature. Across two experimental studies, we contribute knowledge to this important construct by investigating the role of people's ambivalent attitudes, information feedback, individual characteristics, and actual decisions in predicting decision regret. We focus our examination on a timely context, that of vaccination decisions, given a widespread skepticism on inoculation programs worldwide. This skepticism is often supported by feelings of regret for past vaccinations as well as by several personal characteristics and exposure to tendentious information, including the so-called 'fake news.' Overall, we presented participants with a validated vignette describing the hypothetical spreading of a virus through their community; we asked them to make an informed decision, with full disclosure of information, on whether to vaccinate or not. Before taking the actual decision, participants were randomized into two groups: either they were provided a feedback reporting the death of some people after vaccination, or no feedback was provided. Note, the initial vignette clearly explained that the vaccine was not lethal, thereby the feedback, when given, was meant to be 'rationally' identifiable as a false piece of information. In the first behavioral study (n=254), we investigated the extent to which the receipt of false information and a prosocial orientation predicts decision regret in a large online sample. In the follow-up laboratory study (n=129) we replicated the previous experiment and used mouse-tracking and an artificial neural network analytical approach to unpack the participants' decision-making process in real time as a possible predictor of decision regret. Intriguingly, in both studies, we found that the actual decision to vaccinate (or not) did not predict decision regret. Instead, our findings suggest that decision regret can be best explained by a person's prosocial orientation, their sense of cognitive ambivalence, as well as the receipt of false information. Theoretically, our work exposes some salient antecedents of decision regret and its time-sensitive nature. Practically, it alerts to possible strategies to tackle the skepticism around immunization programs, by alerting to the importance of tailoring communication to one's prosocial orientation with the aim to reducing decision regret.

2-B-5 Avoidance of delayed mental effort cost without awareness

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Time and effort are especially precious to humans. Temporal discounting in choice of positive or negative factors were reported in the human or other animals. However, the temporal effect of mental effort cost remains elusive. We hypothesized that, in the human, delayed mental effort cost is more discounted than immediate effort cost. To test this hypothesis, we developed a behavioral experiment and studied in young healthy volunteers (n = 21). In the experiment, at the start of each trial, two options, left and right arrows, appeared, and participants were required to choose one of them at individual trials (Total = 150 trials). Not instructed to them, one option was followed by long inter stimulus interval (ISI: from options to presentations of division problem (see below)) (6.5/8.0/9.5 seconds; jittered) and short inter trial interval (ITI: from answer to division problem to next options) (2.5/4.0/5.5), referred to as delayed cost option. The other option was in the opposite manner, i.e., short ISI (2.5/4.0/5.5) and long ITI (6.5/8.0/9.5), referred to as immediate cost option. After an option was chosen, a mental division problem was presented. Participants were required to divide a 5-digit number by 7 and reported whether the remainder was small (≤ 3) or large (≥ 4). After 150 trials, they answered a questionnaire about their perceptions about the task. We paid them equally. As a result, the choice rate of delayed cost option (median: 0.43, Q1: 0.39, Q3: 0.52) was lower than 0.5 (Wilcoxon signed-rank test, $p=0.035$, z/\sqrt{n} : 0.46), meaning that participants tended to avoid delayed mental effort cost. Moreover, the choice rate

for delayed cost option decreased from the first 50 trials to the last 50 trials by 0.08 at the median (Q1: 0.01, Q3: 0.14; Wilcoxon signed-rank test, $p=0.016$, z/\sqrt{n} : 0.52), indicating that avoidance was learned through experience. As for the questionnaires, 38% of participants answered that they found a difference between the two options. However, when they were asked what the difference was, they did not answer the true difference, not even anything about time. Therefore, they learned to avoid delayed cost option without noticing that the difference between the two options lied in the delay of problem presentation, or more accurately, in both ISIs and ITIs. These results suggest that future mental effort cost can be temporally boosted, not discounted, even if the delay is only a few seconds and does not induce awareness. A possible explanation of this is that sustained task preparation itself is registered as mental effort cost and is learned to be avoided. Further study is needed to explore this and other possibilities.

2-B-6 A common neurocomputational mechanism for visual perception and risky choice

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Objective: Visual illusions, such as the Ebbinghaus illusion, have long been studied to better understand the neural computations of visual perception (Robinson, Hammon, & de Sa, 2007; Schwarkzkopf, Song & Rees, 2011). Similarly, lottery choices are a fundamental paradigm for understanding risk preferences in neoclassical economic theory (Holt & Laury, 2002). Building on recent theoretical advances in visual perception (Wei & Stocker, 2015), neuroeconomic theory has proposed that risk averse lottery choices result from capacity constraints on the perception of numerical magnitudes (Khaw, Li, Woodford, 2019; Frydman & Jin, 2019). This work suggests that there might be a common neurocomputational mechanism underlying both visual perception and the perception of risky rewards. We aim to demonstrate that both risk aversion and susceptibility to the Ebbinghaus illusion can be captured by the same neural computation, divisive normalization (Carandini & Heeger, 2012; Louie, Webb, Glimcher, 2015). We first derive this prediction formally and then conduct a laboratory experiment to test whether subjects who are more susceptible to the Ebbinghaus Illusion will be more risk averse. **Method:** We propose a model of divisive normalization in which a recurrent weight is stronger than all other weights. These weights may vary across individuals, but they are consistent within an individual across decision contexts. We formally derive the conditions under which the model predicts more susceptibility to the Ebbinghaus illusion will be linked to more risk aversion in the subsequent lottery task. To test this hypotheses, 51 subjects participated in a behavioral experiment with two phases. First, subjects compared the size of target dots in the Ebbinghaus illusion in $N=162$ stimuli presentations. Second, subjects conducted $N=612$ trials of a standard incentive compatible lottery, choosing between a sure thing of £10 and a gamble of (£15, £26, £41 and £57) with some probability p (.12, .23, .35, .43, .5, .55, .67, .79, .86), otherwise zero. **Results:** For the case of the Ebbinghaus illusion, we prove that subjects with higher recurrent weights will be more susceptible to the illusion. For the lottery domain, we also prove that high recurrent weights imply a higher degree of risk aversion. This prediction is confirmed in our experimental data. Subjects that demonstrated better performance in the Ebbinghaus illusion task (i.e. better sensitivity) were less risk averse and more sensitive to EV differences in the lottery task. These findings speak to the universality of divisive normalization as a common computation across various domains.

2-B-7 Use of decision heuristics in face of complex decision environments: An eye-tracking study

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Real-world decision making happens in a complex environment requiring processing multiple pieces of information. Prior research suggests use of decision heuristics, however not many studies have tested the associated processing patterns. The current study used eye tracking to investigate information search during a complex decision-making scenario. 53 subjects completed 3 phases of a forced 2-option probabilistic paradigm, while their eye-movements were recorded. Each trial showed two 2x2 grid cues with each cell reflecting different cue domains assigned with probabilistic weights predicting a win among two possible states (D1=0.95/0.05; D2=0.8/0.2; D3=0.65/0.35; D4=0.5/0.5). Training and first testing phase (NP) had these contingencies, while the last phase (EP) had D1-D4 with equal weight distributions (0.8/0.2). Participants chose the cue they considered had higher winning chances, learned through trial and error. Feedback (i.e. "win" or "loss") was provided after each trial. Accuracy was significantly higher in NP than EP ($F(1,52)=93.09$, $p<0.001$), suggesting that our manipulation effectively tampered performance. Analysis of eye-tracking compared the proportion of fixation across D1-D4 as well as the proportion of first and last fixation to D1-D4 to test participants' processing of different cue domains. A significant difference across D1-D4 was found as well as a significant linear contrast in the proportion of fixation ($F(1,52)=14.96$, $p<0.001$), proportion of first ($F(1,52)=14.96$, $p<0.001$) and last fixation ($F(1,52)=10.58$, $p=0.002$), suggesting that participants placed graded attention towards the domains in descending order of importance. To better characterize the nature of the processing strategy, we compared average RT and fixations in the following 4 scenarios: S1 (cue states different in D1); S2 (cue states same in D1 and different in D2); S3 (cue states same in D1-D2 and different in D3); S4 (cue states same in D1-D3 and different in D4). A significant difference across S1-S4 was found for both RT and fixation, as well as a significant linear contrast (RT: $F(1,52)=22.98$, $p<0.001$; fixation: $F(1,52)=7.84$, $p=0.007$). Participants took longer and processed more information when different cue states appeared in less important domains than when they did in the more important ones. No significant interaction between task phase was found in any of these measures, suggesting a consistent use of the same processing strategy despite change in decision environment. Collectively our results show that subjects established a hierarchy among pieces of information and used serial search in descending importance, regardless of the change in contingencies.

2-B-8 The websurf task in an Amazon mechanical Turk sample

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Objective: The WebSurf task, built to parallel rodent behavior on the Restaurant Row task, has demonstrated economic behaviors such as regret and sunk costs in undergraduate sample populations tested in the laboratory (Sweis et al 2018). However, in order to use this task as a digital clinical paradigm, it should generalize to remote experiments. To test this generalizability, we measured WebSurf behavior in a large Amazon Mechanical Turk (mTurk) sample. Methods: We created a web-based version of WebSurf and recruited a sample of 579 individuals on mTurk. 280 people passed our performance check to rule out bots and provided complete data. In the WebSurf task, individuals had 30 minutes to cycle through 4 galleries of different categories of video clips (Kittens, Landscapes, Bike Accidents, Dance). On entering a given gallery, they were informed of a delay (random 1-30s) before the video would be presented. They could choose to wait out the delay to watch the video ("stay"), or to

leave ("skip") and try a new delay at the next category. The delay began counting down after they accepted the delay. While waiting, individuals were also given the option to "quit" and to immediately continue to the next gallery. Because pilot data showed that a large subset of online participants performed as if distracted, an attention check was added during the waiting time. A 2s travel time was imposed between each gallery. Results: The population sample was gender balanced (50% M, 49%F, 1% nonbinary) and showed an age range of 20-70 years. General behavior was similar to the in-person experiments, with most subjects showing reliable thresholds fit by Heaviside functions for each gallery, consistent with post-video ratings (1-5 stars) and explicitly stated gallery rankings done at the end of the experiment. However, a small proportion (4.3%) revealed inverted Heaviside functions and were excluded from further analyses. Z-scored log decision times were higher on low value trials than high value trials, but this asymmetry vanished with age. Older individuals also showed a higher proportion of "bad quits", i.e. quit out of a high value stay trial, even though they overall quit at similar rates to younger individuals. However, the proportion of quits (1.3%) was smaller than previous human studies. Unlike the in person experiments, we did not observe sunk cost behaviors. Whether this was related to changes in the subject population, the addition of the attention check, or to the very small proportion of quits observed remains unknown.

2-B-9 Integration of reward and representational information during categorical decision making in the angular gyrus and ventromedial prefrontal cortex

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Research in reward and value based decision making and categorical decision making have proceeded in relative isolation. Reward is typically associated with a value sensitive neural network including the ventromedial prefrontal cortex (VMPFC) and striatum, whereas categorical decision making is associated with executive control networks in lateral prefrontal and inferior parietal regions along with perceptual cortices. We developed a novel task to test how reward is combined with category representation during categorical decision making. Subjects first learned to categorize novel abstract polygons formed as distortions of underlying prototypes into two categories. During fMRI scanning, on each trial subjects first saw a cue indicating the probability that correct performance would be rewarded (0, 25, 50, 75, or 100%). Subjects then saw a stimulus and categorized it. Finally, subjects received feedback: for a correct and rewarded trial, this was 1 point, otherwise 0. A bar graph indicating total points was shown, and subjects were told that the highest scorers would receive a large monetary bonus. We used model-based univariate and multivariate representational similarity analyses (RSA) to identify areas sensitive to category representation (category membership, distance from the prototype in perceptual space, and distance prediction error at feedback), reward (probability of reward at cue and stimulus, reward and reward prediction error at feedback), and their interactions. Reward was associated with activity in the value network, and category representation with executive control and perceptual regions. Two regions showed different patterns of activity consistent with integration of reward and category representation. The angular gyrus was sensitive during stimulus to the interaction of prototype distance and reward probability, and coded for reward, category, and their interaction in the RSA analysis. The angular gyrus also was sensitive to both reward and prototype distance prediction error at feedback, indicating a possible role in updating representations based on feedback. The VMPFC was sensitive to reward probability at cue, and conjunction analyses between time points in the task found it to be sensitive to both reward and prototype representation across cue, stimulus, and feedback, indicating a role in

maintaining contextual information about reward probability and integrating it with categorical information. These results indicate roles for the angular gyrus in combining sources of information for decision making for each stimulus, and VMPFC in maintaining contextual knowledge that integrates reward with representational information.

C. Consumer Behavior & Marketing

2-C-10 Double decoys and a possible parameterization: Empirical analyses of pairwise normalization

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How do people aggregate and compare attribute information when evaluating choice alternatives? The pairwise normalization theory by Landry and Webb (2019) introduces a basic feature of sensory perception - divisive normalization - into a standard multi-attribute choice framework. This simple model can capture a wide variety of multi-attribute choice phenomena, such as the introduction of a dominant ("decoy") alternative biasing choices towards the dominant alternative, in contrast with existing theories. In this article, we bring the pairwise normalization model to a stochastic setting so that it can be estimated and tested directly with choice data. Our aim is two-fold. First, we examine novel predictions of the pairwise normalization model when multiple decoy alternatives are introduced into the choice set. We contrast these predictions with models which hypothesize that the range of attributes influences choice and conduct an experimental analysis to test for the presence of a "double decoy" effect. To test these predictions, we collected stated preference data from 108 participants over credit card offers from 100 choice sets comprised of 2 to 4 alternatives. Crucially, when we add a second decoy to the choice set, we ensure that it does not alter the range of attributes presented. Therefore a range normalization model predicts no effect from the second decoy, while a pairwise normalization model does. In the full sample, we find significant evidence that the introduction of a second decoy alters the relative choice proportions between alternatives ($p < 0.001$). This pattern is particularly striking if we condition the sample on the number of subjects that demonstrated a single decoy effect: the raw probability that the dominant alternative drops from 60.4% to 55.2% ($p = 0.002$) in the presence of the second decoy. Analyses to rule out regression to the mean effects are also conducted. Second, we offer a parameterization of the pairwise normalization model for empirical settings. This extension includes weights on attribute dimensions to address subjective preferences and/or unit definitions, and allows for hypothesis testing for the presence of normalization in a choice dataset. We then analyze the pairwise normalization model on data from a 4 alternative choice experiment. We find significant evidence for the presence of normalization and find it substantially outperforms the basic Logit model. In an out-of-sample prediction comparison (where the chance prediction is 25%), we find that pairwise normalization has a 40% prediction rate. This is over 5% higher than the Logit per trial, yielding a substantial difference in out-of-sample likelihoods.

2-C-11 Marketing placebo effects on taste perception are not related to the level of trust in marketers and not affected by oxytocin

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Background: Past research showed that marketing actions that create quality expectations in consumers, such as pricing or branding, influence the subjective experience of taste pleasantness. This phenomenon has been coined marketing placebo effects (MPEs). As yet, the neurobiological mechanisms mediating

MPEs are still unclear. The neuropeptide oxytocin has been found to promote interpersonal trust and enhance pain placebo effects. Against this background, we hypothesized that oxytocin may also boost MPEs by increasing trust in marketers. Methods: In a randomized, double-blind, and pre-registered between-group study, 202 male participants performed a tasting task after intranasally receiving oxytocin (24 IU) or placebo. The participants reported experienced taste pleasantness of identical but differently labelled (marketing-label vs. non-marketing label) and packaged (superior vs. inferior packaging) products. Questionnaires were used to assess participants' trust in marketers. Results: Our results showed no significant effect of oxytocin on marketing-induced taste preference, the level of trust in marketers or expectations of marketing products. The strength of MPEs was not associated with the level of trust in marketers. Conclusions: Our study suggests that oxytocin does not affect MPEs on subjective experiences of consumers and provides preliminary evidence for distinct mechanisms of MPEs and placebo analgesia.

2-C-12 Understanding of how consumers evaluate brand extension: An fMRI study

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Brand extension refers to the use of well-established brand name into new goods or services, eliminating an entrance barrier into new markets and reducing marketing costs. To develop a better brand extension strategy, many electroencephalographic (EEG) studies have investigated cognitive processes underlying brand extension evaluation and revealed that conflict, semantic retrieval, and categorization processes are involved in brand extension evaluation. Nevertheless, EEG has a critical limitation of a low spatial resolution and a difficulty to measure deep brain activity such as insula, thalamus or amygdala that are related to diverse cognitive and affective processes. Therefore, the present study aims to investigate neural correlates of brand extension evaluation using a functional magnetic resonance imaging (fMRI). In our S1-S2 experimental paradigm, the stimuli were composed of six beverage brand names (S1) and ten extended goods names (S2), including five beverages and five household appliances. This composition generated a total of sixty S1-S2 pairs. fourteen participants saw one of the extended goods names following one of the brand names for 2 seconds each. Next, they responded whether they would accept a given S1-S2 pair with a 8-scale response (-4, -3, -2, -1, 1, 2, 3 or 4). The experiment consisted of three repetitive blocks in each of which sixty stimuli were presented randomly. We assigned each trial as positive (1, 2, 3 and 4) or negative (1, -2, -3, and -4) according to the response. The paired t-test on behavioral responses showed a significantly larger magnitude in negative responses ($p < 0.001$). Additionally, reaction time was significantly faster in negative responses ($p < 0.05$). These results indicate that participants responded to negative stimuli more decisively. From the neural data, a contrast estimates analysis to compare BOLD activations between S2 and fixation periods revealed that right insula cortex as well as motor cortex were activated during the S2 period. Another contrast estimates analysis on BOLD activations between positive and negative responses showed more activations with positive responses in cerebellum, left sensorimotor cortex and insula ($p < 0.0001$, uncorrected, cluster extents > 30). Finally, a parametric modulation analysis on BOLD activations showed that the activity of anterior insula cortex and thalamus tracked the positive responses. The fMRI results showed that insula, known to be related to emotional processing, was specifically involved in positive evaluation of brand extension, suggesting that brand extension evaluation might recruit deep brain area as well as cortical areas.

2-C-13 The underlying neural mechanism of inaction inertia in consumption

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During panic purchase on big sales, consumers probably reduce purchase intention of a product with an attractive price after they missed a more attractive one, which is referred as inaction inertia. Researchers have big debates about whether inaction inertia is caused by emotion (i.e., regret) or valuation (devaluation of the product for missing an optimal price). Recently, researchers proposed regret and devaluation are working in parallel. The current study firstly explored this issue by fMRI. Twenty-six consumers' brain activity was measured in a panic buying task, in which they pressed a button as soon as possible to get a product at a discounted price (self) or the computer did that for them (computer). Missing the discounted price leads to inaction inertia. We used computational models to analyze the contribution of emotion and valuation and the role of regret and disappointment in inaction inertia. Behaviorally, discount difference between discounted price and final price significantly predicted inaction inertia ($\beta=3.14$, $t=30.77$, $p<0.001$), which was not different in self- and computer- conditions ($p=0.13$). Emotion ($\beta=0.38$, $t=15.11$, $p<0.001$) significantly predicted the inaction inertia whereas valuation ($\beta=0.02$, $t=-0.61$, $p=0.54$) did not, and regression coefficients of emotion were higher in the self-condition than in the computer-condition ($t(25)=2.27$, $p=0.03$). Regret tended to be lower than disappointment in the computer-condition ($t(25)=-1.80$, $p=0.08$). The two emotions were positively correlated with inaction inertia only in the self-condition but not in the computer-condition. Neurally, missing the discounted price activated brain regions involved in emotion (e.g. insula) and deactivated brain regions involved in value coding (e.g., MPFC, IPL), and decision making such as DLPFC. Right insula, caudate, MFG and SFG parametrically track regret in a trial-by-trial manner, suggesting that regret recruits brain regions related to decision-related loss and negative emotions. Regret and disappointment were hard to be differentiated in the snapping buying, which might be caused by both of them are originated from a comparison between the obtained outcome and a possible outcome that might have occurred. Regret affected inaction inertia through insula and IPL, suggesting that the regret-inaction inertia might be an emotion-cognitive decision making process. Disappointment only recruited insula in modulating inaction inertia. Thus, the two emotions work on inaction inertia with both shared and different neural mechanisms. These findings contribute to understanding inaction inertia in consumer behaviors, and provide implications for modulating inaction inertia.

D. Emotion & Affect

2-D-14 Can we change beliefs? Evidence for effects of ketamine on belief-updating in resistant major depressive disorder

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Background: Humans generally consider desirable information and neglect undesirable information when updating beliefs about risks of experiencing life events. Such biased belief updating though is altered in patients with major depressive disorder (MDD). A promising novel antidepressant treatment strategy involves the administration of sub-anesthetic doses of ketamine. Ketamine rapidly improves depression by acting upon NMDA/AMPA signaling pathways within the brain. These pathways are linked to the ability to draw inferences from contingencies in the surrounding environment. Building on this evidence, we hypothesized that ketamine causes early changes in belief-updating mechanisms and through it contributes to an improvement in depression. Methods: Nineteen patients with treatment-

resistant MDD (14/5 males/females, MADRS = 38 ± 1.7) performed a belief updating task 24h before (T0), 4h (T1) and one week (T2) after intravenous injection of ketamine. The task involved estimating one's belief about the risk of experiencing adverse life events before and after being provided with information about the average likelihood of each event's occurrence in the general population (the base rate). We measured how much the estimation error between the first belief estimate and the base rate predicted a change in beliefs as a function of estimation error valence (desirable: overestimation vs. undesirable: underestimation of the first belief relative to base rate) and treatment (T0 vs. T1 vs. T2). Results: We found that patients did update beliefs more after desirable estimation errors ($F(1,113)=37.9$, $p=1.2e-08$). Importantly, this main effect of estimation error valence was driven by ketamine treatment as indicated by a significant interaction valence by treatment ($F(1,113)=4.35$, $p=0.01$). Before ketamine treatment the patients considered both desirable and undesirable information for updating beliefs ($\hat{\alpha}_{\text{desirable}}=0.25 \pm 0.03$; $\hat{\alpha}_{\text{undesirable}}=0.16 \pm 0.07$, $t_{18}=0.9$, $p=0.33$, paired t-test). After ketamine treatment they considered desirable information more, than undesirable information (T1 4h post: $\hat{\alpha}_{\text{desirable}}=0.42 \pm 0.03$; $\hat{\alpha}_{\text{undesirable}}=0.03 \pm 0.05$, $t_{18}=5.4$, $p=3.8e-05$; T2 one week post: $\hat{\alpha}_{\text{desirable}}=0.47 \pm 0.03$; $\hat{\alpha}_{\text{undesirable}}=0.12 \pm 0.07$, $t_{18}=5.4$, $p=3.4e-05$, paired t-tests). Conclusion: Our results indicate that ketamine treatment was associated with biased belief-updating in depressed patients. We will follow up on this pilot finding to rule out effects of time, and to investigate (1) the role of biased belief updating under ketamine for clinical improvement and remission from depression and (2) the specificity of these effects relative to standard antidepressant treatment effects.

2-D-15 Emotion dynamics across adulthood in everyday life: older adults are better at regulating desires and more stable in their affective experiences

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Older adults report experiencing improved emotional health, such as higher levels of positive affect and lower levels of negative affect, in the laboratory and everyday life. However, there are mixed findings on whether older adults are better at regulating emotion--a hallmark feature of emotional health--and most research is based in the laboratory and may not capture how adults of varying ages regulate their emotions in everyday life. We used experience sampling to examine how multiple measures of emotional health, including mean affect, dynamic fluctuations between affective states, and the ability to resist desires--a common form of emotion regulation--differ across adulthood in daily life. Participants ($N = 127$) ranging from 20-80 years of age responded to mobile surveys about how they were feeling and responding to desire temptations, three times a day for 10 days. Older adults experienced higher levels of positive affect and lower levels of negative affect, and these effects remained significant even after controlling for individual differences in well-being. In addition, older adults were more stable in their emotional experiences and more successful at regulating desires. Based on a random community sample of healthy adults, numerous measures of emotional health--including mean affect, dynamic affect, and ability to resist desires--improve across adulthood.

2-D-16 Interaction between mood and adaptive learning

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Prediction errors are widely considered in terms of learning. Subjective well-being is also known to be

substantially affected by prediction errors during risky decision making, a context that requires minimal learning (Rutledge et al., 2014). It has been shown that sensitivity to prediction errors flexibly adapt to statistics of the environment including environmental volatility (e.g., Behrens et al., 2007). However, it is unknown whether the computational parameters that describe the relationship between ongoing experience and subjective well-being are stable traits or instead reflect changing environmental statistics. Unlike behaviour, we find that mood is equally susceptible to prediction errors across learning environments with different degrees of environmental volatility. Mood integrates over the same number of trials in stable and volatile environments. Moreover, we found a significant correlation across participants between the temporal mood integration factors from both environments. These findings suggest that, unlike behaviour, mood does not flexibly adapt to environmental statistics, and how mood responds to ongoing experience is more the reflection of a trait that differs across individuals. Our results constitute a step towards understanding the computational basis of mood in the context of learning.

2-D-17 Agreement with the group majority vote prevents consideration of past outcomes

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Past research on collective decisions focused on their accuracy benefits when compared to individual ones, but there is a lack in empirical studies addressing the individual motivations to engage or not in group decisions (El Zein et al., 2019). We argue that being a member of a group can protect individuals from negative consequences of decisions due to shared responsibility. To empirically test this claim, here we investigated how experienced outcomes triggering emotions of loss and regret impacted people's tendency to make decisions alone or in a group. In an online experiment on Amazon's Mechanical Turk, 125 participants (aged 19-57, mean age=31.72±7.31, 88 males) first selected whether to play alone or in a group with majority rule. Then they chose between two gambles with different probabilities of winning and losing, and both factual and counterfactual outcomes were shown to elicit regret (Coricelli et al., 2005). Expected value and anticipated regret both influenced decision-making about gambles replicating previous results (Coricelli et al., 2005). Interestingly here, individual choices were more strongly driven by loss and regret than choices that were factored into collective decisions. Using computational modelling, we investigated how outcome magnitude and valence (from a combination of factual and counterfactual outcomes) changed individuals' propensity to play alone or in group. Experienced outcomes affected participants' propensity to join a group both when participants were fully responsible (i.e., acting alone) or not at all responsible (i.e., in group minority) for decision outcomes: The higher the negative outcome, the more participants switched their status from deciding alone to deciding in a group or vice versa. However, participants did not consider past outcomes when they shared responsibility with others. When a participant's vote was consistent with the group majority, experienced outcome ceased to have any impact on their propensity to play alone or in a group. These results reveal an alarming consequence of consensual decisions: When bad choices made by majority vote lead to unpalatable outcomes, the protective shield of the collective may render the majority unwilling to make critical changes. To conclude, our study provides a mechanistic explanation of the motivations to join, stay in, or leave groups. It also offers some important insight into questions such as whether belonging to a ruling political party renders its members unresponsive to the party's failure and successes, or whether there is more variance in the decision to stay or leave a group when disagreements arise within a group.

2-D-18 The role of mood in cognitive control

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Making good decisions entails learning the best course of action and flexibly adapting behaviour when required. To study how mood contributes to adaptive behaviour in a sample of healthy subjects ($N = 96$), we used an established probabilistic reversal learning task which was augmented by repeated momentary mood ratings. This allowed us to probe participants as to their affective state after receipt of rewards and punishments. A proportion of subjects (26%) had poor performance, failing to pass a formal learning criterion of eight consecutive correct trials. This criterion requires the subject to ignore instances of misleading punishing feedback on correct responses. We found that subjects who failed to reach criterion were characterized by increased behavioural sensitivity to punishments, manifested by increased tendency to locally shift responding immediately after negative feedback (lose-shift, $p = 0.002$). They also showed reduced behavioural sensitivity to rewards, manifested by a reduced tendency to repeat a response after positive feedback (win-stay, $p < 0.001$). In spite of different behavioural sensitivities, mood dynamics when individuals shifted after a punishment or stayed after positive feedback did not differ from individuals who passed the learning criterion. Therefore, increased local sensitivity to rewards and punishments are not explained by corresponding variations in affective state. We use computational models to describe the quantitative relationship between past experience and behaviour, allowing us to determine whether mood dynamics impact on the ability to learn the best course of action and flexibly adapt when required.

2-D-19 The construction and deconstruction of suboptimal preferences through reinforcement learning

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Introduction. Wealth of evidence in behavioral economics and affective neuroscience suggests that option values are highly dependent of the context in which the options are presented. Building on an analogy with perceptual psychophysics and neuroscience, option valuation seems to be affected by both the spatial and temporal contexts. In a series of recent papers, we demonstrated that contextual adjustments also occur in reinforcement learning. However, the exact algorithmic implementation of context-dependence and how this process is affected by modulating feedback information, still remain unclear. To fill these gaps, we implemented 8 new variants of an instrumental learning task where we orthogonally manipulated outcome magnitude and feedback information, resulting in variations in reward ranges. **Methods.** In a first phase of the task (learning test), participants had to determine by trial-and-error the most favorable option in 4 fixed pairs of options. In a second phase (transfer test), the original pairs were remodeled to investigate the choice preference between options extrapolated from their original context. **Results.** In 8 experiments, subjects learned above chance level. We replicate previous studies indicating partial range adaptation in the learning test and context-induced suboptimal preferences in the transfer test. We found that increasing feedback information (complete feedback) in the learning test increases the context-induced suboptimal preferences compared to the partial feedback case. Further analysis of trial-by-trial dynamics during the transfer test showed that, while complete feedback redresses suboptimal preferences, partial feedback has no effect. In complement to choice rate analysis, we developed a computational model that implements normalization by tracking the range of each decision context and adapting the perceived reward accordingly. Model simulations

show that this model best explains subjects' behavior, capturing both the partial adaptation during the learning test and the context-induced suboptimal preferences in the transfer test. Model comparison indicates that the new model performs better compared to a simple Q-learning model and a previously proposed descriptive model, featuring normalization as a weighted average of absolute and relative outcomes. Conclusions. We provide definitive evidence of context-dependent reinforcement learning in humans and concomitantly propose a more satisfactory computational model to explain these processes. Between-task comparison indicates that increasing feedback information shows counter-intuitive results, since it decreases maximization in the transfer test.

E. Game Theory & Strategic Interactions

2-E-20 Cross-brain neural signatures of strategic competition in humans and monkeys

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In nature, animals compete against each other for resources. Likewise, humans compete for everything from attention and love to wealth and social status. Social competition as such involves at least two agents with opposing goals dynamically interacting with each other. Yet most studies have only focused on examining the behavior and underlying neurobiology of a single agent making reiterated two alternative forced choices, instead of the dynamic crosstalk between two brains when engaged in direct competition. Here pairs of humans and rhesus macaques played a zero-sum competitive soccer game, in which one player (the kicker) tried to continuously circumnavigate the other player (the goalie) to win a point. Simultaneously, neural recordings were obtained using EEG in humans and single unit electrophysiology in monkeys. As previously reported, this game elicited similarly complex behaviors from human and monkey players accompanied by comparable underlying strategies. In monkeys, we found that firing rates of neurons in mid-superior temporal sulcus (mSTS), a potential homologue to human temporo-parietal junction (TPJ), encoded key aspects of the game including previous and current strategy and game outcome. On a single trial, behavioral strategies and accompanying neural activity from two players interlinked and co-evolved; ultimately it was the joint firing rate patterns across two brains that determined game outcome. Over much longer periods of time, local field potentials in monkeys and EEG recordings in humans indicated that slower changes in brain states predicted game performance. In humans, peripheral arousal measurements and self-reported engagement levels also predicted performance. These findings confirm that our computerized soccer game captures the essence of real life competition, and quantifies competitive strategies in various dimensions across species. The observation that mSTS in monkeys functionally contributes to strategic gameplay endorses the hypothesis this area is the homologue of human TPJ. Finally, simultaneous recordings of brain activity in pairs of monkeys and humans reveal that strategic social interaction is an arms race between two parties, during which performance, strategy, and neural activity oscillate on multiple time scales.

2-E-21 An interaction between social affective biases and monetary offer amounts in human interpersonal negotiations

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INTRODUCTION Negotiating the distribution of finite resources between parties who might have competing interests is an important part of human social interactions. Two key cognitive processes relevant to these social interactions are: (i) how people perceive their share of the resource distributions

proposed by others, and (ii) the degree to which social affective biases (e.g. perceiving others' facial emotions more negatively than they actually are) influence these valuation mechanisms. **METHODS** Participants (N=43) completed a brief facial emotion recognition task (bFERT) and rated various affective faces on a 9-point Likert scale (i.e. from negative to positive), allowing an assessment of social affective biases. Participants interacted with human confederates or a computerised opponent in a novel interpersonal monetary negotiation game which incorporates opponents' facial emotions, while undergoing pupillometry. All participants completed questionnaire measures of mood and social value orientation (e.g. Quick Inventory of Depressive Symptoms, Social Value Orientation Slider Measure). Affective biases were evaluated by fitting a 2-parameter weighting function to participant ratings in the bFERT. Participant choice behaviour was analysed using an ordinary least squares (OLS) regression model (e.g. regressors: opponent's facial emotion, offer amount, interaction term) as well as fitting formal computational models of the negotiation process. Pearson's correlation was used to evaluate linear relationships between psychological questionnaire scores and decision-making parameters. **RESULTS** Regression analysis of acceptance probabilities suggested that unfair offers coming from proposers with positive facial emotions were more likely to be accepted (based on Bonferroni corrected t-tests on regression coefficients, all $t > 3.508$, all $p < .001$). Model-based analysis suggested that social affective biases accounting for how people perceive others' emotional states are represented nonlinearly. Decision values, which guide participants' probability of accepting a condition in the negotiation game, are influenced by both the offer amount and an inequality term (i.e. difference between self and other's reward), which is further modulated by social affective biases. Pupillometry results suggested that pupil size encodes opponent's affective states, surprise associated with offers and the noisy fluctuations of the negotiation environment (all $t > 2.01$, $p < .05$). **CONCLUSIONS** The current study describes a computational model accounting for human social interactive decision-making. Central arousal systems (i.e. pupillometry indexing the firing of the central norepinephri

2-E-22 Learning what makes a good offer: A neuro-computational account

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Introduction: Market inefficiencies emerge because buyers offer more than their seller's expectation (leaving money on the table) or too little (foregoing trade). Most of the time, these trading situations are ambiguous, because different sellers -or the same seller in a different environment- might have different evaluations for the same goods. Understanding how buyers adapt their offer to their seller's expectations and create efficient trade is therefore crucial, but remains poorly investigated. **Methods:** We designed a modified version of the Ultimatum Game: proposers (viz. buyers) were repeatedly matched with responders (viz. sellers) drawn from three different populations characterized by different probabilistic acceptance thresholds. In the Social condition, proposers faced actual responders (whose responses were collected in a pilot study; N=210), such that the outcome of the deal affected both parties' payoffs. In the Non-Social condition, proposers faced computer generated lotteries programmed to mimic the different probabilistic acceptance thresholds of human responders (non-social condition), such that the outcome of the deal only affected the proposers' payoffs. **Results:** In two experiment (behavioral N= 100 and fMRI N=50), we found that proposers learn to adapt their offer to the different populations' acceptance thresholds, by trial-and-error. We demonstrate that this learning behavior is efficiently captured by a novel reinforcement-learning algorithm, which parsimoniously evaluates the probability of each possible offer being accepted in the form of a logistic acceptance function, whose

parameters (intercept and slope) can be updated with a delta rule. Model-based fMRI (N = 50) mapped this process in canonical reinforcement learning neural circuitry (ventral striatum, VMPFC). In addition, our results show that learning occurred faster in the non-social condition than in the social condition, indicating that social concern about the receiver's payoff might harm efficient learning. Functional neuroimaging indicated that the non-social and the social conditions elicited different activations in the dorsal anterior cingulate, a region associated with strategic conflict monitoring, as well as the superior temporal sulcus, a region associated with social cognition and theory of mind. Conclusion: Altogether, our results shed new lights on an overlooked aspect of social cognition: the subtle balance between learning to trade efficiently, by identifying the minimally acceptable offer to maximize one's payoff, and social preferences, which encourage proposing fair offers.

2-E-23 Emotions in strategic interaction: The case of anger and guilt

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We used psychological game theory in an fMRI study in order to explore the role of anger and guilt on choice in a social context. Different game payoff structures represented different social contexts and were designed to evoke different levels of anger and guilt. We studied if and how payoff structure triggers these emotions and affects choice. Games and payoff structures were chosen to 1) create a setting that allows us to disambiguate the influence of anger and guilt aversion through observed behavior; 2) investigate how the neural correlates of anger, guilt, and associated beliefs are implemented in the brain and influence decisions; and 3) explore which game properties trigger these emotions in different games. Participants (27 healthy volunteers) in the experiment decided in the role of 2nd mover in four two-stage games. Each game promoted choices consistent with either anger or guilt as expected. Self-reported emotional ratings showed that games where participants were put in a disadvantageous position by the 1st mover's choice induced feelings of disappointment (rather than anger), and games where the participants' choice violated 1st mover's expectations evoked feelings of guilt as predicted. Choices in "guilt games" showed that individual differences played an important role in determining how guilt aversion affected participants' behavior. Neural responses were consistent with the self-reported emotions and emotion intensities elicited in each game. In "anger games" we observed higher activation in several areas bilaterally when the participant observed a choice made by a computer compared to one made by a human (frontal eye fields, inferior frontal gyrus, precuneus, angular gyrus), which was possibly related to increased attentional demands in that setting. When the participant chose in "anger games" the amygdala, often associated with anger related neural responses, exhibited higher activation after the 1st mover's choice had put the participant in a more disadvantageous position. In "guilt games" the left and right temporoparietal junction (TPJ) were activated more when the participant had to follow a prescribed choice compared to making this choice freely. The TPJ is often implicated in theory of mind, mentalizing and processing of social emotions like guilt. The left TPJ also exhibited differential activation depending on the intensity of guilt feelings the game was designed to evoke. Our findings provide evidence that the different game structures are conducive to different emotions and differential brain activations which can lead to different action tendencies and behavior when individual differences are taken into account.

2-E-24 The neural trade-off between social cooperation and competition in the Space Dilemma.

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Competition and cooperation are two fundamental orientations in social cognition that can either hamper or facilitate group or individual achievements. In everyday life, our social interactions entail different motivational goals eliciting both cooperative and competitive states of mind. However the precise neurological rules governing this trade-off are unknown. 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 Space Dilemma (SD). The SD game was designed to provide a continuous, dynamical and probabilistic generalization of the Prisoner's Dilemma. Couples of unfamiliar players (N = 27; with one participant inside the scanner and the other outside) chose a location in a linear space and were rewarded according to their proximity to a target appearing randomly in the space. Each trial was won by the player closer to the target. Players could chose to play cooperatively, coordinating their responses, or competitively, choosing the position that maximised their chance of winning. 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 which dictated differences in the risk associated with defecting cooperation. Participants played the Space Dilemma in three conditions, a cooperative one (where the rewards were shared 50-50 irrespective of the winner), a competitive one (where the loser incurred in a penalty) and an intermediate one. Validating our new approach, participants played more competitively when the risk associated with defected cooperation was higher. The extent of this contextual modulation was reflected in the variability both in the activation and in the functional coupling of a network of areas implicated in decision making, evaluation and theory of mind. This network included the striatum, ventromedial, dorsomedial and ventrolateral prefrontal cortex, temporal parietal junction, middle temporal gyrus and anterior and middle cingulate cortex and encoded both players' and opponents' choices and rewards. This data strongly indicates a distributed representation of social context throughout the valuation and decision-making networks in the human brain. Taken together, this combination of game theory and fMRI allowed us to compare directly brain activity during competition and cooperation and provided primary evidence that the brain continuously and flexibly encodes the social context.

F. Individual & Lifespan Differences

2-F-25 Differential regional decline in striatal and medial temporal dopamine receptor availability across adulthood

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The dopamine system has been implicated in episodic memory function, value-based decision making, and reward processing in general. Although age-related declines in the dopamine system have been well documented for decades, there is emerging evidence for regional variation in decline, which may prove important for both decision making and memory functions. Using PET imaging in a sample of 132 healthy adults between the ages of 20-83 we identified regions of the striatum and medial temporal lobe (MTL) for which there was relatively little age-related decline in D2-like receptor availability (D2R) especially relative to lateral cortical regions which showed much steeper declines. Using a measure of percentage difference in D2R per decade, the weakest effects of age were in the hippocampus, -0.83 [-3.47, 1.69], amygdala -2.73 [-4.39, -0.91], pallidum -0.18 [-2.37, 2.05], ventral striatum -1.43 [-3.38,

0.44], and putamen -3.62 [-4.76 , -2.53], with slightly larger effects of age in the parahippocampal gyrus -5.08 [-7.37 , -2.50] and caudate -5.22 [-6.34 , -3.88]. These initial analyses were conducted with atlas-based regions of interest that averaged across structures. In follow-up voxelwise analyses using an expanded data set ($N = 153$) of healthy adults between the ages of 18-83, we examined whether there were gradients within the MTL and across the striatum. We did not find evidence for gradients across the striatum beyond what was observed in the ROI analyses. However, we did find evidence for a gradient across the anterior to posterior axis of the hippocampus. Although the ROI analyses revealed a lack of an age effect on hippocampal D2R in general, there were greater age-related declines in the anterior-superior and posterior-inferior portions of the hippocampus approximately consistent with the location of CA1. There was a weaker superior to inferior gradient along the parahippocampal gyrus such that there were steeper declines in inferior compared to superior subregions. Although the data set did not include a behavioral measure of memory-based decision making, the relative preservation of hippocampal D2R suggest a potential preservation of dopamine influences within this key MTL region. This raises the possibility that despite declines in episodic memory that occur with age, the influence of dopamine on these processes may remain largely intact. This may prove important for decisions that require episodic memory of past experiences. Overall the data reveal a surprising preservation of the dopamine system within subregions of the striatum and MTL that may support memory-based decision making across adulthood.

2-F-26 Using twitter to detect depression and predict onset of depressive episodes

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Interactions between key symptoms of depression have recently been theorized to form a complex network. Correlations between depressive symptoms are thought to represent causal pathways e.g. less sleep leading to low mood that can trigger cascades of positive reinforcement. Transitions between one stable network state to another are characterized by a set of early warning signals include a loss of resilience, increased autocorrelation, and variance. Rather than use repeated daily momentary assessments, which are highly burdensome for participants, our study attempts to find early warning signals within subjects using already available data from Twitter. We aimed to conduct a proof of concept study to use Twitter as a replacement for ecological momentary assessment to detect within-subject differences in Twitter sentiment over time. Participants were asked to provide basic demographic information (e.g. age, gender), whether they have been diagnosed by a physician with depression, and the dates of any depressive episodes in the past year. A depressive episode was defined as either low mood or loss of interest/pleasure all day nearly every day for at least two weeks. Participants were included if they were over 18, have had a Twitter account for at least 1 year, and have at least 500 Tweets. We made a one-time collection of up to 3,200 Tweets from 150 eligible participants. We developed a custom analysis pipeline to process Tweet sentiments. Linear mixed models within-subject were used to estimate the fixed effect of a depressive episode on sentiments. We also tested for differences in when participants Tweeted throughout the day. We found a significant effect of depressive episodes on negative sentiment ($\beta=0.058$, $p = 0.032$) but not on positive affect ($\beta = -0.015$, $p = 0.66$). We also tested 7-items from the LIWC, previously shown to differ significantly between depressed and non-depressed people. Although none of the LIWC measures reached significance in our pilot sample, the effect sizes for negative and positive affect were in the expected direction. Participants tweeted substantially more at night than during; although there was no difference between when depressed and

non-depressed participants posted Tweets. Depressed participants also Tweeted substantially less than non-depressed participants ($\beta = -7.2$, $p = 0.005$). We have found preliminary evidence for an increase in negative sentiment during a depressive episode. Our study is also the first to use the VADER sentiment library, which is specifically designed to assess sentiments in Tweets. Further work is needed to test for the presence of early warning signals prior to a depressive episode.

2-F-27 Self-efficacy, depressive symptoms, and the pursuit of physical health rewards

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Although people value physical health, most people are not as physically active or healthy as they would like to be. Previous research suggests that both motivation for health rewards and perceived self-efficacy differ between individuals with symptoms of subclinical depression compared to healthier populations. In an ongoing study that uses neuromarketing to optimize mobile digital health messages aimed at increasing physical activity, we examined whether individual differences in depressive symptoms moderated the associations between self-efficacy and physical activity. Fourteen participants (varying from none to many symptoms of subclinical depression according to Beck Depression Inventory, BDI) answered daily surveys on their mood and self-efficacy, defined as their confidence in increasing their daily physical activity, every morning for 7-14 days. Wrist-mounted activity trackers were used to collect data on daily steps. Following this initial baseline 1-2 week period, participants viewed and made motivation ratings on 80 statements about physical activity while undergoing fMRI. These messages were then delivered one per day for the next 80 days while participants wore the activity trackers. To examine initial individual differences related to depression and self-efficacy, we used the baseline activity tracking and daily survey data in a series of linear mixed models. We used random intercepts for participants and analyzed the interaction between self-efficacy and BDI score on physical activity. Self-efficacy ("How confident are you in your ability to increase your daily physical activity?") was positively correlated with step count, $t = 5.97$, $p < .001$. Individuals with higher self-efficacy had a higher step count. The relationship between daily self-efficacy and steps was dependent on BDI score, $t = -2.213$, $p = 0.027$. Individuals with low BDI scores showed the strongest benefits of self-efficacy on physical activity. The benefits of self-efficacy on daily physical activity were weaker in those with higher levels of depressive symptoms. Although BDI scores were not directly associated with physical activity (steps), higher levels of perceived self-efficacy were associated with higher levels of physical activity. This association differed in participants with subclinical depression. Future analyses will examine individual differences in functional brain activation while participants were viewing the health messages delivered during the intervention, with the goal of identifying individual differences in functional brain activity that may be related to individual differences in the effectiveness of motivational messages when delivered in daily life.

2-F-28 Positive illusion is associated with a high responsiveness to reward: evidences from functional magnetic resonance imaging and psychiatry sample

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Superiority illusion (SI) is a positive cognitive bias, manifesting as overestimating self than average peers

in multiple aspects, including cognitive ability and personality trait. SI benefits human's mental health but may also bias people's decision in economic and social domains. Previous studies reported an potential correlation between self and positive stimuli processing, such as reward processing. However, whether SI is associated with reward responsiveness and the corresponding neural mechanism underlying this relationship remains unclear. To investigate this issue, 42 healthy participants (HP) were recruited and underwent a SI task where participants judged the extent to which positive and negative traits match themselves compared with their average peers during functional magnetic resonance imaging (fMRI) scanning. Reward responsiveness was measured by temporal experience of pleasure scale (TESP) and snaitn-hamilton pleasure scale (SHAPS). AS expected, HP exhibited obvious SI, especially for positive traits. For HP, SI score was positively correlated with reward responsiveness, and the overlapped activation associated with SI and reward responsiveness was located at the left insula. The relationship between SI and reward responsiveness was further validated on the sample of 32 patients with bipolar disorder (BD), a psychiatric disorder characterized by distorted self-appraisal. The results of BD showed a decreased SI, lack of pleasure responding to reward, and a significant correlation between decreased SI and increased anhedonia. Furthermore, with the aggravate of the anhedonia of BD, the involvement of the left insula in SI task become less. Our findings proved an association and even co-variation between SI and reward responsiveness at both behavioral and neural levels, in the basis of evidences from healthy and psychiatry samples. This finding highlight roles of self-processing and relative psychiatric disorders in decision making, which might be given more consideration in further studies.

G. Intertemporal Decision

2-G-29 Risk and ambiguity aversion in the domain of self-control

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A growing body of research suggests that choosing tempting rewards that do not align with ones broader goals ('self-control failure') may emerge from a decision-making process that weighs the costs of exerting cognitively demanding control against its perceived benefits. We recently found that the subjective cost of exercising self-control can be measured in humans and that these costs are highly sensitive to changes in affective and motivational states. Specifically, we demonstrated that individuals are willing to incur monetary costs to adopt prospective strategies to restrict access to temptation, offering a quantifiable index of individuals' aversion to deploying effortful behavioral control in the manner predicted by economic models of this process. Here, we aimed to extend this work by testing whether decisions to deploy resource-limited (i.e., costly) control processes are sensitive to risk and uncertainty. That is, do choosers demonstrate a preference for choice sets in which they can fully predict the level of self-control required to support their goals? To test this, a cohort of healthy, hungry dieters (n=30) made a series of incentive-compatible binary choices between spending a predictable amount of time with a tempting food reward (certain option) or a lottery option, for which they could be required to spend a greater amount of time with this food (5-60 minutes), or no time at all (0 minutes). Critically, the probability of each option was either stated explicitly (risk) or with some degree of uncertainty (ambiguity). Results revealed a marked preference for certainty, such that participants were less likely to choose risky and ambiguous lottery choices where the level of self-control required on a given trial was not certain. Further, participants accepted fewer lottery choices when the probabilities of each option were ambiguous as opposed to risky. Finally, the proportion of risky and ambiguous lottery choices was significantly lower when choices were made regarding a tempting food reward as opposed to a non-tempting one that did not require costly self-control to abstain from consuming. Thus, participants are

averse to choice environments in which they cannot fully predict how cognitively costly self-control will be—revealing both risk and ambiguity aversion in the domain of self-control. Collectively, these findings suggest that risk and ambiguity aversion plays a role in choice beyond the domain of monetary outcomes, and that self-control costs are sensitive to increases in effort imposed by greater levels of temptation.

2-G-30 Within-individual changes in temporal discounting induced by shifts in the processing times of immediate and delayed rewards

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The ability to postpone gratification has a profound influence in health, education, and financial outcomes, and varies greatly across individuals and contexts. Individual differences in temporal discounting have been linked to many real-world outcomes, such as well-being, gambling, drug addiction, and mortality rates. However, observed temporal discount rates are inconsistent across contexts and studies, and the neurocomputational mechanisms responsible for this variation remains largely an open question. In Study 1, we use a mouse-tracking intertemporal choice task to measure differences in the speed with which the decision-making circuitry processes immediate and delayed rewards. We find that on average immediate rewards are processed faster and that, across participants, this processing advantage is correlated with the ability to postpone gratification. Moreover, on trials in which delayed information was processed faster, participants were more likely to make a patient choice, even if they generally exhibited more impatience in their choices. In a follow-up Study 2, we designed a causal manipulation in which either the immediate or delayed option was shown first, in order to exogenously manipulate the relative speed of processing. Showing the option first speeded the processing of delayed value information by approximately 300 ms, and decreased the average hyperbolic discounting parameter k by 57%, from 0.07 to .018. Together, these results suggest that a sizable fraction of variation in the ability to postpone gratification might be attributable to variables that affect the speed at which different types of rewards are processed, independently of differences in traditional parameters describing choice preferences.

2-G-31 The effect of bariatric surgery on delay discounting for food and money: A longitudinal study

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We investigate how bariatric surgery impacts delay discounting (DD), its temporal stability, and its domain differences for food and money. DD for money has been identified a potential metric of impulsivity in addictions including eating disorders and obesity. Current literature provides little evidence of causal effect of DD through body weight. DD has not been investigated in morbid obesity, and it is unclear whether obesity-related impulsivity is domain-specific. In Study 1, obese and lean participants made a series of indifference point choices for chocolates and Euros. The obese were recruited from patients qualifying for bariatric surgery and were seen before surgery and twice afterward (3 & 12 months). Lean controls repeated the task 6 months later. Obese patients pre-surgery asked for more

chocolates to wait one week compared to lean controls. The effect was attenuated post-surgery among obese patients but remained stable over time among lean subjects, shown by the significant interaction effect between participant group and time. We found no difference between obese and lean subjects for monetary rewards and no change post-surgery. In Study 2, lean subjects and obese patients from the same hospital pool completed an incentive-compatible, DD task consisting of choosing between smaller-sooner and larger-later rewards for money and monetarily equivalent chocolate rewards. Both groups repeated the task 6 months later, obese patients after bariatric surgery. We estimated the ASAP model and compared differences in its discount parameter between groups and over time. Again, obese patients exhibited greater impatience for food rewards than lean individuals; this difference was most pronounced before surgery. A planned contrast on the interaction between participant groups and time for difference in DD before and after surgery showed that patients became less impatient after the surgery. We found no such effects for money. In Study 3, we eliminate alternative explanations to DD differences across reward domains. Participants of lean, overweight, or obese BMIs repeat DD tasks similar to those of Study 2 but with various reward types. Participants discount less for monetary rewards compared to any food rewards, independent of weight status. DD was consistent in unhealthy and healthy food choices in choices between quantities. In food choices based on quality (less tasty food now or tastier food later with fixed quantities), overweight and obese participants make significantly more impulsive choices than lean participants. Participants do discount future rewards more for food than money, regardless of trade-off type like food or quantity versus quality.

2-G-32 The impact of future perspective on delay discounting: Contribution of socioeconomic status and sociopolitical event

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The current study presents two experiments demonstrating the impact of future expectations on delay discounting (k). The first experiment uses paragraph vignettes to directly manipulate the participant's expectation of the future. The second experiment utilizes a major sociopolitical event, the U.S. 2018 Midterm elections, to see if the difference observed in the lab are also present in a natural environment. In Experiment 1, participants read descriptions of the future which were either pessimistic ($N=50$) or optimistic ($N=50$). Prior to study enrollment, participants filled out a delay discounting questionnaire (MCQ) (Kirby et. al 1999), as a baseline. After reading the priming paragraphs, participants completed the MCQ again. We computed the difference between the post-priming and baseline k and tested for difference in this measure across the prime groups. A significant difference was found ($t=-2.151$, $p=0.034$), suggesting that participants became more impulsive after reading the negative prime. In Experiment 2, we tested participants prior to ($N=89$) and after the election ($N=138$) using an online survey. The survey included a baseline MCQ, personality scales and income demographics. At the end of the survey, participants wrote a response where they envisioned themselves in 10 years and described the world around them. The post-election group was asked questions about the outcomes of the election and were told to envision their future based on the election. The second MCQ was completed after the written response to attain the difference from baseline. The content of the future projection was analyzed using the normalized negative to positive thought ratio. We first tested for the effect of negative (vs. positive) thoughts during future projection and the Midterm election on the change in k by a regression with the thought ratio and election group as predictors. Only the thought ratio was found to be a marginally significant predictor ($\beta=-0.129$, $p=0.053$). We then tested if income level modulates the

difference in the contents of future projection and delay discounting before and after election. A significant interaction between election and income level was found for the k difference ($F(3,227)=3.675$, $p=0.013$). The higher income showed a significant difference pre to post election ($t=2.482$, $p=0.017$), suggesting that they became significantly less impulsive when envisioning their future after the election, while the lower income groups showed no significant difference. Together, these experiments provide evidence that perception of the future can significantly influence delay discounting, which is modulated by both a social event and socioeconomic status.

2-G-33 Present bias for monetary and dietary rewards: Evidence from Chinese teenagers

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Background: To remain healthy, people must exercise self-control to forego the immediate pleasure of high-calorie foods for the prospect of future health. We focus on adolescents because eating habits, established early in life, tend to stay with individuals contributing to the obesity epidemic. However, few studies have elicited adolescents' present bias over money, and none has elicited present bias for primary rewards. **Objectives:** We measure impatience and present bias for different types of rewards to study: (i) are adolescents equally patient for different reward types? (ii) do adolescents show present bias for different reward types? (iii) do laboratory measures of time preference correlate with behaviour in the field? **Method:** From February to March 2019, 923 adolescents participated in our longitudinal experiment, conducted at four high schools in Guizhou Province, China. Since we conducted our experiment during regular school hours, we had virtually no self-selection or attrition in the experiment. In week 1, participants chose what quantity of a reward to receive in weeks 2 and 5 (both rewards delayed). We included three reward types: money, healthy and unhealthy food. In week 2, the same participants chose from the same options except that their decisions were between an immediate reward and a delayed one. We used a modified version of the Convex Time Budget design (Andreoni and Sprenger, 2012) with 14 choice sets for each reward type differing in the interest rate at which the sooner and later rewards were traded. We also use a questionnaire, as well as data obtained directly from the schools, to relate demographic variables and information about subjects' field behaviour (smoking, drinking and school performance) to their time preference. **Results:** Participants were more patient for money than for food and showed strong present bias across all three types of reward. We observed surprisingly strong utility curvature and present bias over monetary rewards. We also observe that adolescents who show stronger present bias for money and unhealthy food are more likely to consume alcohol. **Discussion:** Finding strong utility curvature and present bias over money is surprising and not in line with previous studies. One possible explanation is that we observed much fewer corner solutions in our sample, perhaps because our subjects were more credit constrained.

2-G-34 Individual differences in dopamine predict self-control of everyday desires

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Humans experience a multitude of natural desires in their day-to-day lives. Practicing self-control to avoid giving in to these desires has both immediate and long-term consequences on financial stability, health outcomes, and general wellbeing. What, then, makes some people better at self-control than others? The neurotransmitter dopamine (DA) is believed to underlie individual differences in self-control

abilities. Specifically, DA D2 receptors regulate decisions to inhibit impulsive actions in controlled laboratory studies. However, no study to date has examined whether such associations between dopamine and self-control measured in behavioral experiments also explain self-control for desires that are spontaneously experienced in the real-world. Using ecological monetary assessment (EMA), we repeatedly sampled 74 healthy adults' desires over the course of ten days. Participants used smartphone-based surveys to indicate desires they experienced, attempted to resist, and enacted in their daily lives. They also rated the degree to which the desires conflicted with personal goals--a previously identified predictor of self-control. These participants underwent a positron emission tomography (PET) scan with the high-affinity D2 radiotracer [18F]fallypride. Using mixed-effects logistic regression, we identified novel associations between EMA and PET measures. Within EMA measures, degree of conflict with personal goals strongly predicted attempts to resist desires (OR = 3.36, $p < .001$) and failed attempts to resist desires (OR = .70, $p < .001$), corroborating prior reports. The association between degree of conflict with personal goals and predicted attempts to resist desires was moderated by D2 receptors in the ventral striatum (+1 SD OR = 5.18, -1 SD OR = 2.70, $p < .001$) and midbrain (+1 SD OR = 5.02, -1 SD OR = 2.65, $p = .001$). Individuals with lower D2 receptor availability in these regions were less likely to attempt to resist desires in spite of conflict with personal goals. However, the association between degree of conflict with personal goals and predicted failed attempts to resist desires was moderated by D2 receptors in the amygdala (+1 SD OR = .820, -1 SD OR = 6.40, $p = .050$). Individuals with higher amygdala D2 receptor availability were more likely to fail in their attempts to resist desires in spite of conflict with personal goals. These results are the first to demonstrate that dopamine impacts self-control in everyday life and suggest that individual differences in this system moderate the impact of conflict with personal goals on resistance of everyday desires.

H. Learning & Memory

2-H-35 Dorsomedial prefrontal cortex plays a causal role for imitation learning

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Dorsomedial prefrontal cortex (DMPFC) is routinely activated during observational learning. However, it remains unclear whether the DMPFC is causally involved in observational learning and whether it is important for observational action-outcome learning and/or imitation learning, where only information about actions but not outcomes is available. To close these gaps, we performed a within-subject transcranial magnetic stimulation study targeting DMPFC and vertex with continuous theta burst stimulation. 30 safety-screened participants (18 female, mean age 22.5) visited the lab twice with an interval of one to three weeks. They received standard continuous theta burst stimulation (cTBS, distance-corrected intensity of 80% of active motor threshold) on DMPFC or vertex. The stimulation site was randomized across visits. Participants performed the observational learning task immediately after cTBS. To dissociate observational action-outcome learning from imitation learning, we varied the amount and type of observable information. In the action-outcome learning condition, both the action and the outcome of the demonstrator were observable whereas in the imitation learning condition only the action was observable. To distinguish imitation learning from action-outcome learning, we employed demonstrators with good or bad performance. Bad performance or disrupted action learning can be compensated by observing the outcomes in the action-outcome condition but not in the imitation condition. Participants also predicted what action the demonstrator would perform before observing the actual action in each trial, which allowed us to investigate whether TMS affects acquisition of knowledge about demonstrator behavior or the use of the acquired knowledge by the observer. We found that

DMPFC downregulation led to decreased performance during imitation learning from a superb demonstrator, $F(1,29) = 7.01$, $p = .013$, but not from a bad demonstrator, $F(1,29) = .564$, $p = .459$. In contrast, cTBS had no effect on action-outcome learning, $F(1,29) < .495$, $p > .487$. These findings suggest that DMPFC plays a causal role in imitation learning but not outcome-based observational learning. Consistent with this, we also found decreased accuracy of the predictions in the action learning condition with the superb demonstrator, $F(1,29) = 8.59$, $p = .007$. Moreover, actual performance and correct prediction in this condition correlated significantly, $r = 0.49$, $p = 0.005$. Thus, our data suggest that the DMPFC plays a crucial role in imitation learning that relies on acquired knowledge of demonstrator behavior when outcome information is unavailable.

2-H-36 Learning and individual differences in adaptive persistence

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Objective: Being unconditionally persistent is not always advantageous. Previous studies have shown that decision makers can calibrate their level of persistence in a context-appropriate manner. However, little is known about the learning mechanisms that support this form of adaptive calibration. It is unclear whether conventional reinforcement learning (RL) algorithms are applicable to persistence decisions in foraging-like environments (i.e., choices between a temporally uncertain focal prospect and the alternative of exploring elsewhere). Here we developed a series of RL models to address three specific questions: (1) can RL describe adaptive persistence? (2) do learning rates differ for positive versus negative outcomes? (3) do RL learning parameters provide insights about the computational basis of individual differences in adaptive persistence? **Methods:** We analyzed 3 experimental data sets ($n=142$) involving persistence decisions. Participants decided how long to wait for a delayed reward to maximize total earnings in a fixed period of time. The optimal persistence level was manipulated across environments to be either high or low. We modeled persistence decisions in an RL framework as a series of temporal-state-dependent choices between waiting an additional time increment or quitting. We tested both Q-learning and R-learning variants of the model, and variants either with a single learning rate or with separate learning rates for positive and negative reward outcomes. **Results:** In all 3 data sets, participants adaptively calibrated their level of persistence across environments. RL model reproduced key descriptive features of empirical behavior, including average persistence, variance, and learning dynamics, outperforming a baseline model. Q-learning and R-learning performed similarly, suggesting results did not strongly depend on whether the cost of delay was formulated as a discount function or an opportunity cost. Better fits were obtained by using a higher learning rate for rewards than for negative outcomes and reward omissions. Individual-level parameter estimations were recoverable and successfully captured qualitative differences in behavioral performance across individuals. **Conclusions:** An RL framework successfully accounted for learning in the context of persistence decisions. The finding of asymmetric learning rates for positive versus negative outcomes is consistent with previous findings of "optimism bias". RL model parameters provide a promising means of summarizing latent factors that account for individual differences, not only in persistence per se but also in the flexibility with which persistence is calibrated across environments.

2-H-37 Differences in reinforcement learning dynamics predict major depressive disorder

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Depression has been associated with impaired reward and punishment processing, but the specific nature of these deficits is less understood and still widely debated. We analyzed reinforcement-based decision-making in individuals diagnosed with major depressive disorder to identify the specific decision mechanisms contributing to poorer performance. Depressed individuals (n = 64) and matched healthy controls (n = 64) performed a probabilistic reversal learning task in which they used feedback to identify which of two stimuli had the highest probability of reward (reward condition) or lowest probability of punishment (punishment condition). While both groups showed reinforcement learning-like behavior, depressed individuals made fewer optimal choices and adjusted more slowly to reversals in both the reward and punishment conditions. When participant data was analyzed using reinforcement learning models, depressed individuals showed lower learning rates and, to a lesser extent, lower reward sensitivity in both the reward and punishment conditions. Moreover, parameters from the reinforcement learning model predict depression more accurately than simple performance metrics. These results demonstrate that depression is characterized by a hyposensitivity to positive outcomes, influencing the rate and effectiveness at which depressed individuals learn from feedback. Additionally, we demonstrate that computational modeling provides a more precise characterization of the dynamics contributing to these learning deficits, and offer stronger insights into the mechanistic processes affected by depression.

2-H-38 Individual differences in the mechanistic control of the dopaminergic midbrain

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The dopaminergic midbrain is associated with elementary brain functions, such as reward processing, reinforcement learning, motivation and decision-making that are often disturbed in neuropsychiatric disease. Previous research has shown that activity in the dopaminergic midbrain can be endogenously modulated via neurofeedback, suggesting potential for non-pharmacological interventions. However, the robustness of endogenous modulation, a requirement for clinical translation, is unclear. Here, we used non-invasive modulation of the dopaminergic midbrain activity by real-time neurofeedback to examine how self-modulation capability affects transfer and correlated activation across the brain. In addition, to further elucidate potential mechanisms underlying successful self-regulation, we studied individual prediction error coding during neurofeedback training, and, during a completely independent monetary incentive delay (MID) task, individual reward sensitivity. Fifty-nine participants underwent neurofeedback training either in a veridical or inverted feedback group. Post-training activity within the cognitive control network was increased only in those individuals with successful self-regulation of the dopaminergic midbrain during neurofeedback training. Successful learning to regulate was accompanied by decreasing prefrontal prediction error signals and increased prefrontal reward sensitivity in the MID task. Our findings suggest that the cognitive control network contributes to successful transfer of the capability to upregulate the dopaminergic midbrain. The link of dopaminergic self-regulation with individual differences in prefrontal prediction error and reward sensitivity indicates that reinforcement learning contributes to successful top-down control of the midbrain. Our findings therefore provide new insights in the cognitive control of dopaminergic midbrain activity and pave the way to improving neurofeedback training in neuropsychiatric patients.

2-H-39 Physiological markers predict the adjustment of learning rates in dynamic environments

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Objective: Our beliefs should be updated by new observations. The extent of updating (learning rates) has shown to be adaptively adjusted in two common dynamic environments. In environments in which stable states undergo occasional sudden change-points, learning rates are high immediately after change-points and decline over time with more experience in the current state. In environments in which states evolve continuously according to random drift, learning rates are stable within an environment but depend on the relative size of the drift across environments. Pupil diameter (PD), a measure of physiological arousal, has been shown to track learning rates in change-point environments. However, this relationship has not been examined in drifting environments, nor have multiple measures of arousal been investigated simultaneously. We thus addressed two questions: (1) do similar measures of arousal predict learning rates across both types of environments? (2) do incidental manipulations that induce arousal increase learning rates? Methods: Subjects (n=64) performed a predictive inference task in one of two environments. On each trial, subjects predicted the next outcome, which was a number drawn from a normal distribution with an unknown mean (the state). In the change-point environment, the state changes occasionally ($p=0.1$), with the new state drawn from a uniform distribution. In the drifting environment, the state continuously drifts, with the new state drawn from a normal distribution with a mean at the last state. We also introduced two incidental manipulations: reward and oddball. Subjects were rewarded on a randomly selected half of the trials, with the reward received depending on the prediction accuracy. A sound accompanied the outcome presentation and occasionally ($p=0.1$) this sound was a discrepant oddball. During the tasks, PD, skin conductance, heart rate (HR) and respiration rate were recorded. Results: Average PD during the outcome presentation predicted learning rates in both environments. Across both environments, reward increased both average PD and PD change, while oddball elicited both PD change and HR change. However, only reward, but not oddball, influenced learning rates. Conclusions: We identified a similar relationship between arousal and learning rates across dynamic environments. Interestingly, amongst arousal measures, only tonic PD (the average during outcome presentation) predicted learning rates. Both reward and oddball elicited arousal, but only reward affected tonic pupil measures and learning rates. These results imply that only certain aspects of arousal are critical for the adjustment of learning rates.

2-H-40 Effects of schemas and risk on learning and decision making in ecological settings

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We learn and remember better when new materials are related to prior knowledge. The concept of schema is important in psychology, but the underlying neuroscience has been investigated only recently, finding that new information can be rapidly assimilated into neocortical schemas and become independent of the hippocampus. The influence of schemas on decision making has however not been addressed, particularly in ecological settings. For this purpose, we designed the painting and quote tasks where over 200 participants explored paintings or quotes belonging to different authors (considered as schemas), as they would in a gallery or online. Following free exploration they were given a decision task where they had to choose 4 out of 20 items, with each author linked to a certain payoff. All participants were told that their payoff would be tripled if they chose all 4 items from the same author. Furthermore, participants in the low risk condition had their payoff doubled if they chose 3 out of 4 items from the

same author, incentivizing them to try less familiar and more rewarding schemas. Afterwards the participants continued their learning for up to 2h, with decision tasks coming back regularly where they could earn money. Most items presented in the decision phase were not previously seen, hence it was a schema learning and pattern separation task, not simple recall. We also collected background information (e.g. schema familiarity and likeability, language ability, sleep, tiredness, depressive symptoms) and measured participants' eye movements and stress levels. We found that although most participants improved their performance, there were considerable differences in monetary gains and decision patterns based on the risk condition, tiredness, language ability and depressive symptoms, most of which applied to both tasks. When individual differences and task conditions were both considered, they generally followed the inverted-U-shaped relationship between stress and performance. Eye tracking also provided mechanistic insights into the decision making process. Our findings suggest that individual differences and environmental factors (such as risk) interact in complex ways to control learning and decision making, with stress level being a useful predictor of performance. They also suggest that exploratory behaviour is mostly sensitive to monetary incentives but also to risk and other factors such as schema familiarity and likeability. Understanding these mechanisms, especially through digital phenotyping using online platforms, is key for gaining insights to social processes of enormous importance such as filter bubbles and the spread of fake news.

I. Risk & Uncertainty

2-I-41 Implicit meta-learning of noise and volatility

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Introduction: Human decision makers often face a dilemma: does an unexpected outcome represent a meaningful change in the environment or a noisy outlier? One's response should differ in the two cases: meaningful change warrants a high learning rate, whereas a noisy outlier should be ignored. We have previously shown that people spontaneously adapt their learning rate to different amounts of uncertainty in an implicit spatial prediction task, but it remains unknown whether they can dynamically alter their behavior in response to different types of uncertainty (e.g. noise versus volatility). Methods: In an implicit spatial prediction task, participants made odd/even judgments about briefly presented numerical digits while their eye movements were recorded. Because the task was temporally predictable, anticipatory gaze position served as an indicator of the predicted stimulus location for each trial. The task comprised two conditions in which changes in digit location were matched overall, but sequential contingencies differed. In the change point (CP) condition, small changes tended to represent noise around a stable generative mean, whereas large changes indicated a meaningful shift in that mean. In contrast, in the random walk (RW) condition, small changes represented shifts in the mean, whereas large changes represented non-predictive outliers. Results: In a between-subjects experiment (N=16 per condition), participants adapted their predictions to each environment. In the CP condition, participants exhibited an average learning rate of 0.86 following change points, significantly higher than after outliers in the RW condition (mean=0.49; $p < 0.001$, Mann Whitney U test). Additionally, participants showed evidence of meta-learning over time, with average initial learning rate not being significantly different between CP and RW (CP=0.50, RW=0.66, $p = 0.356$), but showing large, significant differences at the end (CP=0.93, RW=0.43, $p < 0.001$). Although participants clearly modified their behavior in both conditions, they were more optimal in CP. This could suggest a bias towards interpreting outliers as meaningful, or a difficulty suppressing the influence of large, salient observations. These results were also replicated in preliminary within-subject data. Conclusions: Beyond adapting to different amounts of uncertainty as we

have previously shown, these data demonstrate that people can flexibly adapt their behavior to different types of uncertainty. Our results, in concert with prior work on explicit prediction, suggest a prior bias towards interpreting large prediction errors as indicative of meaningful change.

2-I-42 The bounded rationality of probability distortion

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In decision under risk, participants act as if their choices were based on probability values systematically different from those that are objectively correct. Similar systematic distortion is found in tasks involving relative frequency judgments and confidence ratings. For simplicity, we will use the term probability for all these forms of uncertainty. Observed distortions are highly patterned and conform to a simple two-parameter model. They are also dynamic: the same participant can have markedly different distortions in different tasks (Zhang & Maloney, 2012, *Frontiers*). Why do we choose the particular probability distortions that we do choose? **MODEL.** We propose a Bounded Log-Odds (BLO) model of probability that allows us to predict the distortion actually observed in decision tasks and tasks involving judgments of relative frequency. The model is based on four assumptions. First, probability is represented as log-odds. Second, the actual internal representation of probability is on a bounded Thurstone scale with any value on the scale subject to perturbation by Gaussian error. As a consequence, the resolution with which probability values can be stored is limited. Third, the Thurstone scale is adaptive: it can represent any interval of the abstract log-odds scale by an adaptive mapping. It can represent a small range of log-odds at high resolution or a larger range at lower resolution. The fourth assumption is technical: objective probabilities can themselves be random variables (e.g. when based on binomial samples). We assume that the adaptive mapping stabilizes variance in probability estimates. **Experiments.** We test the model in four experiments, two involving judgments of relative frequency (JRF), one concerning decision under risk (DMR), and a fourth involving both. The last experiment allows us to compare probability distortion in two different kinds of task in a single participant. **RESULTS.** We demonstrate that BLO accounts for human performance in all of these experiments. We are able to predict individual choices of probability distortion function across tasks and conditions. We use factorial model comparison to separately test each of the assumptions of the model against alternatives. All are necessary. We show that BLO better accounts for data than any other model in the literature. Finally, we demonstrate that people, in choosing their probability distortions, come close to maximizing mutual information between the objective probabilities in a task and their internal representations (Shannon & Weaver, 1949), a form of bounded rationality (Simon, 1957).

2-I-43 Range sensitivity in decisions under uncertainty

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Decisions are sensitive to available information, suggesting that they may vary, depending on the context in how information is presented and on the degree decision makers can precisely represent them. These effects are especially prevalent in decisions under uncertainty where information is complex and the degree of uncertainty in representing the outcomes is high. Yet, many normative and descriptive accounts in decisions under uncertainty, such as expected utility maximization (e.g., CRRA), cumulative prospect theory (CPT), generally assume stable psychometric properties that map into a representation

of gains, losses, and probabilities. Converging evidence suggests our decisions are heavily influenced by the context of the information given, and prevailing choice models often do not incorporate these context effects explicitly. These effects are crucial in generating both robust predictions on behavior and gaining a deeper mechanistic understanding of the computational processes leading to choice. However, it also remains unclear how these psychophysical features can be mechanistically incorporated in our choice models. Here we propose a model of choice under uncertainty that relies on range and overall magnitude as crucial psychophysical contexts affecting choice. First, range effects have been documented in categorical perception, such that increasing range reduces sensitivity to discriminate stimuli. Second, overall magnitude effects are known in numerical perception; the Weber fraction measures how likely the decisionmaker discriminates between two magnitude stimuli and that these stimuli are encoded in a noisy logarithmic manner. Our proposed range-sensitivity model (RSM) that explicitly accounts for these psychophysical features and a lottery paradigm that exogenously varies the range across risky and ambiguous lotteries with matched expected value, identical stimuli and motor responses. First, successfully recovered RSM parameters in our simulations. Second, RSM can explain all three experiments and five other independent datasets better as opposed to prevailing yet non-context-dependent models of choice, such as CRRA and CPT. Overall, our model shows that both range sensitivity and overall magnitude are crucial perceptual features of the information structure, and the underlying psychophysical processes arising from these features may contextually affect decisions under uncertainty.

2-I-44 The neural correlates of prudent behavior

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Background: A variety of economic traits, such as risk, loss, and ambiguity aversion or temporal preferences, have been extensively studied in neuroeconomics. However, higher order risk preferences, such as prudence, have not yet received similar attention. Kimball (1990) has coined the term "Prudence" with regards to a positive third derivative of the utility function ($U'''(x) > 0$). Prudence can also be regarded as a preference for the "disaggregation of harms" over lottery pairs (positive skewness). In recent years, several studies have found evidence for prudent behavior (Baillon, Schlesinger, & Kuilen, 2018; Deck & Schlesinger, 2010, 2014, Ebert & Wiesen, 2011, 2014; Noussair & Trautmann, 2014). Objective: In the current research we aim to test the robustness of previous findings, develop a trial-specific measure of "Prudence Intensity", and thereon investigate the neural correlates of this measure. Methods: 50 Subjects performed a choice task, consisting of 128 independent decision problems divided into four blocks. In each problem, subjects chose between two lotteries with equal expectations. Two blocks tested for standard (second-order) risk preferences, as one lottery was riskier than the other (greater variance). The other two blocks tested for third-order risk preferences (prudence), where subjects saw two compound lotteries with equal expectations and variance, but positive or negative skewness. In each decision problem, after choosing their preferred lottery, subjects stated how much monetary compensation they want in order to switch to the alternative lottery (similar to a BDM auction). We used this amount as the measure of prudence/risk intensity on a given trial. Results: Most subjects exhibited prudent preferences and risk-aversion. Subjects' stated monetary compensations significantly increased with the riskiness of the lotteries in the risk trials, demonstrating that the stated compensation can reflect the intensity of risk subjects experience. Moreover, the stated compensations in the prudence trials were related to the skewness of lotteries, but only for subjects with an average

response time larger than 3 seconds (30% of subjects, possibly highly attentive to the task). Hence, for this subset of subjects, we were able to generate a novel measurement for the intensity of prudent behaviors. Conclusions: We were able to revise a task that elicits both prudent and risk-averse behavior from subjects and obtain a meaningful measure of risk intensity and prudence intensity on a given trial. Our next step is to look for the neural correlates of prudent behavior on a trial-by-trial basis by repeating the task inside an fMRI scanner.

2-I-45 Ergodicity-breaking reveals time optimal economic behavior in humans

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Ergodicity describes an equivalence between the expectation value and the time average of observables. Applied to human behaviour, ergodic theory reveals how individuals should tolerate risk in different environments. To optimise wealth over time, agents should adapt their utility function according to the dynamical setting they face. Linear utility is optimal for additive dynamics, whereas logarithmic utility is optimal for multiplicative dynamics. Whether humans approximate time optimal behavior across different dynamics is unknown. Here we compare the effects of additive versus multiplicative gamble dynamics on risky choice. We show that utility functions are modulated by gamble dynamics in ways not explained by prevailing economic theory. Instead, as predicted by time optimality, risk aversion increases under multiplicative dynamics, distributing close to the values that maximise the time average growth rate of wealth. We suggest that our findings motivate a need for explicitly grounding theories of decision-making on ergodic considerations.

2-I-46 The effect of subjective loss on negative emotion and risk taking

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The current research examined the influence of subjective loss on financial risk-taking tendency and negative emotion experience. In Study 1, we collected 98 participants (65 females, mean age: 20.49 years, SD = 1.52), found that the subjective loss experience in an auction scenario induced greater financial risk propensity, especially in gambling, and greater negative emotion relative to the no-loss experience. In Study 2, we collected 70 participants (21 females, mean age: 21.89 years, SD = 1.89), and found that the subjective loss induced stronger negative emotion but less risk propensity in investment than the actual loss did, but these two types of loss did not yield a difference in risk propensity in gambling. These results implicate that subjective loss is a distinct experience from no loss and actual loss. The implications of our findings for decision making and consumer behaviors were discussed.

2-I-47 Persistence in base-rate neglect is associated with weighting subjective uncertainty on prior distributions

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Historically, base-rate neglect was demonstrated and discussed without having to incorporate variability in prior distributions and likelihood function. It therefore remains unclear whether people would show the same bias when variability needs to be taken into account in weighting prior and likelihood information. In this study, we developed a novel lottery decision task in which subjects had to combine prior and likelihood information about probability of reward in order to maximize payoffs. We manipulated the variability of both the prior distributions and likelihood function and found that base-rate neglect arose due to insufficient changes in weighting prior information in response to changes in prior variability but not likelihood variability. In a series of 5 experiments aiming to test three different hypotheses on base-rate neglect, we found that subjects consistently underweight prior information even when (1) information about prior variability was explicitly revealed to the subjects, (2) the time gap between acquiring prior knowledge and using it to combine with likelihood information was shortened, and (3) subjects were given the opportunity to learn how to combine prior and likelihood information through feedbacks. Unexpectedly, subjects after learning showed more pronounced neglect that took place irrespective of prior and likelihood variability. Together, these results provide insights into base-rate neglect by identifying a novel cause in subjective uncertainty about prior distributions and its persistent effect through several design strategies previously considered effective in diminishing it.

J. Social Rewards & Social Preferences

2-J-48 Reputational influences on charitable and self-interested motivations

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Objective: If motivations are additive, paying someone to engage in a prosocial act they would otherwise do for free should boost the value of engaging in that prosocial action. However, lab and field experiments in both economics and psychology show that under certain conditions, mixed motivations undermine or "crowd out" each other, decreasing motivation. Here, we investigate whether reputation influences the interaction of self-interested and charitable motivations and explore the neural mechanisms involved. **Methods:** In this study, participants (N=38) engaged in a modified Monetary Incentive Delay (MID) task during fMRI (Knutson et al., 2000). In the MID task, participants pressed a button as quickly as possible when a target appeared to earn rewards. The target was titrated such that each participant earned reward on ~66% of trials. We adapted this paradigm to include reward for charity and a reputational component. On each trial (360 trials), participants saw whether they had the opportunity to earn money for themselves, charity, both, or neither with varying reward amounts (1 or 10 points). In addition, the trials were split into "public" and "private" blocks of 90 trials. In the public blocks, participants knew that their performance would later be rated on generosity. **Results:** Participants were faster (indicating higher motivation) responding to high rewards for both self and charity (self: $b=-0.0023$, $p=0.0014$; charity $b=-0.0040$, $p=0.0010$). They also showed robust reward anticipation responses for both self and charity throughout the brain, including the striatum. Participants responded similarly to charitable rewards in public and private, but were slower to respond to higher rewards for themselves in public compared to private (interaction $b=0.0045$, $p=0.020$), suggesting that reputational context matters for self-interested motivation. Further analyses will compare reward responses in public and private using region of interest and connectivity analyses with the ventral striatum as a seed region to determine how reputation influences valuation for self and charity. **Conclusion:** This study shows behaviorally that reputational concerns shift the value of rewards for self, undermining motivations for high self and high charity rewards compared to high charity rewards alone. These results suggest that reputation modulates valuation of self-interested and prosocial rewards,

providing a foundation for further characterizing how the neural valuation system flexibly adapts to social context to incorporate reputation.

2-J-49 Testosterone administration increases social discounting in healthy males

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Although testosterone is thought to induce antisocial and aggressive behavior, research on social economic interactions has associated it with prosocial and affiliative behavior. Most of the findings are based on social economic games in which the distinction between prosocial motives and other social motives, such as reputation building, strategic responding, and status management, is convoluted. Testing the effects of testosterone using paradigms that less ambiguously target prosocial motives is necessary to more accurately understand the effect of testosterone on prosocial behavior. In the present study, we aimed at investigating the role of testosterone in human generosity by combining testosterone administration with a social discounting task, where prosociality in the form of generosity was not confounded with other social motives. In each trial, healthy male participants were asked to choose between a selfish and a generous alternative. The generous alternative involved sharing money with either a close or a distant other, whereas the selfish alternative yielded a payoff only for the participant. We combined this task with testosterone administration in a double-blind, placebo-controlled, between-subjects design to test whether and how testosterone modulates generosity. Across two studies (total n = 174), we showed that a single dose of testosterone reduced model-free generosity, as indicated by smaller AUC of the amount forgone and steeper discounting in the testosterone group compared to the placebo group. Reduced generosity was particularly evident for interactions with distant others. We also found that testosterone increased perception of social distance; however, perception of social distance did not mediate the effect of testosterone on generosity. Our findings provide causal evidence that testosterone reduces generosity in human economic decision-making. Moreover, they suggest that the valuation and the perception of social distance are independently affected by testosterone.

2-J-50 Does unfairness sound wrong? A cross-domain investigation of expectations in music and social decision-making.

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Objective: We investigated the existence of a shared mechanism for processing expectations across cognitive domains. Violations of expectations in music and language produce similar neural responses and violating the expectation in one domain may influence the processing of stimuli in the other (Carrus et al, 2013). Like for music and language, a system of inherent rules and norms, such as fairness, characterises our social world. Drawing a parallel to the social domain, this study aims to investigate whether a manipulation of melodic expectation can influence the processing of higher-level expectations of fairness. Methods: We embedded a manipulation of melodic expectation within a social decision-making paradigm, whereby more or less expected melodic stimuli were simultaneously presented with more or less unfair divisions in a third-party altruistic punishment game: participants had to decide whether or not to punish one player (A) for taking away some monetary units (MUs) from a second player (B) (Stallen et al 2018). The structure of each trial was the following: "A takes from B X", where X could be 0, 25, 50, 75, 100 MUs out of 200, the amount with which both A and B started each trial. The

words were presented sequentially and each one was paired with a musical note; the division (X) was paired with the last note, which determined whether the melodic structure for that trial was expected or unexpected. We analysed type of choice, reaction times (RTs) and EEG signal (medial frontal negativity (MFN), a well-documented index of unexpectedness (Mothes et al, 2016)). We hypothesised that an interaction between music and social expectancy would suggest that processing expectations involved domain-general mechanisms. At the time of writing, 12 participants out of the 65 planned were tested. Results: A generalised linear mixed model showed that higher unfairness predicted higher likelihood of punishment; a significant interaction between division and music shows that participants are slower to punish when both unfairness and melodic unexpectedness are high, suggesting an interfering effect of music. This could be a depletion of resources effect: unexpected music is taking away expectancy resources to process unexpected (i.e., unfair) divisions. No effect was found for the MFN. Given the small sample size, definite conclusions cannot yet be drawn. Implications: Investigating the cross-domain influence of music on social decisions furthers the understanding of how low-order cognitive processes may influence complex high-order processes. Moreover, it informs the understanding of domain-general mechanisms involved in the processing of expectation.

2-J-51 Plenty more fish in the sea: People forage for fairness among potential social partners

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In a room of strangers, how long would you spend interacting with an unkind person? Research using economic games has focused on how people make decisions in one-shot or repeated games, often highlighting that people are "irrationally" sensitive to fairness, and will forego money to punish other people. But in the real world we would simply choose when to "leave" unfair conspecifics rather than punish them, and travel to find someone else to interact with. Here, we propose that the principles of behavioural ecological theories of foraging behaviour can be applied to fairness, and how long people spend interacting with partners. Foraging theories highlight that to optimally gather resources in patchy environments one must compare the rate at which rewards are being obtained in one's current location (patch), to the background average rate at which rewards could be obtained in other locations in the environment. When the foreground rate equals the background, it is optimal to leave and travel to find a new patch. Such foraging theories predict that in poor environments, where most patches give lower reward rates, more time should be spent in each patch compared to a rich environment. Do people similarly treat fairness as a resource, and base decisions of when to leave partners on foraging principles? We tested a novel game (N = 44) where participants made decisions of when to leave a partner who was sharing sequential pots of money. Mimicking real world situations, if a participant chose to switch partner, there was a delay during which they received no money, whilst they "travelled" to find another player. We manipulated fairness in two ways: (i) The foreground fairness of social partners, which were fair or unfair (proportions of pot share) and (ii) the background fairness of the environment (proportion of fair or unfair partners). Crucially, absolute value was held constant, thus if people's decisions were based on economics alone, fairness would not change decisions of when to leave. We find that leaving times depended on both the fairness of a person, and the background fairness of others in the environment. Participants switched partners more quickly in the generous environment, even though they earned less money doing so. These results indicate that the duration of social interactions depends not only on partner fairness, but also the average generosity of other people in the environment. Fairness may therefore be a resource that is valued and foraged for. Thus,

behavioural ecological theories may be fruitful for understanding healthy and atypical human social and economic behaviours.

2-J-52 Dynamics of Adaptation to Social Norms

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Different social groups solve PD-like (prisoner-dilemma) scenarios in different ways. Some groups opt for cooperation and prosocial behaviour, while other groups are set on competition between group members. When most players behave in a similar manner most of the time, it is to each player's advantage to follow the current norm governing others' behaviour. This entails tracking other's behaviour and adapting one's own behaviour accordingly. However, the cognitive mechanisms underlying learning and adapting to social norms are not well understood. In four experiments I examined the learning process underlying adaptation to social norms. To this end I adapted a sequential social dilemma paradigm to form a grid-world game (http://socialdecisionlab.net/Demo/GW_N/). In this game multiple players moved about a 2D grid, collected stars and could zap each other, sending the affected player to a time-out zone. The participants played with three other players, which were preprogrammed to be either competitive, zapping players that stand between them and a star, or polite, moving out of the way of others. Participants played two consecutive blocks, one with polite players and the other with competitive players. In their first block participants adapted their zapping behaviour to their social surrounding, in both competitive and polite norms. However, in the second block, participants moving from polite to competitive norm adapted their behaviour accordingly, but participants moving from the competitive to polite norm remained competitive. A reinforcement learning model showed that this asymmetric adaptation could be explained by higher learning rates for active behaviour (zaps) than passive behaviour (zap avoidance). In addition, learning was found to be carried in a group level, as participants generalised from one player's behaviour to others', and learned from experienced behaviour (being zapped/spared) and observed behaviour (others being zapped/spared) similarly. However, when social norm conditions were relaxed in follow up experiments, a more elaborate social learning process was found. When one player was polite while others were competitive, participants were more likely to spare the polite player, while in social norm condition they did not treat differently players that zapped less than others. When participants were singled out, and treated differently from other players, they relied more on experience than observation. Taken together, these results indicate the importance of past experience on adaptation to social norms, and its dependence on the extent in which social norm is manifested in the new social environment, and on the valence of the norm.

2-J-53 Role of the rDLPFC in prosocial motivation and self-maximization: rTMS study

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Objective: Previous studies showed that inhibitory repetitive transcranial magnetic stimulation (rTMS) of the right dorsolateral prefrontal cortex (DLPFC) led to a stronger maximization of the budget in the ultimatum game (Knoch et al. 2006), but also led to more generous behavior in the dictator game (Christov-Moore et al., 2017). Here we address inconsistencies in the findings regarding rDLPFC involvement in prosocial behavior. Methods: To control the motivation to maximize the dictator's own

budget, we used a generosity game (Güth et al., 2012), where the dictator chooses the size of the pie (the monetary amount to be divided between two players), knowing that her own share is fixed, thus avoiding any self-maximization motivation. We applied a protocol of "offline" rTMS--continuous theta burst stimulation (cTBS) using between-subjects design: we applied cTBS to the rDLPFC (main rDLPFC-TMS group) or to the MT/V5 brain area (control MT/V5-cTBS group). Overall, subjects underwent cTBS and then they were able to share monetary units (MU) with the partner during the generosity or dictator game. The effect size was estimated based on a recent study with an effect size of 0.66 ($d = 1.06$) (Christov-Moore et al., 2017). Thus, the final sample size will be 25 per group with the expected dropout rate 25%. We hypothesized (Hypothesis I) that inhibitory cTBS of the rDLPFC could increase voluntary transfers in both the (a) dictator and (b) generosity games. Alternatively (alternative Hypothesis II) inhibitory cTBS of the rDLPFC will liberate selfish motives and, consequently, (a) decrease voluntary transfers in the dictator game, while (b) not affecting voluntary transfers in the generosity game, in which the dictator's budget is fixed. Results: So far we collected 10 subjects for rDLPFC-cTMS group ($M=2$), 8 subjects for control MT/V5-cTMS group ($M = 2$). Preliminary results suggested that rDLPFC stimulation led to significantly decreased transfers in the dictator game ($4,9 \pm 2,3$ MU; Mann-Whitney U test: $U = 2054234$, $Z = -10,6$, $p < 0,005$) as compared to control group ($5,5 \pm 1,9$ MU), while in the generosity game rDLPFC stimulation led to increased transfers ($7,25 \pm 3,169$ MU; $U = 171544$, $Z = -4,0$, $p = 0,0001$) as compared to control group ($6,73 \pm 2,98$ MU). The number of subjects will be increased up to 25 per group. Conclusion: Our preliminary data partially support Hypothesis II, suggesting that the rDLPFC plays a crucial role in controlling selfish motives and strategic social behavior. Acknowledgements: The study is supported by the HSE Basic Research Program and the Russian Academic Excellence Project '5-100'.

2-J-54 The effects of type and time of response to unfairness on impression formation

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In a situation of social dilemma, one's decision time, as well as the decision type itself, could provide a clue of one's hidden social heuristics. The ultimatum game can be a good example of such situations in that the responses to unfair offers can be driven by different social motivations depending on individual differences. The present study investigated how the type and time of the decision to unfairness influences the impression of the responder. We hypothesized that the decision type and time could differently affect the two critical dimensions of the social perception, 'Warmth' and 'Competence'. In each trial of the main task, participants ($N=41$) watched a short video clip of an ostensibly recorded response of a responder who had previously participated in an ultimatum game. Each participant watched a total of 150 trials, and only the trials with the unfair offer (i.e., 8:2) were manipulated into a 2-by-2 factorial design with two factors: Decision type (i.e., accept and reject) and time (i.e., fast and slow) of responders' decisions. In the fast and slow conditions, the responses of responders were made 700ms and 3000ms, respectively, after offers. Trials with fair offers were also included as a control condition where all the offers were quickly accepted (i.e., 700ms). Following the video clips, participants were asked to choose whether they would like to choose the responder in the video as their partner for a next ultimatum game. Upon completing the main task, all the participants viewed 4 video clips again each from one of the four conditions and rated the responder in terms of warmth and competence using a 4-score Likert scale (i.e., 1-strongly no, 2-no, 3-yes, 4-strongly yes). Participants perceived as warmer the responders who accept the unfair offers compared to those who reject them, and also the responders

who make slow vs. fast decisions. The interaction effect was not significant. In addition, the fast responder was perceived as more competent compared to the slow responder. The present findings suggest that information about both type and time of response to unfairness could be important indicators of the social preferences inherent in decision-makers and therefore could have a significant impact on the formation of impressions about them.

K. Valuation & Value Systems

2-K-55 Developmental differences in the neural mechanisms underlying effort-based decision-making

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Adolescence is a period of the lifespan associated with greater independence and greater demands to make self-guided decisions. Research suggests that adolescents may be more likely to engage in risky decision-making, suggesting potential differences in the evaluation of the costs and benefits of a given choice during this time. Prior work suggests that optimal effort-based decision-making relies on a distributed network of regions including the ventromedial prefrontal cortex (vmPFC), cingulate cortex, striatum, and anterior insula (ai). However, the role of these regions remain largely unexplored in adolescent decision-making. To this end, 28 healthy young adults (Mage = 20.07; SD = 1.81; range = 18-25) and 35 adolescents (Mage = 15.46; SD = 1.16; range = 13-17) completed a sequential effort-based decision-making task while undergoing functional magnetic resonance imaging (fMRI). As part of this task, information about the high-reward/high-effort option was presented sequentially; one piece of information (effort level or reward magnitude) was presented first followed by the other piece of information. We observed greater ai activity during choice as a function of increasing age. We also observed greater nucleus accumbens (Nacc) activity in adolescents in response to decreasing effort for trials where effort was presented first. Further, adolescents displayed greater NAc and vmPFC activity in response to increasing reward magnitude for trials where reward was presented first. These results suggest developmental differences in response to effort and reward encoding as well as cost/benefit information integration. Specifically, it appears that adolescents may more strongly encode information about effort level and reward magnitude; whereas adults demonstrate increased neural activity when effort and reward information are integrated. Interestingly, these effects appear to be mostly confined to later developing cortical regions in young adults compared to earlier developing subcortical regions such as NAcc in adolescents. These results help uncover changes in mechanisms that underlie cost/benefit decision-making associated with the transition from adolescence to adulthood.

2-K-56 How relations between goods affect valuation

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Consumption is a characteristic feature of modern societies and often concerns not only single goods but combinations of goods. Some goods are more desirable when consumed together with other goods than separately. For example, people may prefer consuming cake together with coffee more than consuming each food separately. These types of goods are called complementary goods. In contrast, substitute goods serve a similar purpose, they are interchangeable to some degree such as coffee and black tea. While the brain circuits that are critical for valuation and decision-making have begun to be identified in the last decades (e.g., Bartra et al., 2013), there is still a lack of understanding of the conditional

valuation processes for different relations between goods. This study aims to investigate such processes at both behavioral and neural levels. In our experiment, participants provided willingness to pay (WTP) bids for the same food items sometimes in isolation (sole condition) and sometimes in combination with other foods (paired condition). In the paired condition, participants were given a free food paired with the food item they were bidding for. This novel design allows us to calculate the changes of WTP between sole and paired conditions ($\Delta WTP = WTP_{\text{paired}} - WTP_{\text{sole}}$) while controlling for the intrinsic value of the food item. We predict that WTP for a specific food item increases when it is paired with a complement ($\Delta WTP > 0$). On the other hand, WTP for the same food item should decrease when it is paired with a substitute ($\Delta WTP < 0$). To independently determine the relation between goods, participants also provided ratings of perceived complementarity and substitutability for each food pair after the experiment. Our preliminary behavioral results (N=20) show that valuation can be affected by the relations between foods. We found variation in ΔWTP (mean: -0.19; range: -4.7 to 4.55), indicating that valuation of particular food items changed as a function of which other items it was paired with. More importantly, ΔWTP increased significantly in foods rated as more complementary (median-split within participants). Conversely, ΔWTP decreased significantly in foods rated as more substitutable. Together, these findings confirm our predictions and show that complementary and substitutable relations between goods differentially affect valuation. At the neural level, nutrition-similar foods (Suzuki et al., 2017) are represented similarly in OFC. The ongoing imaging of 40 participants should allow us to rapidly test our ex ante hypothesis that neural representations in OFC will be more similar for substitute goods and more different for complementary goods.

2-K-57 tDCS-induced modulation of the feedback-related negativity in the MID task

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In humans, a monetary incentive delay (MID) task is frequently employed to study reward processing. Using this task, numerous fMRI studies demonstrated the roles of the striatum, the medial prefrontal cortex (MPFC), the posterior cingulate cortex and the insula in the processing of incentive cues indicating potential monetary rewards (e.g. Knutson et al., 2000; 2001; 2003). As was shown in several EEG MID experiments, the exposure to the negative outcomes is associated with the ERP component, which is called feedback-related negativity (FRN). Represented as negative deflections of the ERP with a fronto-central maximum occurring 240-340 ms after negative feedback, FRN signals reward prediction error (Hajihosseini and Holroyd, 2013). Using a transcranial direct current stimulation (tDCS) approach, we further investigated the causal relationship of the MPFC in performance monitoring. For this, we designed an auditory version of the MID task (Knutson et al., 2001; 2000), where the subjects avoided small or large monetary losses in three contexts. A sixty percent loss avoidance outcome probability was manipulated by continuous adjusting of the target duration using an adaptive timing algorithm. To exert a neuromodulatory effect on the FRN magnitude in the test group, we applied cathodal transcranial direct current stimulation (ctDCS) on the FCz electrode site before each MID session. A control group was exposed to a sham stimulation. We modelled the electric field distribution featuring MPFC using SimNIBS software (Saturnino et al., 2015). We observed a significant increase in the FRN amplitude in the ctDCS group compared to the sham group. Our ctDCS finding contradicts a previous finding by Reinhart and Woodman (2014) regarding the diminished FRN amplitude in a target discrimination task following cathodal stimulation. We explain the opposite modulatory effects between the a.m. and our finding by the distinction between the two experimental tasks (the target discrimination task is a non-monetary

task) and the instability of the direction of modulatory effects--some cathodal tDCS studies report inhibitory influences, while others report facilitatory effects (for a review, see Wiethoff, Hamada and Rothwell, 2014). Overall, we observed a significant increase in the amplitude of the FRN response to the monetary tDCS losses without regard to the monetary game context or the outcome magnitude. Further studies would be necessary to elucidate the neuromodulatory effect of tDCS during performance monitoring (e.g. anodal tDCS on the MID-task performance). Supported by the HSE Basic Research Program and the Russian Academic Excellence Project '5-100'.

2-K-58 Naturalizing motivational salience in brain and behaviour

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Salience can be viewed as the capacity of a stimulus to direct attention. Although it is often ill-defined, an emerging literature operationalizes salience as unsigned value. Thus, cues predicting aversive or appetitive outcomes are more salient than cues predicting neutral outcomes. Formal models differ however in how they capture the impact of more or less predictable outcomes on salience. Mackintosh suggested that salience increases linearly with outcome probability whereas Pearce and Hall proposed a quadratic relation where salience increases with outcome variance (risk). Here we compare these salience models with regard to cue-related 1) response times, 2) pupil dilation and 3) neural responses. 41 healthy, right-handed participants were instructed not to eat or drink for at least 3 h before the experiment. To equate the salience of appetitive and aversive liquids, we individualized liquid types and concentrations in a separate calibration session using rating and Becker-DeGroot-Marschak auctions. In the scanner, each trial started with the presentation of one of seven visual cues: 100% (aversive, neutral or appetitive), 50% (aversive, neutral or appetitive) and 0%. After each cue, participants either identified the outcome associated with the cue or rated the pleasantness of the presented cue. After a variable delay (mean 1.5 s), the fixation cross changed color, the participants received liquid or no liquid and rated the outcome. The salience model of Mackintosh explained cue-related response times and pupil dilation, whereas the salience model of Pearce-Hall explained primarily pupil dilation. Neural responses for the Mackintosh salience occurred in medial and ventral parts of frontal cortex, as well as in temporal and visual cortex. On the other hand, Pearce-Hall salience was processed by visual cortex. Moreover, medial prefrontal cortex expressed Pearce-Hall salience more strongly during cue identification than cue rating, in-keeping with a preferential effect of risk on pupil dilation during identification. Together, our findings suggest that different forms of motivational salience relate to different behaviours and to specific cognitive demands, such as memory for liquid type (identification) versus valuation (rating).

2-K-59 Tired of working: Neurocomputational mechanisms of motivational fatigue in effort-based valuation

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Objective: There is considerable evidence that fronto-striatal systems play key roles in ascribing value to rewarding options and in signaling the subjective value of exerting effort to obtain rewards. The majority of studies present a series of offers and examine how people subjectively devalue rewards by effort. Such studies typically assume that motivation and valuation is static. In contrast, prominent theories suggest that fatigue - a feeling of exhaustion arising from effortful exertion - has a significant impact on

motivation, reducing the willingness to exert effort. How does the brain process the subjective value of effort and reward as it changes due to fatigue? Here, using an effort-based decision-making paradigm in combination with computational modeling and functional magnetic resonance imaging (fMRI), we examined how fronto-striatal systems process levels of fatigue moment-to-moment during a task and how these systems process the subjective value of exerting effort weighted by current levels of fatigue. Methods: Young healthy participants (N=36) made a series of choices between two alternatives: a rest option for a low reward (1 credit) or a work option, requiring the exertion of one of three levels of grip force (30-48% of their maximal grip strength), for one of three higher amounts of reward (6-10 credits). Using this design, we were able to examine how the value of the "work" offer changes systematically over time and to build a computational model of the changes in subjective valuation from trial to trial. Results: Using computational modeling we found that the willingness to exert effort, in particular high effort, fatigues over trials but also fluctuates moment-to-moment (trial-to-trial) as a function of the recent history of effort and rest during the task. Our computational model assumes that levels of fatigue fluctuate across trials and that these fluctuations modulate the subjective value of putting in effort. Preliminary fMRI results suggest that dorsal anterior cingulate cortex and dorsolateral prefrontal cortex track the moment-to-moment, model-estimated levels of fatigue, whereas ventral striatum and frontal pole signal subjective value weighted by fatigue. Conclusions: These results provide novel insights into the neural basis underlying fatigue and the dynamics of motivation, showing that separate but connected systems may underlie momentary fatigue and its effect on effort-based decisions. They thereby point to how fronto-striatal regions, previously implicated in the valuation of effort, may perform distinct computations that underlie how subjective value changes depending on moment-to-moment changes in internal states.

2-K-60 Neural mechanisms underlying effortful persistence

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The adaptive adjustment of behavior in pursuit of desired goals is critical for survival. To accomplish this complex feat, individuals must weigh the potential benefits of a given course of action (e.g., food, safety from predators) against time, energy, and resource costs. Prior work in this domain has greatly advanced understanding of the cortico-striatal circuits that support motivated goal pursuit, characterizing core aspects of subjective valuation. However, these complex dynamic calculations have traditionally been examined at discrete points, for instance evaluation and choice. How time and effort costs are integrated in dynamic valuation remains an open question. When persistence has been examined, it has primarily been limited to temporal costs, leaving the mechanisms underlying individual differences in the dynamic updating of effort requirements during goal pursuit poorly understood. Utilizing tasks that better map onto the dynamic nature of naturalistic goal pursuit will allow us to characterize the neural mechanisms underlying variable success in goal achievement across individuals and contexts. In the present study, participants underwent functional MRI (fMRI) while completing a novel paradigm to examine willingness to exert physical effort to obtain monetary rewards or avoid punishments. Effortful exertion in pursuit of obtaining reward or avoiding punishment recruited a broad network of cortico-striatal and cognitive control regions, including ventromedial prefrontal cortex and dorsolateral prefrontal cortex. Ongoing analyses aim to fit multivariate models to predict trial level effort expenditure. By revealing how willingness to exert physical effort is instantiated and updated in the brain, the current study informs how effort cost weighting impacts goal pursuit and achievement.

Poster Session 3 Sunday, October 6th

B. Choice & Choice Mechanisms

3-B-1 No compromise! No context dependent decision bias in older participants with declining availability of presynaptic dopamine.

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Objective: When we decide we usually consider the context. This can sometimes lead to suboptimal choices, or choice abnormalities. One such abnormality is the compromise effect. Here, the likelihood of a product being selected may be increased by positioning it as a compromise in an available set of extreme options. The effect can be reliably elicited in experimental conditions when participants tend to choose a low price, low quality option over a medium price, medium quality option in a binary choice set but select the medium over the low option when a high price, high quality option is introduced (i.e. trinary choice set). Since previous research suggests that the choice bias may relate to cognitive capacity, we expect its magnitude to be reduced in old age. One neurotransmitter associated with cognitive capacity, dopamine, could be the limiting factor. **Methods:** Two experimental groups of 27 participants each (n=54, both groups 14/13 m/f, 20-32 years considered younger and 62-80 years considered older) played a computerized selection task consisting of 30 consecutive decisions between two goods from six different product categories, contrasted to 30 decisions expanded by a high price, high quality alternative. To isolate the compromise effect's occurrence, we analyzed how often participants selected the low option in the binary choice set, while opting for the medium option in the corresponding trinary choice set. A subsample of the older participants (n=20) further underwent an F-DOPA PET study to access dopamine synthesis capacity in the striatum. **Results:** As expected, younger adults exhibited a tendency to engage in the compromise (exact McNemar $p < 0.001$) whereas this effect was attenuated in the older group ($p = 0.080$). Further, an analysis of individual compromise effect (CE) shares revealed both groups to significantly differ from each other ($U(27,27) = 260$, one-tailed $p = 0.031$) whereby lower CE shares were observed in older adults. Results of the PET study further confirmed our hypothesis that participants' compromise behavior was positively related to striatal dopamine synthesis capacity (measured by the quantitative metric of F-DOPA uptake; $r = .464$, one-tailed $p = 0.030$). **Conclusions:** The present study indicates that compromise behavior is attenuated in older adults. This supports the idea of necessary cognitive resources to engage in the compromise effect. We present a potential neural underpinning with declining dopaminergic synthesis capacity, also associated with aging.

3-B-2 The role of information lifespan and rate of information flow on decisions involving tradeoffs between time and information

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In many decisions we face, collecting more information is beneficial but comes at a cost of time and energy that can otherwise be spent on alternative actions that are equally - if not more - rewarding. Previously, we had shown that people tend to collect less information than they should in a task where information accumulates over time while the size of potential reward for making a correct decision decreases over time. It remains unclear, however, why people exhibit such suboptimal behavior. In this study, using the same task, we investigated two potential causes of suboptimality - information lifespan and rate of information flow. Method. We examined the role of information lifespan by manipulating the amount of time a piece of information, once presented, stayed on the computer screen (0.2 sec, 0.5 sec, 2 sec and "always on"), while controlling for rate of information flow (20 Hz). We examined the rate of information flow by manipulating how fast a new piece of information is presented - 10 Hz, 20 Hz and 30 Hz - while controlling for information lifespan (always on). As a result, there were 6 conditions, with each condition having 20 participants in a between-subject design. Results. We replicated previous findings by showing that subjects collected less information than they should have. In addition, we found that information lifespan affects suboptimal behavior: the shorter each piece of information stayed on the screen, the longer the subjects waited to collecting more information, suggesting that increasing the cost of integrating information over time, elicited by decreasing information lifespan, may promote optimal tradeoff between time and information. By contrast, rate of information flow did not change the suboptimal pattern. Unexpectedly, we found that subjects appeared to base his or her decision timing on the amount of information collected - but not the amount of time needed to collect information - as the pattern of suboptimality was identical between different rates of information flow when analyzing reaction-time data in terms of the amount of information collected. Together, these results indicate a sampling-based, but not time-based, decision strategy that takes into account the cost of information integration over time in decisions involving time-information tradeoffs.

3-B-3 A reversed memory bias on value-based decisions in the loss domain

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Objectives. A growing number of researchers investigate the role of memory in value-based decisions. In previous work, we have shown that people tend to prefer remembered over forgotten choice options even when the latter are more attractive, an effect referred to as memory bias (Gluth et al., 2015). Here, we tested if this memory bias originates from uncertainty aversion, that is, whether people avoid choosing poorly remembered or forgotten options because of the uncertainty that is entailed in such decisions. According to this hypothesis we predicted a reversal of the memory bias in the loss domain, that is, people prefer forgotten over remembered options of negative value - analogous to the reflection effect in decisions under uncertainty (Kahneman & Tversky, 1979). Methods. In two experiments, participants performed memory-based choices between amounts of positive or negative monetary values (experiment 1, $n_1 = 36$) and between pictures of positive or negative valence (experiment 2, $n_2 = 36$). To assess the memory bias, we performed a binary Bayesian hierarchical logistic regression using trials in which participants recalled only one item to predict the choice of the remembered options by their standardized values. A significantly positive (negative) intercept coefficient corresponds to the presence of a positive (negative) memory bias. All analyses were pre-registered on the OSF-platform (osf.io/eumj5). Results. As predicted, participants exhibited a reversal of the memory bias in the loss domain [Experiment 1: $t(35) = -4.31$, $p < 0.001$, $d = 0.72$; Exp. 2: $t(35) = -2.48$, $p < 0.001$, $d = 0.41$].

Furthermore, we found a significant difference in the memory bias between gains and losses [Exp. 1: $t(35) = 5.17$, $p < 0.001$, $d = 1.28$; Exp. 2: $t(35) = 9.31$, $p < 0.001$, $d = 1.89$]. In line with our previous work, participants showed a positive memory bias in the gain domain [Exp. 1: $t(35) = 3.70$, $p < 0.001$, $d = 0.62$; Exp. 2: $t(35) = 8.40$, $p < 0.001$, $d = 1.4$]. Conclusions. The central aim of our two studies was to draw a conceptual link between decisions from memory and decisions under uncertainty. Indeed, we found that - analogous to the reflection effect in decisions under uncertainty - people exhibit a reversal of the memory bias on value-based decisions in the loss domain: They prefer remembered over forgotten options of positive value but forgotten over remembered options of negative value.

3-B-4 Transdiagnostic phenotyping reveals a range of metacognitive deficits associated with compulsivity

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Background: Previous work has shown success utilising transdiagnostic dimensions to disambiguate confidence relationships in psychiatry; in a perceptual decision-making task, anxious-depression manifested low confidence while compulsivity was related to over-confidence (Rouault, Seow et al., 2018). However, it is unclear how confidence estimation deficits are related to behaviour control. Here with an unrelated task, we sought to replicate confidence effects and to probe the relationship between confidence and action in transdiagnostic traits. Methods: An online sample ($N = 437$) performed a predictive inference task via Amazon's Mechanical Turk. We related confidence ratings and its relationship with behavioural measures of action to self-report psychiatric symptoms, which were refactored into trans-diagnostic dimensions. In addition, we investigated the underlying source of abnormal confidence with a quasi-optimal Bayesian observer that enabled the separation of various evidence influences. Results: We found that a reduction in action-confidence coupling was profoundly non-specific--associated with all 9 clinical phenotypes measured (all $P < .05$). However transdiagnostic phenotyping explained the effect to a compulsive symptom dimension ($P < .001$). We also replicated previous work showing bidirectional associations between compulsivity and inflated confidence ($P < .001$), and between anxious-depression and decreased confidence ($P < .001$). Lastly, we found that individuals high in compulsivity were associated with a marked inability to update confidence estimates (but not action) according to unexpected outcomes, uncertainty and positive feedback (all $P < .01$). Conclusions: Consistent with prior work, we showed that anxious-depression was linked to poor confidence, however these world model estimates were found to guide behaviour appropriately. In contrast, compulsivity was associated with overestimated confidence and a deficit in incorporating various sources of evidence into their belief formation to guide behaviour. We thus provide the first sketches of a mechanism through which abnormal metacognitive beliefs take hold and are maintained in compulsivity, and suggest that these dysfunctions might contribute to a broader class of problems high compulsive individuals face with goal-directed planning and execution.

3-B-5 Pupillary and microsaccadic responses to cognitive effort and emotional arousal during multi-attribute decision making

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Background and aim Decision making with multiple attributes is an effortful mental process taxing

working memory and attention. In addition, incidental emotional arousal elicited by external events can interfere with this process. A large body of literature documents the sensitivity of pupil response to cognitive load and emotional arousal, with pupils dilating under high information load and high arousal. Recent empirical evidence also shows that microsaccade dynamics can be modulated by mental fatigue and cognitive load, with scarce evidence for the sensitivity of microsaccades to arousal. The aim of this work was to compare pupillary and microsaccadic measures as indices of cognitive effort and arousal during multi-attribute decision-making. Specifically, we show in a controlled experiment the relation between pupil diameter changes and microsaccade characteristics, i.e., rate and amplitude, in response to information processing during multi-attribute decision making under varying emotional conditions. Method Twenty-one young adults volunteered for the experimental decision-making study and were assigned randomly into three independent experimental conditions (neutral, aversive, and erotic). During the study participants were asked to make multiple judgments which diamond (of two) is more valuable, and choose the more valuable one based on decision cues that they could acquire in a sequential manner. During task performance, participants' eye movements and pupil size were tracked with an eyetracker. In line with earlier results, microsaccade rate decreased when participants used multiple cues to make these choices. We did not find differences in microsaccade dynamics between emotional conditions, but we did find them in pupil diameter. In the aversive condition, pupil dilation substantially increased with increasing number of acquired cues. Conversely, in the erotic condition, pupil dilations decreased with increasing number of acquired cues. Conclusions This pattern of results suggests that microsaccade rate, unlike pupil dilation, is relatively independent of emotional arousal and can be used as an index of cognitive effort in complex decision making. The results also underline the importance of taking into account the valence of emotional stimuli when analyzing the impact of emotional arousal on pupil size changes during complex decision making.

3-B-6 Evaluation of graphical visualization behavioral in a multi-criteria decision making context

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In Multi-Criteria Decision Making (MCDM/A) problems the main task is the preference modeling, which is related to the identification of decision makers (DMs) preferences for the problem scenario and translations of these preferences for mathematical models to solve these problems. The FITradeoff method (de Almeida et al. 2016) is a specific method used to elicit criteria scaling constants, which brings the same axiomatic structure presented in Tradeoff method (Keeney and Raiffa 1976) but offered flexibility and interactivity to decision makers (DMs). Regarding to the flexibility, it is supported by graphics which are presented in the FITradeoff Decision Support System (DSS) and can be used to assistance DMs in the evaluation of the potentially optimal alternatives (POA). Objective: In order to investigate these graphics, specifically how DMs evaluate those and the behavioral during the MCDM/A process, an experiment was developed with an X120 Eye-Tracker by Tobbi Studio. In this experiment the three graphics presented in FITradeoff method (bar graphic, bubble graphic and spider graphic) were presented, in addition to other two (tables and bar graphic with table). Based on the results was concluded that bar graphics and tables presented the higher number of hit compared to the other types (Roselli et al. 2019). Therefore, a new experiment was developed using only bar graphics and tables with X120 Eye-Tracker by Tobbi Studio in addition to the 14 channels EEG by Emotiv. Method: The experiment presented 20 visualization forms, 10 bar graphics and 10 tables, developed in pairs. These visualization forms were built with three, four or five alternatives and criteria, which presented equal

and decreasing weights. Other two forms of visualization, bar graphic with table, were included in order to generate insights for future experiments. The experiment was applied to 51 management engineering students from Federal University of Pernambuco (UFPE), the sample was composed for: 28 graduated and 23 postgraduate students, being 25 women and 26 men. Results: The Hit Rate (HR) variable was evaluated, as well as in Roselli et al. 2019, this variable was calculated based on the ratio of the number of correct answer by the number of total answers. The number of correct answers was verified using the Multi-Attribute Value Theory--MAVT (Keeney and Raiffa 1976; Belton and Stewart 2002). The Response Time (RT) was also evaluated, being collected directly from eye-tracking software. Based on these variables were possible to suggest that tables presented higher number of hits and higher response time on 60% of comparisons. Conclusion: This result confirms the conclusions su

3-B-7 Computational markers of individualized learning: Large-scale meta-analysis of nonreinforced preference modification studies

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Introduction. While most preference modification methods rely on external reinforcements, in the Cue Approach Training (CAT) paradigm, a simple association of image stimuli with a neutral cue and speeded button press response resulted in a durable preference modification effect, lasting months. Well-learned association can be manifested in the form of faster anticipatory reaction times (RTs) preceding the actual cue-onset. These in turn, can be used to identify individual differences in learning and predict subsequent preference change. In the current work using Bayesian computational framework with a large-scale dataset of over 800 participants, we aimed to identify markers for individualized learning in order to uncover the mechanisms underlying successful nonreinforced preference modification.

Methods. Data from 28 experiments with CAT were standardized into a large dataset with a total of N = 828 participants. Participants underwent CAT followed by a probe phase, examining subsequent preference modification. The RTs of the training task were modelled with a novel Bayesian computational framework. In a competitive dual process model, RTs were sampled either from a distribution of late cue-dependent RTs, or early anticipatory responses. Individualized learning was modelled as the probabilistic transition from cue-dependent responses in early stages of training, to anticipatory RTs in later stages of training.

Results. Across all experiments pooled together, CAT had consistently resulted in enhanced preference for the associated Go stimuli over similarly valued NoGo stimuli (mean proportion = 59.06%, OR = 1.52, 95% CI [1.45, 1.60], $p = 5.2E-59$, one-sided logistic regression). Using Bayesian modelling, we were able to fit a bimodal RT distribution composed of two competing distributions - one of early anticipatory RTs ($\mu = 914.89$ ms from trial-onset, 95% CI [913.55, 916.20], $\sigma = 164.19$) and a later cue-dependent ($\mu = 960.00$ ms from trial-onset; $\mu = 268.79$ from cue-onset, 95% CI [268.22, 269.34], $\sigma = 53.15$), with most participants demonstrating greater proportion of early response as training progressed (Mslope = 3.93, 95% CI [3.53, 4.34], $\sigma = 5.3$). Furthermore, individualized slope parameter estimates were also correlated with subsequent probe effect of preference modification ($\beta = .233$, $F(1,826) = 47.4$, $p = 9.92E-12$).

Conclusions. Our results demonstrate that Bayesian modelling of RTs in nonreinforced training with CAT can be used to identify markers of individualized learning. We propose that using this computational framework can be a powerful tool both for model fitting as well as prediction of future effect on preferences modification.

3-B-8 Influence of chronic stress on economic decision-making in mice

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In the core of the nucleus accumbens, corticotropin-releasing factor (CRF) increases evoked dopamine (DA) release and produces conditioned place preference in stress-naïve animals. However, following two-day, repeated forced swim stress (rFSS), neither of these effects are present. To ascertain the degree to which this mechanism influences integrated, reward-based decision making, we developed a novel operant concurrent-choice task where male (n=19) and female (n=16) mice could nosepoke to choose between two liquid receptacles containing a [0.1M] sucrose solution or water delivery. Following initial training, either a CRF or DA antagonist, α -helical CRF (9-41) [500ng/200nL] and flupenthixol (20 μ g/0.5 μ L), respectively, or vehicle was administered intracranially to the nucleus accumbens core, counterbalanced over two sessions (separated by one baseline session). Next, the animals underwent rFSS, were reintroduced to the task, and were retested with α -helical CRF (9-41) or flupenthixol. Antagonizing CRF and DA should reduce overall response vigor which is represented by reduced sucrose receptacle preference (percentage of nosepokes into either sucrose or water receptacles regardless of trial type) and reinforced choice preference (percentage of choice trials where the animal chose sucrose), longer sucrose choice latency (how long it takes an animal to nosepoke into a receptacle following its associated discrete cue), and an increase in the number of trials omitted during the session. Prior to stress, mice exhibited a significant preference for sucrose over water and made more total nose pokes into the sucrose receptacle than the water receptacle throughout the session. In their stress-naïve states, injections of α -helical CRF into the nucleus accumbens core did not elicit any robust changes in either preference or latency to choose. Interestingly, following stress, α -helical CRF decreased sucrose choice percentage, sucrose receptacle preference and sucrose choice latency compared to animals that received injections during their stress-naïve state. Regarding DA antagonism, flupenthixol increased their sucrose choice percentage, increased both water and sucrose choice latencies, and increased the number of trial omissions which could indicate lack of motivation to complete the task. These data suggest that vigor during concurrent choice selection is dopamine- and stress-dependent, but also has separate components that are sensitive to CRF antagonism. Specifically, effects of either CRF or DA antagonism within the ventral striatum were larger following stress, indicating the importance for understanding the interaction between stress and decision-making.

3-B-9 Explicit value cues alter the decision process

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An important question in value-based decision-making is whether peoples' decisions are affected by the overall value of presented options. Evidence from multiple studies indicates that response times (RT) decrease as the value of the options increase. This suggests that people might not always be aware of the magnitude of their decisions. In the current study, we investigated whether the decision process changes when subjects know the stakes of the decision ahead of time. We conducted 4 experiments where subjects made binary choices between either food items, abstract art images, complex lotteries, or colored-boxes. In each experiment, we segregated the items in each choice set by the overall value, such that each binary choice contained items that were either both high value, middle value, or low value items. In the food and abstract art tasks, values were based on subjective ratings given on a 0-10 scale prior to the choice task. In the complex lottery task, values were based on the expected value of

the lotteries. In the colored-boxes task, values were based on a reinforcement learning task completed prior to the choice task. In all experiments, subjects made binary choices in two conditions. In explicit-information (EI) blocks, subjects were first informed that the items they would be choosing between were from the top, middle, or bottom third of the rating scale. In mixed-information (MI) blocks, subjects were told that the items could be from any of those categories. We used the DDM to study the difference between EI and MI blocks. We hypothesized that subjects would spend more time in the high value EI blocks, and less time in the low value EI blocks. In the DDM, we hypothesized that subjects in the EI blocks would have wider thresholds in high value blocks and narrower thresholds in low value blocks. Replicating past results, we found that subjects were faster when choosing between high value items, relative to middle value items, in the MI blocks. Unexpectedly, we found that choices in EI blocks were faster overall than those in MI blocks. In our DDM fits, decision thresholds were higher in the MI blocks than in the EI blocks, indicating subjects' need for more evidence before making a choice (i.e., longer RTs). We also found that decision thresholds for high value choices increased in EI blocks relative to in MI blocks. Overall, these results indicate that providing explicit information about overall value leads people to be less cautious overall, but also affects how they allocate their time between low and high value decisions. In particular, providing explicit value information reduces the speed of high value decisions.

3-B-10 Predicting and choosing for others: Bridging the gap with mouse-tracking

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Being able to learn and implement another person's preferences is key for functioning in a social society. Often, we simply have to predict what another person will do. Other times, we need to make decisions on the behalf of others. Here, we address the question of what people do when they make decisions for another person. Do they try to use the other's preferences? Do they simply choose in line with their own preferences? Or do they choose what they think the other person should choose? Can we use process-related analyses to better understand how people choose? We address these questions with two studies. In Study 1 (N = 44), subjects observed several monetary risk "choices" made by a deterministic algorithm and then predicted what the algorithm chose on previously-unseen trials, earning money for each correct prediction. In Study 2 (N = 162), subjects observed choices made by recipients (i.e. six subjects from Study 1) and then predicted or chose on each of their behalves. Some subjects earned a bonus for each "correct" response (i.e. when they correctly predicted the option chosen by the recipient), as in Study 1. For other subjects, the recipient earned a bonus based on the surrogate's accuracy. In the third condition, we implemented one randomly-selected choice made by the subject and paid the recipient accordingly. In Study 1, subjects were quite accurate (M = 82%), and significantly more accurate when both parties made the same choice (paired t-test: $t(43) = 6.21$, $p < 0.01$). There was a significant relationship between self-other similarity and accuracy (mixed-effects regression: $\beta = 0.53$, $p < 0.01$). In Study 2, accuracy in the two accuracy-rewarded conditions was very similar (M = 80%; 81%). In the implemented-choice condition, most subjects' (44/53) choices most closely mimicked their own preferences or expected value maximization, rather than the recipient's preferences (9/53), resulting in lower accuracy (M = 76%). The mouse-tracking data show that expected value/subject preferences predicted mouse movements earlier than recipient preferences in the implemented-choice condition, but not in the accuracy-rewarded conditions. Overall, we find evidence that subjects can learn the preferences of others, but don't generally implement this knowledge into surrogate choices unless

incentivized to do so. This project sheds light onto prior, conflicting research about how subjects make choices for others; rather than a simple "people can/can't accurately choose for others," we conclude that other factors, such as self-other similarity and social norms about what people should choose, play an important role in the process.

3-B-11 Efficient noisy sampling and decision behavior

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Given the overwhelming evidence that decisions emerge via information sampling, what are the sources of noise, variability and "irrational" biases in the system's percepts guiding decision behavior? Can these observations be explained within a single, unifying and biologically plausible framework while accounting for the organism's goals? From the theoretical point of view, we clarify for the first time that optimal decision behavior in capacity-limited systems can be parsimoniously achieved via discrete information sampling where, crucially, noise serves to optimize decision behavior while accounting for the organism's goals and environment statistics. This result makes it clear, why decisions must be noisy, given that: 1) one's nervous system relies on collecting discrete samples of information (e.g., high/low readings from neuron's action potentials), 2) is limited in its capacity to collect and represent information, and 3) we show that these noisy codes must be adaptive as they depend on the current goal of the organism (e.g., representing the world accurately or maximizing fitness). Crucially, this unifying theory is derived from first principles and with a parsimonious biological implementation. We test this theory on numerosity perception, as to the best of our knowledge, it has not been formally tested whether humans have evolved their number sense to maximize discrimination accuracy or to maximize fitness. Therefore, we implemented a set of numerosity decision experiments, where the goal of the decision maker is either to maximize fitness or accuracy (across four days of psychophysical testing for each participant (n=13, 2400 trials per participant) in a within subjects design), while carefully controlling for the environment statistics. Surprisingly, the results show that humans do not directly follow the normative efficient-coding recipes, but rather appear to rely on suboptimal but efficient proxy mechanisms of sampling from memory irrespective of the goals of the task. That is, while suboptimal, this sampling from memory strategy efficiently considers the environment statistics which is in turn the optimal strategy if neural systems are constrained to rely on comparing past experiences. Crucially, this model can explain the data better than other competing models including the well-established logarithmic model of number perception. These theoretical and empirical findings provide a novel mechanistic framework for understanding decision behavior while accounting for biological restrictions of noisy information coding and organism's goals, which could be extended to any other decision-making domain in humans, other species, and machines.

3-B-12 Understanding Dishonesty: Investigating the Neurocognitive Processes underlying Cheating Behavior

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Dishonest behavior is quite prevalent and is, for example, manifested in financial fraud, scientific misconduct and software piracy. Whereas a lot of neuroimaging research has focused on deception of interaction partners in social exchanges almost no research has been conducted on dishonest behavior

in situations where no direct interaction partner is present, such as in the examples mentioned above. Self-concept maintenance theory (Mazar, Amir & Ariely, 2008) proposes that participants are torn between maintaining a positive self-concept and benefiting from dishonesty. This is supported by the observation that people behave dishonestly enough to profit, but honestly enough to maintain their self-concept. It has frequently been put forward that cognitive control is needed to resolve this ethical dissonance. However, there is disagreement in the literature on whether cognitive control is needed to refrain from cheating or to override the default inclination to be honest. This study aims at investigating how cognitive control processes influence our moral decisions. To answer this question, a novel behavioral paradigm was developed in which participants repeatedly, deliberately and voluntarily acted dishonestly inside the MRI scanner without suspicion of the real purpose of the task. This novel paradigm further allowed us to assess the neural correlates of cheating on a trial-by-trial basis. To reduce dependence on reverse inference, we also added localizer tasks aimed at evoking the neural correlates associated with cognitive control. Our behavioral results indicate high variability in propensity to cheat. Based on self-report measures, we found that more impulsive and risk seeking participants seem more prone to dishonest behavior. Our fMRI analysis (N = 40) revealed that when given the opportunity to cheat, relatively honest participants engaged in more self-referential thinking than dishonest participants, reflected in higher activations in the PCC, bilateral TPJ and MPFC. Moreover, using multilevel modelling to analyse trial-by-trial behavior we found that higher activation in the cognitive control network, represented by higher activations in the left dlPFC, ACC and bilateral IFG, increased the probability of cheating for honest participants and decreased it for cheaters. In summary, our research suggests that more impulsive individuals tend to cheat more and require cognitive control to remain honest. In contrast, more honest individuals engage in self-referential thinking and require cognitive control to cheat. In combination, our results suggest that the effect of cognitive control depends on our default inclination for honesty or dishonesty.

3-B-13 Apparent preferences for cognitive effort fade when multiple forms of effort and delay are interleaved in a foraging environment.

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Introduction: Cognitive and physical effort are typically regarded as costly, but recent findings have suggested that exerting effort can boost the value of prospects under certain conditions. Here we embedded mental and physical effort in a "diet choice" foraging task, which required decision makers not only to evaluate the magnitude and delay of a focal prospective reward, but also to estimate the general opportunity cost of time. **Method:** In two experiments, independent sets of participants collected rewards that required equivalent periods of cognitive effort, physical effort, or unfilled delay. Monetary offers varied per trial, and the two experiments differed in whether the type of effort or delay cost was the same on every trial (between-subjects, n=21 per condition), or varied across trials (within-subjects, n=48). Participants were free either to accept or reject the cost/reward prospect offered on each trial. **Results:** All participants were more likely to accept offers when rewards were higher and delays shorter, in line with a reward-maximizing strategy. Participants almost never reversed their acceptance decisions, and error rates in completing the effort requirement were low and decreased over time. When participants faced only one type of cost, cognitive effort persistently produced the highest acceptance rate compared to trials with an equivalent period of either physical effort or unfilled delay. This could be because cognitive effort was directly rewarding, or because it modulated foraging-related

factors such as the perceived duration of delays or the estimated richness of the environment. We theorized that if cognitive effort were intrinsically rewarding, we would observe the same pattern of preferences when participants foraged for varying cost types in addition to rewards. In the within-subject experiment, an initially higher acceptance rate for cognitive effort trials disappeared over time amid an overall decline in acceptance rates as participants gained experience with all three conditions. Conclusion: Our results extend the view that cognitive demands may reduce the discounting effect of delays, but also suggest that differences in cost can eventually fade if individuals actively experience alternative forms of demand. Rather than assigning intrinsic value to cognitive effort, our findings support the idea that a cognitive effort requirement might influence contextual factors such as subjective delay durations or the perceived opportunity cost of time. Such altered estimations can be recalibrated if multiple forms of demand are interleaved.

3-B-14 Divisive normalization of value explains choice patterns in risk taking behavior

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Numerous examples of violations of the independence of irrelevant alternatives have been documented in the decision-making literature and many theories have been suggested to explain why the addition of seemingly irrelevant alternatives influences choice. In this study we theoretically contrast the predictions of divisive normalization, salience, range normalization, and attraction effect theories and present empirical evidence from a laboratory experiment in which we test how adding dominated lotteries to the choice set affects behavior under risk. 121 participants were asked to select their preferred option from choice sets including two, three or four binary lotteries. Each choice set included one of the twelve target binary lottery pairs. The remaining lotteries in the choice set, the distracter lotteries, were always dominated by either one or both of the target lotteries and therefore should not be (and indeed were not) selected. Our careful design of the target and distracter lotteries allowed us to test the predictions of divisive normalization, salience (Bordalo et al., 2012), range normalization (Kontek and Lewandowski, 2018) and attraction effect theories (e.g. Ok et al., 2015) in situations where these models make different predictions. Consistent with the predictions of divisive normalization model, participants' risk attitudes were not affected by the addition of distracter lotteries to the choice set, instead participants were more likely to make mistakes as more distracters were added to the choice set or/and as the expected value of these distracters increased. The observed behavior cannot be explained by salience, range-normalization, or attraction effect theories.

3-B-15 Modulation of reward learning by social context in suicidal behavior.

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The predisposition to suicidal behavior is complex and may include enduring traits that also manifest in interpersonal dysfunction and decision-making deficits. The mechanisms of this disturbance remain largely unknown, but one hypothesis is that people vulnerable to suicide fail to learn from interactions with others. To test this hypothesis, we used a repeated trust game and manipulated the share rate (50%, 25%, 88%) of the trustees (good, bad, neutral, computer) to examine how healthy controls (HC: 29), depressed non-suicidal (D-NS: 23), ideators (depressed individuals with suicidal ideation, IDEA: 20) and suicide attempters (SA: 32) optimize their decision-making to varying reward schedules. Group

membership, trustee type, decisions made by participant on the previous trial (PSD), recent (decisions made by trustee on the previous trial: PTD) and average reinforcement history predicted probability of investing with a trustee and response times. One's recent decisions predicted to the lesser extent the choices of suicidal (SA + IDEA) than non-suicidal (HC + D-NS) individuals (Group \times PSD). Whereas recent reinforcement history influenced investment choices of HC and SA more so than that of D-NS and IDEA (Group \times PTD). We refined a reinforcement learning model based on the comparative model analyses (Vanyukov et al., 2019). In this "social" RL model, prediction errors (PEs) indexed a mismatch of participant's policy with trustee's decisions. Model-derived PEs were added to the subject-level GLM to predict voxelwise blood oxygenation level-dependent (BOLD). Whole-brain analyses revealed weaker PEs responses in SA vs. HC in regions that included prefrontal (inferior frontal gyrus, middle frontal gyrus), anterior cingulate, and thalamus, D-NS (cuneus) and, at a lower cluster threshold, IDEA (left precentral gyrus and cuneus). Follow-up region of interest analyses, using independent meta-analytic PE masks (Chase et al., 2015), confirmed that the blunting of PE signals in SA vs. HC was more pronounced in the striatum than in other canonical PE regions. Finally, the brain-to-behavior analysis, in which we included neural PE responses as a co-variate in the behavioral model, showed that stronger neural PE responses in striatum were associated with lower reactivity to the trustee's last action in all groups except for SA (Group \times β \times PTD). Overall, our findings suggest that people vulnerable to suicidal behavior fail to optimally integrate their social experience when choosing between cooperation and defection. One neural mechanism underlying this failure is a disruption of cortico-striatal social learning signals.

3-B-16 Neural correlates of deliberation across rating, choice and learning tasks

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Some decisions are made impulsively, without properly weighing costs and benefits, whereas others are made thoroughly, after careful consideration of every potential outcome. Response time (RT) is a good proxy for the duration of deliberation and hence, for the effort invested in a choice. In the decision-making literature, RT is known to vary with the (subjective) value of choice options and the (subjective) difficulty of the choice task. Subjective difficulty can be conceived as the opposite of confidence in the response, which relates to the distance between choice options. Here, we investigate the residual variance in RT, once value and confidence factors have been regressed out. We have defined value, confidence and RT regressors across standard rating, choice and learning tasks. In the rating task, subjects had to judge how much they would like to receive various rewards (e.g. a chocolate cake) and how much they would dislike exerting various efforts (e.g. filling a tax form). In the choice task, they had to decide between accepting and declining to exert an effort (e.g. a 1km run) in order to obtain a reward (e.g. a movie ticket). In the learning task, they had to figure out, by trial and error, which of two symbolic cues was providing more frequent financial gains, or less frequent financial losses. Both fMRI data in healthy participants and intra-cranial EEG in epileptic patients showed that RT correlated with activity in the dorsal medial prefrontal cortex (dmPFC). This functional cluster was dissociated from the cluster reflecting value (summed over choice options) in the vmPFC and the cluster reflecting confidence (quadratic function of decision value) in the mPFC. We interpret dmPFC activation with RT as reflecting the effort invested in the deliberation process, because it was positively correlated with pupil size. Furthermore, the time course of dmPFC activity suggested that deliberation was not only prolonged but also more intense. Thus, we conclude that dmPFC activity provides a signature of the effort invested in the duration process that is common to all value-based judgement or decision tasks. The sources of

variation in the level of effort expenditure remain to be explored, as they were not related to known factors such as option value and task difficulty.

D. Emotion & Affect

3-D-17 A neurocomputational model for mood dynamics during decision making

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The happiness of individuals is an important metric for societies, but we know little about how daily life events are aggregated into subjective feelings. Research from our lab has previously shown that momentary happiness, a proxy for mood, is explained by the history of rewards and expectations during decision making under uncertainty. Receipt of extrinsic rewards relates to neural responses in the ventromedial prefrontal cortex (vmPFC). Despite their importance for major life decisions like which career to choose, little is known about how intrinsic rewards (e.g., playing a musical instrument without errors) are represented in the brain, partly because measurement is poorly suited to standard economic approaches like asking how much someone is willing to pay for an item. We tested subjects (n=33) in a reinforcement learning task incorporating a skilled performance component that did not influence payment. Although performance was held constant across subjects by design, we found considerable variation in how much successful performance contributed to the momentary happiness of subjects. Computational modelling of behavior revealed that momentary happiness depended on past extrinsic rewards and also intrinsic rewards related to successful skilled performance. Individuals for whom intrinsic rewards more strongly influence momentary happiness exhibit stronger vmPFC responses for successful versus unsuccessful skilled performance. Our findings suggest that the vmPFC represents the subjective value of intrinsic rewards and that computational models of mood dynamics provide a tool that can be used to measure implicit values including the value of a job well done.

3-D-18 The stress response as a mechanism for biological search

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The stress response is an adaptive response to physical and social challenges. It is mediated by a hormonal circuit known as the hypothalamic-pituitary-adrenal (HPA) axis. The HPA axis controls multiple behavioral and physiological end-points over several timescales, and the dysregulation of the HPA axis is a hallmark of psychiatric disorders including major depression and addiction. Understanding the stress response and these disorders would benefit from a theoretical framework to unify the dynamical and behavioral features of the HPA axis. We address this by presenting a dynamical model of HPA-axis activity over the timescale of weeks to months. We show that many features of the HPA axis, including regulation of tissue dynamics by hormones, co-regulation of ACTH and endogenous opioids, and glucocorticoid feedback through several receptor types, can be explained when viewing the HPA axis as a search circuit that guides behavior to optimal stress levels. Our model can explain dynamical aspects of HPA axis dysregulation that are observed in psychiatric disorders, including addiction, anorexia nervosa and depression.

3-D-19 Positive mood amplifies the accumulation in momentary confidence during learning

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The confidence we experience related to our decisions depends on many factors. Previous work has shown that mood can bias the perception of reward value during learning (Eldar & Niv, 2015). Whether mood is a factor that impacts confidence during learning is not understood. We tested whether positive moods increase momentary confidence within a reinforcement learning context. 35 participants performed two blocks of a learning task, one prior and one after a positive or negative mood induction. In each block, participants were presented with two options and had to learn their value through trial-and-error, whilst giving momentary confidence ratings every 4-5 trials. The mood induction consisted of a wheel of fortune in which participants won (n=18) or lost (n=17) a larger sum of money (£6) than what they earned from their decisions. Between-group analyses were used to examine the effect of mood induction on confidence during the second learning block. We predicted that positive mood would increase overall confidence throughout the block, compared to negative mood. Contrary to our predictions, average confidence across the block was not higher in participants in a positive mood compared to negative mood. However, there was an interaction between mood and confidence rating, such that positive mood led to increasing confidence over time relative to negative mood. We also found a mood x outcome interaction, such that confidence on trials following rewards was enhanced in the positive mood condition. A positive mood does not appear to exert a global effect on confidence during learning. Rather, a positive mood appears to interact with learning and amplify the accumulation of confidence over time.

3-D-20 Vigour as a quantitative diagnostic of apathy: sensitivity to opportunity costs of time predicts action latencies

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Objective: Choosing how fast to act is critical. Prolonged latencies of self-initiated behaviour are a hallmark of apathy, a common and disabling neuropsychiatric symptom. Central to this is the opportunity cost of time (OCT). Slow responses deny participants benefits that might accrue from alternate activities, (they incur opportunity costs), which are greater when rewards are larger. Here we demonstrate that highly apathetic participants are more sensitive to changes in OCT when compared to less apathetic participants. **Methods:** We designed a novel free operant task, called the 'Fisherman Game'. 21 healthy participants were each instructed to play as fisherman earning money, in fictional Yen, by catching fish by pressing a keyboard button. They were free to respond quickly or slowly, at their own pace. Participants were told that they would play the fisherman game in two 'environments', each determined by the exchange rate between Yen and £. In the HIGH value environment, earning Yen 3000 would result in £4.00; in the LOW value environment Yen 3000 would only result £0.50. We fit participant's behaviour using an average reward RL [c.f. Niv et al, 2007] model linked to tonic dopamine in the brain, in which subjects trade-off the cost of responding quickly with the OCT. **Results:** Latency of responses decreased with reward per action, in both environments ($r = -0.78$, $r^2 = .66$, $p < 0.001$, $R^2 = 0.81$). High apathy participants showed a substantial change in the latency distribution across rewards per action and environment conditions. Their latency distributions had large means and variances when [reward per action, and environment] conditions were low, and small means and variances when they were high. In our model, since high sensitivity to opportunity costs implies that the OCT is greater for higher rewards and environments than lower ones, the latency distribution would consequently shift from having a large mean and variance to a small mean and variance. Our model captures these

distributions per participant, with low and high apathy participants having high and low sensitivities, respectively. Across participants, apathy scores significantly increased with sensitivity to opportunity cost and decreased with vigour cost. Conclusion: We showed with a novel task and within-subject experimental design, together with quantitative modelling of behaviour, that individuals with high apathy have a high sensitivity to the opportunity cost of time. Our results provide new avenues for stratifying clinical populations with precise, task-based quantitative diagnostics and for individual variation in vigour that explains how fast people choose to act.

3-D-21 Multiscale neurobiological pathways to comfort food consumption in response to stress

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Excessive high energy density food consumption has been associated with increased risk for obesity and is thought to be one of the factors associated with the current obesity epidemics. Stress has an important influence on the preference for such high palatable food, and traditional consumer research has traditionally explored this under a psychological perspective alone, whereas stress reactions are known to be an embodied experience consisted of psychological, hormonal, and neurophysiological components. We hypothesized that whole body response to stress would better predict palatable food preference than psychological state alone following acute stress, where (H1) consumers under stress, self-reported negative affect, autonomic responses and endocrine responses will be positively associated with consumption of high-fat or sweet foods and (H2) consumers under stress, autonomic and endocrine responses will make incremental contribution to the prediction of stress-induced preference for high-fat or sweet foods, above and beyond the contribution of self-reported affect. This an experimental, one-factor repeated measures (stressful vs. non-stressful), within-subjects design, with 40 healthy post-menopausal women aged 58 +/-7.8y from local community (Montreal/Quebec). Each participant went through two lab sessions on two separate days, one week apart and were exposed to control condition (neutral imagery) on session 1 and stress (health stress mental imagery) on session 2, separate one week apart. After the task subjects were presented with snack buffet and had consumption recorded. Measurements were mood (Profile of Mood States (POMS-SF)), heart rate variability (HRV), skin conductance and salivary cortisol reaction. Main results were: 1) interaction between HRV and fat intake showing that HRV was positively associated with consumption of high-fat but had no effect on the consumption of low-fat, and 2) three-way interaction among cortisol, stress condition, and taste showing that in the stressful condition, cortisol was associated with an increased intake of sweet snacks while in the non-stressful condition, cortisol decreased the consumption of sweet foods. These results confirmed that the autonomic and endocrine responses contributed to explaining stress-induced food preferences, above and beyond the psychological variables.

3-D-22 The elusive effects of anxiety on reinforcement-learning

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A growing body of research has investigated the impact of anxiety on learning. However, the results from prior research were not consistent and failed to offer a comprehensive framework that explains the underlying mechanisms. To address these issues and to examine how anxiety is involved in learning, we enriched standard experimental designs and analyzed data with both model-free and model-based

approaches. Specifically, we investigated how anxiety impacts performance in a simple reinforcement learning and subsequent transfer task when outcome valence (gains or losses) and emotional state (safe and threat) were orthogonally manipulated. Moreover, incidental anxiety was induced via a well-established paradigm: threat-of-shock (ToS) in two experiments (N= 2x50). A total of 100 healthy subjects learned probabilistic associations (75% and 25%) between cues and monetary outcomes through trial-and-error to maximize gains (+0.5EU, 0EU), and to minimize losses (-0.5EU, 0EU) under either a prolonged threat or safe condition. In the threat condition, subjects received electric shock(s) at unpredictable time points (and independent of performance), but were free from shocks in the safe condition. After the learning task, a transfer task assessed subjects learned preferences for the cues. Across two model-free approaches (ANOVA and GLME), we consistently found no effect of anxiety ($F=1.63$; $p=.2042$) and anxiety did not interact with outcome valence to influence learning ($F=1.45$; $p=.2319$). Interestingly, results from the transfer task revealed that cues with higher quality (i.e., cues associated with 75% gain and cues associated with 25 % loss) were more likely to be preferred (Quality: $F=241.60$; $p<.001$), and this effect was modulated by the anxiety manipulation (Quality x Anxiety: $F=6.37$; $p=.0131$). The post-hoc analysis further showed that cues with higher quality were preferred more if they were learned under threat than safe condition ($t=2.32$; $p=.0212$). These results suggest that anxiety enhances the tendency of choosing better cues in transfer task, despite the fact that learning performance was equal in safe and anxious conditions. Moreover, model-based results showed that learning is overall asymmetric and context-dependent (i.e., the winning model contains three learning rates for positive and negative prediction errors, and a contextual value). However, when any parameter in the winning model was divided into safe and threat conditions, no significant difference was found ($ps>0.12$). In sum, our results suggest that anxiety significantly altered learned option preferences, but the impact on learning was not captured in our reinforcement-learning setup.

F. Individual & Lifespan Differences

3-F-23 Neural circuitry underlying individual differences in context-dependent facial emotion reading

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Background: Understanding other's emotion depends critically on not just visual images of facial expression but also contextual information. In the present study, we investigated the neural circuitry underlying individual differences in the degree to which people put weight on contextual information when they read others' emotion revealed on the face. Method: 38 female participants were recruited and scanned while performing a novel experimental task where they viewed emotion-eliciting or neutral odor-related contextual cues and emotionally neutral face videos of posers. In each trial, the context information was presented with a name of odor (i.e., urine, fish, rose, and water), which was followed by a short video clip (4 sec) of the emotionally neutral poser sniffing a water cup of the supposed odor. Then, participants were asked to assess the valence of the poser's emotion on a five-point Likert scale. Results: Behavioral data analysis revealed that participants' ratings were significantly influenced by contextual information, the degree of which varied widely across participants. Neuroimaging data analysis revealed that the individual differences in the sensitivity to contextual information were positively associated with the activities of the inferior frontal gyrus (IFG) and negatively with the subgenual anterior cingulate cortex (sgACC) when observing the video stimuli. On the other hand, the neural activities of the amygdala and pregenual anterior cingulate cortex (pgACC) tracked individual differences in contextual information processing at the decision phase. Conclusion: Our findings would shed light on the neural mechanism whereby contextual information modulate one's perception of

others' emotional responses and the key neural signatures of individual differences in such a context-dependent emotion comprehension.

3-F-24 I like it like that: Reward discounting and appetitive responses to amphetamine in a drug naïve sample of healthy adults

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Temporal discounting of monetary rewards has been shown to be increased in various forms of addiction. In particular, abuse of psychostimulants like cocaine and methamphetamine have been linked to higher discounting of delayed rewards and increased reward sensitivity. It has been speculated that the underlying neural circuitry that supports discounting behavior also supports appetitive responses to reinforcing drugs. We sought to identify whether individual differences in monetary reward discounting behavior in drug-naïve adults explained subjective responses to amphetamine--a dopamine agonist that has similar properties to cocaine and methamphetamine. Healthy adults (N = 21, Mage = 35.7, SDage = 7.6) completed a delay-discounting task for monetary rewards and on a separate visit, received 0.4 mg/kg of oral placebo and d-amphetamine (Mdose= 29.8 mg, SDdose = 5.36 mg) prior to a neuroimaging session as part of a larger study. Subjective ratings after placebo and drug were collected using the Drug Effects Questionnaire in which participants identified how much they: Like, Dislike, Feel, Feel High, and Want more of the drug. Ratings were collected across eight timepoints over approximately 4-6 hours after placebo/drug administration. For each of the five subjective effects, we used a linear mixed model with random effects fit by maximum likelihood estimation. For each rating, we fit a null model testing the interaction of drug condition x rating timepoint. We then tested the continuous covariate interaction with individual differences in delay discounting using the "k" parameter from a hyperbolic discounting model. Null models for each of the appetitive ratings were statistically significant but not for dislike ratings. Although three-way interactions between timepoint (8), condition (2), and discount rate were not statistically significant for the appetitive ratings, simple effects analysis identified significant condition x discount rate interaction effects at specific timepoints (consistent with typical curvilinear drug effects over time). Specifically, 90 to 120 minutes after drug administration, high discounters rated liking the drug more than low discounters. Additionally, while high discounters peaked in feeling (and feeling high from) the drug approximately 60 minutes after drug administration, low discounters did not peak until 120 minutes after drug administration. This analysis is the first to identify a relationship between appetitive drug responses and a behavioral measure of reward sensitivity. Observed effects in this drug-naïve sample suggests the presence of underlying individual differences in susceptibility to appetitive drug responses.

3-F-25 Functional neural signal variability increases with age during decision making

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Most functional neuroimaging research focuses on differences in mean BOLD activation in various brain regions across experimental conditions. However, recent studies have shown that it can be useful to look beyond the mean; accruing evidence suggests that the variability of the neural signal can act as an important individual difference measure. Several studies have examined adult age differences in variability and the results have been mixed. Some researchers have reported increases in variability with

age during task and rest, while others have reported the opposite. Here, we investigated whether functional neural signal variability increases or decreases across the adult life span during decision making tasks. 75 participants (22-83 years old) made choices between smaller rewards and larger rewards in three different (temporal, probability, and effort) discounting tasks while undergoing fMRI. We measured the temporal variability of the BOLD signal by calculating the mean squared successive difference (MSSD) of the signal across all time points. A whole brain analysis revealed that variability increased with age in the bilateral striatum, hippocampus, and parietal cortex ($p < .0001$, 20 voxel cluster threshold). These age-related increases in variability are consistent with previous studies of reward-based decision making, but inconsistent in direction with some other resting state and cognitive task-based effects. Further investigation is needed to determine exactly what (i.e. sample characteristics, tasks, analysis methods) drives these differences across studies and elucidate the role neural signal variability plays in behavioral variability.

3-F-26 Using EEG to evaluate an early childhood intervention

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Early childhood interventions -- such as preschool -- are now observed to have a large impact on academic skills and Kindergarten readiness of disadvantaged children. While these programs have been used by researchers and policymakers to argue for expanded preschool access, exactly why and how preschool works has remained a black box. This paper provides the first evidence that a large-scale early childhood intervention can change an important biological input to the education production function, children's executive function brain activity. We take advantage of the Chicago Heights Early Childhood Center (CHECC) RCT that randomized children to a free preschool or to a control group for a year (Fryer et al., 2018). Following the intervention, we collected electroencephalography (EEG) measures to assess the children's brain activity as a complement to ongoing behavioral assessments. We recorded event-related potentials (ERPs) from 72 4- to 6-year-old children (36 treated, 36 control; 33 female, 39 male) who participated in CHECC while they completed an academic and an executive function task, a modified Peabody Picture Vocabulary Test (PPVT) and Animal Go-NoGo (AGNG), respectively. Our main outcome measures are academic and executive function ERP components: N4, which measures language processing, and N2 and P3, which measure attention and effort. We find evidence that the CHECC preschool had an impact on executive function brain activity during AGNG: compared to children in the control group, the treated children had lower N2 mean amplitude ($p < 0.05$) measured in the Cz cluster. Furthermore, this measure is predictive of longer-term executive function skills. Four years after the end of the CHECC intervention (and after the EEG data collection), we recruited children from our EEG sample to participate in a behavioral follow-up assessment of their academic and executive function skills. We find that our EEG measures collected are predictive of children's scores in the three-year follow-up, above and beyond the predictive power of baseline abilities. All results use linear regressions with gender, age, race, and baseline ability controls.

G. Intertemporal Decision

3-G-27 Medial forebrain bundle structure is associated with impulsivity in humans

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Comparative studies implicate dopaminergic projections from the ventral tegmental area (VTA) to the

nucleus accumbens (NAcc) in motivated behaviors. However, quantification of the structural qualities of these white-matter tracts in humans has proven difficult. Using diffusion-weighted imaging and probabilistic tractography, we aimed to identify white matter tracts connecting VTA and NAcc. We then tested whether structural properties of the tracts were related to individual differences in trait impulsivity, as assessed with the Barratt Impulsiveness Scale (BIS). Tractography was successfully performed in every subject from two independent samples (sample 1: n=40, 17 female, 32.7±11.8 years old; sample 2: n=31, 14 female, 51.7±19.5 years old). This revealed two distinct fiber trajectories between VTA and NAcc: an inferior trajectory that coursed from VTA through the lateral hypothalamus (LH) and entered NAcc from below the anterior commissure (AC), and a more superior tract that coursed above the AC and entered the internal capsule before reaching NAcc. Tract coherence metrics of fractional anisotropy (FA) and inverse mean diffusivity (1-MD) in the inferior VTA-NAcc tract were negatively associated with impulsivity (BIS-inverse MD correlation: $r=-0.49$, $p=.002$; BIS-FA correlation: $r=-.37$, $p=.02$). This was not the case with the superior VTA-NAcc tract (BIS-inverse MD correlation: $r=.05$, $p=.77$; BIS-FA correlation: $r=-.08$, $p=.63$), suggesting that the observed relationship was specific to the inferior VTA-NAcc tract. This relationship was strongest in a portion of the left inferior tract where it coursed through the LH ($r=.50$, $p=.001$; mean MNI coordinates: X=-5 to -7, Y=-8 to -2, Z=-10 to -9). To test the replicability of this association, we characterized the inferior VTA/SN-NAcc tract in a second sample. Calculating the correlation between BIS and inverse MD for the portion of the tract where the correlation was strongest in the first sample revealed a remarkably similar relationship (BIS-inverse MD correlation: $r=0.45$, $p=.014$). Discount rates (based on Kirby delay-discounting) were also correlated with inverse MD, and partial correlation analysis revealed that shared variance with trait impulsivity accounted for this relationship. Conventional DWI analyses which spatially normalized subjects' data from individual to standard space did not reveal the association. Collectively, the findings suggest that decreased coherence of the inferior VTA-NAcc tract is associated with increased impulsivity, and highlight a novel structural target for assessment in individuals with disorders marked by low impulse control.

H. Learning & Memory

3-H-28 Blocking opioid and D2 dopamine receptors increases model-based learning

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Background Failures to exert top-down control over maladaptive habits can lead to damaging behaviour such compulsive drug taking. The degree to which people are able to learn in a goal directed manner has been experimentally addresses with the Two-step task, where subjects can learn about dynamically changing reward predicting stimuli either in a model-free or model-based way. Model-based learning increases with higher dopamine availability in the prefrontal cortex, whereas higher striatal dopamine levels underlie both types of learning in a way that might depend on differential roles of dopamine receptors. Furthermore, mesolimbic reward areas are densely enervated by opioid receptors that have been implicated in formation of habits and impulsive behavior and could play a modulatory role in habitual learning. The first aim of this project was to test whether blocking opioid receptors leads to increased model-based learning. Our second goal was to investigate the role of inhibitory D2 dopamine receptors in applying cognitive control. We hypothesized that blocking D2 receptors would lead to a reduction of inhibitory tone in the striatum and an increased model-based learning in subjects with higher prefrontal levels of dopamine. Methods A non-specific opioid receptor antagonist (Naltrexone), a selective D2/D3 receptor antagonist (Amisulpride) or placebo were administered to 118 subjects before

and after playing the Two-step Task. Baseline striatal and prefrontal dopamine levels were indexed by the COMT and DAT1 polymorphism. Participant's degree of model-based behaviour was assessed with a dual system reinforcement learning model estimating a model-based/model-free weighting parameter w , that represents a trade-off between completely model-based ($w=1$) and model-free ($w=0$) learning. We estimated the effects of the pharmacological manipulation and genotype on the difference of the weighing parameter before and after administration with Bayesian linear models using with weakly regularizing priors on regression coefficients ($N(0,1)$). We used leave-one-out cross-validation information criteria to compare fits of different models. Results All subjects performed a mix of model-based and model-free behaviour (mean $w = 0.578$, $sd = 0.246$). The best performing model included the treatment variable and the Dat1 polymorphism. Naltrexone and amisulpride both increased the degree of model-based behaviour on average by 0.27 (95% CI = (0.11, 1.44)) and 0.22 (95% CI = (0.06, 0.38)), respectively. Interestingly, carriers of 10/10-repeats (homozygotes) had on average an increase of model-based behaviour of 0.20 (95% CI = (0.05, 0.35)). The response to the pharmacological m

3-H-29 Similarity-based episodic memory sampling processes in value-based decision-making

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Objective: Our decisions are often guided by past experiences. Previous research on this experience-based decision-making has focused mainly on reinforcement learning (RL), but the RL framework has limitations in explaining the complex and sparse nature of real-world decision environments. To address these limitations, some researchers have begun to focus on the role of episodic memory in value-based decision-making. Although several studies have investigated how the values of single past episodes contribute to decisions, it is unclear whether and how they contribute to the valuation of novel stimuli that never repeats. Here, using a novel experimental paradigm, we investigated whether episodic memory could also guide novel decisions based on the similarity between the present and past experiences. **Methods:** In a behavioral study (Study 1; $n=25$), participants had to explicitly estimate the value of each novel stimuli. On each of 144 trials, they viewed a trial-unique naturalistic image and were instructed to estimate the value of the image based on the outcomes of previous trials. Reward probabilities were assigned based on the representation of the deep convolutional neural network (CNN) layer so that images with similar representations had similar reward probabilities. In an fMRI study (Study 2; $n=26$), participants had to make decisions on whether to accept or reject each novel gamble based on the offer and the expected value of each image. **Results:** Study 1: We found that, overall, participants' value rating was significantly predicted by the reward probability ($p < .001$), such that the higher the reward probability assigned to the image, the higher the value rating on that image. To further examine the role of similarity, we conducted a multiple regression analysis predicting the value estimate in the current trial with the outcome values of the past five stimuli that are most similar to the current stimulus. The results revealed that each of the outcomes of the five images had a significant effect on the value ratings, and the regression weights were higher for the more similar stimuli. Study 2: As in Study 1, the regression analysis revealed that the outcome values of the five most similar trials were significant predictors of choice. Moreover, the choice behavior was predicted by a computational model of kernel-based value estimation, and a model-based fMRI analysis revealed that vmPFC activity was correlated with the expected value of the chosen option. **Conclusion:** Our finding provided empirical evidence that the similarity between present and past experiences plays a key role in enabling episodic memory to guide value-based decision-making.

3-H-30 Context-dependent learning explains overconfidence

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Objectives Accurately estimating confidence in one's choices being correct is important for evaluating and adapting strategies. However, confidence is biased: for the same objective difficulty, people are more confident when seeking gains than when avoiding losses. We recently show how this bias can be explained by the sum of 1) a context-dependent learning mechanism (considering outcomes on a relative scale centered at the learnt average value of the context), and 2) the use of the learnt context value for computing confidence. Here we generalize these results to a larger dataset, while also testing a wider range of computational models to better characterize this bias. **Methods** We use data from five experiments (N = 90) with the same learning paradigm: on each trial participants saw pairs of abstract stimuli (probabilistically paired with monetary gains/losses) and chose one, then provided a confidence rating (11-point scale), and finally, they saw the outcome of the chosen option. Context valence (losses vs gains at play) and information completeness (feedback about the unchosen option present vs absent) were manipulated. We test variations of a context-dependent model, which updates context value based on the average of the obtained and forgone outcomes in a trial. For the incomplete feedback condition, the only new information available for context updating is the obtained outcome, but participants may use a fictive forgone outcome. We also test different implementations of the valence bias in confidence (some of which do not require context value), and compare these in contextual and non-contextual models. **Results** 1)The best prediction of observed behavioral effects is offered by a contextual model that uses as the fictive forgone outcome the other possible outcome in that condition 2)The confidence bias is best explained by a context dependent model, regardless of the specific implementation of forgone outcome 3)Confidence depends on the difficulty (value difference between options) but also biased by the context value, which can be captured by the value of the chosen option, the sum of the values, or the context value 4)Combined learning and confidence models account for the pattern of choices and confidence judgments observed in learning and a transfer task **Conclusions** Our results add to the evidence that contextual learning explains choice and confidence. Building on our previous work, we rule out variables extracted from a non-context dependent model as a source for the confidence bias. Contextually learnt values may affect confidence beyond affecting subjective choice difficulty.

3-H-31 Computational mechanisms of social inference in Borderline Personality Disorder

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Objective: Borderline Personality Disorder (BPD) is a serious mental illness characterized by marked disturbances in interpersonal relationships, including difficulties with trust and forgiveness often resulting in premature relationship termination. Here, we tested a hypothesis that forming impressions about the moral character of others is disturbed in BPD. Specifically, we predicted that BPD would be associated with slower updating of initially bad moral impressions, and that this deficit would be restored following treatment in a Democratic Therapeutic Community (DTC), which has shown some promise in ameliorating interpersonal disturbances in BPD. **Methods:** Participants predicted and observed 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.

Periodically, participants rated their subjective impressions of the agent's morality, and the certainty of those impressions. We used a hierarchical Bayesian learning model to describe participants' evolving beliefs about the character of the good and bad agents. Results: Relative to a sample of matched healthy controls (N=106), patients with BPD (N=20) formed more certain beliefs about bad agents and more uncertain beliefs about good agents. Thus, beliefs about bad agents were slower to update in BPD patients, whereas beliefs about good agents were faster to update. Slower updating of beliefs about bad agents and faster updating of beliefs about good agents were also associated with subclinical levels of BPD symptoms in a separate sample of adults (N=70). Finally, we demonstrate that DTC treated BPD patients (N=23) were faster to update beliefs about bad agents relative to untreated patients. Conclusions: We show that the effect of BPD on Bayesian belief updating is intrinsically related to the morality of the agent. More volatile beliefs about good agents may help explain why patients rapidly shift from a period of admiration to dislike and abruptly end relationships. Conversely, more rigid beliefs about bad agents may help explain patients' characteristically unforgiving behavior. However, DTC may shape social interactions in BPD by increasing patients' openness to learning about adverse social interaction partners. The results provide a mechanistic explanation for social deficits in BPD and demonstrate the potential for combining objective behavioral paradigms with computational modelling as a tool for assessing treatment outcomes.

3-H-32 Dopaminergic manipulation eliminate the learning asymmetry between experienced and counterfactual reward

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OBJECTIVE: It is well established that dopamine plays an important role in reinforcement learning and previous studies showed that dopaminergic activity tracks reward prediction error. Boosting and reducing dopamine levels would increase and decrease the degree of learning, respectively. However, how dopamine affects counterfactual learning still remains elusive. Here we designed a pharmacologic experiment to investigate dopamine's role in counterfactual learning. **METHODS:** We conducted a double-blind, placebo-controlled, within-subject design experiment to investigate the effect of dopamine on counterfactual learning in healthy male subjects. During experiment subjects (N = 30) made a series of choices between alternative options with probabilistic payoffs (determined by independent random walk processes) under the administration of madopar (L-Dopa, a precursor of dopamine), haloperidol (a dopamine D2 receptor antagonist) and placebo with the sequence counterbalanced across subjects. Under each treatment subjects were required to perform a partial feedback (240 trials) and a complete feedback session (240 trials), where they only observe the outcome of chosen option and the outcomes of both options, respectively. **RESULTS:** We adopted the Q-learning model to fit subjects' choices and different learning rates were assumed for the chosen and the unchosen options in the complete feedback trials. Similar to previous literature, subjects showed larger factual relative to counterfactual learning rate under placebo treatment. However, such asymmetry disappeared when dopamine level was manipulated by madopar and haloperidol, demonstrated by the significant interaction effect of a 2 (factual and counterfactual) × 3 (madopar, haloperidol and placebo) repeated measure ANOVA analysis. Post hoc analysis showed that dopaminergic drugs altered the magnitude of counterfactual learning rate, but not the factual learning rate. This is consistent with our results in partial feedback trials where pharmacological treatments only affected subjects' choice perseveration, but not learning rates, suggesting a more nuanced role for dopamine in both partial and complete feedback learning paradigms.

CONCLUSIONS: Dopaminergic manipulation eliminates the learning asymmetry between factual and counterfactual reward.

3-H-33 Diminished model-based learning in the older adults

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Human decision-making is mainly driven by two fundamental learning processes: a slow, deliberative, goal-directed model-based process that maps out the potential outcomes of all options and a rapid habitual model-free process that enables reflexive repetition of previously successful choices. (Balleine & O'Doherty, 2010; Daw, Niv, & Dayan, 2005; Dickinson, 1985; Doll, Simon, & Daw, 2012). Two classes of reinforcement learning (RL) models have been proposed to capture the key behavior patterns of the two learning strategies, namely "model-free" and "model-based" models. (Daw et al., 2005). Studies have shown that age-related decline in dopamine functions have an impact on working memory in older people and affect multiple decision-making processing requiring information short-term storage and updating (Bäckman et al., 2011; Braver & Barch, 2002). Moreover, studies also found that the dopamine decline in the elderly was associated with age-related deficits of the reward-based reinforcement learning ability (Chowdhury et al., 2013). In the present study we investigated age-related differences and the underlying mechanisms in habitual (model-free) and goal-directed (model-based) decision-making by using a modified two-stage Markov decision task in combination with computational modeling and functional magnetic resonance imaging (fMRI) (Daw, Gershman, Seymour, Dayan, & Dolan, 2011). Results from computational modeling showed that younger adults demonstrated a higher degree of model-based decision-making (as reflected in the ω -parameter) than older adults [95% Highest Density Interval (HDI): (0.1868, 0.5699)]. At the neural level, for model-free process, older people relative to young adults significantly activated bilateral ventral striatum (left: -15, 9, 10, $Z=4.14$, $p(\text{FEW}) < 0.001$, svc; right: 15, 12, -8, $Z=3.41$, $p(\text{FEW})=0.005$, svc) and right anterior insula (40, 12, 14, $Z=3.39$, $p(\text{FEW})=0.022$, svc). No significant activation was found for the reversed comparison, suggesting that older adults engage more in model-free reward processing. For model-based learning, compared with older adults, younger adults significantly activated caudate tail (20, -31, 20, $Z=3.36$, $p(\text{FEW})=0.016$, svc). Older people, relative to younger adults, had a marginal significant activation in left anterior insula (-30, 12, 14, $Z=3.06$, $p(\text{FEW})=0.057$, svc). Our findings indicate distinct neural signatures of model-based learning among younger and older people.

I. Risk & Uncertainty

3-I-34 Circadian effects on risk taking for losses but not for gains

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The extent to which risk taking is affected by diurnal patterns is currently unknown. Large data sets are required to observe how attitudes to risky decisions may change throughout the day. We used a large data set ($N = 19,156$) from a gamified decision-making task from the smartphone application 'The Great Brain Experiment'. Participants chose between risky gambles where they could potentially gain or lose points and options with a guaranteed amount. Participants also self-reported their mood at regular intervals during the task. We analysed the first plays of all participants. The number of risky options chosen in trials with potential losses increased with the time of day when the task was completed ($p < 0.00001$). This effect was seen in trials that included both potential losses and gains, but not trials which

exclusively contained potential gains ($p > 0.1$). We also observed mood-related differences in propensity to gamble. Participants who rated their mood as more extreme before performing the task (either positive or negatively) gambled more when potential losses were present, but not when potential gains were available. Given how many critical decisions have a diurnal pattern (e.g., when people cast votes, when traders in different countries are active) understanding changes in risk preference through the day are of paramount importance. One possible contributing factor to the effects observed here is serotonin, which shows a strong diurnal rhythm and has been linked to loss-related behaviours.

3-I-35 Risky business: Dopamine D2/D3 receptor availability and economic versus naturalistic risk

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The neural and behavioral mechanisms that govern risky behavior are relevant for day-to-day functioning in both clinical and general populations. Although certain brain regions appear to be involved, risk is inconsistently defined and assessed across studies. Economic risk tasks that clearly define risk allow for the decomposition of complex behaviors into distinct cognitive components, but lack the naturalistic element favored by clinicians. In contrast, naturalistic tasks offer more ecological validity without disentangling cognitive mechanisms. Because risk-taking affects the vulnerability to and persistence of addictions, identifying its underpinnings can help advance evidence-based treatments for addictive disorders. We therefore combined a naturalistic risk task, the Balloon Analogue Risk Task (BART), with computational modeling and an economic choice task, the Loss Aversion Task (LAT), to assess risk-taking in individuals with Methamphetamine (MA) Use Disorder and healthy controls (HC). On each trial of the BART, participants choose to pump a virtual balloon for increasing reward, or to cash out. If the balloon bursts, rewards accrued on the trial are lost. Risk-taking was scored as mean number of pumps on non-burst trials, and also using a re-parameterized version of a cognitive decomposition model, which provides parameters of risk-taking (γ) and learning rate (η). The LAT presents 50/50 choices of winning and losing varying amounts of money. Both tasks were analyzed using Hierarchical Bayesian Modeling. Participants underwent positron emission tomography with [¹⁸F]fallypride to assess dopamine D2/D3 receptor (DRD2/3) binding potential (BPND). For HC, loss aversion was positively correlated with pumping ($p=0.02$) and negatively correlated with cashing out ($p=0.018$), but the opposite was true for MA participants. HCs may be computing value by learning that more pumps yield more money, therefore viewing cashing out as a loss, whereas MA participants may persist in viewing the bursting balloon as a loss. Indeed, MA participants had a slower updating rate (η) than HCs ($p<0.0001$), consistent with this view. Further, BPND in the caudate ($p=.02$) and putamen ($p<0.005$) was significantly correlated with risk-taking (γ), and loss aversion was negatively correlated with BPND in the nucleus accumbens ($p=0.018$) and amygdala ($p=0.02$). Thus, while striatal and amygdala BPND contribute to risky decision-making, the underlying cognitive mechanisms may differ between HC and MA participants. Here we show that economic choice tasks can be combined with naturalistic tasks to help identify distinct cognitive constructs and neurobiological substrates of risk-taking.

3-I-36 Increased anterior cingulate cortex gray matter volume in entrepreneurs

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Objective: Entrepreneurs are known to show a higher risk tolerance than other people (e.g., Sexton and Bowman, 1986; Begley & Boyd, 1987, Knight, 1921) and the ability to tolerate risk and uncertainty may partly explain why some people become entrepreneurs. On the other hand, a recent study found that the gray matter volume in the right posterior parietal cortex (PPC) significantly predicts individual risk attitudes (Gilae-Dotan et al., 2014). Here we conducted a voxel-based morphometry (VBM) study to investigate whether neuroanatomical features would separate entrepreneurs from a control group in general, and whether the gray matter volume in the PPC would predict participants' risk attitudes in particular. **Methods:** To conduct a VBM study, we used structural brain images from 43 male subjects (21 entrepreneurs and 22 managers). The regions of interest (ROIs) used in the VBM analysis were defined based on previous studies on brain basis of decision-making under risk (anterior cingulate cortex, ACC, Brown & Braver, 2007; PPC, Gilae-Dotan et al., 2014). The same subjects also participated in a fMRI session, where they were presented a variety of "lottery tickets" and their task was to state minimal prices at which they were willing to sell (WTS) each one of the lottery tickets (the Becker-DeGroot-Marschak -mechanism). There were 98 trials, half of them risky and half included also ambiguity. Participants' pricing decisions during the risky trials were used as a behavioral data in this study. **Results:** The VBM analysis comparing regional gray matter volume in entrepreneurs and managers identified a small cluster in left anterior cingulate cortex within the ACC ROI. On average, entrepreneurs priced the risky lotteries 18% above their expected value whereas managers' average WTS price rose above the expected value only by 8%. A ROI analysis in the right PPC did not indicate a difference between the groups. However, OLS panel regression explaining the relative WTS price confirmed that the gray matter volume in the right PPC significantly predicts participants' pricing behavior. **Conclusions:** Our preliminary results suggest that entrepreneurship is not only associated with increased risk-taking but also with increased gray matter in ACC, a brain area involved in action-outcome prediction (Alexander & Brown, 2011). Our results also suggest that entrepreneurs' and managers' choice behavior in a risky decision-making task is associated with the PPC, which is in line with previously reported association between the PPC and individual risk attitudes.

3-I-37 Ambiguity in risky versus intertemporal choice: similarities and differences

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Objective: In (real-world) decision-making, uncertainty is present both when an outcome occurs with a certain probability (i.e., risky choices), and when an outcome occurs after some delay (i.e., intertemporal choices). Often, exact probabilities and delays are unknown when making decisions (i.e., what is the chance someone discovers you are cheating; how long do you need to wait before this investment in your career pays off), which is called ambiguity. However, it remains unclear to what extent risky choice, intertemporal choice, and ambiguity therein involve similar (vs. distinct) underlying behavioral and neural mechanisms. **Methods:** We developed a novel fMRI paradigm where participants (N=80) made 200 choices between a fixed option of ?5 today for sure and a variable option that had a larger amount but was either delayed or probabilistic. For half of the delayed options, delay information was exact (e.g., 100 days), and for the other half ambiguous (e.g., 50-150 days). Similarly, for half of the probabilistic trials, probability information was exact (e.g., 50% chance of winning) and for the other half ambiguous (e.g., 25-75% chance of winning). **Results:** Behaviorally, ambiguity was disliked in both intertemporal and risky choice, with stronger ambiguity effects in risky choice. Furthermore, sensitivity to exact and ambiguous probabilities was positively correlated, while no such correlation was observed for exact and

ambiguous delays. Neurally, we found great overlap in activations during exact and ambiguous risky and intertemporal trials (i.e., executive control, valuation, and salience regions). For ambiguous versus exact trials (collapsed across probabilities/delays), we found increased activation in PPC and dlPFC during ambiguity, while vmPFC, PCC (extending to precuneus), and OFC showed decreased activation. These differences might reflect, respectively, an increased need for executive control and a reduction in subjective value under ambiguity. For intertemporal versus risky trials (collapsed across exact/ambiguous), we found stronger activation in the PCC, precuneus, and angular gyrus during intertemporal trials (suggesting more need for prospection), while no region was more active for risky than intertemporal trials. Lastly, the 2-way interaction showed no significant activation differences. Conclusions: It seems that ambiguity is disliked in both the time and probability domain, and has some distinct neural correlates. However, we found overall more overlap than differences, suggesting that ambiguity in real-life might also be treated mostly similarly regardless of whether it is in the delay or probability domain.

3-I-38 Transcranial magnetic stimulation of the PPC modulates probability weighting but not risk aversion

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Objective: 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. Recent neuroeconomic research suggests that posterior parietal cortex (PPC) may play a role in risky decision-making. In the present study, we employ transcranial magnetic stimulation to explore the effects of decreased posterior parietal cortex (PPC) excitability on distinct components of risky choice. **Methods:** In the present study, a within-subject design is employed. Nineteen participants attended the laboratory for three sessions separated in time by 3 to 4 days (N=19). In each session, they first underwent a 40-second repetitive TMS by a perturbation continuous theta-burst (cTBS) protocol on either the right PPC or left PPC or a sham stimulation on the right in a randomized and counterbalanced order. After the stimulation, participants answered a series of 85 binary lottery choice questions presented in a randomized order purely in the domain of gains. These 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. Random lottery pair design was implemented. 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 two different versions of the probability-weighting function (Kahneman-Tversky and the 1-parameter Prelec function). Both specifications deliver qualitatively identical results. **Results:** The results suggest that decrease in the PPC excitability leads to a significant change in the probability weighting function parameter relative to the sham condition. The effect is more pronounced on the left PPC. Both model specifications suggest that probability weighting function becomes more linear (less distorted) following the reduced excitability of the PPC. At the same time, no effect on the risk aversion parameter (marginal utility of money) is observed in either stimulation condition relative to sham.

3-I-39 Context effects on probability estimation

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Many decisions we face rely on how we perceive potential outcomes associated with options under consideration and estimate their corresponding probabilities of occurrence. Decades of research from psychology indicate that outcome evaluation is subjective and context-dependent. However, despite its subjective nature, it remains unclear whether and how context impacts probability estimation. The purpose of this study was to investigate how contexts impacts probability estimation at the behavioral and computational and neural implementation levels. **Method.** In a simple stimulus-reward associative learning task, human subjects were asked to estimate probability of reward associated with visual stimuli. On each trial subjects saw a stimulus and had to estimate its probability of reward. After estimation, a feedback on whether they won a reward was provided. At the beginning of the experiment, subjects did not know the probability but can learn through feedback over the course of the experiment. Context was established by pairing two stimuli each carrying a unique probability of reward in a block of trials such that they appeared in random order. To investigate context effect, for a given probability of reward, there were two visual stimuli each assigned to a unique context where the reward probability of the other stimulus differed between the two contexts. A total of 4 behavioral experiments and one fMRI experiment were carried out so as to investigate the full dynamic range of probability. **Results.** We found that probability estimation is context-dependent. Probability estimate of a stimulus was affected by the reward probability of the other stimulus present in the context such that probability estimate was biased against the reward probability of the other stimulus in the context. Further, the magnitude of such context effect appeared to be scaled by the estimated outcome uncertainty associated with the stimulus. Multivoxel pattern analysis revealed that dorsal anterior cingulate cortex and ventromedial prefrontal context represented context effect. Together, these results provide insights into the computational building blocks and neural mechanisms for probability estimation.

3-I-40 Arousal and attention in risky choice

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Objective: We study the role of attention, physiological arousal and salience in connection with the process of choosing between risky alternatives. Previous research associated individual differences in eye movement patterns with departures from expected utility maximization. One explanation is that decision makers overweight the likelihood of more salient payoffs. In addition, recent work suggests that physiological arousal is associated with increased attention to salient stimuli. To investigate how salience affects choice process, we measured pupil dilation and gaze fixation during an incentivized lottery choice experiment that varied the difficulty of calculating expected utility. **Methods:** Fifty participants made a series of 120 decisions that involved choosing between two lotteries that included both a positive outcome and a zero outcome. In our within-subject design, participants made choices that involved either easy or difficult expected payoff computations. We collected pupil dilation and gaze fixation data at 1000Hz using an EyeLink 1000 Plus eye tracker (SR Research). We compared reaction time, pupil dilation, eye-movement pattern, and gaze fixation data to examine the effect of increased computational difficulty on the choice process. **Results:** When expected utility computations were easier, participants had significantly more eye movements between payoffs and probabilities, which is consistent with expected utility maximization. Interestingly, we found more pupil dilation when expected utility

calculations were easier. Defining salience as the normalized distance between the two payoffs, we found that increasing the saliency of the riskier lottery increases its fixation duration and its likelihood of being selected. Moreover, we found that pupil linked arousal is associated with increased risk avoidance when the riskier option is more salient. Conclusion: Our results highlight the important role of top down saliency in the choice process, which guides the decision-maker towards looking at and selecting the more salient alternative. Transition patterns and pupil dilation suggest that when payoffs are easy to compute participants use more cognitive effort to integrate probabilities and payoffs into subjective values. Interestingly, we also find that a higher arousal level is associated with choosing the less salient alternative. This suggests that choosing the less salient alternative requires a higher level of cognitive control. These results demonstrate that comprehensive choice process models of decision making under uncertainty need to integrate information about physiological states with the computation of subjective value.

J. Social Rewards & Social Preferences

3-J-41 Prosocial behaviour is associated with transdiagnostic markers of affective sensitivity in multiple domains

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Prosocial behaviours fundamentally shape our interactions with other people. Psychiatric and personality disorders have been suggested to be related to prosocial alterations, which may underlie many of their social dysfunctions. However, broad affective traits, irrespective of psychiatric categorisations (e.g. empathy, alexithymia, apathy) have been found to either obstruct or facilitate prosocial behaviours. Therefore, it is unclear whether prosocial variability is better explained by discrete psychiatric conditions or rather broad affective traits. The present study aimed to examine which constellation of traits, in a psychiatric and affective spectrum, are more predictive of prosocial behaviours. METHODS: We used computational modelling of two decision-making tasks that measure people's aversion to other people's pain, and their willingness to put in effort to obtain rewards for others, and used transdiagnostic statistical techniques (canonical correlation analysis [CCA]) to identify those traits highly linked to prosocial behaviours. CCA allowed us to examine two aspects: first, whether there is a common variance between prosocial behaviour in both tasks, suggesting deep prosocial preferences independent of the context. Second, which traits are more strongly associated with this deep prosociality, testing whether psychiatric and/or broad affective traits are predictive of prosocial behaviours when multicollinearity and suppression effects are controlled for. RESULTS: Across two online studies (n=325), we show that people are more averse to others harm than their own, but are less willing to invest effort to obtain rewards for others than themselves. However, despite these different patterns of behaviour, people who were more motivated to exert effort for others, gave up more money to prevent harm them, manifesting deep prosocial preferences. Crucially, we found that participants who reported being more affectively reactive across a broad cluster of traits, including empathy and apathy, manifested greater frequencies of prosocial actions in these two different contexts. CONCLUSIONS: Here, by using this computational, transdiagnostic approach, we show that people manifest prosocial actions whether they are making a moral decision or they need to be motivated. Importantly, we show that being prosocial across different contexts is underpinned by a constellation of predominantly affective traits, providing a key link for future investigations of the neural mechanisms underlying prosociality and their disruption in psychiatric and neurological disorders.

3-J-42 Increasing honesty with "smart drugs": The effects of methylphenidate and atomoxetine on cheating behavior

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Objective: Dishonest behavior such as accepting bribes and tax evasion causes substantial societal damage across the globe. And trust in honest behaviour is needed to sustain the functioning of companies, industries and societies. Research on the neural mechanisms of honesty implicates a frontostriatal circuitry that receives modulatory input from dopaminergic and noradrenergic neurons. However, the neuromodulation of honesty has yet to be investigated. To examine the role of neurotransmitters in honesty, we examined the effects of methylphenidate (increases striatal dopamine (DA), frontal DA and norepinephrine (NE)) and atomoxetine (increases frontal DA and NE) on cheating behaviour. Both of these substances are used off-label as "smart drugs" to enhance attention and memory in educational and workplace settings. Methods: In a double-blind, placebo-controlled design, participants (N = 154) in our study were randomly assigned to receive either placebo (n = 52), methylphenidate (n = 50), or atomoxetine (n = 52). Participants then played a die rolling task that incentivized cheating and allowed us to distinguish different levels of cheating, from minor to severe. The die rolling task was embedded in a series of other incentivized tasks that measured self-interest, patience, and risk preferences. Results: We found substantial levels of cheating in the placebo condition. Relative to placebo, methylphenidate reduced cheating by 72% in total, and significantly reduced cheating at all levels, from minor to severe. In fact, participants who received methylphenidate showed no evidence of any cheating. Atomoxetine, by contrast, did not reduce cheating overall relative to placebo. However, we do find evidence that atomoxetine reduced cheating in those who felt a conflict between their honesty norms and their self-interest. Discussion: Our results suggest that striatal DA plays an important role in increasing the value of honesty. In particular, we find that methylphenidate, which increases striatal DA, dramatically decreased cheating. Atomoxetine, which does not increase striatal DA, only modulated cheating in those who perceived cheating as wrong before the experiment. Given the high prevalence of "smart drug" use, with 14% of people world-wide reporting use in the last 12 months, our results also have important practical implications, suggesting that at least some smart drugs not only increase attention and memory, but also honesty.

3-J-43 To give or not to take ? insular cortex activation subserves framing-induced generosity boosts towards strangers during social discounting

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Sacrificing own resources for the benefit of others is a prerequisite for society to function well. The willingness to do so, however, greatly declines as the perceived social distance from the other persons increases. Here, we asked if describing a generous choice as preventing a loss to others rather than granting them a gain would promote generosity, even towards socially remote strangers. We adapted a social discounting task where participants chose between a selfish option - high gain to self and zero-gain to other - and a generous option - lower gain to self and non-zero gain to other. We manipulated the description of the decision problem in two economically equivalent frame-conditions: in the gain frame, a costly generous choice yielded a gain to the other, while, in the loss frame, it implied preventing the loss of a previous endowment to the other. In four behavioral replications, we found that social discounting was strongly reduced in the loss frame, implying that participants were more generous

toward remote strangers in the loss than in the gain frame. Using functional magnetic resonance imaging (fMRI), we replicated our previous finding of temporoparietal junction (TPJ) involvement in social discounting. Importantly, we found that insular cortex was recruited during generous choices in the loss, but not the gain frame. In particular, insula was selectively activated when participants prevented the other-loss, suggesting that insula promoted generosity towards strangers by encoding an expected harm prevention signal. Our results extend our understanding of the role of insula in nudging prosocial behavior.

3-J-44 Information about others' ratings changes willingness-to-pay for snack food items

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Background and objective: What and how much we eat is important for health and well-being. Dietary decision-making is influenced by many factors, including taste and health aspects of food, but also socio-cultural factors. Social norms regarding food preferences may shape food wanting and brain responses to food cues, but so far it is unknown whether and how incentive-compatible measures of wanting, such as willingness-to-pay (WTP) are influenced by others' ratings. In two studies, we tested how information about others' ratings changes participants' own wanting of and WTP for food items. Methods: Study 1 was conducted online using Qualtrics and a Clickworker sample (N=180). Study 2 (N=66) was conducted in the lab. Participants were presented snack food items that varied on normative healthiness and tastiness. In addition, participants were shown the ratings of several other people. These social ratings were either reflecting low (Social-LOW) or high wanting on average (Social-HIGH). In a third condition no social ratings were shown (No-Info). Condition-to-food assignments were counterbalanced across participants. A multi-level GLM quantified the effects of tastiness, healthiness, and social information on self-reported wanting of trial-wise food items (Study 1) and on WTP for food items as measured in a Becker-DeGroot-Marschak auction (Study 2). Results: In both studies, social information significantly influenced participants' self-reported wanting (Study 1) or WTP for food items (Study 2) (p 's < 0.001; Cohen's d = 0.46 in Study 1, d = 0.72 in Study 2), with the Social-HIGH condition leading to higher food wanting or WTP than the Social-LOW condition, and intermediate levels for the No-Info condition. Conclusions: Information about other people's food wanting and willingness-to-pay is a powerful modulator of self-reported food wanting and WTP for food. Social factors may be a promising target for dietary and health interventions.

3-J-45 Testosterone affects learning of implicit social dominance hierarchies through competitive interactions

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Learning your position and that of others within a social dominance hierarchy is vital for successful social interactions. Androgen testosterone has been associated with social dominance behaviour, monitoring social threats, and reduced punishment sensitivity. Moreover, testosterone has receptors in brain regions associated with reward and learning of dominance hierarchies such as medial prefrontal cortex (mPFC), amygdala, hippocampus, and striatum. Here, we examined how exogenous testosterone influences the

learning of dynamic social dominance hierarchies and competitive decision-making. To test this, forty-five males ($M = 25.2$ years, $SD = 3.64$) partook in a double-blind, placebo-controlled, crossover fMRI study. Participants learnt an implicit dominance hierarchy while playing a competitive task against three opponents of different skill. Each round, participants had to decide whom they wanted to compete against, and received feedback whether they won or lost. As a control, participants played a non-social reinforcement learning task. To assess learning, we used a selection of reinforcement-learning models, and a softmax decision rule to translate opponent-specific dominance values into choice probabilities. Results revealed that participants learnt the dominance ranks as shown by an increased choice preference for the lower ranked (i.e. weaker) opponent of each pair ($p < .001$). Compared with placebo, testosterone did not influence choice behaviour for specific opponents, but affected the learning of their dominance ranks as shown by model comparison ($p < .05$). A model including different learning rates for wins and losses in updating the dominance value of the specific opponent showed that exogenous testosterone (vs. placebo) decreased the learning rate for losses over wins ($p < .01$). Importantly, testosterone (vs. placebo) did not differentially influence learning during the non-social task ($p < .05$). Analysis of brain data revealed increased activity of the ventral mPFC, striatum and amygdala for social wins over social losses. The opposite contrast exhibited increased activity of the dorsal mPFC and anterior insula. Competitive prediction errors (PE) were tracked by the mPFC similarly in both treatment groups. To conclude, testosterone caused asymmetric updating of the dominance ranks of social opponents following wins and losses. Testosterone did not affect learning in the non-social task. This suggests that testosterone specifically reduces the sensitivity to losses in competitive interactions when establishing one's own social dominance. Brain responses to social outcomes and tracking of competitive PEs were not modulated by testosterone.

3-J-46 Positive and Negative reciprocity: Assessing the roles of intentionality and prior expectations

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OBJECTIVES: Reciprocity is key to the maintenance of high cooperative levels in society. In general, individuals enforce social norms by reciprocating both negative actions (e.g., punishing unkind behavior) and positive actions (e.g., rewarding generous behavior). Despite the widespread belief that both kind and unkind behavior elicit comparable reciprocity, the relationship between positive and negative reciprocity is yet not well understood. To this date, no studies have yet directly compared positive and negative reciprocity using a single within-subject design that allows for perfect equivalence between both behaviors. **METHODS:** 18 participants ($M_{age} = 21.4$ years, $SD_{age} = 1.5$ years, 11 female) took part in the experiment as second movers (M2) while undergoing functional MRI. We conducted an experiment where subjects received either negative or positive transfers ranging from -18 to +18 experimental currency units (ECU) from first movers (M1). To investigate the effect of intentionality, in half of the trials, M1 could not make a free decision on how much to take or give to M2, as this decision was determined by a computer. After learning the transfer they received, participants could reciprocate by either giving or taking ECUs from M1. Participants' choice could range between 0 to 8 ECUs and every ECU used to punish/reward would respectively decrease/increase M1's budgets by 3 ECUs. Rewarding and punishing were equally costly to M2. Since perceived gains/losses are likely to be influenced by expectations, before learning how many ECUs the first mover decided to transfer, participants expressed their beliefs regarding first movers' actions. **RESULTS:** Behavioral results show that responses to absolute positive and negative transfers from M1 (proposed intentionally or not) are symmetric. Moreover, an effect of

intentionality is observed: intentional positive transfers are more strongly rewarded than non-intentional positive transfers. After accounting for expectations, asymmetries in positive and negative reciprocity are observed. Participants react more strongly to perceived negative transfers than to perceived positive offers. No effect of intentionality is observed when expectations are taken into account. **CONCLUSIONS:** Behavioral results indicate the existence of asymmetries between positive and negative reciprocity only when expectations are taken into account. Moreover, when accounting for expectations, intentionality does not influence reciprocal behavior. Altogether results suggest expectations play an important role in reciprocal behavior. Imaging data is currently being analyzed and results will be available for presentation at the conference.

3-J-47 A human subcortical network underlying social avoidance revealed by risky economic choices

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Social interactions have a major impact on mental well-being. While many individuals actively seek social situations, others avoid them, at great cost to their private and professional life. However, the neural mechanisms underlying approach or avoidance tendencies in social situations are poorly understood. Here we investigated how much human volunteers with different degrees of social anxiety valued engaging in a social task. Each participant chose between a social task involving an interaction with a human partner providing social feedback and a monetary amount. With increasing social anxiety, the subjective value of social engagement decreased; amygdala BOLD response increased both during the decision to engage in the task and when experiencing social feedback; ventral striatum BOLD response to positive social feedback decreased; and connectivity between ventral striatum and bilateral amygdalae during decision-making increased. These data suggest how activity differences in a subcortical network during social decision-making may lead to social avoidance.

3-J-48 Neural mechanisms for tracking self and other reward in dictator game

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Objective: Estimating the costs and benefits for oneself and others was essential during social decision-making. Recent studies reported that the anterior cingulate gyrus (ACCg) and anterior cingulate sulcus (ACCs) process rewards for other and self, respectively. Chen et al. (2017) showed that, in ultimatum game (UG), the ACCg had higher activation when proposers chose a fair offer in higher stakes while the ACCs and ACCg were more activated when proposers chose a slightly selfish offer over a fair offer. However, in UG, the responder can either accept or reject the proposal, influencing the outcome for both players. It remains unclear whether distinct brain regions represent rewards for self and other and how these brain activations associate with proposing behaviors. Thus, this study used fMRI to examine brain activations when participants expected making offers in a dictator game (DG), in which recipients could only accept. Methods: Twenty-eight right-handed participants (14 males, age = 21.64 ± 1.39) from National Chengchi University were recruited. Participants were asked to imagine proposing different offers to the next participant in DG in the scanner. The mean stake size was NT\$300 (range = 228-372). There were two independent variables: the share size and the order of agency. There were five types of share sizes: 10% vs. 90%, 30% vs. 70%, 50% vs. 50%, 70% vs. 30%, and 90% vs. 10%. Half of the trials showed

the reward for oneself first while the other half of trials presented the reward for the other first. After scanning, participants rated the likelihood of each proposal and their preference of each offer. Results: Behavioral results indicated that participants were more likely to propose fair offers than selfish and altruistic offers whereas their preference for selfish and fair offers were both higher than altruistic offers. Neuroimaging results showed that, the ACCs and dorsal medial prefrontal cortex were more activated for self/ other-regarding information respectively. Moreover, ACCg and ventral medial prefrontal cortex (vmPFC) was found in the Agency \times Amount interaction. Parametric modulation analysis revealed that the left nucleus accumbens (NAcc) and thalamus tracked reward for oneself while ACCg and vmPFC tracked reward for the other. ROI analysis showed that activations in the NAcc were negatively correlated with the selfishness index and positively correlated with the fairness index of proposing offers. Conclusion: This study suggested that NAcc and ACCg played different roles in reward representation in DG. More importantly, it is the activation in NAcc, which tracked reward for oneself, that associated with equitable decision

3-J-49 Whose pain matters more? : neurocomputational mechanism underlying other-harm involved moral dilemma and links to trait empathy

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Moral dilemmas often involve conflicts between maximizing the overall utility and avoiding harmful violations. To investigate how people make decisions in such dilemmas, previous works typically used hypothetical scenarios where people make decisions in one-shot, with few or no parametric variations. However, it has been relatively less studied how people make decisions in real situations where people sacrifice one person against many people. Also, the computational processes involved in such decisions are not well known. This is a critical gap given that decisions in hypothetical moral scenarios don't seem to predict real-world moral behaviors. Also, our decisions may vary with contextual factors such as magnitudes of harms involved in trade-offs and the default consequence when no action is implicated. To this end, we developed a novel task where a participant has to repeatedly choose between actually harming one person against many people in experimental settings. In addition, we built computational models to quantify how participants represent and compute the value of one and many people's pain. Our preliminary results reveal a computational mechanism, which drives other-harm decisions in humans, and characterizes individual differences in making such decisions. Overall, participants valued the pain of one individual than that of many people, sacrificing the overall utility. However, trait empathy was related to the choice of minimizing the overall harm. Also, more empathic people showed less consistency in their choices across different contexts as the default option varied. Our work has implications for understanding the underlying computational mechanisms of moral decision-making in real situations and the link between the individual differences in trait-empathy and the value representation of others' pain as well as its stability.

K. Valuation & Value Systems

3-K-50 Cognitive aspects during elicitation process with FITradeoff Decision Support System

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Given the complexity of many multicriteria problems, several Decision Support Systems (DSS) have been developed. In these systems, decision-maker (DM) preferences are incorporated into a model that aims

to generate a decision recommendation. However, depending on the amount of information and time required, such systems may become inadequate for some DMs. Incorporated into a DSS, FITradeoff is based on the Tradeoff method, inheriting its strong axiomatic structure, but requiring less cognitive effort and time. Objective: This work seeks to identify the cognitive aspects during the preference elicitation process with the use of the FITradeoff DSS, in order to generate recommendations for the DSS project, making it more efficient and effective. Method: 15 subjects applied a self-made decision problem in the FITradeoff DSS and provided their preference information until an acceptable recommendation was provided by the system. Data related to pupil diameter and frequency band power were obtained through a system of Eye-Tracker and EEG during the experiments. Results: With the EEG data, it was analyzed the Frontal Alpha Asymmetry (FAA) during the three main steps of the elicitation process: ordering the scale constants, flexible elicitation and evaluation of the recommendation. Greater positive FAA was observed during flexible elicitation, indicating a greater engagement in this stage. In addition, during flexible elicitation, a growth was observed in the power of theta and alpha bands for problems with up to 5 criteria, while beta and gamma power increased for those with more than 5 criteria in the frontal areas of the brain. The results demonstrate greater cognitive effort when more criteria are involved. This result was corroborated by the pupil dilation data that showed higher values for problems with more than 5 criteria. Conclusion: Recommendations for changes in DSS can be made from the findings of this study in order to provide better support to DM through new functionalities in the system that aim to minimize the risks of high cognitive effort and uncertainty in providing information that can lead to inconsistencies in the results. Since the inconsistency is related to inadequate DSS recommendations, it is something to be avoided. Understanding that a greater number of criteria require more DM can direct efforts to improve the system for such types of problems and guide the decision analyst to provide greater support to DM in such cases.

3-K-51 Investigation of the role of the ventro-medial prefrontal cortex local morphology in its functional organization

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In humans, the ventro-medial prefrontal cortex (vmPFC) is, on one hand, assumed to be a key region for supporting decision-making processes. It is in particular associated with the ability to assign values to options that we are facing in our everyday life choices. On the other hand, the vmPFC is also one of the main hub of the Default Mode Network, a network classically activated during resting state and mind wandering. However, the term "vmPFC" does not refer to a specific anatomical delineated brain area. Functional neuroimaging studies that are classically based on statistical inferences established on the average brain activity of a group of subjects showed that "vmPFC" is used to label a large portion of the prefrontal cortex. It comprises various cytoarchitectonic subdivisions such as Brodmann area 10, 14, 25 and 32 and vmPFC boundaries are debated. Moreover, the fact that the classic neuroimaging approach is to average results across subjects in the MNI referential induces a glossing over of the interindividual variability of the morphological sulcal patterns of the vmPFC. In our study, using a dataset of 57 subjects from the Human Connectome Project for which anatomical MRI, resting-state MRI and functional reward-related task MRI data are available, we provide a precise description of the vmPFC sulcal patterns. First, we showed that sulcal patterns could vary either in terms of presence/absence of sulci but also in terms of shape or relative position to one from another. Importantly, we showed that the position of the main sulci influences the localization of the vmPFC peak of functional MRI studies. Those

results are critical for the investigation of the function of the vmPFC. First, they show that the brain area that we label "vmPFC" in two different contexts might be two distinct functional areas. In conclusion, we show that taking into account the variability in sulcal patterns might be essential to guide the interpretation of neuroimaging studies of the vmPFC.

3-K-52 Reduced neural satiety responses in obese women

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Objective: Overweight and obesity are major risk factors for a number of chronic diseases, and obesity rates are on the rise worldwide with women more frequently affected than men. Hedonic responses to food seem to play a key role in obesity, but the exact mechanisms and relationships are still poorly understood. In this project we investigate the perceived pleasantness of food rewards in relation to satiety and food intake in women. **Methods:** We combined fMRI with a gustatory task that measured various components of the hedonic response to experienced foods. Specifically, participants rated the pleasantness and intensity of low and high caloric milkshakes four times, during two menstrual cycle phases (perioovulatory or luteal), and different levels of satiety (hungry or sated). We investigated possible differences in how healthy weight ($n=32$, BMI: 19-25) and overweight or obese ($n=34$, BMI: 25-37) women respond to experienced food cues and satiety signals. **Results:** We found that effects of satiety on perceived pleasantness depended on the calorie content in the milkshakes ($p = 0.026$). After eating, participants experienced low caloric milkshakes as less pleasant and high caloric milkshakes as more pleasant. Moreover, we found that the relationship between hedonic responses and food intake differed as a function of BMI ($p = 0.011$). The higher the obese women rated the pleasantness of high caloric milkshakes with respect to low caloric, the greater their food intake during the meal. At the neural level, we observed increased activation in hedonic brain regions (insula, thalamus and caudate), the temporal cortex and the cerebellum to both low and high caloric milkshakes with increasing BMI ($p < 0.05$, whole-brain corrected). Moreover, we found a significant interaction between satiety, BMI and milkshake calorie content in constituents of both hedonic/reward and homeostatic systems (frontostriatal regions and hypothalamus, respectively) ($p < 0.05$, whole-brain corrected). Interestingly, in obese women the hypothalamus showed weaker phasic responses to the milkshakes, both in sated and fasted states. This pattern of activity contrasts with that of the hedonic regions, where responses to milkshakes were stronger in obese than healthy weight women. **Conclusion:** Stronger experienced pleasantness for high caloric milkshakes was associated with more food intake in obese, but not healthy weight women. At the neural level, satiety affected obese women to a lesser degree than healthy weight women. Thus, obese women showed both a stronger link between hedonic responses for high caloric foods and food consumption as well as reduced satiety effects.

3-K-53 Enhancement of the reward prediction error signal of midbrain dopamine neuron by the cost of obtaining the reward

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The midbrain dopamine neuron plays a central role in reward processing and represents the reward prediction error (RPE) to update the value of options. Here, we examined whether the RPE signals coded

by the midbrain dopamine neuron are modulated by the cost paid to obtain the reward. Two macaque monkeys performed a saccade task. After fixation on a fixation point, the subjects were required to make a saccade to a condition cue and then a target appeared. In the high cost condition, long fixation to the target was required. In the low-cost condition, only a short fixation was required. After fixation on the target, the subjects made a saccade to the reward cue. Choice trials between condition cues and between reward cues were inserted randomly to test if the subjects showed a preference. Free reward and free air-puff trials were also inserted randomly to determine whether each dopamine neuron was of a salience or motivation subtype. Dopamine neurons were found to respond less when a cue was presented signaling that the monkey would have to perform a costly action compared to a cue signaling a less costly action, but dopamine neuron responses to cues predicting reward and to the delivery of rewards were found to be enhanced after the monkey had performed a costly action compared to a less costly action. These findings suggest that dopamine neurons incorporate the cost of performing an action into the prediction error signal, and specifically that reward prediction errors are enhanced following the performance of a costly action. The finding of an enhanced prediction error signal by cost generated a hypothesis about a novel behavioral effect: that monkeys would be faster to learn stimulus-reward associations after performing a costly action compared to a less costly action. This hypothesis was confirmed in a subsequent behavioral experiment. Thus, information about action cost is processed in the dopamine reward system in a manner that amplifies the dopamine RPE signal, thereby producing more rapid learning under situations of high cost.

3-K-54 A quantitative neuroeconomic approach to political preference valuation and change

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Introduction: Unlike value-based decisions, it is unclear if political decisions are made using a principled evaluation of alternatives and are represented in brain areas associated with value-based decision making, or are distinct. Scholars long considered political preferences to be a privileged class of decision-making, much like religious beliefs, that defy logical thought processes. Since the mid-20th century, political science has tried to make sense of this behavior, first using normative economic and later decision theoretic models. Competing schools of thought disagree on the influence of trait political awareness--one's tendency to keep up with politics--as compared to partisanship or in-group identification on voters' preference malleability. **Methods:** Using a novel psychophysical task that orthogonalizes partisanship and political information, we employed a neuroeconomic approach to examine how political information alters preferences. Two behavioral studies, one online (N > 500) and another in the lab (N > 80), made preference ratings on real proposed laws that have appeared before US Congress. Subjects first reported their preferences based solely on a synopsis of the law, and later reevaluated those preferences after learning about the percent of members of Congress in each party who voted in favor of the law. Proposals tiled the space of Democratic and Republican support. **Results and conclusion:** The laws' true congressional support were unrelated to their perceived partisanship (i.e., the true levels of support for each bill were completely uncorrelated with participants' estimates of that support). Partisanship predicted preference alignment with the in-group for members of both parties. However, desire for social esteem only predicted alignment with Democrat-favored laws and degree of self-regarding preference only did so for Republican-favored laws. A third study employs a version of this task adapted for functional neuroimaging to pinpoint the neural locus of political preference representation in the brain. While previous studies reported a common neural representation for

differing goods types and personal preferences, it is still unclear whether political preferences lie on this same axis.

3-K-55 Abstract value computation in the individual and social domain

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Previous research has shown that during valuation neural activity in the ventromedial prefrontal cortex (VMPFC) correlates with subjective value (SV) of different stimulus types, including various individual (food, money, consumer items) and social (charitable donations, faces) rewards. In this fMRI study we investigated the encoding of SV in the individual and social domain when the task does not involve choice (only valuation) and valuation is not on a quantifiable scale (e.g. monetary). We used a free-thinking valuation task to explore value-related activation elicited during valuation of abstract social causes (e.g. gun control, wildlife preservation, refugee aid) and individual primary rewards (food items). In the scanner participants (24 healthy volunteers) were instructed to view the presented items and freely imagine how much pleasure they would derive from eating the presented snack food or from contributing to the presented social cause. Each item was a short two-word description of a snack or a social cause (e.g. blueberry muffin, refugee aid). After scanning participants completed two behavioral tasks (binary choice task, rating task) in order to derive the SV measure for each item. We used a general linear model (GLM) in which the amplitude of individual items of each category was scaled according to a linear and a quadratic distribution for each category (snacks, social causes). This way we tested for areas that tracked SV in a linear and/or quadratic fashion, i.e. areas in which activity scaled linearly with SV versus areas in which activity changed for items at the extremes of the SV distribution (i.e., quadratic). For the snacks we found that activation in VMPFC, ventral anterior cingulate cortex (vACC), posterior cingulate cortex (PCC) and subgenual area exhibited a linear correlation with SV, corroborating earlier findings. No areas exhibited a significant correlation with the quadratic predictor. For the social causes, activation in the inferior frontal gyrus (IFG) was correlated with the quadratic predictor of SV but not with the linear predictor. Further, a physio-physiological interaction (PPI) analysis showed that the interaction term between VMPFC and IFG timecourses accounted for the variation in the ratings for the social causes, but not for the snacks. Our findings provide evidence that SV encoding for social causes and snacks is possibly supported by partially different mechanisms, where the integration of a salience/arousal related neural signal plays an important role in the value computation process for social causes but not for snacks.

3-K-56 The whole is greater than the sum of the parts: Evidence for a unique role for vmPFC in evaluating objects based on multi-attribute configuration

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Most real-life decisions are made between multi-attribute options. Leading neuroeconomic models propose that the value associated with each attribute is integrated to form a global option-value, and that the ventromedial prefrontal cortex (vmPFC) plays a key role in this integration. We recently found that vmPFC damage impaired decisions between objects whose value was predicted by the configural association of their attributes. However, such damage spared decisions when value could be assessed by combining individual attribute-values (Pelletier & Fellows, 2019). This suggests that vmPFC is not a

general value integrator, but has a more specific role in inferring the holistic value of complex objects. Here, we aimed to gather converging evidence for this hypothesis using functional magnetic resonance imaging (fMRI) in healthy participants. We tested whether different neural substrates are involved in the neural representation of the value of complex objects, contrasting a 'configural' condition where value was inferred from attribute configurations and an 'elemental' condition where global value was estimated by integrating individual attribute-values. Participants first learned outside the scanner the values of novel, multi-attribute objects (Fribbles) through trial-and-error reward learning. Reward was paired with single attributes, two of which then had to be summed to evaluate the whole object (Elemental condition), or linked to the configuration of two attributes (Configural condition). After training, participants entered the scanner and made value judgments, while fMRI was acquired, of individually presented objects drawn from both conditions in mixed order. In line with our preregistered hypothesis (Open Science Framework; osf.io/4d2yr), preliminary analysis of the first 15 participants points to a cluster of voxels in the vmPFC in which activity correlates with value in the Configural condition ($p < 0.001$ uncorrected, whole brain). In the Elemental condition, value-related activity was not found within the vmPFC, but in more lateral clusters in the orbitofrontal cortex. These preliminary results add to our previous finding in lesion patients, suggesting that vmPFC has a specific role in inferring value from configural associations, and that elemental value representations might be supported by different brain regions. We offer here a triangulation approach using fMRI to further study the roles of prefrontal regions and ventral visual stream regions in attribute-, and whole object-value estimation.

3-K-57 Transcranial alternating current stimulation alters reward-dependent corticostriatal interactions

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The striatum is a major hub within the reward circuit. Although a host of studies have shown that activation within the striatum is associated with the anticipation of and consumption of reward, recent work has suggested that connectivity with ventrolateral prefrontal cortex (VLPFC) can determine reward-related functions (Smith et al., 2016, Scientific Reports). Yet, it remains unclear whether these corticostriatal interactions play a causal role in the striatal response to reward. To examine this issue, we applied 10 Hz transcranial alternating current stimulation to the VLPFC and a control site (temporal-parietal junction; TPJ) while participants ($N = 32$) played a popular card-guessing task used to study reward consumption (Delgado et al., 2000, Journal of Neurophysiology). On each trial, participants were asked to guess whether the number on a mystery card was above or below the number 5. Correct guesses increased the likelihood of winning a monetary bonus while incorrect guesses reduced the likelihood of earning a monetary bonus. Trials were presented in blocks of mostly reward or mostly punishment (i.e., 75%), and each block of trials lasted 30 seconds. Task blocks were separated by fixation blocks lasting 20 seconds. We applied tACS during each task block and recorded neural responses with functional magnetic resonance imaging. Consistent with prior work, receipt of reward (relative to punishment) evoked activation in the ventral striatum. Contrary to our hypothesis, however, tACS applied to VLPFC (relative to TPJ) did not alter striatal responses to reward or punishment. Instead, tACS applied to VLPFC decreased reward-dependent connectivity with the precuneus. Taken together, these results suggest that tACS applied to cortical regions that are connected to the striatum can have downstream effects on reward-dependent corticostriatal interactions. Understanding how tACS can be

used to modulate reward-dependent corticostriatal interactions may have important implications for psychopathologies characterized by aberrant corticostriatal responses to reward.

3-K-58 Flexible combination of reward information across primates

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A fundamental but rarely contested assumption in economics and neuroeconomics is that decision-makers compute subjective values of risky options by multiplying functions of reward probability and magnitude. In contrast, an additive strategy for valuation allows flexible combination of reward information required in uncertain or changing environments. We hypothesized that the level of uncertainty in the reward environment should determine the strategy used for valuation and choice. To test this hypothesis, we examined choice between risky options in humans and monkeys across three tasks with different levels of uncertainty associated with reward probability. We found that whereas humans and monkeys adopted a multiplicative strategy under risk when probabilities are known, both species spontaneously adopted an additive strategy under uncertainty when probabilities must be learned. Moreover, the level of volatility influenced relative weighting of certain to uncertain reward information (i.e., reward magnitude to reward probability) and this was reflected in the encoding of reward magnitude by neurons in the dorsolateral prefrontal cortex. Our results suggest that human and non-human primates are not hard-wired to follow fixed strategies assumed by normative models, and instead, are endowed with flexibility needed for learning and choice under uncertainty.

3-K-59 The neural correlates of bundle valuations: an eye-fixation related potentials study

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Previous electroencephalography studies found that evoked potential components encoded value relevant signals during decision making tasks. However, it is not clear how these value-sensitive components encode the value of product bundles comprised of complementary or non-complementary products. Participants completed a Becker-DeGroot-Marschak auction task, producing willingness-to-pay (WTP) for a set of individual products and complementary/non-complementary product bundles. All stimuli were split into low and high value based on subjective WTP. Neural activity in response to fixation onset was extracted and submitted to an independent component analysis to identify unique brain components representing economic valuation. Independent components were clustered across subjects to identify common brain components across subjects. A single cluster demonstrated increased activation for low value products and non-complementary bundles, originating from the right insula. Another cluster showed increased amplitude for high value products and product bundles, originating in the precuneus. This cluster also showed a significant relationship with bundle additivity. Additionally, non-complementary bundles produced a larger decrease in WTP than when purchased separately, in comparison to complementary bundles. Results provide further evidence for the coarse encoding of subjective value within the brain via unique brain components. Specifically, low value appears to be encoded in the right insula, and high value in the precuneus, producing activation over a left parietal region. Additionally, results indicate that the precuneus may be responsible for encoding bundle

additivity for both complementary and non-complementary product bundles. We demonstrate for the first time a potential neural substrate of economic additivity from bundle valuations.

3-K-60 Acute suppression effects of sucralose on WTP and brain activity during a food bid task

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Sucralose is the world's most commonly consumed artificial sweetener, and is primarily used by individuals interested in reducing caloric intake. Yet little is known about how its consumption impacts subsequent appetite. Here we use functional Magnetic Resonance Imaging and a BDM auction task (with attractive visual food presentation) to investigate the acute impact of sucralose on 1) "willingness to pay" (WTP) for food and 2) CNS activity related to appetite and food valuation. Healthy normal-weight participants (n = 25 at present, with data collection ongoing) participated in three imaging sessions. Participants came to each session after at least 12 hours of fasting, and were given 300 ml of water that included either 1) .24 g sucralose 2) 75 g glucose or 3) no sweetener. Because sucralose is much sweeter than glucose, the smaller quantity of sucralose approximately matched the sweetness of the glucose condition. We carried out both whole-brain and region-of-interest (ROI) analyses directed at identifying changes in food valuation after each drink condition. WTP for depicted food items was significantly lower after sucralose than after water consumption ($p < .01$) and not significantly different than after glucose. Across conditions, WTP was associated with greater activity in a large network of regions previously implicated in food cue and food valuation (including insula, hypothalamus, thalamus, nucleus accumbens, medial OFC, putamen). Interestingly, even after removing variance related to WTP of each item, fat content of food items was positively associated with activity in several of these same regions including thalamus, caudate, nucleus accumbens, and putamen). Within the apriori ROI of Orbital Frontal Cortex (OFC) previously associated with food WTP, activity was reduced after sucralose relative to water. Results of this study showed that non-caloric sweetener sucralose can suppress the value tracking network, though these data only address a single time period relative to consumption.

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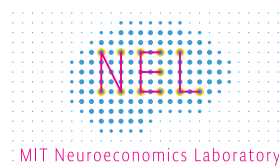
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