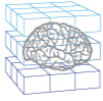


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The Fred Kavli Plenary Lecture

Gut Feelings

Dana Small¹

¹*Yale University*

Optimal decision making in a changing environment requires evidence accumulation. Typically, this evidence is amassed from the external environment. Within this framework unconditioned rewards are encapsulated within the outcome of an action, for example, the consumption of the food and the oral sensation simultaneously evoked. Tens of thousands of experiments on reinforcement learning are based on this premise, which largely rely on evidence accumulation from the external environment without regard for internally generated signals. However, here it will be argued that evidence must also be accumulated from the internal milieu and a revised view of food reinforcement learning will be presented that is based upon the integration of external and internal sources of evidence accumulation. Specifically, emerging work from our and other laboratories demonstrates that the critical signals underlying food reinforcement are generated during nutrient metabolism and are conveyed outside of conscious awareness to the brain to modulate dopamine release and support learning. According to this view, conscious oral sensations serve as both outcomes (e.g., the red strawberry is sweet as expected) and predictions (e.g., X amount of sweetness predicts X amount of glucose), enabling the formal integration of conscious and unconscious nutrient sensing. Further, the system is not singular, but rather multivariate with different sources of energy (e.g., fat vs. glucose) signaling through distinct pathways that can interact to potentiate reinforcement and thereby promote intake variety. These body – brain circuits also adapt overtime time to tune perception, metabolism and learning to a changing food environment.

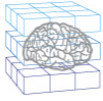
Workshops

Workshop II – The rational use of cognitive resources

Tom Griffiths¹

¹*Princeton University*

There is a long-standing tension in the decision-making literature between approaches that are based on classical notions of rationality and those that emphasize heuristics or cognitive strategies. This tension is not just the result of behavioral phenomena that are inconsistent with classical rationality, but rather an incompatibility of the basic assumptions behind these approaches: classical accounts of what it means to be rational say nothing about cognitive processes or the effort they require. In this talk I will present an alternative theoretical framework for defining rational action in which cognitive processes take center stage, and which makes clear and generalizable predictions about what cognitive processes rational agents should engage in when solving specific problems. This framework makes use of mathematical ideas that will be familiar to researchers in neuroeconomics, such as Markov decision processes, but uses them in a way that naturally leads to a new set of theoretical and empirical questions about human minds and brains.



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Symposium

S.01: Symposia I, Features and functions of intrinsic rewards

S.01.01: Intrinsic rewards: Domain General Mechanism & Responses

Bastien Blain¹, India Pinhorn¹, Tali Sharot²

¹UCL, ²UCL Institute of Neurology

Objective: Humans engage in activities that are intrinsically rewarding (e.g., walks in nature, reading). On the surface these different activities don't have common features or goals. This contrasts with primary rewards, which all have direct survival benefits, and secondary rewards, which are all associated with primary rewards. It is possible, however, that different intrinsic rewards do share characteristics, mechanisms, and goals not readily transparent (e.g., enhancing self-efficacy). Here, we examine if (1) sensitivity to intrinsic rewards is domain general and shared with other rewards; (2) related to mental health; and (3) characterised by the same set of responses as other rewards. **Methods:** Participants' (Study: N=132, Replication: N=183) sensitivity to different intrinsic rewards (e.g., viewing landscapes, consuming information, social confirmation), secondary reward (money) and a neutral stimulus (horizontal lines) was measured using (1) a 'liking' scale (2) a choice task (measuring 'wanting') and (3) a reinforcement learning task (measuring 'reinforcing strength'). **Results:** All rewards (but not neutral stimulus) were liked, wanted, and reinforcing (t -values > 8 , p -values $< 10^{-14}$), suggesting intrinsic rewards trigger the same responses as secondary rewards. A Principal Component Analysis performed on liking, wanting, and Reinforcing across all stimuli revealed that ~33% of the variance in behaviour was explained by a first component corresponding to sensitivity to all rewards, but not to the neutral stimulus. This suggests that sensitivity to intrinsic and non-intrinsic rewards is partly domain general. This sensitivity was negatively correlated with depression score (Study: $\beta = -0.26 \pm 0.09$, $t(123) = -3.0$, $p = .003$; Replication: $\beta = -0.17 \pm 0.08$, $t(163) = -2.3$, $p = .024$, controlling for demographics and IQ). The association was primarily driven by intrinsic rewards (Study: $\beta = -0.22 \pm 0.08$, $t(124) = -2.6$, $p = 0.009$; Replication: $\beta = -0.23 \pm 0.07$, $t(163) = -3.0$, $p = 0.003$) than monetary rewards (Study: $\beta = -0.10 \pm 0.09$, $t(120) = -1.14$, $p = 0.26$; Replication: $\beta = -0.07 \pm 0.08$, $t(161) = -0.8$, $p = 0.42$), $\Delta BIC > 20$). **Conclusions:** The results suggest a common mechanism underpins sensitivity to different types of rewards (intrinsic and secondary), which is impaired in depression and explains ~33% of individual differences in reward sensitivity. Our results may help explain flourishing and suffering; individual with high reward sensitivity will be inclined to engage in a variety of intrinsically rewarding activities, increasing the likelihood that they will eventually find those they excel at, while individuals with low sensitivity will be disinterested in many activities.

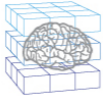
S.01.02: Neural computation underlying aesthetic experience

Kiyohito Iigaya¹, Sanghyun Yi², Iman Wahle², Koranis Tanwisuth², John O'Doherty²

¹Columbia University, ²Caltech

(1) study's objective The overarching goal of this study is to elucidate the neural computation underlying the aesthetic value construction of visual stimuli. While previous research into value computation has

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primarily focused on how the brain updates values of familiar stimuli based on experiences associated with the stimuli (e.g., reinforcement learning), little is known about how the brain can construct values of novel stimuli in the first place. Inspired by visual neuroscience literature and our recent behavioral findings, we hypothesize that the brain forms the visual aesthetic value of a stimulus by combining elementary visual and emotional features of the stimulus. This mechanism would allow the brain to compute aesthetic values across a wide range of stimuli, including those never encountered before. (2) methods used We approach this problem using a combination of computational modeling and fMRI experiments (n=6). Each participant evaluated 1000 paintings in the MRI scanner over three days of experiments (20 scan sessions per participant). We fit a lasso regression model with various visual and emotional features and a convolutional neural network (DCNN) model to each participant's preference data using within-subject cross-validation. We analyzed fMRI data using a lasso regression model with the linear model's features and the DCNN model's features to examine how features are represented across the brain and how those features are integrated to construct the aesthetic value of paintings. (3) results obtained We found that both the linear and the DCNN models captured participants' subjective ratings about paintings ($p < 0.001$ permutation test). We also found that features of the linear model and the DCNN model are hierarchically encoded across the visual stream in the brain. Low-level features (e.g., color) and early layers of the DCNN model are encoded in lower visual areas ($p < 0.001$ permutation test). In contrast, high-level features (e.g., emotional features) and deeper layers of the DCNN model are encoded in higher visual areas ($p < 0.001$ permutation test). Finally, we found evidence suggesting that features are combined to construct subjective value between the medial prefrontal cortex and lateral prefrontal cortex ($p < 0.001$ permutation test). We replicated our findings across participants. (4) conclusions While aesthetic experience may be considered enigmatic and subjective, our findings demonstrate that people may rely on a common neural computational mechanism to generate aesthetic value. Our results also provide insights into how the brain constructs subjective values of complex, novel stimuli.

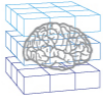
S.01.03: The intrinsic reward of sensory experiences

Anne Briellmann¹, Max Berentelg², Peter Dayan²

¹Max-Planck Institute for Biological Cybernetics, ²Max-Planck Institute for Biological Cybernetics; University of Tuebingen

Objective: Listening to music, watching a sunset, eating your favorite ice cream even when sated - all of these sensory experiences are rewarding in and by themselves. Why? And why does this differ so much between individuals and across time? We propose that particular sensory experiences are intrinsically rewarding because they serve the ethologically-grounded task of fashioning a sensory system that effectively processes objects that it expects to encounter, both now and in the future. We discuss a recent theory and computational model in which the sensory system comprises a generative model of objects in the sensory environment. This system is shaped through learning occasioned by the objects the observer encounters. Two interlinked components generate intrinsic sensory value: immediate sensory reward from fluency operationalized as the likelihood of the current object given the observer's state, and the reward of learning, operationalized as the change in expected future reward. Methods: We report findings from a simple image rating task in which participants (N = 59) rate how much they like a set of dog images (n = 55) that we created from seven source images in a rigorously controlled

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manner using the NeuralCrossbreed morphing algorithm. Following our theoretical assumption that object recognition and sensory valuation are linked, we derive stimulus feature representations from deep neural nets pretrained on image recognition (e.g., VGG-16). Results: A full realization of our model is able to capture liking judgments on a trial-by-trial basis (median $r = 0.65$) and far outperforms predictions based on population averages (median $r = 0.01$; comparison of prediction errors for held out trials $p < 0.001$, $BF = 7.8 \times 108$). In addition, we show image sequence dependent changes in liking ratings that justify the learning component of our model: The model explains on average 20% less variance for simulated random trial orders compared to the true trial order (pairwise comparison $W = 7.0$, $p < 0.001$). Conclusions: In sum, we show that a computational model can capture the dynamics of individual sensory value judgments. The components of our theory map directly onto those of conventional reinforcement learning-based accounts of decision making, offering the opportunity for understanding how primary, secondary, and sensory rewards jointly drive behavior.

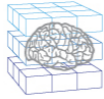
S.01.04: The pursuit of happiness: A reinforcement learning perspective on habituation and comparisons

Rachit Dubey¹, Tom Griffiths¹, Peter Dayan²

¹Princeton University, ²Max Planck Institute for Biological Cybernetics

Objective: In evaluating our choices, we often suffer from two tragic relativities. First, when our lives change for the better, we rapidly habituate to the higher standard of living. Second, we cannot escape comparing ourselves to various relative standards. Habituation and comparisons can be very disruptive to our happiness and decision-making, and to date, it remains a puzzle why they have come to be a part of cognition in the first place. This study's objective is to provide a precise characterization of how and why these relative aspects might be desirable features of intelligent agents. **Methods:** Here, we adopt the computational framework of reinforcement learning (RL). In standard RL theory, the reward function serves the role of defining optimal behavior i.e., what the agent ought to accomplish. However, recent work on reward design has embraced the observation that the reward function plays a second, critical, role in RL in steering the agent from incompetence to mastery. These steering reward functions, often provided by the designer to the agent, have subjective features detached from the particular task but can nevertheless guide the learning of the agent. Here, we use this idea and endow agents with a subjective reward function that, in addition to the reward provided by the underlying task, also depends on prior expectations and relative comparisons. We then embed these agents in various parameterized environments and compare their performance against standard RL agents whose reward function depends on just the task reward value. **Results:** Extensive simulations reveal that agents equipped with this reward function learn and explore very efficiently in a wide range of settings. Notably, they significantly outperform standard reward-based agents in sparsely-rewarded, $t(198) = 35.6$, $p < 0.01$, and non-stationary environments $t(198) = 30.1$, $p < 0.01$. Our simulations also reveal potential drawbacks of this reward function and show that agents perform sub-optimally when comparisons are left unchecked and when there are too many similar options. **Conclusions:** Our results suggest that a subjective reward function based on prior expectations and comparisons might play an important role in promoting adaptive behavior by serving as a powerful learning signal. This provides computational support for a longstanding assumption in the field and explains why the human reward function might be based on these features. Together, our results help explain why we are prone to becoming trapped in

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a cycle of never-ending wants and desires, and may shed light on psychopathologies such as depression, materialism, and overconsumption.

S.02: Symposia II, Biases across different timescales, species, and behavioral paradigms

S.02.01: Neuronal origins of reduced accuracy and biases in economic choices under sequential offers

Weikang Shi¹, Sébastien Ballesta¹, Camillo Padoa-Schioppa¹

¹*Washington University in St. Louis*

Finding the mechanism behind choice biases is a long-term goal of neuroeconomics, but the progress on this front has been modest. Here we examined the neural origins of choice biases measured when goods available for choice were offered sequentially. In the experiments, monkeys chose between two juices offered in variable amounts. In each session, two choice tasks were randomly interleaved. In Task 1, offers were presented simultaneously; in Task 2, offers were presented sequentially. Comparing choices across tasks revealed four phenomena: (1) monkeys were substantially less accurate in Task 2 compared to Task 1; (2) monkeys had increased choice hysteresis in Task 2; (3) choices in Task 2 were biased in favor of the second offer (order bias); (4) choices in Task 2 were biased in favor of the preferred juice (preference bias). Economic choices entail two mental stages: value computation and comparison. In theory, choice biases may emerge during any of these stages. Previous work identified in the orbitofrontal cortex (OFC) different groups of neurons encoding individual offer values, the binary choice outcome and the chosen value. These variables capture both the input and output of the decision process, suggesting that OFC participated in both mental stages and decisions might be formed within OFC. Recent work showed that choices under sequential offers and simultaneous offers engaged the same cell groups. If so, suitable analyses of different functional cell groups may shed light on the origins of choice biases at different mental stages. Building on this idea, we examined the activity of 1,204 cells from the OFC of two monkeys. Our analyses revealed that different biases emerged at different mental stages. Specifically, we found that the weaker value signals of offer value cells in Task 2 led to a value compression, and such effect correlated with the reduced choice accuracy and the increased choice hysteresis. The results indicated that the two behavioral effects emerged, at least partly, at the valuation stage. The order bias found in Task 2 did not have neural correlates during valuation, but correlated with the activity of chosen juice cells and chosen value cells, indicating its emergence during the comparison stage. Finally, the preference bias found in Task 2 emerged late in the trial through chosen juice cells, possibly due to failures in working memory of choice outcome. In conclusion, different functional cell groups in the OFC might engage differently in the value computation and comparison stages. By examining their correlation with choice biases under sequential offer, we found these choice biases emerged during different mental stages.

S.02.02: History-dependent biases compete with evidence by shifting the prior of the choice options

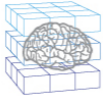
Thomas Luo¹, Diksha Gupta¹, Verity Elliott¹, Carlos Brody¹

¹*Princeton University*

Decisions are often biased by previously made choices, even when past choices are irrelevant to the current decision. How history-dependent biases interact with relevant information, i.e. the evidence, to

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influence the current decision remains unclear. It is possible that history-dependent biases 1) influence the current decision independently of evidence, 2) reflect epiphenomena that result from the updating the decision strategy through reinforcement learning, or 3) compete with the evidence to influence the current decision. These hypotheses predict distinct behavioral effects from the perturbation of a brain region that causally contributes to the influence of evidence. To test these hypotheses, we first identify dorsomedial frontal cortex (dmFC) in rats to be causally involved in the accumulation of evidence in an auditory decision, using large-scale electrophysiological Neuropixels recording paired simultaneously with either optogenetic or chronic perturbation. We found that the results across different methods of perturbing dmFC are inconsistent with history-dependent biases and evidence having independent influences on the decision, and also inconsistent with history-dependent biases being epiphenomena of the updating of decision strategy. Instead, the results support a competition between history-dependent biases and evidence. To elucidate the mechanism underlying the competition, we quantified the internal decision process using spike trains from hundreds of neurons simultaneously recorded during perturbations. We found that the competition between history-dependent biases and evidence is parsimoniously explained by shifting the starting point of the decision process, i.e., the prior probabilities of the choice options, toward the previous, irrelevant choice. We therefore elucidate the mechanism through which irrelevant information from past decisions affect the current decision.

S.02.03: Neural correlates of social decision-making biases in younger and older adults

Camilla van Geen¹, Michael Cohen¹, Karolina Lempert², Kameron MacNear³, Frances Reckers¹, Laura Zaneski¹, David Wolk¹, Joseph Kable¹

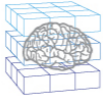
¹University of Pennsylvania, ²Adelphi University, ³University of Illinois -- Urbana Champaign

1. Objective This study aims to uncover the neural mechanisms that support social decision-making in younger vs. older adults. When people decide whether to re-engage with others, various sources of information compete to shape their choice. One source of information people may use is their memory of their previous interactions with someone. Conversely, they may infer the person's internal characteristics based on their external attributes. For example, certain facial features are known to be associated with perceptions of trustworthiness (Todorov et al., 2008), which may make people more likely to re-engage. Aging has been shown to modulate the weight given to these two sources of information: older adults exhibit a decline in associative memory, which hinders their ability to make memory-based decisions. However, they demonstrate an increased reliance on irrelevant features of facial appearance during choice (Lempert et al., 2022). Here, we ask whether age-related differences in neural activity while participants are learning about others' behavior underlie these behavioral effects.

2. Methods We collected fMRI data from 45 younger (ages 21-40) and 39 older (ages 65-85) adults while they performed a simple decision-making task. Participants first learned associations between images of faces and reward outcomes. They then decided whether to interact with each of the faces again, or rather with an unknown face chosen at random.

3. Results Behaviorally, older adults made fewer adaptive decisions than younger adults ($p = 0.013$), meaning that they were less likely to re-engage with a high-reward face or avoid a low-reward face. During the reward learning phase, we found a significant parametric effect of the face's perceived generosity (as assessed by a group of independent raters) in the amygdala and the striatum (whole brain analysis: $p < 0.001$ voxel threshold with parametric cluster correction to $p < 0.05$). Furthermore, the magnitude of this effect in the striatum was inversely

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correlated with the proportion of adaptive choices in the decision task for older but not younger adults ($r = -0.37$ in older adults vs. $r = 0.007$ in younger adults, Fisher Z difference in correlation coefficients: $p = 0.043$). 4. Conclusions Both younger and older adults show striatal activation in response to task-irrelevant features of social stimuli. However, the magnitude of this effect is only negatively correlated with performance in older adults. This suggests that a stereotyping bias may underlie older adults' suboptimal social decisions, while younger adults are less prone to letting it influence their choice.

S.02.04: Long-term regularities of reward environment impact learning and choice behaviors in mice and monkeys

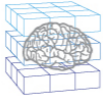
Jae Hyung Woo¹, Bilal Bari², Ken-Ichiro Tsutsui³, Fabian Grabenhorst³, Jeremiah Cohen², Wolfram Schultz³, Alireza Soltani¹

¹Dartmouth College, ²The Johns Hopkins University School of Medicine, ³University of Cambridge

Objective: Recent studies have suggested that statistics of the reward environment can influence different aspects of behavior. To examine whether and how animals are able to use long-term regularities of the environment to guide their behavior in volatile environments, here, we re-analyzed data from mice ($n=16$) and monkeys ($n=2$) performing dynamic foraging tasks with variable block lengths. **Methods:** To quantify how choice strategies are dynamically modulated by higher-order expectations, we utilized recently developed behavioral metrics based on information theory (Trepka et al., Nat Comm 2021). Specifically, we used the entropy of reward-dependent strategies (ERDS), equal to the conditional entropy of stay/switch given the reward feedback in the previous trial, that measures the dependence of surprise in adopting a response strategy on reward feedback. Lower ERDS values correspond to decreased uncertainty in the variable and thus more consistency in the utilized strategy. To quantify animals' expectation about reversals in reward contingency, we defined expected block length, $E(L)$ that was updated after each reversal using the block length prediction error, $BLPE = L - E(L)$, equal to the discrepancy between actual and expected L . To study how choice strategies of the animals are modulated by the expectation of a reversal in the environment, we compared ERDS as a function of BLPE. Additionally, we also fit choice behavior of the mice and monkeys using standard reinforcement learning (RL) models with feedback-dependent learning rates and an inverse temperature parameter. **Results:** Using entropy-based metrics, we found that mice and monkeys can use reward history to form higher-order expectations about environment and adjust their behavior accordingly. More specifically, ERDS was significantly larger for blocks with expected block lengths longer than the actual L ($BLPE > 0$) than those shorter than actual L ($BLPE < 0$). This was observed for both mice (Cohen's $d = 0.253$, $p < .001$) and monkeys (Cohen's $d = 0.476$, $p < .01$), suggesting that animals formed expectation of reversals and their response to reward feedback became less consistent as they passed expected reversal time. Results from fitting with RL models showed that this effect was mediated by different underlying mechanisms for each species: inverse temperature for mice and negative learning rate for monkeys. **Conclusion:** Together, our results illustrate how higher-order statistics of the reward environment influence learning and choice strategies in a dynamic world.

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O.01: Strategic Interactions

O.01.01: Dynamics of Bargaining

Miruna Cotet¹, Wenjia Joyce Zhao¹, Ian Krajbich¹

¹*The Ohio State University*

Objective. Hesitation in the marketplace has the potential to betray private information. Lab experiments have confirmed that subjects' response times (RT) reveal their strength-of-preference or belief, and that the Drift Diffusion Model (DDM) can account for their behavior. In lab bargaining data, Konovalov & Krajbich (2017) demonstrate that subjects' RTs reveal their private values in a bargaining game. One open question is whether these results extend beyond the lab to markets with experienced agents. To this end, we analyze a dataset consisting of millions of bargaining exchanges from eBay and ask whether RT reflects the gap between sellers' prices and buyers' offers, even when RT is on the order of hours instead of seconds. **Methods and results.** We use an online dataset of all bargaining exchanges on eBay in one year. On eBay, a seller can post an item for sale, but they can also enable a bargaining feature at no cost. With this feature, buyers can make offers to sellers and seller can either accept, reject, or counteroffer. In the eBay dataset ($N = 1,018,858$), over most of the offer range ([25%, 100%]), median acceptance times decreased monotonically with offer size, from 2.1 hours down to 1.0 hours. Similarly, over most of the offer range ([0, 65%]), median rejection times increased monotonically with offer size, from 1.4 hours up to 2 hours. Moreover, the point at which sellers were equally fast at accepting and rejecting offers (50%, $RT = 1.3$ hours) is close to the sellers' average indifference point (43%). We also fit the DDM to a randomly selected sample of sellers ($N = 46$) who had more than 50 and less than 200 observations for each response type. We let the drift rate depend on the difference between the seller's list price and the buyer's first offer. We find that the DDM fits the eBay data surprisingly well. Although the correlation between the data and the model is high and significant for the eBay data, the model slightly overpredicts the fastest RTs, slightly underpredicts the median RTs, and greatly underpredicts the slowest RTs. We continue to work on extending the standard DDM to better capture these hour-long RTs. **Conclusions.** In summary, using a dataset of millions of eBay bargaining exchanges, we found that sellers' RTs are strongly related to the size of the offer that they receive. They are quick to accept good offers and to reject bad offers, and slow to accept bad offers and to reject good offers. This field evidence supports laboratory experiments showing that agents' RTs reflect their strength of preference, even in strategic situations. However, the DDM misses some aspects of the field bargaining RT data.

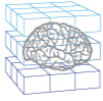
O.01.02: CHASE - A Bayesian model for characterising mentalization during strategic interactions

Niklas Brger¹, Gkhan Aydogan¹, Arkady Konovalov¹, Christian Ruff¹

¹*University of Zurich*

Objective: Mentalizing - the ability to infer emotions, intentions and desires of others - is indispensable for sustaining complex interactions in social, political and economic decision-making. Previous research has identified neurocomputational processes related to specific mentalizing mechanisms in strategic interactions. However, these studies have employed one of two distinct approaches, either based on (1) simple learning rules (e.g. reinforcement learning) that are unable to capture higher levels of reasoning,

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or (2) models of recursive reasoning (e.g. level-k) that have not been adapted for belief updating processes in repeated interactions. Our goal is to expand the scope of these two approaches using a unified framework. Methods: Here, we propose and test the CHASE (Cognitive Hierarchy Assessment) model, a novel Bayesian approach that addresses those limitations by modelling dynamic changes in levels of reasoning for arbitrarily high levels of strategic sophistication (i.e. $k > 2$). Our approach is based on three general assumptions: i) non-strategic play (i.e. level-0) is governed by a trial-by-trial updating rule (delta rule), ii) players update beliefs about their opponent's level, and iii) iteratively form a response using a soft-max function. To test the model's predictions, we ran a series of behavioural and fMRI experiments ($N=300$), in which participants played rock-paper-scissors type games against artificial and human opponents. We designed the artificial opponents to mimic human gameplay at different levels, forcing subjects to adapt their strategy. This approach allowed us to systematically investigate belief updating processes in strategic interactions. Results: We find that human players were not able to distinguish human opponents from artificial ones ($N=54$, $p > .63$). By using Bayesian model comparison, we find evidence that our proposed model outperformed other existing models (e.g. influence learning and EWA). Moreover, we find evidence that (a) human players indeed dynamically adapt their level of reasoning to their opponent's level and (b) up to 80% of our subjects were capable of reaching level-k of 3, which previous dynamic models were not able to capture. Furthermore, in line with our model, initial analyses of fMRI data ($N=50$) point to separable neural processes corresponding to different levels of strategic sophistication. Conclusions: Our novel approach opens up new model-based ways of examining neurocomputational mechanisms underlying mentalization. Furthermore, by designing a sophisticated artificial opponent, we provide a new tool to systematically measure mentalizing capabilities in clinical and non-clinical settings.

O.01.03: Neural predictors of sensitivity to distinct social inferences during altruistic choice

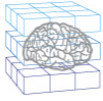
Lisa Bas¹, Ian Roberts², Cendri Hutcherson², Anita Tusche¹

¹Queen's University, ²University of Toronto

Objective: Why do people act altruistically in some contexts but not in others? Here, we examine the hypothesis that individuals differ in their sensitivity to distinct characteristics of a target (i.e., merit and need) and that these differences result from stable individual variation in sensitivity of distinct social cognitive brain regions to specific social inferences. **Methods:** In separate sessions, subjects ($N=32$) completed two tasks while undergoing fMRI scanning. In an altruistic choice task (modified dictator game), subjects repeatedly accepted or rejected different monetary offers for themselves and different partners who varied in their immediate need (high/low) and perceived deservingness (low/high/unknown). A need-merit social inference localizer task served to identify individual differences in neural response to need and merit judgments unrelated to altruistic choices. In this task, participants made inferences about the need or merit of different individuals displayed in visual scenes (factual inferences served as a non-social control condition). **Results:** Using drift-diffusion models together with behavior in the altruistic choice task, we showed that a partner's need and merit act independently to modulate attention to self and partner outcomes during altruistic choice. Notably, the influences of need and merit on generosity were uncorrelated across individuals, suggesting that they might be supported by different mechanisms. Next, we examined neural substrates of need and merit

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judgments in the separate localizer task. Importantly, although both types of social inference reliably activated the brain's mentalizing network, activity in different regions predicted sensitivity to need and merit during the altruistic choice task. Dorsolateral prefrontal cortex response during need judgments predicted an individual's sensitivity to partner need, while temporoparietal junction response during merit judgments predicted sensitivity to partner merit. Conclusions: Overall, our results provide insights into the neurocomputational mechanisms of altruistic choice across contexts. We demonstrate that different types of social inferences provide distinct inputs into the decision process. Moreover, our results suggest that variation in sensitivity to different social judgments may derive from stable differences in distinct social cognitive brain regions. These findings point to the complex interplay of context, target, and perceiver characteristics guiding social behavior.

O.01.04: Searching for Orthogonal Neurocomputational Modules that Shape Levels of Rationality in Strategic Interactions

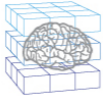
Vered Kurtz-David¹, Adam Brandenburger², Maria Olifer¹, Paul Glimcher¹

¹New York University, ²New York University and NYU Shanghai

Objective: Seminal work in economics indicate that bounds on cognition limit sophistication in strategic interactions. Nonetheless, the study of levels of rationality in games still lacks a neurocomputational-psychometric basis. Here, we develop a novel neurocognitive framework to examine strategic interactions. Our goal is to investigate how the brain manages strategic interactions as subclasses of orthogonal cognitive functions associated with different cortical modules. Employing modelling architectures from game theory alongside experimental design concepts from psychophysics, we take a behavioral approach to identify elastic modules in strategic choice. Methods: The complexity level of any strategic interaction can be defined as the product of the social-mentalizing demand and the number of options that must be represented independent of social factors. As complexity increases, subjects face increasing demands to fully represent the strategic setting. We hypothesize that this effect is instantiated as an elastic allocation tradeoff between mentalizing and valuation demands. In two samples, one recruited from the general population (N=56) and one of highly capable undergraduates (N=54), we utilized the Ring Game (Kneeland, Econometrica, 2015) to directly measure the allocation strategies of subjects managing varying demands across these two domains. In the Ring Game, each subject's payoff depends on her own choices and the choices of the next player in the ring. The number of players in each ring determines the mentalizing requirements, while the raw complexity of the choice structure imposes domain-general demands on value representation. By varying the number of players and the number of choice options in each ring, we developed a full psychometric characterization of behavior in an array of strategic interactions. Results: For each additional player and choice option in the game, the chances of following game-theoretical predictions declined by 4.3% and 8.9% respectively ($p < 0.0001$, fixed-effects regression). Importantly though, for each subject, we also identified that player's position along the mentalizing-valuation tradeoffing axes, and report the player's "capacity frontier," defined as the subset of games she was able to reason about. This approach should allow us to develop a subject-specific "cognitive production function" and, therefore, a parametric account of a player's cognitive process in a strategic game. Conclusions: Our framework provides a novel approach

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for examining the psychophysics of strategic interactions, and can be applied in neuroimaging to study tradeoff mechanisms between social and reward networks in the brain.

O.02: Reward Processing

O.02.01: Neural Representation of Latent Cause in Credit Assignment

Yanchang Zhang¹, Phillip Witkowski¹, Seongmin Park¹, Erie Boorman¹

¹*University of California-Davis*

Objective. Humans have a remarkable capacity to use an internal model of the environment to make inferences about unseen outcomes. Such adaptive behavior may depend on the ability to update our models by learning the causal relationships between the outcome and the underlying latent cause from choices. How the human brain assigns credit for outcomes to such latent causes is poorly understood. **Methods.** We scanned hungry participants (N=28) while they tracked 2 probabilistic systems of stimulus-reward associations for 2 desserts, with each system comprising 2 stimuli of different visual categories but sharing the same reward probabilities. We hypothesize that the underlying latent cause is reinstated in the lateral orbitofrontal cortex (OFC). **Results.** Behavioral results from a Bayesian learning model and logistic regressions analyses show that participants efficiently learned to track reward probabilities both from their choice and the inferred stimulus in the same system (direct and indirect choices 1back: $t(27) > 3.5$ $p < 0.001$). An univariate analysis of the Kullback-Leibler divergence as a measure of belief confirmation of stimulus-outcome probabilities at feedback shows significant effects in the OFC, ventromedial prefrontal cortex and hippocampus ($t(27) > 4.3$, $p < 0.0001$, uncorrected). We then used multivariate pattern analysis to test for a reinstatement of the causal choice at feedback (cross-validated across runs). Left lateral OFC and the hippocampus show a significant decoding accuracy relative to label-shuffled permutations, consistent with a role of OFC in choice reactivation during credit assignment ($t(27) > 3.745$, $p < 0.001$, uncorrected). To test if this reinstatement constitutes the identity representation of the stimulus, we trained a classifier on the stimuli in separate forced choice trials and decoded choice identity at feedback in free choice trials. Significant decoding accuracy was found in the bilateral OFC and the amygdala ($t(27) > 4.6$, $p < 0.0001$). We then tested for the reactivation of the inferred stimulus by training a classifier at forced choice for the paired but unrepresented stimulus, and decoding at feedback in free choices. Left lateral OFC shows significant decoding accuracy ($t(27) > 3.7$, $p < 0.0005$) for the inferred stimulus that is informative for future decisions. **Conclusion.** These findings support a model whereby choices and inferred causes are reinstated at feedback time, coincident with prediction errors, to drive plasticity between co-active neural ensembles for the outcome and cause in the service of learning.

O.02.02: Neural mechanisms underlying the expectation of rewards resulting from effortful exertion

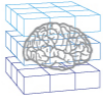
Aram Kim¹, Vikram Chib¹

¹*Johns Hopkins University*

Our expectations shape our decisions to engage in effortful activity. If we exert a large amount of effort while expecting payment in return, but receive less than expected, we might feel dissatisfied with the outcome. However, if we receive more rewards than expected, we might feel more satisfied. In this way,

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reward expectations can serve as a reference point that motivates effortful activity. Despite the fundamental role of reference points in human performance, little is known about how the brain encodes expectations to guide motivated exertion. In this experiment, 34 participants completed a reward-based effort task and we used functional magnetic resonance imaging (fMRI) to investigate the neurobiology of reference-dependent effort exertion. During each trial, participants were presented with a risky option that would either result in a fixed monetary payment, regardless of their effort exertion, or a piece-rate payment where the payment was in proportion to the amount of effort exerted. Each of these options had an equal probability of occurring, and we varied the fixed payment so that participants had different expectations. The actual payment was revealed after individuals had the opportunity to exert effort. We found that participants exerted more effort as the fixed payment increased ($t=7.28$, $p<0.001$, Cohen's $d=0.45$), suggesting that the fixed payment influenced the reference point for effort exertion. To examine how the brain processes expectations of exertion, we examined brain activity when individuals were presented with the outcome of the risky option (i.e., either the fixed payment or their piece-rate earnings). We found activity in the ventral striatum was significantly correlated with the difference between participants' piece-rate earnings and the fixed payment, consistent with previous studies showing that the ventral striatum is responsible for encoding reward expectations. Overall, these results suggest that value-related brain areas, particularly the ventral striatum, encode expectation as a reference point to motivate effortful exertion.

O.02.03: Orbitofrontal network-targeted TMS disrupts midbrain signaling of identity prediction errors

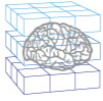
Qingfang Liu¹, Thorsten Kahnt¹

¹*National Institute on Drug Abuse Intramural Research Program*

Previous work in rodents and humans has shown that the orbitofrontal cortex (OFC) represents the identity of expected rewards. Moreover, single unit and functional magnetic resonance imaging (fMRI) activity in the dopaminergic midbrain responds to reward identity prediction errors, that is, value-matched mismatches between expected and received reward identity. We hypothesized that reward identity expectations in the OFC directly contribute to the computation of identity prediction errors in the midbrain. To test this, we used network-targeted transcranial magnetic stimulation (TMS) to modulate activity in the lateral OFC network bilaterally. Thirty-one healthy human subjects performed a trans-reinforcer reversal learning task inside the fMRI scanner in two separate sessions (order counter-balanced); once after sham stimulation and once after 40 seconds of continuous theta burst stimulation (cTBS) on each hemisphere. Stimulation coordinates in the left and right lateral prefrontal cortex (LPFC) were individually selected based on maximal resting-state fMRI connectivity with seed regions in the left and right lateral OFC, respectively. The trans-reinforcer reversal learning task required subjects to learn the associations between visual cues and equally-valued food odor rewards. Unpredictably for the subject, these associations were reversed multiple times throughout the task. Subjects responded faster on trials following a reversal compared to reversal trials ($p < 0.0012$). This effect was larger after cTBS relative to sham in the first block of the experiment ($p < 0.008$), suggesting that TMS affected behavioral adjustments after reversals. Consistent with previous findings, fMRI activity in the midbrain, OFC, LPFC, medial prefrontal cortex, posterior parietal cortex, and insula was significantly ($p < 0.001$) correlated with identity prediction errors, showing increased responses on reversal trials compared to the trial

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after the reversal. Importantly, these responses were significantly attenuated by cTBS relative to sham (midbrain: $p < 0.037$, OFC: $p < 0.028$, LPFC: $p < 0.001$, all FWE small-volume corrected), indicating that OFC network-targeted TMS disrupted the neural coding of identity prediction errors. These results suggest that representations of expected outcome identity in the OFC directly contribute to signaling of identity prediction errors in the midbrain, presumably by providing the predictions necessary for computing the error signal. Taken together, our findings support a model in which midbrain identity errors are generated by comparing incoming sensory information with outcome identity expectations that are represented in the OFC.

O.02.04: Value representation of delayed and probabilistic rewards in supplementary eye field

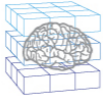
Jacob Elsey¹, Jaewon Hwang², Veit Stuphorn¹

¹*Johns Hopkins University*, ²*National Institute of Mental Health*

OBJECTIVE: Neurons in the supplementary eye field (SEF) have been shown to encode action value during saccade preparation, i.e. the expected value of a target associated with a specific action made to its location. However, action value signals have only been tested in the context of an oculomotor gambling task where monkeys chose between options that varied in reward amount and probability. In this study, we test if SEF neurons encode action value invariant of task context, where the subjective value of options is influenced by different attributes. **METHODS:** We trained two rhesus monkeys on an intertemporal choice task and a gambling task where reward delivery delay and probability were varied, respectively. We recorded single-unit neural activity from SEF (312 isolated neurons) while the two tasks were alternated in a block-wise fashion. **RESULTS:** We found action value to be robustly encoded by 26% of SEF neurons with saccade-related activity in the intertemporal choice task only and 24% in the gambling task only. 12% of neurons encoded action value in both tasks. SEF neurons also encoded different task-relevant variables during the delay period immediately after the choice was made. 28% of neurons encoded the delay associated with the chosen option in the intertemporal choice task, and 24% encoded the probability of the chosen option in the gambling task. To determine if the number of neurons encoding task-relevant variables in one or both tasks departed chance levels, we constructed a contingency table in which the rows and columns represented the task variables and computed the odds ratio of each cell. When aligned to saccade onset, we found significant subpopulations of neurons encoding action value, reward amount, chosen probability, chosen delay, and choice in one task context alone ($p < 0.05$, two-tailed Fisher's exact test). Interestingly, action value was the only variable significantly encoded across both tasks by the same subpopulation of neurons ($p < 0.001$, two-tailed Fisher's exact test). During the delay period immediately after the choice was made; chosen value, chosen probability/delay, and choice were all significantly encoded across both task contexts by the same subpopulations of neurons ($p < 0.05$, two-tailed Fisher's exact test). **CONCLUSIONS:** Our results indicate a robust subpopulation of SEF neurons encode action value when a saccade is generated regardless of task context and the attributes that influence subjective value estimation. In general, our study provides neurobiological support for the economic theory that value is represented as a universal internal currency used to compare and choose rewarding options.

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O.03: Learning & Decision Making

O.03.01: The neural dynamics associated with computational complexity

Juan Pablo Franco¹, Peter Bossaerts¹, Carsten Murawski¹

¹University of Melbourne

(1. Objectives) Many everyday tasks require people to solve computationally complex problems. Yet, little is known about the neural dynamics that support problem-solving in these tasks. Indeed, to date, there is no general theoretical framework to study the neural underpinnings of problem-solving. Here, we present and test a framework, grounded in computational complexity theory, to study the neural underpinnings of problem-solving that overcomes previous limitations. Rather than studying problem-solving starting from "what people are thinking," we rely on the theory of computational complexity to identify intrinsic properties of a problem related to cognitive requirements and associate these with neural dynamics. (2. Methods) We performed an experiment in which 20 participants solved several instances of the 0-1 knapsack problem, a combinatorial optimization problem, while undergoing ultra-high field (7T) functional magnetic resonance imaging (fMRI). Instances varied in two task-independent measures of intrinsic computational hardness: complexity and proof hardness. (3. Results) We first replicated previous behavioral results. We show that the task-independent metrics of complexity do affect decision quality. Participants spend more time on instances with higher complexity and perform worse on these instances. When considering the neural correlates of complexity and proof hardness, we characterise a network of brain regions whose activation was correlated with both measures but in distinct ways, including the anterior insula, dorsal anterior cingulate cortex and the intra-parietal sulcus/angular gyrus. Of note, in line with our conjecture, we found neural markers of proof hardness in the cingulo-opercular network. These overlap with regions associated with neural markers of uncertainty in probabilistic tasks. Additionally, we investigated the effect of proof hardness and complexity on functional connectivity. We found, in line with our hypothesis, that during the solving stage of the task, connectivity patterns changed. However, contrary to our expectations, we found no significant effect of proof hardness nor complexity on the strength of this connectivity. (4. Conclusions) Task-independent metrics of computational hardness allowed us to discover relevant neural markers and their dynamics, similar to how risk and variance have been shown to affect decisions in probabilistic tasks. Our results suggest that computational complexity theory provides a suitable general and well-founded theoretical framework for the study of the neural underpinnings of problem-solving, that unlike previous frameworks, can be applied to a large collection of problems.

O.03.02: A Neural Autopilot Theory of Habit: Evidence from Canned Tuna

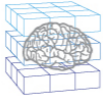
Colin Camerer¹, Peter Landry², Matthew Osbourne², Ryan Webb², Clarice Zhao³

¹CalTech, ²University of Toronto, ³McGill University

Habits are an important feature of human behaviour. They are not merely prevalent, there is also a wide and implicit recognition of their significance to our well-being. In economic modelling, habits are typically modelled as preference complementarity, whereby the utility for a good increases after consumption (Becker & Murphy, 1988). While this "state-dependent utility" approach captures

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persistence in consumption over time, it ignores the primary benefit of a habit as conceptualized in psychology and neuroscience -- that seemingly complex behaviours can be automated at little cognitive cost. In this paper, we study a model of habitual consumption behaviour based on findings in psychology and neuroscience, and compare it to the state-dependent utility approach. In psychology, habits are considered a form of automatic behaviour which is directly cued by contexts (e.g., locations and preceding actions) that have been learned to be rewarding. Building on this definition, Landry, Camerer & Webb (2021) introduce a theory of habitual choice based on the finding in neuroscience that the reliability of 'reward prediction errors' guide human learning. Two modes of decision-making are proposed: a "habitual" mode in which the previous choice is automatically repeated, and a "model-based" mode in which utility is maximized using all available information. To arbitrate between these systems, the consumer learns utility predictions and tracks their reliability. The consumer enters a habit when outcomes are reliable (i.e. when choice outcomes match predictions) and exits habit mode when there is sufficient doubt about their utility predictions. To test our theory of habit, we analyze 12,524 consumer purchases of canned tuna from 2006-2010: a tumultuous period in the tuna industry. In 2008, producers shrunk the size of their packaging in the US market from 6oz to 5oz per can, staggered across brands and stores. This downsizing event occurred in a product category that had been relatively stable, and preceded a significant adjustment in prices and relative market share between brands. Both factors make it ideal to test a model of how fluctuations and instability in the economic environment can lead to broken habits. Our structural model of habitual choice provides a direct test for habitual autopilot, as well as an estimate of the proportion of consumers who are habitual in any given period. We compare this model to the state-dependent utility model and find that Neuro-Autopilot provides a significantly stronger account of persistence in consumer choices, and that the degree of state-dependence in utility has been previously over-stated.

O.03.03: Uncertainty alters the balance between incremental learning and episodic memory

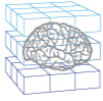
Jonathan Nicholas¹, Nathaniel Daw², Daphna Shohamy¹

¹Columbia University, ²Princeton University

1. Objective: Memory can guide effective decision making in at least two ways: incremental learning, which consists of consulting an average value acquired from trial-and-error over many past experiences, or one-shot learning, which relies on unique episodic memories. While there have been major advances in understanding incremental learning, less is known about the circumstances under which episodic memory guides choice, and about how these two approaches interact. Here we hypothesize that uncertainty about rewards modulates the extent to which decisions are guided by either episodic memory or incremental learning. In particular, we reason that episodic memory contributes to decisions when value estimates derived from incremental learning are uncertain. 2. Methods: We developed a task that allowed us to i) independently measure the contribution of episodic memory to choice and ii) manipulate the impact of uncertainty on episodic memory-based choices. Participants chose between two decks of cards for which expected value reversed periodically across two environments: one more volatile (higher uncertainty) and one less volatile (lower uncertainty). Each deck also featured trial-unique objects that could re-appear once after being chosen and were worth an identical amount both times. Participants could thus use either incremental learning or episodic memory to guide their choices.

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We assessed how deck volatility and trial-wise uncertainty (derived from a computational model) affected the degree of episodic choice. Two online samples of healthy young adults (ages 18-35; primary $n=254$; replication $n=223$) completed the task. Analyses were conducted using mixed effects logistic regressions fit with Bayesian inference. 3. Results: Consistent with our hypothesis, we found greater evidence for episodic choices in the high compared to the low volatility environment ($\beta = 0.8$, 95% CI = [0.02, 0.15]). Episodic value also impacted choices more when trial-wise uncertainty was high ($\beta = 0.09$, 95% CI = [0.05, 0.13]). These results replicated in a separate sample. 4. Conclusions: The uncertainty induced by volatile environments impacts whether incremental learning or episodic memory is recruited for decisions. Greater uncertainty increased the likelihood that single experiences were retrieved for decision making. This effect suggests that episodic memory aids decision making when simpler sources of value are less accurate. By focusing on uncertainty, our results tie together disparate findings about when episodic memory is recruited for decisions and shed light on the exact circumstances under which the computational expense of episodic memory is worthwhile.

O.03.04: Reduced certainty preference after solving problems with insight versus analysis

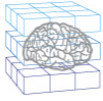
Yuhua Yu¹, Carola Salvi², Mark Beeman¹

¹Northwestern University, ²University of Texas at Austin

Objectives: Many significant discoveries are associated with insight, or Aha! moment. Few studies, however, have examined the impact of insight on subsequent decision making. This is an important question because, after people have an insight to solve a hard problem, they often have to make the decision on the next step. The current project investigated how, on a trial-by-trial basis, different ways of solving problems affect individuals' risk preferences on a separate decision involving monetary payout. An insight often involves sudden reorganization of a mental representation. In contrast, when people solve with analysis, they take a gradual and step-by-step approach. Prior work suggests the two ways of solving emphasize different cognitive processes. Insight often invokes positive affect and is putatively associated with activity in reward processing circuits. We hypothesized that, after an insight, people are more likely to choose a bonus payout with a higher reward possibility. **Methods:** Participants recruited from Amazon Mechanical Turk were asked to solve compound remote associates (CRA), a type of short verbal puzzle that can be solved via insight or step-by-step analysis. Following each CRA, participants were asked to make a bonus choice between a fixed payout (25¢), or a risk payout with 50% chance to receive a low (5¢) and 50% chance to receive a high amount (e.g., 45¢). The bonus choice was calibrated to each participant's baseline risk preference using a survey conducted at the beginning of the session. Because we set each participant's choice around their own neutral baseline, the subtle effect of solving puzzles with insight may bias them toward choosing the risk payout. **Results:** In Experiment 1, we retained data from 149 participants (out of 331 total tested) after excluding participants for failing the attention check or for not providing data in all conditions. As predicted, participants chose the risk payout more often after solving with insight ($41.6 \pm 2.7\%$) than solving with analysis ($37.4 \pm 2.7\%$) [$t(149) = 2.07$, $p = 0.040$]. Analysis by sex showed that this difference is primarily driven by men [$t(65) = 2.35$; $p = 0.025$] rather than women [$t(84) = 0.84$, $p = 0.402$]. We replicated these findings in a second online experiment with a highly similar design. **Conclusions:** Across two experiments, we demonstrated a carryover effect: participants showed reduced certainty preference on a separate decision after solving

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with insight versus with analysis. The current project has implications in everyday life, especially in understanding investor behavior.

O.04: Self and Other

O.04.01: Is Social Decision-Making linked to the Gut Microbiome?

Marie Falkenstein¹, Marie-Christine Simon², Aakash Mantri², Leonie Koban¹, Hilke Plassmann³

¹Paris Brain Institute (ICM), INSERM, CNRS, Sorbonne Université, ²Universität Bonn, ³INSEAD, Paris Brain Institute (ICM), INSERM, CNRS, Sorbonne Université

Objective: Social decision-making is crucial for successful cooperation and social interactions in general. It is therefore important to understand contextual and physiological factors that influence social decision-making. The gut-brain axis - the bidirectional flow of information between gut and brain - can potentially influence behavior and previous research suggests effects of dietary factors on decision-making. Yet, whether and how the composition of gut microbiome - the bacteria and other microorganisms populating the human gut - may influence social decision-making in humans is largely unknown. Here, we tested the effects of a dietary intervention targeted to alter the gut microbiome on social decision-making in an Ultimatum Game (UG). We hypothesized that 1) the intervention changes the diversity and the composition of the microbiome, and that 2) changes in social decision-making can be explained by changes in microbial composition. **Methods:** We used a double-blind placebo-controlled study design. We tested 102 male participants (Mage = 32, SD = 11) before and after a 7-week intervention, in which they consumed either a placebo or a synbiotic supplement every day. The composition of the microbiome was assessed by 16S rRNA V3V4 gene sequencing of collected fecal samples. In 20 trials of a UG (one-shot with different other people), participants had to decide whether to accept or reject offers ranging from 0 to 5 out of 10 Euros. We used non-parametric tests and linear models to test our hypotheses. **Results:** 1) Linear regression revealed a group difference in β -diversity (change in microbiome composition from pre to post intervention), controlling for Firmicutes/Bacteroidetes ratio (FB; linked to maintaining normal intestinal homeostasis), age and BMI ($R^2 = 0.21$, $F(5, 74) = 3.91$, $p = .003$). We also found an interaction between baseline FB ratio and group to influence β -diversity ($p = .050$). 2) Changes in rejection behavior for medium offers were predicted by an interaction of baseline FB ratio and group ($p = .013$), such that participants in the treatment group with a high baseline FB ratio, showed a greater increase in rejection of medium offers. **Conclusion:** In sum, we found that a small dietary intervention influenced gut microbiome composition and social decision-making, as a function of baseline gut microbiome factors. Future research could further investigate the mechanistic pathways of this effect and test the gut microbiome as a potential target for interventions to improve social decision making.

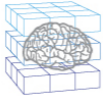
O.04.02: Neuroforecasting Online Dating: Deconstructing Aggregate Choice Forecasting From Small Samples Using Neural and Behavioral Measures

Steven Shaw¹, Vinod Venkatraman², Carolyn Yoon¹

¹University of Pennsylvania, ²Temple University

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The ability to predict the behavior of individuals or future events (e.g., new product success) is of extreme value to marketers. In this paper, we advance our understanding of decision-making and choice by assessing behavioral and neural approaches to forecasting aggregate choices in a simulated online dating market sample ($n > 600$). In accordance with the affective-integration-motivation (AIM) framework, we propose that affective neural components of individual choice are most useful for aggregate forecasting from small samples. **Methods** We developed 36 standardized dating profiles using a factorial design: attractiveness (high, medium, low), age (19-23, 24-28), facial expression (neutral, smiling), and profile description (hobbies/likes, SES/occupation, and personality traits). While in an fMRI scanner, respondents made binary 'like' or 'pass' choices, and subsequently rated each profile on attractiveness, career prospects, likability of personality, and likelihood that the individual in the profile will 'like' them back (i.e., choice decomposition variables). **Results** Hierarchical regression analyses revealed that affective neural activity in the nucleus accumbens (NAcc) peaked earlier than integrative neural activity in the ventromedial prefrontal cortex (vmPFC) for liked profiles, and was significantly associated with out-of-sample aggregate choice likelihood ($t = 0.67$, $p < 0.001$). Similarly, fMRI sample aggregate attractiveness ($t = 0.24$, $p < 0.001$) and likeback ($t = 0.10$, $p < 0.01$) were associated with greater choice likelihood in the market data. Further, the relationship between NAcc activity and market-level aggregate choice was attenuated when participants' ratings of attractiveness, a key proxy for affect in this context, were included in models ($t = 0.03$, $p = 0.69$). Training models with aggregate fMRI sample choice decomposition variables to forecast aggregate choice likelihood of held out profiles in the market sample (75/25 train/test; 50 iterations) resulted in 33.1% accuracy using attractiveness alone and 29.2% accuracy using NAcc activity alone, the highest among behavioral and neural variables, respectively. **Conclusions** The present research complements the AIM framework, and illustrates that in the context of online dating decisions, affective components of choice can effectively neuroforecast consumers' choices. Further, we provide evidence that in certain contexts, researchers may be able to create proxies of affect that can effectively scale to forecast market-level choices without neural data.

0.04.03: Damage to ventromedial prefrontal cortex decreases effortful prosocial behaviours

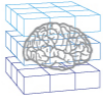
Jo Cutler¹, Matthew Apps¹, Daniel Drew², Deva Jeyaretna², Masud Husain², Sanjay Manohar², Patricia Lockwood¹

¹University of Birmingham, ²University of Oxford

AIMS: The precise role of vmPFC in decision-making remains strongly debated. Neuroimaging suggests a key role in social behaviour, effort-based decisions and reward processing. In parallel, lesion studies show vmPFC damage changes these cognitive processes. However, imaging methods cannot establish causality and many experiments with patients use small samples and unincentivized or hypothetical social paradigms. Here we dissociated the causal contribution of vmPFC in prosocial behaviour (decisions causing real beneficial outcomes for another person), effort and reward with an effort-based decision-making task that manipulates these factors independently. **METHODS:** Participants chose to rest or 'work' (30-70% of their maximum grip strength) to earn rewards for themselves or prosocially for an anonymous other person. We compared a large group of patients with focal vmPFC lesions ($n = 25$, age 37-76, 14F) to patients with lesions elsewhere (lesion controls; LC; $n = 16$, age 28-74, 11F) and healthy controls (HC; $n = 40$, age 36-67, 23F), all carefully matched on age, gender and education. Taking

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a computational neurology approach, we used models to quantify how the required effort cost was integrated with reward to determine choices. RESULTS: Strikingly, vmPFC patients earned significantly less for the other person, but similar amounts for themselves, compared to both control groups (vmPFC vs LC $\beta=0.86$, $p=0.006$; vs HC $\beta=0.88$, $p=0.002$). Analysis of choices showed this self-other difference was due to decreased willingness to work for other following vmPFC damage, whilst self-benefitting choices were preserved (vmPFC vs LC OR=0.46, $p=0.007$; vs HC OR=0.60, $p=0.026$). Computational modelling further revealed that vmPFC patients' reduced prosociality was due to higher discounting of reward by effort (κ) when decisions benefitted another person (vmPFC vs LC $\beta=1.49$, $p<0.001$; vs HC $\beta=1.36$, $p=0.002$). Changes in decision noise did explain group differences in prosociality. Finally, decreased energisation of prosocial actions also reduced earnings as vmPFC patients exerted less force for others (interaction $ps<0.05$). Lesions to vmPFC additionally altered sensitivity to effort overall, but not reward, compared to healthy controls (OR=0.44, $p<0.001$). CONCLUSION: Our findings suggest a specific and causal role of vmPFC in prosocial behaviour. Damage to this region decreases how much patients choose to help and energise actions that benefit others. vmPFC lesions also affect sensitivity to effort, whereas reward sensitivity remains intact. This computational neurology approach could be key for understanding the causal role of specific brain areas in prosociality, effort and reward.

O.04.04: Listen to yourself: An fMRI study of motivational interviewing effects on dietary decision-making

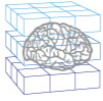
Belina Rodrigues¹, Martine Rampanana¹, Solène Frileux¹, Iraj Khalid¹, Liane Schmidt¹

¹Paris Brain Institute - ICM (Institute du Cerveau (ICM), UMR 7225, U1127, Institut National de la Sa

Motivational interviewing (MI) is an evidence-based approach which aims at strengthening one's motivation for a specific goal by eliciting the reasons for change, i.e. change talk (CT), and decreasing reasons against change, i.e. sustain talk (ST). MI emerged in the context of addiction treatment, and unhealthy, addiction-like behaviour. However, whether and how MI changes valuation and decision-making in the food context is unknown. Here, we built on models of economic choices, which propose that choice formation involves a valuation phase during which features, such as healthiness and tastiness of food, are integrated into stimulus value (SV) that approximates preferences and drives choices. Activation of the ventromedial (vmPFC) and dorsolateral prefrontal cortex (dlPFC) have been shown to play a crucial role in valuation. Objectives: Here, we focused on these two brain regions, and tested whether (1) the type of talk influenced valuation and valuation-related brain responses, and (2) how one's readiness to change moderated these effects. Methods: Twenty-seven healthy female participants (age=29±2.01 y, BMI=23.4±1.09kg/m²) underwent a MI session from which 5 CT and 5 ST statements were extracted along with a measure of the extent to which one was ready to change a given eating pattern (via the readiness ruler). One week later, prior to the fMRI session, participants rated the food items in terms of tastiness and healthiness. Then, during the fMRI session, they listened to their statements before making incentive-compatible dietary choices. Results: The behaviour results showed a significant interaction between type of talk (CT vs ST) and type of rating (healthiness vs tastiness), which indicated that participants weighted the tastiness more and the healthiness less after ST. On the contrary, healthiness and tastiness determined food choices to a similar degree after CT ($F(3, 104)=15.06$, $p\leq.001$). Interestingly, this interaction was mirrored by the activation of the vmPFC in

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response to tastiness and healthiness at the time of choice formation ($p_{FWE} \leq .05$ small volume corrected, $\beta_{ST \times HR} = -.097 \pm .050$, $\beta_{ST \times TR} = .170 \pm .047$, $\beta_{CT \times HR} = -.014 \pm .034$, $\beta_{CT \times TR} = .028 \pm .031$, $F(3, 104) = 7.39$, $p \leq .001$). Correlations to the readiness to change revealed that those who were least ready to change activated the superior frontal gyrus, part of the dlPFC, more strongly in response to healthy food after CT ($p_{FWE} \leq .05$). Conclusion: These findings indicated that CT and ST differentially influenced how healthiness and tastiness features predicted food SV, and how regions within the brain's valuation and cognitive self-regulation systems encoded these features during dietary decision-making.

Poster Spotlights

Poster Spotlights I

PS.01.01: A rational account of the repulsion effect

Rahul Bhui¹, Yang Xiang¹

¹MIT

OBJECTIVE: The attraction effect occurs when the presence of an inferior option (the decoy) increases the attractiveness of the option that dominates it (the target). Despite its prominence in neuroeconomics, recent evidence from both economic and perceptual judgment points to the puzzling existence of the opposite phenomenon (where the decoy reduces preference for the target)---a "repulsion effect". In this project, we formally develop and experimentally test a normative account of the repulsion effect, based on the idea that a decoy can signal that the target also has low value when both are believed to be generated by a similar process. **METHODS:** Theoretically, we formalize this logic using a hierarchical Bayesian cognitive model that makes predictions about how the strength of the repulsion effect should vary with statistical properties of the context. We show how this theory can help account for several documented phenomena linked to the repulsion effect. We also conducted four new experiments to test our theory. In experiments 1 ($n = 449$) and 2 ($n = 449$), we used a multi-attribute consumer choice paradigm and varied whether the decoy was said to be from the same group as the target. In experiments 3 ($n = 80$) and 4 ($n = 86$), we used an abstract value judgment paradigm and varied the extent to which items had correlated values. **RESULTS:** In experiments 1 and 2, preference for the target was reduced ($p = .004$ and $p = .017$) and was lower than the competitor ($p < .001$ and $p = .004$) when the decoy and target were from the same group. In experiments 3 and 4, judgments of target value were biased downward by decoy attributes ($p = .002$ and $p < .001$) especially when their latent values were more correlated ($p < .001$ and $p = .002$). **CONCLUSION:** Our results support this unifying normative account of the repulsion effect, which complements more mechanistic perspectives and sharpens our understanding of when and why decoys can be detrimental.

PS.01.02: Searching for Happiness: How Web-Browsing Patterns are Related to Wellbeing

Christopher Kelly¹, Tali Sharot¹

¹University College London

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Objective: People spend half of their waking hours online. Most of this time is dedicated to searching for and consuming information. A critical question is whether the characteristics of information that people expose themselves to online reflect and shape their well-being. If information-seeking patterns can be measured by analyzing individuals' web searches, then we can use this approach to facilitate the diagnosis and intervention of mental health problems. Here, we combine natural language processing and machine learning to test whether individuals with poorer mental health consume more negative/positive information from self-guided searches and whether this information is more/less semantically similar across webpages browsed (i.e., more/less erratic). **Methods:** Participants (Exp 1 N = 307; Exp 2 N = 356) submitted the history of their web-browsing sessions. We extracted the text from the webpages they visited. The text was fed to algorithms that use natural language processing and supervised machine learning to quantify two characteristics: the valence (positive/negative) of information and semantic similarity (i.e., the extent to which webpages are semantically related to each other). These scores were then related to a composite score of self-reported mental health questionnaires and mood ratings before and after browsing. **Results:** Within individuals, valence and semantic similarity scores were fairly stable over time (Valence: ICC = 0.621, $p < 0.001$; Semantic Similarity: ICC = 0.617, $p < 0.001$), suggesting they partially reflect 'trait-like' features. Importantly, individuals whose self-guided searches led to more negatively valenced information reported poorer mental health (Exp 1: $R = -0.129$, $p = 0.02$; Exp 2: $R = -0.160$, $p = 0.002$;) and worse mood post-browsing (Exp 1: $\beta = 0.048$, $p = 0.015$; Exp 2: $R = 0.110$, $p = 0.047$; controlling for pre-browsing mood). We did not observe a relationship between the semantic similarity and well-being. All analysis control for age and gender. Algorithmic scores correlated with those of human raters (Valence: $R = 0.565$, $p < 0.001$; Semantic Similarity: $R = 0.745$, $p < 0.001$), suggesting they are valid. **Conclusion:** We provide evidence for a relationship between the characteristics of information people consume online and their mental health. The research can inform the development of tools for early detection of mental health problems from analysis of web-browsing patterns, as well as the development of tools that improve mood by altering online information consumption choices.

PS.01.03: Expectation-dependent evidence evaluation in legal decision-making

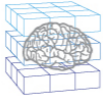
Seth Madlon-Kay¹, Artemis Malekpour, David Ball, Donald Beskind¹, Pate Skene², John Pearson¹

¹Duke University, ²University of Colorado Boulder

Objective: How do people integrate opposing pieces of evidence when making decisions in realistic situations? Here, we study legal decision-making from the perspective of a juror as is a real-world example of a situation requiring the integration of complex and opposing pieces of evidence in order to make a judgment. **Methods:** We asked 465 participants to read a series of 31 criminal cases and judge them as though they were serving on a jury. Each case contained a brief description of the criminal charge against the defendant and up to four pieces of evidence. Each piece of evidence could take on three possible levels: inculpatory, exculpatory, and ambiguous. The level of each piece of evidence was randomized for every case. We also examined the role of expectations by assigning participants to one of two contexts: a "balanced" context in which inculpatory and exculpatory evidence were equally likely, and a context with only "credible" cases, in which inculpatory and ambiguous evidence always outnumbered exculpatory evidence. **Results:** We found that legal judgments were well-explained by a

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model derived from perceptual decision-making in which participants independently assign evidentiary weights to each piece of evidence, and integrate evidence by adding those weights together. We also find that in the "balanced" context, judgments favor the prosecution in two ways: first, a criminal charge without any evidence is treated as inculpatory evidence, and second, inculpatory evidence outweighs exculpatory evidence. Changing the distribution of evidence to show only credible cases caused paradoxical changes: the evidentiary value of an accusation increased to even further favor the prosecution, but the weights of all evidence shifted downwards to favor the defense. To explain these opposing effects, we develop a model in which agents learn via an error-driven update rule to anticipate the evidentiary strength of the average case, and they evaluate observed evidence relative to that expectation. When the average case is strong, the weight of an accusation is high because the agent expects it to be backed up by evidence; observed evidence then favors the prosecution less because inculpatory evidence is expected, but exculpatory evidence is surprising. Conclusion: We demonstrate that models of learning and decision-making derived from cognitive research in laboratory tasks can be directly applied to complex real-world decisions like legal judgments. Our results suggest that judgments are biased towards prosecutors in part because of expectations that they have strong evidence, but that also these expectations can be modified by learning.

PS.01.04: Early and late neural components distinguish expectation formation and outcome processing

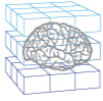
Matthew Bachman¹, Kaya Scheman², René San Martín³, Marty Woldorff⁴, Scott Huettel⁴

¹University of Toronto, Scarborough, ²National Institute of Health, ³Universidad Diego Portales, ⁴Duke University

Objective: Decision makers must form and update their expectations about the likelihood of possible outcomes and adapt accordingly as new information is acquired. Previous EEG studies have shown how reward expectations can influence the processing of actual outcomes, but far less work has investigated expectation formation. In this study, we investigated the neural processes underlying expectation formation in addition to outcome processing. Furthermore, we leveraged the high temporal resolution of EEG to uncover how reward expectations influence both early and late components of outcome processing. **Methods:** EEG data were collected as participants ($n=32$) tried to earn money by correctly selecting which of two colored circles would win on each trial. We manipulated participants' expectations after each choice by delivering information about that trial's outcome in two stages. First, participants learned their probability of winning, ranging from 0% to 100%. Then the actual outcome was revealed in a second stage. Our analyses focused on two temporally distinct ERPs: the Reward Positivity (RewP), an early latency component reflecting a signed reward prediction error in the anterior cingulate cortex, and the P3, a later latency component reflecting the attention-driven updating of outcome-related information. **Results:** We used rmANOVAs to assess how RewP and P3 amplitude changed during each stage. At the outcome-probability stage, we tested their sensitivity to outcome valence (win vs loss) and certainty (certain vs uncertain outcomes). We found that the earlier RewP was independently larger for wins and certain outcomes. The later P3 was also larger for certain outcomes and larger still for certain losses. At the actual-outcome stage, we tested these ERPs' sensitivities to valence and expectations (expected, 50/50, and unexpected). Here, the RewP was sensitive to

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expectations but only when the participant won, with larger RewPs for more unexpected wins. P3 win activity was also larger for more unexpected wins. P3 loss activity was sensitive to expectations as well, peaking in the most ambiguous condition. Conclusions: Our results indicate that the earlier RewP displays a preferential sensitivity to wins and especially unexpected ones, aligning with prior work suggesting that it may reflect a signed reward-prediction error. Conversely, the P3 displayed several unique interactions between valence and certainty/expectations across both stages, indicating that each circumstance requires a differential distribution of attentional resources. These findings highlight the various ways in which reward expectations can exert their influence upon neural processing.

PS.01.05: Representations of Flexible Cognitive Maps for Value-based Decision-Making

Sarah Sweigart¹, Seongmin Park¹, Nam Nguyen¹, Charan Ranganath¹, Erie Boorman¹

¹*University of California, Davis*

Objective: Neural representations of relationships between entities, known as a cognitive map, allow for quick learning, generalization, and inferencing for efficient decision making. Regions such as the entorhinal cortex (ERC), hippocampus (HPC), and medial prefrontal cortex (mPFC) have been implicated in constructing and storing cognitive maps. However, it is currently unknown how the brain flexibly uses cognitive maps to solve novel problems and how changing task-relevant features are represented in the brain. **Methods:** Here, we designed a novel 2D wine-space characterized by two dimensions: taste (sweet to dry) and body (light to full). Participants (n=21) learn the space through dyad comparison and could construct a cognitive map to guide novel inferences between novel wine pairs. Critically, the subjects never visually see the wine space nor get feedback on the size or shape of the space. During fMRI scanning, participants completed a country task, where they had to evaluate which wines would be preferred based on a country's preference. Countries preferred either one attribute (e.g., full) or preferred two attributes equally (e.g., sweet and light). This required the participants to combine their knowledge of the different contexts to correctly choose the correct wines in the absence of feedback. **Results:** Neurally, we found strong univariate effects for task-relevant value difference information in the HPC, ERC, and mPFC ($p < 0.05$ TFCE-corrected). Whole-brain representational similarity analyses identify flexible rank 'position' (or context-dependent 'value') representations in posterior parietal cortex and orbitofrontal cortex. **Conclusion:** These findings suggest that cognitive maps are used more flexibly than some previous models have indicated and elucidate the mechanisms of value-based decision-making based on a cognitive map.

PS.01.06: Emotional lability relates to adaptive learning across environmental contexts

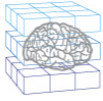
Sophie Paolizzi¹, Michael Hallquist¹

¹*University of North Carolina at Chapel Hill*

Introduction. Adaptive learning in volatile contexts requires frequent updating of behavior in response to surprising information that indicates an environmental shift. For example, tracking when a conversational counterpart's tone has shifted is critical in adapting one's own social behavior. However, behavioral adjustments are not always made precisely when true changes occur. Instead, learners adapt when they infer such a "change point" (CP) in the environment. We hypothesized that sensitivity to CPs

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relates to the ability to adaptively shift learning strategies differentially across stable and volatile states. Furthermore, we examined whether emotional lability would relate to an increased propensity to interpret large prediction errors as CPs. **Methods.** We collected task data from 135 individuals. The goal is to place a "shield" in the optimal location to prevent a cannonball strike. In a "volatile" condition, it is advantageous for participants to incorporate large prediction errors (PEs) in shield placement into their updated shield placement on the following trial, as these large PEs indicated that the cannonballs had shifted locations. In another "stable" condition, it is adaptive to discount large PEs that reflect "oddballs", or stray shots that were not reflective of a broader CP in the cannonball distribution. Using multi-level models, we tested the effects of both task characteristics (e.g., true CPs, task conditions) and scores on self-report measures related to specific behavioral traits (e.g., emotional lability, anxiety) on participant's updating behavior across the task. **Results.** We found that (1) PEs were tightly linked with updating behavior, suggesting that participants utilized information from PEs throughout the task ($B = .64, p < .0001$); (2) PEs and CPs drove updating differentially in a manner consistent with our hypothesis: people made comparatively smaller updates in the face of "oddballs" in a relatively stable distribution of shots, while "changepoints" preceded larger updates ($B = -.28, p = .0001$); and (3) self-reported emotional lability predicts increased sensitivity to potential CPs in the underlying distribution in the task ($B = -.01, p = .003$). We are in the process of fitting task data with a reduced Bayesian model designed to flexibly update in the face of uncertainty. **Conclusions.** This study confirmed our hypotheses related to adaptive learning dynamics across stable and volatile contexts and confirmed that the detection of environmental shifts is critical in shaping learning dynamics. We also found evidence for our second hypothesis, that emotional lability modulated sensitivity to environmental volatility.

Poster Spotlights II

PS.02.01: Continuous Tracking of Perceptual and Value-Based Evidence

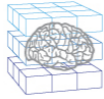
Minhee Yoo¹, Giwon Bahg², Brandon Turner¹, Ian Krajbich¹

¹The Ohio State University, ²Vanderbilt University

(1) **Objective.** While the literature tends to focus on two-alternative forced choice, many decisions we make are based on a continuous scale and require temporal integration of incoming information. For example, how much we like a restaurant may be based on the average of prior experiences in that restaurant. Despite the abundance of these types of decisions in our daily life, the neural and computational mechanisms of such decisions has not been well studied. Our study investigated the evidence averaging process using a modified interrogation paradigm along with computational modeling, eye tracking, and fMRI. (2) **Methods.** The evidence averaging task had two blocks each of a perceptual task and a value-based task. In each trial, 30 pairs of square grids (perceptual task) or snack foods (value-based task) were presented in series; subjects ($N = 38$) had to judge the whiteness of the grids or the tastiness of the foods. Subjects continuously reported their estimates of the average evidence favoring left vs right (using a joystick) while we measured their brain activity and eye gaze. We modeled behavior with the Averaging Diffusion Model (ADM) (Turner et al., 2017). A temporal weighting function was added to ADM to assign differential weights to information sampled at different time points in a trial. ADM was fitted separately to each subject's perceptual and value-based data. (3) **Results.** Modeling results revealed that subjects had a recency bias in the evidence averaging process.

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The degree of this bias was very stable within an individual (Correlation between parameter estimates in the perceptual and value-based tasks: primacy: $r(36) = .57$, $p < .001$; recency: $r(36) = .63$, $p < .001$; noise: $r(36) = .84$, $p < .001$). Neuroimaging analyses revealed domain-specific brain regions for tracking instantaneous evidence (IE), the evidence favoring left vs right in a single pair of stimuli. Intraparietal sulcus tracked IE in the perceptual task, whereas the reward network - VMPFC, VS, PCC - tracked IE in the value-based task. We also found domain-specific brain regions for tracking average evidence (AE), the evidence favoring left vs right averaged over all the sampled stimuli in the trial. Visual cortex was involved in tracking AE in both tasks, whereas dorsolateral prefrontal cortex was selectively engaged in tracking AE in the value-based task. (4) Conclusions. Results from our study provide novel evidence on how the brain tracks average evidence over time. Despite remarkable behavioral consistency between perceptual and value-based tasks, the evaluation and integration of evidence appears to arise, at least partly, in distinct neural circuits.

PS.02.02: Gaze and choice dynamics in decisions with interacting attributes

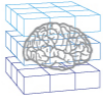
Xiaozhi Yang¹, Wenjia Zhao¹, Lisheng He², Sudeep Bhatia³, Ian Krajbich¹

¹*the Ohio State University*, ²*Shanghai International Studies University*, ³*University of Pennsylvania*

Objective: In multi-attribute decisions, one attribute value may influence the evaluation of another attribute. For example, in risky choice, a payoff might be weighted more (through increased sampling) if its associated probability is higher. It has been argued that this "interactive sampling" strategy is important, because otherwise paired elements do not influence each other any more than unpaired elements. In this project, we examine this sampling strategy and test its impact on choice, using eye-tracking & computational modelling in multiple choice domains. **Method:** Subjects ($N = 52$) in this study first rated how much they would like to consume various foods and donate to various charities. Subjects then proceeded to the four choice tasks while we tracked their eye movements. For all the tasks, each option included two pairs of elements. Subjects were told that there was a 50/50 chance that they would receive one or the other pair. The following are descriptions and examples of a single option for each task: 1) risky choice: two gambles (e.g., 70% to win \$4.50 or 45% to win \$7.00) 2) intertemporal choice: two delayed outcomes (e.g., \$10 in 1 day or \$5 in 4 days) 3) charity choice: two donations (e.g., \$10 to CARE or \$0.80 to LGBT Fund) 4) consumer choice: two foods (e.g., 10oz of chestnuts or 3oz of walnuts) **Results:** We found that attribute value is correlated with complementary attention in all the tasks. However, the strength of the association depended on the task and the attribute. For example, in the risky domain, we found both strong and positive effect for probability driving attention to payoffs ($r = 0.85$; $p < 0.01$) and for payoffs driving attention to probabilities ($r = 0.71$; $p < 0.01$). In contrast, in the food domain, we found a marginal effect of food tastiness on attention to food quantity ($r = 0.19$, $p = 0.06$), but no effect of food quantity on attention to food identity ($r = 0.15$, $p = 0.58$). Next, we tested the correspondence between interactive sampling and choice. We found this mechanism is positively correlated with the proportion of choice consistent with expected value in risky ($\beta = 0.41$, $p < 0.01$) and charity choice ($\beta = 0.37$, $p = 0.01$), but not in the consumer and intertemporal choice. **Conclusions:** In summary, we do find fairly consistent evidence for the hypothesis that gaze patterns (i.e. information sampling) depend on paired attribute values. Moreover, the strength of these tendencies predicts choice behavior in some domains. These results reveal important attentional considerations for models

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of multi-attribute decision making.

PS.02.03: The impact of overall value on preferential and perceptual choices

Chih-Chung Ting¹, Sebastian Gluth¹

¹University of Hamburg

Study objectives: There is growing empirical evidence that decisions are not only affected by value differences or perceptual discriminability but also by the overall sum of option values or by overall perceptual intensities. Specifically, people tend to make a faster decision when choosing between two very attractive/high-intensity options than choosing between two less attractive/low-intensity options. However, the underlying mechanism of these effects of overall value on the speed of decisions remains elusive. Similarly, whether and how overall value also affects choice accuracy is unclear. Accordingly, in this project we set out to address the questions of how overall value is involved in the choice process in different domains of decision making and influence other decision patterns beyond response time (RT). **Methods:** The experiment consisted of two tasks, a value-based (food) choice task, and a perceptual (brightness discrimination) task. Each task was separated into a rating and a choice stage. In the rating stage, participants (N=30) were asked to rate the subjective value/brightness of snacks/grayscale patches. The options were categorized into a 3-by-3 matrix of value difference levels (VD) and overall value levels (OV). In the choice stage, participants made binary decisions between food snacks/grayscale patches, with options being systematically sampled from all of the nine cells of the VD-by-OV matrix. In addition to measuring choices and RT from these binary decisions, we also asked participants to state their confidence about choosing a better option and recorded eye movement during the binary-choice tasks. **Results:** In line with previous work, we found significantly negative effects of OV on RT in both choice domains (perceptual: linear regression coefficient (β)=-2.83, $p=.0289$; preferential: β =-3.89, $p=.0046$), as well as positive effects on confidence ratings (perceptual: β =5.42, $p<.001$; preferential: β =9.73, $p<.001$). In contrast, the effect of OV on choice consistency/accuracy was more complicated and differed across tasks. In particular, participants tended to be more accurate when overall objective brightness was higher (β =1.95, $p=.0501$). In preferential decision, however, we found a quadratic relationship between OV and choice consistency with participants making being least consistent when OV was at a medium level (quadratic regression coefficient=4.50, $p<.001$). **Conclusions:** Our results demonstrate that OV strongly influences various choice processes, challenge some of the effects of OV on choice consistency reported in previous literature, indicate that OV effects are in part domain-specific.

PS.02.04: Testing the optimisation hypothesis by tracking changes in decision strategy in a reward maximisation task

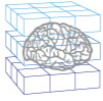
Erik Stuchlí¹, Casimir Ludwig², Gaurav Malhotra¹

¹University of Hamburg, ²University of Bristol

Normative theories of decision-making examine how behaviour is guided by the process of optimising a task variable. In models of perceptual decision-making, a task variable that is frequently implicated to modulate behaviour is reward-rate - the average reward gained over a sequence of decisions. Many

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studies have argued that optimising reward rate guides the selection of parameters used to accumulate evidence during the process of making perceptual decisions. Indeed, empirical evidence has shown that participants modulate their decision thresholds in response to a change in the reward structure of a task. Most of these studies only looked at the average behaviour of a participant over the entire experiment; however, optimizing reward rate involves a learning component, which is very likely accompanied by a change in decision strategy over time. As such, if participants truly aim to maximise reward rate, one should be able to observe how their behaviour is guided by this goal over the course of the experiment. In order to investigate this, we analysed data from an expanded judgment task where the goal was to maximize reward rate ($n = 24$ participants) and used a logistic regression model to estimate the height and slope of the decision threshold in a sliding window of trials. We observed that the majority of participants explored the threshold parameter space throughout the task, rather than settling on a specific threshold early on. Importantly, this exploration was seemingly not driven by the search for a maximum reward-rate - throughout the experiment, participants frequently switched to parameters that yielded relatively lower reward rate. Consequently, the majority of participants (17 out of 24) failed to approach the threshold parameters that were optimal with respect to the task. This pattern can likely be attributed to the noisy estimates of reward rate over a short window of trials, making the optimization of average reward rate more difficult. Our findings indicate that the assumption of a singular decision threshold is inaccurate for standard perceptual decision-making tasks, because it fails to reflect the significant degree of strategy adjustments over time. More generally, these results challenge the standard assumption made by normative models that behaviour in decision-making tasks is guided by the process of optimising reward rate. Future modelling work should address whether the adjustment of behaviour over time is based on random exploration of the threshold parameter space due to the noise in estimated reward rate, or whether it is guided by the decision-maker's attempt to optimise a different outcome variable.

PS.02.05: Revealing the time-course of Pavlovian-instrumental conflict using mouse-tracking and drift diffusion modeling

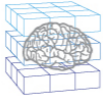
Hoyoung Doh¹, Yunseo Jeong², Harhim Park¹, Daeyeol Lee³, Woo-Young Ahn¹

¹Seoul National University, ²The Catholic University of Korea, ³Johns Hopkins University

Decisions result from the interaction between multiple decision-making systems such as Pavlovian and instrumental systems. The Pavlovian system provides preprogrammed responses to rewards and punishments, while the instrumental system learns appropriate responses to get more rewards and avoid punishments. Studies using laboratory tasks such as the orthogonalized Go/Nogo task have revealed that while Pavlovian and instrumental systems cooperate in many situations (Pavlovian-congruent responses), they sometimes compete with each other (Pavlovian-incongruent responses) hindering adaptive behavior (Cavanagh et al., 2013; de Boer et al., 2019; Guitart-Masip et al., 2012; Ousdal et al., 2018). While the orthogonalized Go/Nogo task has been widely used, it only yields final behavior responses but provides no information about the time-course of cooperation or competition between the two systems. To address this limitation, we developed a new version of the orthogonalized Go/Nogo task with mouse-tracking requiring an active response on every trial, with which we can track both the time-course of decision-making and final responses. We also developed a novel "change-of-

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mind" drift diffusion model to account for participants' mouse trajectories and final responses. We recruited 77 healthy adults and replicated the behavioral findings of the original orthogonalized go/no-go task when using the final responses. The mouse-tracking data revealed greater initial movement to Pavlovian-congruent targets compared to Pavlovian-incongruent targets ($p < 0.001$). Similarly, mouse trajectories deviated more from the shortest path to the Pavlovian-incongruent targets compared to Pavlovian-congruent targets ($p < 0.001$). Our drift diffusion model explained individual differences in human participants' initial response accuracy and directional change. This work demonstrates the utility of mouse tracking and sequential sampling models in explaining the within-trial dynamics of the cooperation and competition between multiple decision-making systems and provides novel insights into the computational mechanisms underlying Pavlovian-instrumental conflict.

PS.02.06: Identifying a signature of delay discounting using machine-learning applied to whole-brain cortical structure

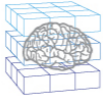
Valérie Godefroy¹, Marie-Christine Simon², Bernd Weber², Leonie Koban³, Hilke Plassmann¹

¹Paris Brain Institute / INSEAD, ²University of Bonn, ³Paris Brain Institute

OBJECTIVE: Delay discounting reflects the extent to which a reward loses its subjective value when it is received with a delay. It is an individual marker of impulsive decision-making, predicting important life and health outcomes. Our aim is to identify a brain signature (i.e., a typical brain pattern) of delay discounting in adults from structural brain features. Using a multi-variate method of machine-learning applied to structural MRI data is an original way to investigate the neural mechanisms of delay discounting, more reliable and reproducible than usual univariate methods. **METHODS:** We used data collected in healthy male participants ($N=117$; mean age=31.9) who performed a delay discounting task consisting of 108 choices between smaller sooner and larger later monetary rewards, and computed each participant's discounting parameter ($\log(k)$). Structural MRI data were preprocessed using voxel-based morphometry to assess local grey matter density across the cortex in each participant. We applied LASSO-PCR (least absolute shrinkage and selection operator-principal component regression) to the preprocessed MRI data, to obtain a pattern of brain cortical structure that predicts $\log(k)$. The predictive accuracy of the classifier was assessed using a stratified 10-fold cross-validation procedure. Bootstrapping (5,000 samples) was used to identify the brain areas that contributed most significantly to predict $\log(k)$. We further explored the spatial similarity between the obtained brain pattern and meta-analytic maps corresponding to specific functional networks. **RESULTS:** We identified a structural brain pattern predicting $\log(k)$ (called 'structural k-marker') with a cross-validated prediction-outcome correlation of $r = 0.35$ (permutation test: $p=0.003$), a mean squared error of 3.45 (permutation test: $p = 0.003$), and a mean absolute error for predicted $\log(k)$ of 1.46 (permutation test: $p = 0.002$). Significant predictive weights of the structural k-marker were found in the lateral parietal cortex and posterior cingulate cortex (at $p < 0.05$, FDR-corrected), as well as in the orbitofrontal cortex and amygdala (at $p < 0.001$, uncorrected). Comparing with meta-analytic maps showed that the structural k-marker was mostly similar to the maps associated with valuation, emotion and conflict processing. **CONCLUSIONS:** The identified structural k-marker evidenced the preponderant role of regions (such as lateral parietal cortex) not typically associated with delay discounting in the literature. This biomarker of impulsive decision-making could be used for the early detection of individuals at risk of different health conditions,

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in particular neurodegenerative diseases.

PS.02.07: Reward-Dependent Corticostriatal Connectivity: A Meta-analysis of Psychophysiological Interactions

Jeffrey Dennison¹, Fatima Umar¹, Avi Dachs¹, David Smith¹

¹Temple University

Objective: A host of neuroimaging studies have shown that reward processing and decision making are associated with activation in striatum and parts of the prefrontal cortex (PFC). Building on these findings, other studies have probed connectivity between the striatum and PFC during a wide array of reward processing tasks, particularly those involving anticipation, consumption, learning, and valuation. Yet, it remains unclear whether these studies are associated with consistent and specific patterns of corticostriatal connectivity. To address this problem, we conducted a meta-analysis of reward processing studies that utilized psychophysiological interactions to assess corticostriatal connectivity. **Methods:** We identified a list of 3,689 potential studies for inclusion through a database search of PubMed. Next, we screened the potential studies and identified 64 reward PPI studies, with 42 using a striatal seed and 22 using a PFC seed. Additionally, studies were organized by reward task based on whether they analyzed connectivity before (anticipation and valuation) or after (consumption and learning) receipt of reward. The meta-analysis was conducted using activation likelihood estimation (ALE) via GingerALE with a cluster-forming threshold of $p < 0.001$ and a family-wise error rate of $p = 0.05$. **Results:** Across all studies analyzing reward-dependent connectivity with the striatum, we saw consistent connectivity with the anterior cingulate cortex (ACC). A similar analysis focused on studies using PFC seed regions did not reveal consistent patterns of connectivity, possibly due to the heterogeneity of PFC seed locations across studies. In order to identify patterns of connectivity that were common and distinct between the striatum and PFC we conducted a subtraction and conjunction analysis, but revealed no significant effects. Within the set of studies using a PFC seed and reward learning paradigms, we found a consistent PPI with the amygdala. **Conclusions:** We found that ACC is a common feature of reward-dependent connectivity with studies using the striatum as a seed region, irrespective of reward task. And for studies using a PFC seed region during reward learning tasks, we found that the amygdala was a consistent target region. Overall, this meta-analysis can help to consolidate a body of literature exploring the corticostriatal interactions that are involved in the encoding of rewards. This information can help to motivate future research to better understand how these other regions support reward encoding within the striatum and PFC.

Poster Spotlights III

PS.03.01: The social brain: Domain-general contributions to decision making?

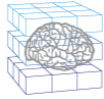
Claire Lugrin¹, Arkady Konovalov¹, Christian Ruff¹

¹University of Zurich

Objective. The "social brain" refers to a network of areas commonly activated during social behavior. However, many of these regions (e.g. temporo-parietal junction (TPJ), dorsolateral (dlPFC) and dorsomedial prefrontal cortex (dmPFC)) are also activated during non-social choices. We propose that

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the involvement of these regions in both social and non-social decisions may reflect a common function: Integrating sensory and memory inputs into salient conceptual representations, such as Gestalt representations of objects or typical social situations. To test this hypothesis, we designed a non-social paradigm that compared, for identical sensory input and motor output, integration of sensory stimuli based on salient Gestalt principles versus alternative arbitrary rules. To control for difficulty, we also compared different response rules that had different motor planning demands but did not differ in terms of stimulus integration. **Methods.** 54 subjects underwent 3T fMRI while judging which of two clouds of elements contained most items (squares and diamonds). We varied mappings in a 2x2 design (salient vs alternative, stimulus vs response): Under salient stimulus mappings (SS), subjects had to select the cloud with the largest total number of elements, whereas under alternative stimulus mappings (AS), they had to select the cloud with the largest number of specific elements. To control for difficulty, we also varied representation-response mappings: Under salient response mappings (SR), subjects selected the first (second) cloud by pressing the response button once (twice); under alternative response (AR) mappings, this salient correspondence was reversed. **Results.** Compared to the salient mappings (SS/SR accuracy = 89%, RT = 628ms), participants were indeed less accurate (AS accuracy = 82% $p < .001$, AR accuracy = 86% $p < .001$) and slower (AS RT = 711ms $p < .001$, AR RT = 718ms $p < .001$) for both alternative mappings. As hypothesized, several "social" brain regions (bilateral TPJ, dmPFC, left anterior dlPFC, precuneus, corresponding to a "social" meta-analysis map from Neurosynth) were activated for salient stimulus mappings (SS > AS). These activations did not reflect task difficulty, as alternative response mappings (AR > SR) instead led to activation in distinct cognitive control regions. **Conclusion.** Our results reveal an important mechanism that could lead to misinterpretation of fMRI results in studies of the "social brain". Specifically, our findings suggest that integrating sensory information onto salient conceptual representations may be a key contribution of "social" brain areas to behavior in both social and non-social situations.

PS.03.02: Conforming to generous vs. selfish group norms during charitable donations: an fMRI study of the moderating role of internalized social values

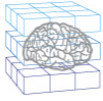
Paloma Diaz-Gutierrez¹, Christophe Boone¹, Harshil Vyas¹, Carolyn Declerck¹

¹*Universiteit Antwerpen*

Study's objective: Sharing behavior is known to be facilitated by social norms. Although the mechanisms underlying norm compliance are well studied, a remaining question is to what extent normative influence depends on one's own intrinsic values, and how the interaction of both jointly shape sharing behavior. We investigate how the brain deals with, and solves conflict between one's internalized values and external social norms (prosocials confronted with selfish norm and vice versa). We expect generous norms to foster sharing in proselves, supported by increased activation in regions linked to norm compliance and/or reputation. Conversely, selfish norms require self-control mechanisms for prosocials to resist temptation and continue sharing. **Methods:** We used an fMRI donation task, where 50 participants (preselected by their social value orientation, SVO; decided how much to donate to 120 different charities. Social norms were manipulated by presenting the average donations (generous vs. selfish) made by others to each charity, resulting in mismatches (prosocials-selfish norm, prosself-generous norm) and matches (prosocial-generous norm, prosself-selfish norm). **Results:** Consistent with

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the hypotheses, whole-brain analysis (all fMRI results are FWE-corrected at $p < .05$) showed increased activation in IFG for prosocials processing a mismatch. Donation decisions parametrically modulated by the distance from the norm covaried with activation in IPL, MTG and IPFC for prosocials in a match, and proselves in a mismatch. Conclusions: Together the data indicate so far that conforming to a generous norm is supported by a similar mechanism when it matches as well as mismatches values. However, processing a selfish norm that mismatches values (prosocials) requires additional cognitive control (IFG). We next compute ROI analyses to better differentiate how prosocials and proselves make generous decisions in a mismatch condition.

PS.03.03: Emergence of Probability Weighting in the Choice Circuit

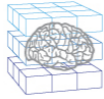
Marcin Penconek¹

¹University of Warsaw

OBJECTIVE: Probability weighting proposed by the Prospect Theory (Kahneman and Tversky, 1992) transforms the objective probabilities into subjective probability assessment to explain the nonlinearity of human decision-making under risk. Probability distortion postulated by the weighting function exhibits underweighting of high probabilities (certainty effect) and overweighting of low probabilities (possibility effect). The effects were investigated and confirmed experimentally in numerous behavioral studies. However, the neuronal mechanism behind these effects remains unknown. The computation of categorical decisions performed in the brain through the integration-to-the-bound process is non-linear (Peixoto, Verhein, Kiani, et al., 2021). Thus, the choice circuit is a natural candidate for the potential locus of probability distortion emergence. **METHOD:** The hypothesis is investigated with computational analysis using the decision-making model based on the recurrent attractor network (Penconek, 2020). The model exhibits non-linear integration, which is consistent with neurophysiological experiments. **RESULTS:** Analysis confirms the emergence of probability distortion when computing risky choices in the gain domain. The analysis assumes no distortion of the representation of probability in the brain. It produces underweighting of high probabilities and overweighting of low probabilities with realistic parameters of the Prelec weighting function: 0.994, 0.842. Elicitation is conducted in the framework suggested by the Prospect Theory with the non-parametric method proposed by Abdellaoui (2000) with no assumptions on the shape of the weighting function. Elicitation of probability weighting in the subjective utility space requires no assumptions about the shape of the value representation function. **CONCLUSIONS:** The study provides a biophysically plausible explanation of the neuronal mechanism of probability weighting observed in behavioral studies. The analysis provides new testable predictions which can be verified in future experimental research. Abdellaoui, M. (2000). Parameter-free elicitation of utility and probability weighting functions. *Management Science*, 46(11), 1497-1512. Peixoto, D., Verhein, J.R., Kiani, R. et al. (2021). Decoding and perturbing decision states in real time. *Nature* 591, 604-609. <https://doi.org/10.1038/s41586-020-03181-9> Penconek, M. (2020). Decision making model based on attractor network with binary neurons. *Procedia Computer Science*, 176, 1930-1939. Tversky, A., & Kahneman, D. (1992). Advances in prospect theory: Cumulative representation of uncertainty. *Journal of Risk and Uncertainty*, 5(4), 297-323.

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PS.03.04: Honesty sometimes decreases cooperation in Prisoner's Dilemma games with communication

Abdelaziz Alsharawy¹, Eric Bahel², Sudipta Sarangi², Sheryl Ball²

¹Princeton University, ²Virginia Tech

Objective: An important role of communication is to coordinate action. Economic theory tells us, however, that communication is "cheap talk" in social interactions with compromised incentives to coordinate like the Prisoner's Dilemma (PD) game. Yet, communication regularly increases cooperation in experiments. Recent work models a two stage PD game where players believe that their counterpart is lying averse (suffering a cost when telling a lie) and characterizes the conditions that facilitate cooperation (Bahel, Ball, and Sarangi, 2022 - BBS). Our objective was first to design an experimental setting of social interaction (with communication) that varies individuals' cost of lying and, importantly, their perception of the underlying population's honesty level. Second, we applied this setting to test the predictions and comparative statics of the PD model with lying aversion and pre-play communication. **Methods:** We modify the standard PD game by 1) exogenously assigning lying costs to participants, 2) manipulating the underlying prevalence of lying costs in the population, and 3) restricting communication to sending either a conditional cooperation message (promise to cooperate) or a non-cooperative message. Participants (N=100) completed 60 rounds divided into 8 blocks that varied lying costs and the PD incentives (potential gains/losses). In each round, participant's counterpart lying cost (financial penalty incurred when not keeping one's promise) was drawn from either a uniform urn of penalties or a skewed urn where high penalties were twice as likely. **Results:** The frequency of cooperation decreased with the monetary gain of lying or loss incurred when being deceived and with lower assigned penalties. Using elicited forecasts of a counterpart's lying cost, we verify that the skewed urn significantly shifted participants beliefs about their counterpart's penalty. Surprisingly, cooperation did not necessarily increase in a more honest population. Confirming the BBS model predictions, the frequency of cooperation was instead driven by the interaction between the incentives to cooperate and the population's honesty. **Conclusion:** Our results demonstrate that the nature of communication, beliefs about one's opponent's honesty, and an individual's incentives operate in synergy in social interactions. Future modifications to our malleable experimental setting will allow us to examine how the information and neural processing changes when the level of honesty in the population is manipulated in social interactions. Bahel, E., Ball, S., & Sarangi, S. (2022). Communication and cooperation in Prisoner's Dilemma games. *Games and Economic Behavior*, 13.

PS.03.05: Split In Probability Weights - Scarcity, Cognitive Load And Tunnelling

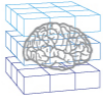
Suvarna Pande¹

¹University of East Anglia

This work presents the conceptual framework that investigates decision-attribute dependent bifurcation in preferences. We propose a process model that begins with financial scarcity, works through the cognitive load, draws attention, and controlled cognitive systems to the need at hand, thus simultaneously making those preferences rational and all other choices more biased. We focus on risk preferences and probability weighting. We implement the lab-in-field design with 600 people in

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Bwikhonge in Uganda, a predominantly rural region with a bimodal annual harvest cycle. Our design is composed of two between-within-subject treatment arms and a control group. It is spread across the naturally occurring monsoon cycle in the area. With a randomised sample in both seasons, we prime half the group with shock financial concerns, following which we introduce the cognitive load test. We use the Stroop and the digit span test to measure the role of working memory, attention, and inhibitory control. Finally, we offer two 5- prospect lists that differ only in one aspect, the decision attribute. Each subject allotted to one of the four states makes two rounds of decisions- scarcity relevance and irrelevance. At this stage, the within-subject assignment controls for all other variables. Therefore, the difference in choices is due to decision attributes alone. We also construct a psychological index from the post-experiment survey in our logistic analysis with other demographic factors. We plot and estimate the one parameter pwf on STATA for both gains and losses and find the significant role of the level of scarcity and cognitive load on splitting the pwf. Participants in the lean season and shock scarcity are most cognitively loaded with the most significant effect on attention, leading to the greatest split in the pwf. Known decision biases disappear for the scarcity relevant choices for this group. The pwf is a straight line. At the same time, all other decisions are the most biased for the group. This points to the driving role of cognitive load and scarcity relevance in guiding the neural systems to become rational decision-makers for urgent needs and affect driven for all else. The results advance the study of the psychology of poverty. This rational-bias split as a function of what matters can explain many counterintuitive behaviours like low pickup rates of preventative health or high-interest borrowing that seem self-sabotaging. To our knowledge, this is the first study to present a single phenomenon (financial scarcity) behind a variety of behaviours operating via two core neural mechanisms (bifurcation- decision neglect and cognitive load).

PS.03.06: Cognitive Effort Discounting in Adolescents: Evaluating the Role of ADHD in Effort-Based Decision Making

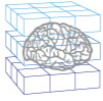
Deborah Sevigny-Resetco¹, Joel T. Nigg¹, Suzanne Mitchell¹

¹Oregon Health and Science University

Objectives: While the diagnostic criterion for ADHD encompasses several heterogeneous symptoms, one symptom frequently reported by the parents and teachers of adolescents with ADHD is a diminished willingness to initiate or maintain effort with schoolwork. Unfortunately, identifying the mechanisms underlying this phenomenon has been a challenge, partly due to the lack of a systematic procedure to quantify deficits and influential variables. To address this issue, we compared adolescents with and without ADHD on two cognitive effort discounting tasks, which characterized individual preferences between small monetary rewards obtained with no effort exerted and larger monetary rewards (\$10, \$25, \$50) requiring either sustained attention or working memory to be engaged for a specific duration (1, 5, 10, 20 minutes). **Methods:** Participants were ADHD-diagnosed and healthy control participants aged 16-21 years (n=54). Participants performed and rated six variants of a sustained attention task and a working memory task, each with varying difficulty levels, produced by varying display rates (inter-stimuli-interval: 750 or 1000 ms and stimulus durations: 200, 400, 800 ms). A variant of each task, rated as moderately effortful, was identified for each participant. Participants subsequently completed two associated cognitive effort discounting tasks. Preferences and decision response time were recorded.

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Discounting was measured by calculating the area under the discounting curve (AUC). Results: In both cognitive effort discounting tasks, adolescents across the two groups demonstrated similar systematic cognitive effort discounting patterns. There were differences in decision response times, demonstrating that individuals with an active ADHD diagnosis invested significantly more time making choices during the working memory task ($F(1,49) = 4.27, p=.04$). This trend was also seen for the sustained attention task; however, it did not rise to the level of significance. Conclusions: The data from this study, while potentially in contention with research highlighting inhibition deficits in ADHD, provide evidence that although adolescents with ADHD are not more inclined to select low effort alternatives compared to healthy controls, increased decision response times are consistent with ADHD individuals experiencing higher levels of cognitive dissonance when contemplating effort-based decisions. As this research develops, we hope that we may ultimately find new targets for clinical interventions with improved insight into the cognitive barriers hindering optimal decision-making in adolescents with ADHD.

Posters

Poster Session 01

P1-A-1: The Effect of Time Pressure on Skewed Gambling Preference across Adulthood

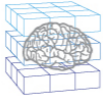
Christopher Garza¹, Harold Robinson¹, Sreeya Reedy¹, Kendra Seaman¹

¹University of Texas at Dallas

Objective: Humans prefer positively skewed gambles, or ones with a big chance of a small loss and a small chance of a big win. This preference seems to increase with age, with older adults liking these gambles even more than younger adults. This could be due to selective loss avoidance in older adults. Older adults face higher costs for engaging their diminishing cognitive resources and may only choose to do so when avoiding a large loss associated with negatively-skewed gambles, creating a bias towards positively-skewed gambles. The ability to engage cognitive resources is often inhibited by placing people under time pressure. Time pressure has been used to illicit intuitive choices and has a larger effect on older adults. We hypothesize that time pressure will decrease the positive skew bias for older but not younger adults. **Methods:** Healthy participants ($N = 23/81$, Age: $M=61.87$, $SD= 14.53$, Range= 29-80) were recruited to complete a series of surveys and tasks. Participants completed a demographic survey, questionnaires for emotion, affect and finance, the NIH Toolbox Cognition Battery, and a Skewed Gambling task. The task consisted of 10 blocks of 20 gambles each, for a total of 200 gambles. Blocks alternated between the experimental and control conditions. Participants were given 2 or 4 seconds to choose between accepting or rejecting a skewed gamble, with the shorter time limit being the experimental condition. The gambles varied systematically between 9 positive, 9 negative, and 2 symmetrical gambles. Two linear models were created to analyze the data. The first model consisted of skew bias predicted by condition, with age and its interaction with condition added in the second model. **Results:** There was a small negative skew bias in our participants. This bias became more negative with age, however being under time pressure moderated this. The main effect of condition failed to reach statistical significance in either model, however both age and its interaction with condition were significant. Older adults were likely to choose negatively skewed gambles than younger adults, but this difference was smaller when older adults were under time pressure. We assumed participants would

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demonstrate a positive skew bias and that this would be reduced with time pressure. Instead, we observed a negative-skew bias that decreased under time pressure. Conclusion: Our results suggest that the adults in our sample prefer negatively-skewed gambles to positively-skewed ones. However, the size of the effect is small, and we are only a quarter of the way through data collection. It is possible that our current results will change when data collection is complete

P1-B-3: A rational account of the repulsion effect

Rahul Bhui¹, Yang Xiang¹

¹MIT

OBJECTIVE: The attraction effect occurs when the presence of an inferior option (the decoy) increases the attractiveness of the option that dominates it (the target). Despite its prominence in neuroeconomics, recent evidence from both economic and perceptual judgment points to the puzzling existence of the opposite phenomenon (where the decoy reduces preference for the target)---a "repulsion effect". In this project, we formally develop and experimentally test a normative account of the repulsion effect, based on the idea that a decoy can signal that the target also has low value when both are believed to be generated by a similar process. **METHODS:** Theoretically, we formalize this logic using a hierarchical Bayesian cognitive model that makes predictions about how the strength of the repulsion effect should vary with statistical properties of the context. We show how this theory can help account for several documented phenomena linked to the repulsion effect. We also conducted four new experiments to test our theory. In experiments 1 (n = 449) and 2 (n = 449), we used a multi-attribute consumer choice paradigm and varied whether the decoy was said to be from the same group as the target. In experiments 3 (n = 80) and 4 (n = 86), we used an abstract value judgment paradigm and varied the extent to which items had correlated values. **RESULTS:** In experiments 1 and 2, preference for the target was reduced ($p = .004$ and $p = .017$) and was lower than the competitor ($p < .001$ and $p = .004$) when the decoy and target were from the same group. In experiments 3 and 4, judgments of target value were biased downward by decoy attributes ($p = .002$ and $p < .001$) especially when their latent values were more correlated ($p < .001$ and $p = .002$). **CONCLUSION:** Our results support this unifying normative account of the repulsion effect, which complements more mechanistic perspectives and sharpens our understanding of when and why decoys can be detrimental.

P1-B-4: Emotional lability relates to adaptive learning across environmental contexts

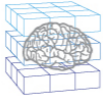
Sophie Paolizzi¹, Michael Hallquist¹

¹University of North Carolina at Chapel Hill

Introduction. Adaptive learning in volatile contexts requires frequent updating of behavior in response to surprising information that indicates an environmental shift. For example, tracking when a conversational counterpart's tone has shifted is critical in adapting one's own social behavior. However, behavioral adjustments are not always made precisely when true changes occur. Instead, learners adapt when they infer such a "change point" (CP) in the environment. We hypothesized that sensitivity to CPs relates to the ability to adaptively shift learning strategies differentially across stable and volatile states. Furthermore, we examined whether emotional lability would relate to an increased propensity to interpret large prediction errors as CPs. **Methods.** We collected task data from 135 individuals. The goal

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is to place a "shield" in the optimal location to prevent a cannonball strike. In a "volatile" condition, it is advantageous for participants to incorporate large prediction errors (PEs) in shield placement into their updated shield placement on the following trial, as these large PEs indicated that the cannonballs had shifted locations. In another "stable" condition, it is adaptive to discount large PEs that reflect "oddballs", or stray shots that were not reflective of a broader CP in the cannonball distribution. Using multi-level models, we tested the effects of both task characteristics (e.g., true CPs, task conditions) and scores on self-report measures related to specific behavioral traits (e.g., emotional lability, anxiety) on participant's updating behavior across the task. Results. We found that (1) PEs were tightly linked with updating behavior, suggesting that participants utilized information from PEs throughout the task ($B = .64, p < .0001$); (2) PEs and CPs drove updating differentially in a manner consistent with our hypothesis: people made comparatively smaller updates in the face of "oddballs" in a relatively stable distribution of shots, while "changepoints" preceded larger updates ($B = -.28, p = .0001$); and (3) self-reported emotional lability predicts increased sensitivity to potential CPs in the underlying distribution in the task ($B = -.01, p = .003$). We are in the process of fitting task data with a reduced Bayesian model designed to flexibly update in the face of uncertainty. Conclusions. This study confirmed our hypotheses related to adaptive learning dynamics across stable and volatile contexts and confirmed that the detection of environmental shifts is critical in shaping learning dynamics. We also found evidence for our second hypothesis, that emotional lability modulated sensitivity to environmental volatility.

P1-B-5: Early and late neural components distinguish expectation formation and outcome processing

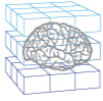
Matthew Bachman¹, Kaya Scheman², René San Martín³, Marty Woldorff⁴, Scott Huettel⁴

¹University of Toronto, Scarborough, ²National Institute of Health, ³Universidad Diego Portales, ⁴Duke University

Objective: Decision makers must form and update their expectations about the likelihood of possible outcomes and adapt accordingly as new information is acquired. Previous EEG studies have shown how reward expectations can influence the processing of actual outcomes, but far less work has investigated expectation formation. In this study, we investigated the neural processes underlying expectation formation in addition to outcome processing. Furthermore, we leveraged the high temporal resolution of EEG to uncover how reward expectations influence both early and late components of outcome processing. **Methods:** EEG data were collected as participants ($n=32$) tried to earn money by correctly selecting which of two colored circles would win on each trial. We manipulated participants' expectations after each choice by delivering information about that trial's outcome in two stages. First, participants learned their probability of winning, ranging from 0% to 100%. Then the actual outcome was revealed in a second stage. Our analyses focused on two temporally distinct ERPs: the Reward Positivity (RewP), an early latency component reflecting a signed reward prediction error in the anterior cingulate cortex, and the P3, a later latency component reflecting the attention-driven updating of outcome-related information. **Results:** We used rmANOVAs to assess how RewP and P3 amplitude changed during each stage. At the outcome-probability stage, we tested their sensitivity to outcome valence (win vs loss) and certainty (certain vs uncertain outcomes). We found that the earlier RewP was independently larger for wins and certain outcomes. The later P3 was also larger for certain outcomes and larger still for certain losses. At the actual-outcome stage, we tested these ERPs' sensitivities to valence and expectations (expected, 50/50, and unexpected). Here, the RewP was sensitive to

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expectations but only when the participant won, with larger RewPs for more unexpected wins. P3 win activity was also larger for more unexpected wins. P3 loss activity was sensitive to expectations as well, peaking in the most ambiguous condition. Conclusions: Our results indicate that the earlier RewP displays a preferential sensitivity to wins and especially unexpected ones, aligning with prior work suggesting that it may reflect a signed reward-prediction error. Conversely, the P3 displayed several unique interactions between valence and certainty/expectations across both stages, indicating that each circumstance requires a differential distribution of attentional resources. These findings highlight the various ways in which reward expectations can exert their influence upon neural processing.

P1-B-6: Searching for Happiness: How Web-Browsing Patterns are Related to Wellbeing

Christopher Kelly¹, Tali Sharot¹

¹University College London

Objective: People spend half of their waking hours online. Most of this time is dedicated to searching for and consuming information. A critical question is whether the characteristics of information that people expose themselves to online reflect and shape their well-being. If information-seeking patterns can be measured by analyzing individuals' web searches, then we can use this approach to facilitate the diagnosis and intervention of mental health problems. Here, we combine natural language processing and machine learning to test whether individuals with poorer mental health consume more negative/positive information from self-guided searches and whether this information is more/less semantically similar across webpages browsed (i.e., more/less erratic). **Methods:** Participants (Exp 1 N = 307; Exp 2 N = 356) submitted the history of their web-browsing sessions. We extracted the text from the webpages they visited. The text was fed to algorithms that use natural language processing and supervised machine learning to quantify two characteristics: the valence (positive/negative) of information and semantic similarity (i.e., the extent to which webpages are semantically related to each other). These scores were then related to a composite score of self-reported mental health questionnaires and mood ratings before and after browsing. **Results:** Within individuals, valence and semantic similarity scores were fairly stable over time (Valence: ICC = 0.621, $p < 0.001$; Semantic Similarity: ICC = 0.617, $p < 0.001$), suggesting they partially reflect 'trait-like' features. Importantly, individuals whose self-guided searches led to more negatively valenced information reported poorer mental health (Exp 1: $R = -0.129$, $p = 0.02$; Exp 2: $R = -0.160$, $p = 0.002$;) and worse mood post-browsing (Exp 1: $\beta = 0.048$, $p = 0.015$; Exp 2: $R = 0.110$, $p = 0.047$; controlling for pre-browsing mood). We did not observe a relationship between the semantic similarity and well-being. All analysis control for age and gender. Algorithmic scores correlated with those of human raters (Valence: $R = 0.565$, $p < 0.001$; Semantic Similarity: $R = 0.745$, $p < 0.001$), suggesting they are valid. **Conclusion:** We provide evidence for a relationship between the characteristics of information people consume online and their mental health. The research can inform the development of tools for early detection of mental health problems from analysis of web-browsing patterns, as well as the development of tools that improve mood by altering online information consumption choices.

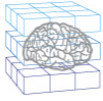
P1-B-7: Representations of Flexible Cognitive Maps for Value-based Decision-Making

Sarah Sweigart¹, Seongmin Park¹, Nam Nguyen¹, Charan Ranganath¹, Erie Boorman¹

¹University of California, Davis

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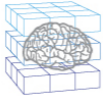


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Objective: Neural representations of relationships between entities, known as a cognitive map, allow for quick learning, generalization, and inferencing for efficient decision making. Regions such as the entorhinal cortex (ERC), hippocampus (HPC), and medial prefrontal cortex (mPFC) have been implicated in constructing and storing cognitive maps. However, it is currently unknown how the brain flexibly uses cognitive maps to solve novel problems and how changing task-relevant features are represented in the brain. **Methods:** Here, we designed a novel 2D wine-space characterized by two dimensions: taste (sweet to dry) and body (light to full). Participants ($n=21$) learn the space through dyad comparison and could construct a cognitive map to guide novel inferences between novel wine pairs. Critically, the subjects never visually see the wine space nor get feedback on the size or shape of the space. During fMRI scanning, participants completed a country task, where they had to evaluate which wines would be preferred based on a country's preference. Countries preferred either one attribute (e.g., full) or preferred two attributes equally (e.g., sweet and light). This required the participants to combine their knowledge of the different contexts to correctly choose the correct wines in the absence of feedback. **Results:** Neurally, we found strong univariate effects for task-relevant value difference information in the HPC, ERC, and mPFC ($p < 0.05$ TFCE-corrected). Whole-brain representational similarity analyses identify flexible rank 'position' (or context-dependent 'value') representations in posterior parietal cortex and orbitofrontal cortex. **Conclusion:** These findings suggest that cognitive maps are used more flexibly than some previous models have indicated and elucidate the mechanisms of value-based decision-making based on a cognitive map.

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P1-B-8: Expectation-dependent evidence evaluation in legal decision-making

Seth Madlon-Kay¹, Artemis Malekpour, David Ball, Donald Beskind¹, Pate Skene², John Pearson¹

¹Duke University, ²University of Colorado Boulder

Objective: How do people integrate opposing pieces of evidence when making decisions in realistic situations? Here, we study legal decision-making from the perspective of a juror as is a real-world example of a situation requiring the integration of complex and opposing pieces of evidence in order to make a judgment. **Methods:** We asked 465 participants to read a series of 31 criminal cases and judge them as though they were serving on a jury. Each case contained a brief description of the criminal charge against the defendant and up to four pieces of evidence. Each piece of evidence could take on three possible levels: inculpatory, exculpatory, and ambiguous. The level of each piece of evidence was randomized for every case. We also examined the role of expectations by assigning participants to one of two contexts: a "balanced" context in which inculpatory and exculpatory evidence were equally likely, and a context with only "credible" cases, in which inculpatory and ambiguous evidence always outnumbered exculpatory evidence. **Results:** We found that legal judgments were well-explained by a model derived from perceptual decision-making in which participants independently assign evidentiary weights to each piece of evidence, and integrate evidence by adding those weights together. We also find that in the "balanced" context, judgments favor the prosecution in two ways: first, a criminal charge without any evidence is treated as inculpatory evidence, and second, inculpatory evidence outweighs exculpatory evidence. Changing the distribution of evidence to show only credible cases caused paradoxical changes: the evidentiary value of an accusation increased to even further favor the prosecution, but the weights of all evidence shifted downwards to favor the defense. To explain these opposing effects, we develop a model in which agents learn via an error-driven update rule to anticipate the evidentiary strength of the average case, and they evaluate observed evidence relative to that expectation. When the average case is strong, the weight of an accusation is high because the agent expects it to be backed up by evidence; observed evidence then favors the prosecution less because inculpatory evidence is expected, but exculpatory evidence is surprising. **Conclusion:** We demonstrate that models of learning and decision-making derived from cognitive research in laboratory tasks can be directly applied to complex real-world decisions like legal judgments. Our results suggest that judgments are biased towards prosecutors in part because of expectations that they have strong evidence, but that also these expectations can be modified by learning.

P1-C-11: Neural signatures of socioemotional processing relate to persistence of false accusations against novel political candidates

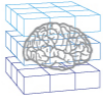
Michael Cohen¹, Victoria Halewicz², Joseph Kable¹

¹University of Pennsylvania, ²Brown University

Objective: False information has a persistent impact on judgments even after a correction. Prior work on Continued Influence Effects (CIEs) has shown that mock political candidates accused of misconduct will be rated more negatively than candidates who have not faced such an accusation, even when subsequent reports fully clear the candidate of responsibility for the alleged misconduct. Here, we examine neural mechanisms that underlie persistent negative evaluations of political candidates targeted by false accusations. **Methods:** We developed a set of 36 mock candidates with novel faces and

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names. We created mock social media posts of accusations and refutations, based on false allegations against real political candidates, as well as neutral control stimuli. We used fMRI to examine neural activity in 24 young adult participants as they viewed accusations (vs. control) and refutations (vs. control), and when they subsequently made explicit "feeling thermometer" ratings of the candidates. Results: We observe within-participant behavioral CIEs on immediate ratings and later in a series of binary "vote"-style choices. Brain activity during explicit ratings is greater for candidates targeted by accusations (whether corrected or uncorrected) in regions including dorsomedial prefrontal (dmPFC) and lateral orbitofrontal cortex (IOFC) in whole-brain analyses (voxel threshold $p < .001$, parametric cluster corrected $p < .05$). Magnitude of ratings is also negatively associated with brain activity during the explicit rating task in regions including IOFC and L TPJ, and IOFC is more active during processing of refutations in individuals for whom those refutations are less effective. Individual difference analyses also find that individuals showing larger behavioral CIEs (corrected accusation < neutral) on later choices have less activity in the right temporal-parietal junction (R TPJ) and posterior superior temporal sulcus (pSTS) for corrected accusation vs. neutral candidates during both refutation and rating periods. Conclusions: Socioemotional mechanisms appear to play an important role in persistence of negative impacts from false accusations against political candidates. Corrections seem to be more effective when regions associated with theory-of-mind and empathy (e.g., R TPJ, pSTS) are activated, and less effective when regions associated with social dislike (e.g., IOFC) are activated. A tentative implication is that corrections to false accusations should aim to evoke an emotional/empathetic response, rather than or in addition to a factual refutation. This work is a step towards more effective countering of toxic false information in the information ecosystem.

P1-C-12: Neural Evidence for Conflicting Motives That Guide Cooperation

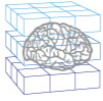
Arkady Konovalov¹, Claire Lugrin¹, Christian Ruff¹

¹University of Zurich

Objective. Cooperation is a hallmark of human behavior and is essential for the functioning of societies. Typically, cooperative behavior requires individuals to incur some personal cost to achieve a benefit for the group, but many conflicting motives may contribute to this trade-off, including social attitudes (e.g., altruism or reciprocity) as well as individual preferences (e.g., risk). The neural mechanisms implementing and arbitrating between these conflicting motives are not well understood. Here we elucidate these neural mechanisms using fMRI recordings and a social dilemma game that allows us to disentangle social and individual motives. **Methods.** Subjects ($N = 84$) were placed in a 3T MR scanner and played a series of one-shot Prisoner's Dilemma (PD) games, paired with a real opponent who made decisions in a separate room. On every trial, the players choose one of two options (cooperate or defect) and receive the highest payoff if they both cooperate; however, the dominant strategy is to defect since this guarantees a higher payoff independent of the choice of the opponent. We used 96 unique PD games with systematically varying payoffs, displayed in a matrix form in random order. Subjects received no feedback and one randomly chosen game determined the pair's outcomes at the end of the session. To identify neural underpinnings of the different motives guiding cooperation, we used the varying payoff values as well as composite indices of risk, inequality concerns, and efficiency, computed from these values as parametric modulators in general linear models implemented in SPM12 (first-level) and SnPM13 (second level). **Results.** Subjects' cooperation decisions indeed depended

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systematically on the varying payoff values. We found that all four values per game significantly predicted trial-level cooperation rates ($p < 0.001$), and two composite indices reflecting risk and inequality concerns were able to explain most variance in choices. We found distinct patterns of BOLD activity correlating with these two motives: Dorsolateral prefrontal cortex (dlPFC) activity correlated with the risk index and cooperation benefit value, while activity in the right temporoparietal junction (TPJ) reflected the level of inequality and the loser's payoff. **Conclusions.** Our results suggest that the brain employs separate mechanisms to evaluate risk and social costs/benefits of cooperation. We are currently extending this work using a neurocomputational model that offers a mechanistic framework for how these motives are integrated to guide cooperation. This project has received funding from the ERC under the EU Horizon 2020 research and innovation programme (grant agreement No 725355 BRAINC0DES).

P1-D-13: Peripheral visual information halves attentional choice biases

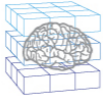
Brenden Eum¹, Stephanie Dolbier², Antonio Rangel¹

¹Caltech, ²UCLA

[Objective] A growing body of research has shown that simple choices involve the construction and comparison of values at the time of decision. These processes are modulated by attention in a way that leaves decision makers susceptible to attentional biases. Here we study the role of peripheral visual information on the choice process and on attentional choice biases. [Methods] We use an eye-tracking experiment where subjects (N=50 adults) make binary choices between food items that are displayed in marked screen "shelves" in two conditions: (1) where both items are displayed, and (2) where items are only displayed when subjects fixate within their shelves. [Results] We find that removing the nonfixated option approximately doubles the size of the attentional biases. [Conclusions] The results show that peripheral visual information is crucial in facilitating good decisions, and suggest that individuals might be influenceable by settings in which only one item is shown at a time, such as e-commerce.

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P1-D-14: Does social-self threat increase the preference for status goods?

Felix Nitsch¹, Zsafia Margittai², Gideon Nave³, David Dubois¹, Tobias Kalenscher², Hilke Plassmann¹
¹INSEAD Business School, ²Heinrich-Heine-University Düsseldorf, ³The Wharton School, University of Pennsylvania

Study Objective: Many accounts in marketing suggest that social-self-threats (SST) lead to increased preference of status-signaling products. However, work on consumer behavior under stress suggests the opposite: a consumption focus on necessities and overall reduced willingness-to-pay. While marketing has treated SST and stress as disconnected concepts, biopsychology has established a robust causal link that SST lead to acute stress. This implies that there are competing predictions about whether SST and the stress they trigger would increase preference for status-signaling products. The goal of this paper was to bridge the gap between these streams of literature and investigate their competing hypotheses. **Methods:** In N=158 (power=.80 for medium sized effect $d=0.5$) healthy, male participants, we manipulated SST via the Trier Social Stress Test (TSST). We measured stress and SST via self-reports. Further, harnessing the well-defined hormonal profile of the stress response allowed us to define a biological criterion of stress that generalizes beyond and is distinct from SST (which are only defined on a psychological level in marketing). We measured status preferences with two established tasks, either utilizing existing associations with consumer brands or manipulating product associations via advertisements. **Results:** Using psychological and hormonal measures, we confirmed that the TSST lead to SST ($F(2.33, 351.68)=12.66, p<.001, \eta^2=0.08$) and was characterized by a stress response (Cortisol: $F(1.93, 288.99)=30.06, p<.001, \eta^2=0.17$; Perceived Stress: $F(2.63, 396.70)=19.20, p<.001, \eta^2=0.11$). Hence, we confirm that there is a causal link from SST to stress and establish that an integration of research on SST and stress in marketing is necessary. However, in contradiction to previous accounts on the influence of SST on consumer behavior, we find no evidence for an increased status-preference operationalized via brand preference ($b=-0.14$ ($SE=0.11$), $p=.207$; $BF_{01}=3.01$) or product liking ($b=0.11$ ($SE=0.16$), $p=.476$; $BF_{01}=52.55$) following a stressful social-evaluative threat. **Conclusions:** Our findings contribute to consumer psychology theories by integrating two important lines of consumer research on SST and stress, demonstrating a causal relationship between both concepts. Our results contradict previous accounts on the influence of SST on status-preferences, but do not contradict similar research on the influence of stress. As shown here for the stress response as the physiological process underlying social-self-threats, our work showcases the consideration of physiological underpinnings of consumer phenomena to refine behavioral predictions.

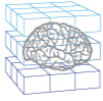
P1-D-15: Mechanisms for solving the explore-exploit tradeoff in the human dorsal stream

Michael Hallquist¹, Kai Hwang², Beatriz Luna³, Alexandre Dombrovski³
¹University of North Carolina, ²University of Iowa, ³University of Pittsburgh

Organisms face a difficult tradeoff between exploiting known good options and exploring potentially better alternatives. In environments with a few discrete options this dilemma can be resolved by the vertebrate striatum and amygdala and the explore-exploit balance is tuned by the meso-striatal dopamine system. In more complex environments, quadrupeds rely on world-centric hippocampal cognitive maps, which also encode reinforcement, stored in long-term memory. Primates' advanced visuo-motor systems have likely evolved as an adaptation to hunting and foraging in the rapidly swinging

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terminal branches. Exploration here requires fast visually guided actions that rely on the cortical "where" stream, or the dorsal attention network (DAN). In the DAN, visual information from temporo-occipital areas is dynamically integrated with parietal somatosensory information in the posterior parietal cortex (PPC), which builds dynamic world-centric maps and sends output to frontal premotor regions. In contrast to basal forebrain and hippocampus, live visuomotor data in PPC maps enable inference about actions likely to succeed in current and upcoming spatio-temporal locations, e.g. when an insect can be grasped on a moving branch. It remains unclear, however, how reinforcement is incorporated into PPC maps. Our general hypothesis was that reinforcement-based updates to PPC maps, reflected in BOLD and posterior oscillatory power, would subserve the transition from exploration to exploitation. Our first hypothesis was that local prediction error updates reflected in BOLD would invigorate exploration. We also examined the role of theta oscillatory responses to prediction errors, which have been proposed to underlie exploration. Our analyses of exploitation focused on entropy of option values reflecting whether multiple regions on the map are competing in the selection process (higher entropy) or a single region dominates and can be exploited. Our RL model (Hallquist & Dombrovski, *Cognition*, 2019) predicts learning dynamics where preferred actions are selectively maintained and nonpreferred alternatives are compressed out. Thus, we hypothesized that these entropy dynamics would facilitate the transition to exploitation. We specifically predicted that entropy change will modulate beta1/alpha oscillatory power. Two studies of BOLD and one MEG study of posterior oscillations found support for both hypotheses, with replications out-of-session and, in the case of BOLD, out-of-sample. However, early theta modulation by reinforcement reflected a binary error/correct response rather than a parametric prediction error response, and its role in exploration was strongly unsupported.

P1-D-16: Affect-Rich vs. Affect-Poor Risky Decision Making in Older and Younger Adults

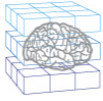
Colleen Frank¹, Thorsten Pachur¹

¹*University of Texas at Dallas*

Study objective. While risky decision making is often tested using monetary outcomes in the laboratory, many decisions in the real-world elicit considerable levels of affect (e.g., when deciding about a medical treatment that have bodily consequences, such as side effects). We call these kinds of outcomes 'affect-rich.' Previous research suggests that choices systematically diverge between affect-rich decision problems and economically equivalent affect-poor problems, leading to what is called an 'affect gap' in risky choice. However, it is unknown to what extent this pattern holds in older adults, who make some of the most consequential medical and financial decisions among the population. It has been hypothesized that affect may be a more important guide for older, compared to younger, adults. Thus, in the present, preregistered study, we examined age-related differences in the affect gap of risky decision making. **Method.** We compared decision quality and risk attitude between affect-rich (medical side effects) and structurally identical affect-poor (monetary losses) decisions in 100 older (aged 65-80, M=69.7) and 100 younger (aged 18-29, M=23.5) adults. For the affect-rich decisions, participants made a series of hypothetical choices between two medicines that could each lead to a particular negative side effect (e.g., fatigue, depression, fever) with some probability and reported which medicine they would choose. For the affect-poor decisions, participants chose between hypothetical gambles that could each lead to a loss of some amount of money with some probability. Each affect-poor choice problem was

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created by replacing the side effects of the affect-rich problems with their willingness-to-pay values--i.e., the amount of money each participant reported they would pay for a medicine without each side effect. Results. We ran two mixed-effects logistic regressions using Bayesian inference for interpretation. In line with previous findings, individuals were more risk-averse (Odds Ratio (OR) = 1.52) and made worse quality decisions (OR = 2.13) for affect-rich, compared to affect-poor, problems. There were no overall age differences in decision quality (OR = 0.95) nor risk attitudes (OR = 1.00). However, while older and younger adults made similar quality decisions on the affect-rich trials, older adults made better choices than younger adults on the affect-poor trials (OR = .73). Follow-up work using computational modeling will reveal if decision strategy differed between age groups. Conclusions. These findings indicate that the affect gap is also present in older adults, which has serious implications for risk communication in medical decision making.

P1-D-17: Shared mechanisms underlying perceptual and value-based decision making

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¹Dartmouth College, ²Heinrich Heine University

Our brain uses information in the environment to make very different types of decisions; from low-level perceptual to high-level value-based choices. Despite extensive experimental and modeling evidence for overlapping circuits involved in these two types of decision making, there is little evidence for shared mechanisms underlying these processes within individuals. To address this, we measured performance of 60 human participants across three different tasks: random-dot motion discrimination (RDM), gambling, and a value-based learning task. The main difference between the value-based learning and gambling tasks was that reward probabilities must be learned vs. being explicitly presented, resulting in the adoption of different strategies for how reward probabilities and magnitudes are integrated or compared (Farashahi et al, Nature Human Behaviour 2019). By fitting choice behavior and examining correlation between the sensitivity of choice to different types of information in these tasks, we tested whether sensory integration in RDM is related to different aspects of choice behavior during the two value-based tasks. Overall, we found a hybrid model consisting of additive and multiplicative components (i.e., addition and multiplication of reward probability and magnitude), and an additive model to best fit choice behavior in the gambling and learning tasks, respectively. In addition, we found significant correlations between sensitivity to motion coherence during RDM and the weight of reward probability (but not reward magnitude) on choice during the gambling task; and between sensitivity to motion coherence during RDM and the weight of reward magnitude (but not estimated probability) on choice during the volatile environment of the learning task. These findings provide evidence that during value-based decision making, relevant information is integrated by mechanisms similar to those used during perceptual decision making.

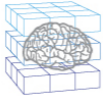
P1-D-18: Neural dynamics underlying divergent influences of reward and punishment on control allocation

Xiamin Leng¹, Romy Froemer¹, Amitai Shenhav¹

¹Brown University

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Introduction To decide how much mental effort to invest in a task, people need to weigh the cost of this effort against the potential benefits. These benefits include potential positive consequences for achieving one's goal (e.g., money or praise) and the avoidance of potential negative consequences (e.g., criticism or rejection). The neural and computational mechanisms governing the translation of these incentives into different control strategies are poorly understood. Our previous work showed that people normatively should and empirically do allocate control differently depending on the reward for achievement (responding correctly) versus the punishment for failure (error commission). An outstanding goal of this work is to understand the mechanism and time course by which different incentives translate into distinct strategies for control allocation. Specifically, it is unclear whether potential reward and punishment are processed differently and how these incentives affect proactive and reactive control adjustment. **Methods** We recorded EEG from participants (N=41) performing self-paced intervals of an incentivized Stroop task. At the start of each interval, we cued participants to the level of reward for correct responses and punishment for errors. We analyzed ERP components locked to the incentive cue (N2, CNV, P3b) and to the response (ERN, Pe). **Results** Replicating the key behavior findings from our previous work, reward primarily increased selective attention while punishment primarily improved response caution. In the cue-locked ERP analysis, we found that 1) fronto-central N2 (a proxy for early monitoring) selectively increased with higher punishment; 2) centro-parietal P3b (a proxy for cue evaluation) increased with both higher reward and higher punishment; and 3) fronto-central CNV (a proxy for control allocation) consistently increased with higher reward whereas the direction of punishment effects depended on the magnitude of reward. Response-locked ERP analyses revealed that Pe (a proxy for error evaluation), but not ERN (a proxy for error detection), increased with both higher reward and higher punishment. **Conclusion** While punishment selectively modulates early monitoring, reward and punishment converge in the common evaluation and integration processes for proactive control allocation. Our response-locked findings suggest that both incentives also modulate error evaluation, but not detection, which may inform reactive control. Taken together, our findings provide new insights into the dynamics of incentive processing and lay the groundwork for understanding how these incentives translate into distinct control strategies.

P1-E-20: Neural activity partially mediates the influence of candidate smiling on voter endorsement

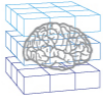
Dylan Christiano¹, Lester Tong¹, Golijeh Golarai¹, Brian Knutson¹

¹Stanford

Objective: Can political candidates' facial expressions influence voters' endorsement, and if so, how? We sought to test whether an "emotionality" hypothesis that emotional expressions influence social trait inferences might extend to political endorsement (Knutson, 1996; Oosterhof & Todorov, 2008), as well as whether brain activity might help account for such an influence. **Methods:** We presented smiling and neutral faces of 15 Democratic Primary candidates to self-identified Democratic voters (n=41) prior to the United States Democratic presidential primary elections of 2020, as Functional Magnetic Resonance Imaging (fMRI) scans were acquired. 30 faces were presented in each of two runs (either smiling or neutral). During each trial, subjects first saw a candidate's face (4 sec), followed by their position on four issues (8 sec), and then rated their endorsement of and affective responses to that candidate (12 sec), followed by a variable intertrial interval (2-6 sec). Neuroimaging data were preprocessed using AFNI

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software, and time courses of activity were averaged by trial type and extracted from volumes of interest implicated in choice (Nucleus Accumbens, NAcc; Anterior Insula, AIns; and Medial Prefrontal Cortex, MPFC; Knutson et al., 2007). Results: Within subjects, viewing smiling (versus neutral) faces increased activity in bilateral NAcc and MPFC, as well as ratings of candidate endorsement and self-reported positive arousal (PA). Notably, left MPFC activity in response to candidate faces partially mediated the influence of smiling on candidate endorsement ($p < 0.027$). MPFC activity partially mediated the association between candidate smiling and increased endorsement ($p < .05$). Conclusions: These findings extend an "emotionality" account of social trait inference to political endorsement since candidates' smiles influenced subsequent endorsement. Neuroimaging findings further suggest that this influence partially relies upon increased MPFC activity. Notably, the within-subject manipulation rules out potential explanations related to candidate or subject identity. Future research may examine whether the findings generalize to other elections, as well as to forecasts of aggregate political choice (Knutson & Genevsky, 2018).

P1-E-21: Neuroforecasting nature imagery impact on internet donations

Tara Srirangarajan¹, Nik Sawe¹, Tierney Thys², Brian Knutson¹

¹Stanford University, ²California Academy of Science

Donations to endangered species can help offset threats and internet campaigns facilitate these donations, but it is not always clear whether individuals efficiently donate to protect the most endangered species or use some other psychological proxy (e.g., salience or cuteness in the case of charismatic megafauna). Therefore, to better understand and forecast why people donate to protect endangered species, we combined behavioral, neuroimaging, and representative survey experiments. We found that brain activity in brain regions associated with anticipatory affect predicted individual donations and also forecast donations on social media. Physical attributes that elicited excitement (e.g., cuteness) and anxiety (e.g., threat) tended to increase donations. These findings suggest that the efficiency of donations to offset extinction might be enhanced by boosting affective elements of the presentation of endangered species.

P1-E-22: Modeling Teacher Behavior in the Field Using Reinforcement Learning

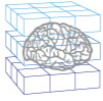
Marcos Gallo¹, Benjamin Manning², Colin Camerer¹

¹California Institute of Technology, ²Massachusetts Institute of Technology

This paper aims to apply learning models with field data. We model the decision-making process of teachers ($n = 30,000$) in a math-teaching platform named Zearn with an RL algorithm. Akin to a multi-armed bandit, teachers choose how much effort to put in per week (in minutes) based on a function of the cost of teachers' time and the number of lessons their students earn as rewards. Every teacher is attempting to both "learn" (i.e., explore) and "optimize" (i.e., exploit) the number of minutes spent on Zearn and learn over time how they should engage with the platform. We use two algorithmic strategies: (1) Temporal Difference with discretized options and (2) a gaussian policy gradient with continuous choice, and we estimate them using a hierarchical Bayesian approach. Teachers with higher learning rates tend to fluctuate their strategies too often, resulting in suboptimal behavior. Teachers also prefer to explore during the beginning of the school year, whereas they prefer to exploit during

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other times. These results show the flexibility of neuroeconomic approaches applied to large field datasets and reveal insights that more traditional social science techniques would otherwise miss.

P1-E-23: Time Heals: A Trust Game Experiment of Anger

Kamyar Kamyar¹, Marco Palma², Ian Krajbich¹

¹The Ohio State University, ²Texas A&M University

Psychological literature has shown that emotions calm down as time passes. However, few studies have tried to apply this phenomenon to cases where economic decisions are involved. Do people remain angry at each other over time when treated unfairly in cases involving monetary stakes? To study this, we have designed trust game experiments with monetary stakes. Specifically, we are studying the effect of time on anger in economic decision making. We use a game-theoretical framework (Battigalli, Dufwenberg, and Smith, 2019) of anger to carry out experiments in lab settings. We employ a repeated "trust game", in which two subjects are anonymously matched with each other and are randomly determined to be the "investor" or the "trustee". The investor initially receives an amount of money and chooses how much of it, if any, to "invest" (double the amount while transferring) to the trustee. Then, the trustee chooses how much of the doubled budget, if any, to give back to the investor. Low degrees of cooperation have been indicated to bring up feelings of anger. We study how the subjects' cooperation decisions changes when they have to wait variable lengths of time before making their decisions. Furthermore, to elicit the degree of anger resulted from lack of cooperation, we employ choice-process data measures: Galvanic Skin Response, a device measuring the degree of frustration through physiological production by sweat glands in the skin, and face-reading software, a neural-network based software identifying the type and degree of emotions in the face. These measures are intended to examine how people react to different kinds of investments/repayments, and how those emotions dissipate (or not) during the delay period.

P1-E-24: Neural circuits underlying the integration of reward and efficacy to determine the expected value of control

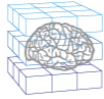
Romy Froemer¹, Joonhwa Kim¹, Mahalia Prater Fahey¹, Amitai Shenhav¹

¹Brown University

Objective– Investing mental effort is costly, and yet people do so all the time. How do people determine that the benefits of a given effort investment outweigh the costs? The expected value of control (EVC) theory proposes that people do so by integrating information about how much effort is worth (i.e. expected rewards) and how much effort is worthwhile (i.e., how much effort matters for obtaining these rewards). Previous work has yet to identify the neural circuits that underly the integration of the expected reward and efficacy of effort, and how this integrated value (EVC) is used to guide subsequent effort investment (i.e., control allocation).– Method– Participants (N=48) underwent fMRI while performing self-paced intervals of an incentivized Stroop task. Before each time interval, they were cued with the magnitude of rewards they could obtain on the upcoming interval, and whether these rewards would be more likely to depend on their performance (high efficacy) or determined at random (low efficacy). Incentives and interval duration varied pseudorandomly throughout the experiment, and reward outcomes for low-efficacy intervals were yoked to match reward rate across the two

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conditions.– Results– Consistent with EVC predictions and our previous work, we found that participants performed best (completed the most correct responses per second) when higher rewards were at stake and when their efforts were more efficacious, suggesting that effort investment reflected the integration of these two incentive components. Regions of ventral striatum and supplementary motor area tracked all motivationally salient properties of the cue (reward, efficacy and their interaction), whereas caudal dorsal anterior cingulate cortex (dACC) and other regions more selectively tracked the interaction (EVC) both in anticipation and during the task. Overlapping regions of rostral dACC independently tracked reward level and indicators of performance (errors and slow responding).– Conclusion– People integrate information about the worth and worthwhileness of effort to determine how much effort to invest in a task. Here we provide the first direct examination of how these two quantities are integrated to determine the overall value of control (EVC). Our results provide preliminary evidence consistent with the theory that this integration is reflected in dACC, but also distinguish these integrative representations from incentive representations that occur in anticipation of a trial (e.g., within ventral striatum) and additional evaluations of performance that occur while engaging control. Further analyses and experiments will examine the mechanisms by which these integrated values guide distinct forms of control allocation.

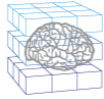
P1-E-25: Behavioral and Neural Alterations in Competitive Behavior in Depression

Zhuoya Cui¹, Lusha Zhu², Iris Vilares³, John Wang¹, Vansh Bansal¹, Pearl Chiu¹, Brooks King-Casas¹
¹Virginia Tech Fralin Biomedical Research Institute, ²Peking University, ³University of Minnesota

Objective: This study examines social competitive behavior in individuals with and without depression to delineate whether aspects of social difficulties in depression may be attributed to altered reward valuation and excessive interpersonal guilt. Methods: Using a novel multiplayer economic game involving social competition and functional neuroimaging, we examined 65 unmedicated depressed participants and 47 non-psychiatric controls at two time points (T1 & T2) with a three-month interval in between. A computational model with two parameters of interest, i.e., preference for dominance and interpersonal guilt, was fit to the observed behavioral choices. Results: Model estimation suggested comparable valuation of social dominance between individuals with and without depression. However, the depressed group exhibited higher guilt at T1 (group parameter for guilt was significantly greater than 0 given that the lower bound of its 95% highest density interval was greater than 0), which was found to be positively correlated with depressive symptoms at T1 ($r=0.26$, $p=.004$). Change of guilt from T1 to T2 scaled with change of symptom severity among individuals with depression ($r=0.29$, $p=.04$). Neurally, depressed participants exhibited comparable striatal response to winning social contests, relative to controls. Higher guilt was associated with greater activations in the ventral medial prefrontal cortex underlying increased cooperativeness (SVC $p<.05$ with cluster threshold at $p<.001$, $r=0.26$, $p=.01$), and hypersensitivity to social contests in the anterior cingulate cortex (SVC $p<.05$, $r=0.26$, $p=.006$), and right anterior insula (SVC $p<.05$, $r=0.29$, $p=.002$). Conclusions: Taken together, enhanced guilt along with preserved neurobehavioral valuation of social status suggest that altered competitive behavior in depression may be attributed to elevated social preference to avoid unequal outcomes rather than decreased valuation of social rewards.

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P1-F-26: Trait-like confidence: Participants' confidence ratings across a social, an emotional, and a perceptual task are positively correlated

Nathan Torunsky¹, Iris Vilares¹

¹University of Minnesota - Twin Cities

Objective: Every decision we make is accompanied by uncertainty. Previous work has illustrated that within-individual estimates of uncertainty are nearly identical across different sessions of the same task, and are even highly similar across tasks that engage different sensory modalities, specifically audition and vision, so long as these tasks have a similar structure. The goal of the present study was to examine the extent to which individuals' consistency in confidence ratings generalizes beyond low-level sensory tasks and into higher-level social and emotional perception and decision-making. **Methods:** We pre-registered three studies that drew from different samples: in-person participants at the 2019 Minnesota State Fair ($n = 123$), in-person students ($n = 125$), and online students ($n = 360$). Participants completed three tasks: a visual motion detection task using a random dot kinematogram with four different SNRs, an emotional/mentalizing task called the Reading the Mind in the Eyes Task (RMET), and one round each in the investor and trustee roles of the Trust Game, in which tickets to a raffle were being exchanged. In the RMET and Dot Task, participants rated how uncertain they felt about their response accuracy after every trial, whereas in the Trust Game it was a single rating of their uncertainty in anticipated returns from the game. **Results:** Across all three samples, participants' median confidence ratings in the RMET and Dot Task were moderately, positively correlated for all SNR levels ($E(r) = .49$), as were the median confidence ratings in the RMET and Trust Game ($E(r) = .29$). Likewise, participants' Trust Game confidence rating and total Dot Task confidence (ignoring SNR levels) were moderately, positively correlated across all three samples ($E(r) = 0.283$), but this trend did not hold for all SNR levels of the Dot Task. Nearly all correlations had $p < .001$. These effects were much stronger than the cross-task correlations for accuracy and metacognitive sensitivity, which failed to reach significance in two of our three samples. **Conclusions:** Confidence ratings appear to have a noteworthy proportion of shared variability across tasks indexing low- and high-level cognition. Notably, the strength of the correlations may be related to the structure of the task: notice that the RMET and Dot Task were both forced-choice tasks whereas the Trust Game offered an ordinal response (number of tokens invested). This may be indicative of an idiosyncratic, domain-general mechanism that processes perceived uncertainty, which produces trait-like differences in "core-confidence" across individuals.

P1-F-27: Assessment of mental states in FITradeoff DSS steps with reference activities using EEG

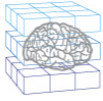
Ana Paula Cabral Seixas Costa¹, Anderson Lucas Carneiro de Lima da Silva², Jefferson Souza Medeiros²

¹No., ²Universidade Federal de Pernambuco

Multi-criteria decision-making is part of the daily lives of people, companies and organizations (DE ALMEIDA et al. 2015). Within this context is the FITradeoff method which is implemented in a decision support system (DSS) (DE ALMEIDA et al. 2021). Given its flexibility, it has been widely used in various problems. Despite this, some questions remain unsolved about how the different steps of FITradeoff demand the decision maker. **Objective:** This work aims to carry out a comparison study between two steps of FITradeoff, namely, scale constants ordering and elicitation by decomposition, with two reference activities, calculation (state of greater cognitive involvement) and music (state of less

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involvement cognitive). The considered steps of FITradeoff have different paradigms present in other multi-criteria approaches. Thus, through comparison, we seek to assess how such paradigms cognitively demand decision-makers, also considering the effect of the number of criteria on decision problems. **Methodology:** A 16-channel electroencephalogram (EEG) was used in a sample of 36 undergraduate and graduate students in production engineering. Each participant developed their own decision problem to be solved in the DSS. All experiments were performed in the NeuroScience for Information and Decision Laboratory. For the analyses, the total sample was divided into two groups: up to five criteria in their decision models; more than five criteria in their models. The Wilcoxon test was applied, using a statistical rigor of 5% to assess the theta band (4-8 Hz) that represents a state of higher associative memory and levels of attention and task engagement (PUMA et al. , 2018). **Results:** The analysis of the theta band suggests from the P8 channel for the first group that there is proximity of the ordering and elicitation steps to the activities of calculation. As for the second group of the sample, according to the F3 channel, it was possible to suggest that the elicitation step is more distant from the music activities. Thus, it is suggested that with the increase of the number criteria in the decision model, there is a reduction in the cognitive effort applied in the ordering step. The analysis also suggests that, in the elicitation, participants are able to remain more cognitively engaged. **Conclusion:** The present research has the potential to contribute to studies in the area of multi-criteria decision-making, providing valuable insights for the improvement of the FITradeoff DSS and allowing the expansion of knowledge in other contexts.

P1-F-28: Flexible integration of cost and evidence during information sampling

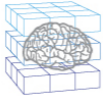
Abigail Hsiung¹, John Pearson¹, Jia-Hou Poh¹, Shabnam Hakimi¹, R. Alison Adcock¹, Scott Huettel¹
¹*Duke University*

To guide effective decision making in an uncertain world, humans must balance seeking relevant information with the costs of delaying choice. Optimal information sampling requires computationally expensive value estimations while information sampling heuristics are computationally simple but rigid. Efficient and flexible information sampling, therefore, must leverage the advantages offered from both approaches. In the present study, human participants completed a sequential information sampling paradigm under two reward conditions. We examined how behavior maps onto potential information sampling strategies, finding that choices are best described by a strategy that lies between optimality and heuristics; one that integrates the magnitude of evidence favoring a category and the number of samples collected thus far. Integration of these informational sources resulted in a trade-off between evidence and sampled collected, in which the strength of evidence needed for stopping decreased linearly as costs accumulated over the course of the trial. This strategy best accounted for choice behavior even under high reward contexts. Our results demonstrate that unlike optimal strategies, humans are performing simple accumulations instead of computing expected values, and that unlike simple heuristic strategies, humans are dynamically integrating multiple sources of information in lieu of using only one source. This evidence-by-costs tradeoff illustrates a computationally efficient strategy that balances competing motivations for accuracy and cost minimization.

P1-F-29: Identifying latent motives of individual normative behavior

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¹University of Zurich

Objective Recent political crises in the USA and the UK illustrate how norm violations can impact the functioning of societies. Addressing this issue requires a solid understanding of the private motives leading people to violate norms in the first place. There are several candidate motives. First, violation may depend on context: For example, individuals may not prevent passive harm but refrain from actively causing it. Second, individuals may be differentially sensitive to social stakes (cost/consequences) of their decisions. Third, distributional preferences may lead some to decide based on efficiency, whereas others may favor equity. Finally, individuals may have different general prosocial vs selfish biases. Violation may also depend on misunderstanding of the injunctive norms (normative judgements). It is unclear, however, if choices are guided by normative judgments, or if the mechanisms underlying these two behaviors are different. **Methods** We present a unifying experimental and modelling framework to disentangle the effect of these factors on norm violation and judgments. In a first study, 70 subjects (Players A) chose to either comply with a norm or violate it to gain money, in two separate contexts framed as either helping a Player B recover some money or erasing Player B's payoff. Varying payoff distributions allowed us to quantify the effects of the different factors on norm violation. A second group (N=75) judged the appropriateness of the same choices made by fictive Players A. This allowed us to measure the injunctive norm and quantify the effects of the same factors on judgments. In a second study, we examined choice consistency across violation and judgments in 169 subjects who completed both tasks. **Results** Our modelling results reveal that violation vs judgments are guided by different latent motives. While both behaviors were best explained by a combination of all factors, judgments failed to accurately predict violation. Efficiency played an important role in violation, whereas judgments relied on social stakes. Average violation strongly varied across subjects (mean=66%, std=25%), whereas judgments were more consistent (std=15%). Study 2 confirmed that most individuals did not consistently follow what they judged be the injunctive norm. Norm violation increased with inconsistency across tasks ($c=0.62$, $p<0.001$), suggesting that subjects who employ different strategies in their judgments and choices are more likely to violate norms. **Conclusions** Our framework allows to identify and compare the latent motives responsible for individual differences in norm violation and judgments. Such a framework may be crucial for understanding the mechanisms guiding pathological normative behavior.

P1-F-30: Amygdala structural integrity is associated with social feedback-based learning in older adults

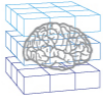
Karolina Lempert¹, Michael Cohen², Camilla van Geen², Frances Reckers², Kameron MacNear³, Laura Zaneski², Sandhitsu Das⁴, David Wolk⁴, Joseph Kable²

¹Adelphi University, ²University of Pennsylvania, ³University of Illinois ? Urbana-Champaign, ⁴Hospital of the University of Pennsylvania

OBJECTIVE: Even a generous person might occasionally act unfairly. Thus, when learning about someone's intentions, people often have to integrate over multiple experiences with them. Previous research has shown that aging negatively impacts the ability to learn incrementally from probabilistic feedback, but few studies have directly contrasted age-related changes in this process between the social and non-social domains. Moreover, while the amygdala has been shown to play an important role

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in social feedback-based learning, it is unknown whether structural integrity of the amygdala in older adults is associated with learning in this context. Here we examined social feedback-based learning in older adults and related it to gray matter thickness in the amygdala. **METHODS:** Young (ages 18-38; $n = 113$) and cognitively normal older (ages 61-92; $n = 108$) adults completed a task in which they learned about four other people (social condition) and four images of houses (non-social condition) through trial-and-error. In the social condition, they learned how much previous participants shared out of \$10 in a Dictator game (\$5, \$4, \$2, or \$1). The houses were randomly paired with these same values. On each trial, participants selected one of two stimuli and received feedback, but feedback was noisy, such that they only saw the true value of the stimulus 60% of the time. Participants' goal was to learn the true value associated with each stimulus and then choose the higher-valued stimulus on each trial. In the final block, they were no longer given feedback; the proportion of correct choices in this "test" block was the primary outcome measure. A subset ($n = 84$) of older adults underwent structural MRI to obtain gray matter thickness measures in bilateral amygdala. **RESULTS:** Compared to young adults, older adults were less accurate on both social ($t(219) = 3.59$; $p < 0.001$) and non-social ($t(219) = 3.22$; $p = 0.001$) trials in the test block, with no significant domain differences. Among older adults, mean amygdala thickness was associated with learning in the social condition (partial $r = 0.35$; $p = 0.001$, controlling for age, gender, and education). This relationship was weaker and not significant in the non-social condition (partial $r = 0.18$; $p = 0.102$). **CONCLUSIONS:** We observed age-related decline in probabilistic feedback-based learning in both social and non-social domains. In addition, amygdala thickness was associated with learning performance in older adults, particularly on social trials. Although this study was cross-sectional, it suggests that atrophy of the amygdala may impact the ability to learn about other people's intentions from noisy feedback.

P1-G-31: Changes in memory-guided decision-making underlie increased model-based planning across development

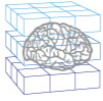
Nora Harhen¹, Aaron Bornstein², Catherine Hartley³

¹CCN Lab, ²University of California, Irvine, ³New York University

Objective: Through experience, we learn how effective an action is towards reaching desired outcomes. Action values can be estimated from experience in multiple ways, including a recency-weighted average of past outcomes ("model-free" reinforcement learning), a prospective simulation of outcomes using a mental model of the environment ("model-based" reinforcement learning), and retrieval of individual memories of outcomes that followed past actions (episodic memory). Prior work has shown that the use of these different valuation mechanisms undergoes change across development. Specifically, the use of model-based planning increases into young adulthood (Decker et al, 2016). However, it remains unclear how the use of memory to guide value estimation and, consequently, decision making changes with age. Episodic memory-guided action selection may be particularly beneficial during development. Episodic control allows for robust learning from limited experience and is computationally simpler relative to model-based control (Lengyel & Dayan, 2008). However, episodic memory has also been empirically shown to contribute to model-based computations and shares the same neural substrates (Vikhbladh et al 2019, 2017) Therefore, we asked: (1) How does memory-guided decision-making change with age? and (2) Do age-related changes in memory-guided decision making correspond to changes in model-based planning? **Methods:** Participants ($N=85$, ages 8-25 years old, data collection ongoing) completed

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two tasks -- a two-day version of a decision-making task optimized to distinguish the influence of recent rewards versus memories of distant, past rewards on choice (Bornstein & Norman, 2017) and a reinforcement learning task designed to differentiate between use of a model-free versus model-based strategy (the "two-step" task; Daw et al 2011; Decker et al 2016). Both tasks were designed such that use of a memory-guided or model-based strategy did not result in more reward on average relative to a recent reward-guided or model-free strategy. Results: Both the use of memory to guide decision-making and use of a model-based strategy increased with age (β memory= 0.098, $p = .006$; β model-based = 0.070, $p = .053$). Furthermore, we found that age-related changes in memory-guided decision making mediated the relationship between age and model-based planning (standardized indirect effect = 0.029, 95% CI = [0.003, 0.06] , $p = .031$). Conclusion: Consistent with memory's proposed contributions to mental model construction and prospective simulation, these findings suggest that the ability to use memory in support of decision making provides a foundation for model-based planning.

P1-H-32: Choice between multi-attribute and multi-modal uncertainties

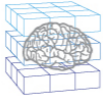
Zeynep Enkavi¹, Gabriela Tavares¹, Antonio Rangel¹

¹Caltech

Neuroeconomics studies of decision making under uncertainty use either choice between repeated experiences of uncertain rewards or between explicitly described rewards and their probabilities. Yet, real-world decisions involve multiple attributes from different modalities (e.g., choosing a college based on a campus visit and graduation rates). We designed a paradigm to study multi-attribute decisions under uncertainty and examine: How does the effect of each attribute on choice change as a function of its relevance for reward? Is learning about experienced uncertainties distorted when this attribute does not solely determine the outcome? 25 subjects completed five runs of 60 trials in the scanner. In each trial subjects chose between a left or right bundle. Each bundle consisted of a fractal and a lottery. Once subjects chose a bundle, a first draw determined the rewarding attribute for the trial. A second draw determined the reward based on the rewarding attribute's reward probability. We manipulated the relevance of each attribute by changing the probability that the reward depended on the fractal or the lottery in the first draw. In each trial subjects first saw the relevance of each attribute followed by the bundles. On the reward screen they saw the trial reward, the rewarding attribute and whether each fractal yielded a reward. The effect of attributes on choice changed appropriately with the attributes' relevance. Still, the lotteries affected choice more than the fractals at equal attribute relevance. Learned Q-values explained choice better and had larger effects than the true (but to the subjects unknown) values of the fractals. Model comparison revealed that consistent learning, where the fractal values are updated after each trial, explained choice best, i.e., the relevance of each attribute was distorted while learning was not. RT showed interesting patterns too. Choice was slowest when each attribute mattered equally and sped up similarly the more either attribute was more relevant, except for categorically faster decisions when fractals were the only relevant option. Choice was faster the larger the lottery value difference when lotteries were more relevant, but fractal value difference had no effect on RT. These patterns can be captured by a drift diffusion model with an integrator for each attribute and a third arbitrator integrator. We found that choice is biased towards described attributes (lotteries), the attribute with less uncertainty about its potential value but learning from repeated experiences is not distorted. We are in the process of modeling the RT patterns and analyzing the fMRI data.

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P1-H-34: Model based control can give rise to devaluation insensitive decisions

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¹University of East Anglia, ²Princeton University

Objective: A core idea in neuroeconomics is that the brain simplifies laborious computations using habits. A well-developed version of this idea comes from reinforcement learning concerning the trade-off between model based (MB) and model free (MF) systems. Here we present a new approach to MB in which agents are given the capacity to maintain separate sets of their environment's dynamics (formally a Markov Decision Process, MDP). Which MDP to update and use for planning is modelled as a process of Latent Cause Inference (LCI). We test the theory in a series of simulations that examine whether this exclusively MB learner can generate the devaluation insensitive decisions interpreted as a hallmark of habits (i.e., arising from MF), in a classic laboratory test. **Methods:** We test the model in simulations of the reinforcer devaluation procedure. Agents learn to leverpress to obtain food (acquisition). Food is then devalued by pairing it with illness (devaluation). We then observe whether agents select to leverpress again (lever test). The model combines LCI with standard MB learning. Observations on each trial (comprising a set of contextual stimuli and the state trajectory of an MDP) are conditioned on a latent cause with a Chinese Restaurant Process prior. Actions are chosen via a softmax that compares Q values (computed by value iteration) under each cause in the MDP, marginalized over the latent cause inferred given observations up until the current point in the trial. At the end of each trial, we infer the current cause and update its statistics using a particle filter to approximate the posterior over the assignment of trials to causes and the associated cause-specific learned models. **Results:** Simulations reveal that segregating MDP learning during acquisition and devaluation phases into different latent causes prevents devaluation generalizing to the lever test. This gives rise to insensitivity to reinforcer devaluation (persistent lever pressing in the lever test) despite the model omitting any habitual (MF) component from the model. "Ersatz habits" (just like laboratory ones) emerge after overtraining, interact with contextual cues and show preserved sensitivity to reinforcer devaluation in a consumption test (a standard control). **Conclusions:** While these results do not rule out a contribution of MF per se, they highlight the need for caution in using devaluation procedures to rule in (or out) the contribution of different learning mechanisms. They also offer a new perspective on the neurocomputational substrates of repetitive behaviours prevalent in clinical pathologies such as OCD and addiction.

P1-I-35: Investigating How Attentional Distractors Impact Value-Based Choices and Choice Processes

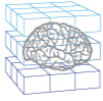
Deborah Cesarini¹, Matthew Bachman², Scott Huettel¹

¹Duke University, ²University of Toronto

Study's objective. This study aimed to examine whether and how attentional distractors influence value-based decision making. Previous studies have shown that measuring changes in attention (e.g. eye gaze) can improve predictive measures of choice, suggesting that attention plays an influential role upon choices and choice processes. Recent work has also suggested that attention can play a causal role upon valuation processes. However, such studies were often conducted in settings where people were able to maintain uninterrupted attention on the items they were evaluating. These circumstances are not representative of how we make many choices in the real world, which is frequently filled with distracting stimuli. Here, we periodically introduced attentional distractors during the decision process

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and measured their subsequent impact upon choices and patterns of visual attention. Methods. Participants ($n=50$) first rated 40 food items based on how much they wanted to eat them, then completed an incentive-compatible binary-choice food task. On two-thirds of trials, participants made choices without interruption. On one-third of trials, we briefly introduced a task-irrelevant attentional distractor partway through their first fixation on a food item while simultaneously removing the food images from the screen. After a brief delay, we removed the distractor and allowed the choice process to complete normally. We measured choices and eye-gaze patterns during each trial in order to test for differences between the no-distractor and distractor conditions. Results. Mixed-effect regressions found that participants' choices and choice times aligned with their self-reported wanting ratings such that highly- or lowly-valued items were chosen or rejected faster, respectively. While there were no differences in choice selection between conditions, participants made significantly slower choices in the distractor conditions. After the distractor, participants were more likely to look at the second item in 83% of cases ($p < 1 \times 10^{-10}$), but this effect was modulated by the value of the first item that they had partially viewed. In both conditions, participants were more likely to choose the first item they looked at ($p = 3 \times 10^{-4}$). Conclusion. This study shows that distractors may interrupt the decision making process but do not necessarily reset it since the information gathered beforehand may still influence subsequent fixations as well as the final decision. We also introduce a more realistic way of studying how attention affects decision making via distractions that simulate the attentional disruptions people encounter when making choices in the real world.

P1-I-36: Developing Real-Time Surveillance for Mental Health Risk: A Machine Learning Model for Suicide Ideation Detection

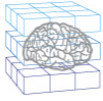
Laurette Dubé¹, Jocelyne Whitehead², Jian-Yun Nie³

¹McGill, ²McGill University, ³Université de Montréal

Objective: While neuroeconomics and decision sciences provide understanding of risk in laboratory settings, such knowledge has yet to permeate professional practices to support vulnerable populations. Public Health Agencies use health surveillance strategies that rely primarily on historical sources, where timeliness can be problematic for policy development. In contrast, a social media platform could provide rich, real-time data to be leveraged for surveillance and understanding of mental health problems, and for evidence-based support. Here, machine learning (ML) techniques were applied to classify suicide ideation from de-identified Twitter data. Model evaluation used real-world data to highlight the potential for, and challenges of, integrating ML decision tools into real-world applications. **Methods:** De-identified Twitter data was collected over a one-year period (Jan 2018 to Jan 2019), filtered using defined search terms, and annotated based on an extensive review of suicide ideation literature. Data was grouped into four "suicide" classes across eight potential risk factors. A total of 549,811 English tweets were submitted to a series of ML experiments: a neural network (BERT-MLP) and traditional models (Naive Bayes, Random Forest). BERT is a state-of-the-art deep learning model for creating contextualized representations for sentences. Under supervised training, features for suicide detection are automatically generated from tweets. Pre-trained BERT with fine-tuning offers a solution for managing limited training data in real-use situations. **Results:** BERT demonstrated the best classification accuracy, consistent with the ML literature. The algorithm achieved an accuracy of 84% (AUC of 72%) for the most important class of suicide ideation. All ML results showed that the risk factor depression had

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the greatest influence on model performance for "suicide ideation" (40%) and "suicide related" (60%) classes of tweets. Loneliness was mentioned in 11% of suicide ideation tweets and 23% related to suicide without specific ideation. Fear/anxiety-related tweets were less frequent, mentioned in 7% suicide ideation and 9% suicide related tweets. Conclusion: Based on these results, it seems feasible to design and implement an automatic suicide detection tool using social media data to provide real-time surveillance information. The relatively high accuracy of BERT combined with the ability to integrate expert knowledge to enhance learning performance describes a system that is responsive and sustainable. This automation could increase understanding of expressions of suicide-ideation, helping to implement accurate and timely public health responses.

P1-I-37: fmri.factory: An R package for facilitating model-based fMRI analysis on high-performance computing clusters

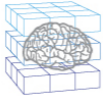
Michael Hallquist¹

¹*University of North Carolina at Chapel Hill*

Many neuroscientific studies of decision-making in humans depend on the integration of signals from computational models with concurrent neural activity during a functional MRI scan. Computational models typically instantiate hypotheses about what individuals represent as they make choices during experimental paradigms. When paired with fMRI data collected during the same task, researchers can examine which neural circuits may be involved in representing a given signal such as the well-studied reward prediction error. Despite these strengths, model-based fMRI analysis using the general linear model (GLM) can be prohibitive to setup, requiring a deep knowledge of both the trial-varying signals from a computational model and the corresponding regressors to test against the BOLD data. Even when one succeeds in setting up a model-based analysis, it is often laborious to test multiple competing models. Finally, the compute time of model-based fMRI analyses can be substantially reduced by using high-performance computing (HPC) clusters, yet this requires a level of technical expertise that is difficult to access for most applied researchers. Here, I present the *fmri.factory* package, developed in the open-source R language. This package addresses three challenges in the setup of model-based fMRI analysis. First, it walks users through human-readable prompts for constructing fMRI GLM models, including the automatic coding of contrasts for both within- and between-subject designs. Second, it provides a unified framework for managing multiple fMRI models that vary in terms of the corresponding computational model and the parameterization of fMRI regressors (e.g., 'beta series' or temporal derivatives). Third, it hides the complexity of job scheduling on HPC clusters (both TORQUE and SLURM are supported) by generating interlocking jobs that complete each step of the analysis (e.g., subject models versus group models). The pipeline uses field-leading estimation methods and on moderns HPCs, often completes analyses of large fMRI datasets (> 100 participants) in 24 hours or less. In addition to these features, the *fmri.factory* package provides user-friendly familywise error correction methods (pTFCE and permutation-based cluster correction) and functions to organize, label, and combine voxelwise maps across the models that comprise a given analysis. Perhaps most importantly, these features can be implemented in a single short script (50-100 lines) that is human-readable and accessible to people who are entering this exciting field. I believe that the neuroeconomics community would appreciate the conceptual and technical agility offered by *fmri.factory*.

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P1-I-38: Ventral Tegmental Area and The Hippocampus Differentially Track Reward Prediction Errors in a Reinforcement Learning Task

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¹The University of North Carolina at Chapel Hill, ²University of Pittsburgh

Study's Objective: Dopaminergic (DA) inputs from the ventral tegmental area (VTA) to the hippocampus help bind reinforcement representations onto a cognitive map via reward prediction errors (PE). We previously showed that posterior hippocampus (PH) sensitivity to PEs modulated exploration (shifting one's choice) and anterior hippocampus supported exploitation (convergence on the best option). In this study, we examined the contributions of PE representations in the VTA on exploration versus exploitation. Specifically, we tested whether 1) event-locked BOLD activity in the VTA predicted exploration, and 2) the hippocampus and VTA differentially modulate reward learning via local (PE-related) and global (change in the entropy of the learned value distribution) update signals. **Methods:** 70 participants completed a spatiotemporal reward task in the fMRI scanner (the "clock task"). Data were analyzed using computational model-based voxelwise GLM analyses and a Multilevel Event-Related Deconvolved Signal Analysis (MEDuSA). MEDuSA consists of multilevel models of deconvolved trial-by-trial BOLD activity, allowing us to see the effect of within- and between-person interactions of brain activity and behavioral outcomes. It also quantifies changes in the strength of neural signals across different time points relative to events in the experiment (e.g., -5 - 10 seconds around the stimulus and feedback onset), helping us investigate learning effects on regional activity. **Results:** Individuals with stronger VTA responses to PEs showed greater exploratory shifts in response times between consecutive trials. This was especially true after rewarded trials (Win-Shift) and held when hippocampal PE responses were included in the behavioral model. Additionally, in MEDuSA analyses, the VTA showed a phasic response to feedback that was stronger for omissions. Entropy change was differentially related to activity in the VTA and along the hippocampal long axis: Positive entropy change was associated with higher VTA and PH activity while the AH showed stronger activation in response to negative entropy change at the time of feedback. **Conclusions:** Our results support VTA's role in PE-related exploration in a complex task with a continuous reward function. VTA and PH modulate local updates to immediate feedback (PE) and they respond to increases in the complexity of the global landscape (positive entropy change). AH shows the opposite pattern, supporting its role in exploitation while learning the broader structure of the environment. Altogether, VTA and PH representations of reward prediction errors promote exploratory behavior, but are not redundant with each other, while AH is more sensitive to convergence on the best option.

P1-I-39: Assessing the Relationship between the Human Learned Helplessness Depression Model and Anhedonia

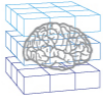
Xin Song¹, Iris Vilares¹

¹University of Minnesota, Twin Cities

Objective: The learned-helplessness (LH) model is one of the most widely used Depression models and has been shown to be able to induce depressed-like behaviors and corresponding psychophysiological changes. However, there is little evidence showing that the LH paradigm can produce anhedonia, a core symptom seen in all forms of depression in humans. In the present study, we use a modified LH task to

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experimentally and temporarily induce learned-helplessness in participants and to examine if the LH paradigm can produce state anhedonia in humans. Methods: We adapted the original version of the human LH task and made a computer task using a triadic design. The triadic design was a 3-group paradigm that allowed us to manipulate the controllability of the identical stressor (loud tone) by assigning different levels of uncontrollability to each group: a master-escapable shock group, a helpless-inescapable shock group, and a control-no treatment group. Participants ($n = 85$, randomly assigned) went through two phases of the experiment; in the first phase when helplessness was experimentally manipulated, the master group was given 30 unsignaled but escapable loud tones; the helpless group 30 unsignaled inescapable loud tones, and the control group passively listened to loud tones identical to the ones used in the other two groups. In the testing phase, all participants were given 18 signaled and escapable loud tones and were told that they could terminate the tone by finding out the correct keyboard sequence. Successfully escaped trials and response latency were measured for all three groups. To investigate if learned-helplessness could induce state anhedonia, we instructed participants to report their self-rating of hedonic capacity on two state anhedonia surveys (FCPS and DARS) before and after the LH task. In addition, response bias towards rewards in a behavioral signal detection task was measured to cross-validate the self-reported anhedonia survey scores. Results: Participants in both the LH and the control groups showed impaired escape learning compared to the master group, evidenced by significantly more failed trials and longer response latency. However, two-way mixed factor ANOVAs revealed no significant group differences in either state anhedonia scores or in response bias ($p > 0.05$). Conclusions: The results suggested that contextual learned-helplessness can be induced by a lack of controllability. However, there was no evidence that learned-helplessness could reliably induce state anhedonia in humans participants. Our results add to our understanding of the learned-helplessness depression model and cast doubt on its construct validity.

P1-L-40: Computational mechanisms underlying learning and recalling of trustworthy partners

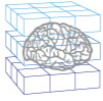
Gabriele Bellucci¹, Peter Dayan¹

¹*Max-Planck-Institute for Biological Cybernetics*

Learning the personalities of others is fundamental for navigating social environments. Previous work has identified which traits are central to the impression of trustworthiness, but how these traits are inferred and remembered to influence social decisions in repeated interactions is underexplored. Objectives We studied how individuals learn another person's trust attitude, and tested memory effects on prosocial behaviors. We used a novel modification of a multi-round investment game in which participants interact with multiple partners. On each trial, participants, as trustees, need first to choose one of two teams from which an investor is randomly chosen to play. Importantly, each investor sports a trial-unique avatar that participants can use to remember their interaction. Methods Team members have different trust attitudes which participants can infer. They can benefit from playing and reciprocating with the currently more trustworthy team. Investor behavior is actually generated by a novel computational model that parametrizes the teams' trust attitudes as the trade-off for the investor between potential losses and the gains expected from the players' joint choices. Occasionally, participants are shown an avatar and are asked to remember whether they have already played with the associated investor; this reminds them of their interaction. Results Preliminary results show that participants come to make good inferences about the teams' trust attitudes (which are not directly

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observable) and change their team preferences and reciprocal behaviors accordingly. Consequently, participants prefer to play with teams with greater trust attitudes and reciprocate according to their (putative) associated beliefs. In particular, participants reciprocate with higher back-transfers to an investor whose team they believe to have a greater trust attitude. Further, retrieval of a team with a greater trust attitude (at storage) increases participants' likelihood of choosing that team (at retrieval). The strength of these memory effects decayed linearly over trials. Conclusions This study provides important insights into memory effects on sequential, social decisions in interactive contexts, showing how individuals remember social interactions and how their retrieval biases subsequent decisions with other social partners.

Poster Session 02

P2-A-41: Investors' brain activity relates to future stock market performance

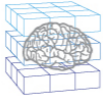
Leo van Brussel¹, Ale Smidts¹, Roeland Dietvorst², Maarten Boksem¹

¹Erasmus University Rotterdam, ²NN Investment Partners

Objective: Successfully forecasting stock market performance remains notoriously difficult, if not entirely impossible. Interestingly, research on 'neuroforecasting' (Genevsky & Knutson, 2019) suggests that future market-level behavior can be explained by neural predictors of choice. Recently, Stallen et al. (2021) showed that neural predictors can forecast stock price dynamics. Our aim was to extend their findings, by investigating whether brain activity of professional investors assessing complex real-world investment cases relates to their long-term future market performance. **Methods:** We invited 36 professional investors to participate in the Stock Performance Prediction Task (SPPT), while undergoing fMRI. The SPPT consisted of 43 anonymized, real-world investment cases of companies either overperforming or underperforming in their market segment 12 months in the future. Per investment case, five consecutive, information screens containing objective stock indicators were presented: (1) Company profile, (2) Price graph, (3) Fundamentals, (4) Relative Valuation, (5) News Item. Next, participants were asked to predict whether the company's stock would overperform or underperform its sector benchmark in exactly 12 months in the future. We used logistic regression analyses to test whether brain activity related to stock market performance, in addition to participant's predictions and stock indicators. **Results:** We find that our sample of investors could not successfully predict future market performance of the investment cases, confirming that conscious choice does not predict the market. Objective stock indicators were not predictive of future performance either. Following the neuroforecasting literature, we selected the Nucleus Accumbens (NAcc), Anterior Insula (AIns) and Medial Prefrontal Cortex (MPFC) as neural predictors. We find that average NAcc activity positively predicted future stock performance at the Company profile screen ($b = 1.66$, $SE = 0.72$, $p = 0.021$) and the Price graph screen ($b = 2.15$, $SE = 0.90$, $p = 0.017$). This finding remained robust in combined models, with stock indicators and conscious choice added as predictors ($b = 2.09$, $SE = 0.88$, $p = 0.017$). Cross-validated prediction analysis indicated that NAcc activity could significantly predict future stock performance with an accuracy of 70%. **Conclusions:** We find that brain activity of professional investors assessing real-world investment cases relates to future performance of stocks, resonating with recent neuroforecasting studies. Our study advances neuroforecasting literature by presenting complex, realistic real-world information to professionals making long-term predictions.

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P2-B-42: Testing the optimisation hypothesis by tracking changes in decision strategy in a reward maximisation task

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¹University of Hamburg, ²University of Bristol

Normative theories of decision-making examine how behaviour is guided by the process of optimising a task variable. In models of perceptual decision-making, a task variable that is frequently implicated to modulate behaviour is reward-rate - the average reward gained over a sequence of decisions. Many studies have argued that optimising reward rate guides the selection of parameters used to accumulate evidence during the process of making perceptual decisions. Indeed, empirical evidence has shown that participants modulate their decision thresholds in response to a change in the reward structure of a task. Most of these studies only looked at the average behaviour of a participant over the entire experiment; however, optimizing reward rate involves a learning component, which is very likely accompanied by a change in decision strategy over time. As such, if participants truly aim to maximise reward rate, one should be able to observe how their behaviour is guided by this goal over the course of the experiment. In order to investigate this, we analysed data from an expanded judgment task where the goal was to maximize reward rate ($n = 24$ participants) and used a logistic regression model to estimate the height and slope of the decision threshold in a sliding window of trials. We observed that the majority of participants explored the threshold parameter space throughout the task, rather than settling on a specific threshold early on. Importantly, this exploration was seemingly not driven by the search for a maximum reward-rate - throughout the experiment, participants frequently switched to parameters that yielded relatively lower reward rate. Consequently, the majority of participants (17 out of 24) failed to approach the threshold parameters that were optimal with respect to the task. This pattern can likely be attributed to the noisy estimates of reward rate over a short window of trials, making the optimization of average reward rate more difficult. Our findings indicate that the assumption of a singular decision threshold is inaccurate for standard perceptual decision-making tasks, because it fails to reflect the significant degree of strategy adjustments over time. More generally, these results challenge the standard assumption made by normative models that behaviour in decision-making tasks is guided by the process of optimising reward rate. Future modelling work should address whether the adjustment of behaviour over time is based on random exploration of the threshold parameter space due to the noise in estimated reward rate, or whether it is guided by the decision-maker's attempt to optimise a different outcome variable.

P2-B-43: Is Responsiveness to Food Marketing Linked to Metabolic Health and Biological Markers of Decision-Making (Serotonin)?

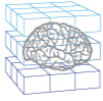
Shemal Doshi¹, Yann Cornil, Pierre Chandon¹, Leonie Koban, Marie Christine Falkenstein, Bernd Weber, Marie-Christine Simon, Hilke Plassmann¹

¹INSEAD

Objective: Serotonin has been implicated in the regulation of appetite and caloric intake. However, whether the effects of serotonin on caloric intake are purely homeostatic, or they also modulate cognitive processes involved in dietary decision making is less clear. A previous study showed that higher serotonin levels in the brain increased healthy food choices (Vlaev et al. (2017)). Given that

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tryptophan is the only precursor of serotonin, here, we investigated whether fasting-state tryptophan levels are linked to biases in calorie estimation induced by marketing actions. We know from the literature that tryptophan metabolism is linked to various metabolic parameters of obesity. Moreover, Cornil et al. (2022) showed that the people with obesity show higher calorie estimation errors compared to lean people. Hence, we further explored whether such biases in calorie estimation are linked to the metabolic health profile of participants. Methods: We tested 117 male participants, who estimated the amount of calories (per portion) of 12 branded snacks (6 brands framed and perceived as 'healthy' and the other 6 as 'indulgent') used to compute calorie estimation error (CEE %). To test our two main questions whether CEE is linked to individual differences in (1) tryptophan (2) metabolic health, we sampled participants' blood at fasted state. For (2) we computed a metabolic health risk score (MHRS) based on the medical literature by categorizing 12 different markers into three categories (very high-risk, high-risk and normal). The higher the MHRS, the unhealthier the metabolic state and higher the risk of obesity. Results: We found that participants did exhibit marketing-induced CEE (overall CEE =31.1%). Those CEE were mainly driven by the overestimation of calories of 'indulgent snacks' (30.2%). We found a negative association between CEE (%) and tryptophan levels, independently of controlling for metabolic health ($r = -0.24$, $p = .007$) or not ($r = -0.26$, $p = .007$). Hence, people with higher levels of blood tryptophan correlates to lower CEE. The metabolic health risk score was significantly associated with CEE (%) ($r = .2$, $p = .027$). Put differently, participants with higher MHRS, and thus with a higher degree (of risk) of obesity, were more responsive to CEE. Conclusions: The study provides the first evidence of an interaction between food marketing, serotonin and metabolic health linked to obesity. Further intervention studies (like selective serotonin reuptake inhibition) could provide a causal link between serotonin and food marketing which can have vital implications to fight and reduce marketing responsiveness specifically in consumers with (risk of) obesity.

P2-B-44: Inter-Individual Neural Similarity of Automobile Brands Predicts Brand Recall and Is Explained by Brand Personality

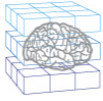
Jin Ho Yun¹, Michael Platt¹, Feng Sheng²

¹University of Pennsylvania, ²Zhejiang University

OBJECTIVE: The mental associations consumers form with brands are crucial for marketing success. One approach to measuring these associations is to ask consumers to make person-based judgments of brand personality attributes, which have been shown to coalesce in both semantic space and patterns of brain activity (Chen, Nelson, and Hsu, 2015). A second approach probes the free recall of brands, which predicts market share in a manner consistent with prototype-based retrieval (Hutchinson, Raman, and Mantrala, 1994). Here we use fMRI and representational similarity analysis (RSA) to connect brand personality and brand recall via multivariate patterns of brain activity. **METHODS:** Participants ($n = 33$) were presented with three types of words: (1) fourteen automobile brand words (e.g., "Ford"), (2) the two product categories "car" and "computer," and (3) the control condition "nonwords." Each word was presented twelve times in each of two runs per participant. Participants were instructed to think about the meaning of each word and press a button whenever they saw a nonword. **RESULTS:** Preliminary functional localization revealed neural activation patterns for automobile brands were more similar to the pattern for the 'car' product category than to the pattern for either the 'computer' category or 'nonwords' within the angular gyrus (AG), anterior temporal lobule, and temporal pole-- regions

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associated with semantic processing. RSA across consumers revealed that neural similarity of automobile brands predicted brand recall within the AG ($p = .021$), parahippocampal gyrus ($p = .019$), and occipital fusiform gyrus ($p = .027$), regions associated with semantic processing, memory retrieval, and object perception, respectively. Further, brand typicality assumed to be familiar to and liked by consumers was not represented in the localized brain, ruling out these confounds. Finally, brand personality traits of aggressiveness ($b = .18$), activity ($b = .09$), and simplicity ($b = .02$) were significant predictors of brand typicality within the AG. CONCLUSION: Here we show that automobile brands that are more prototypical in the brains of consumers were similarly recalled and share similar personality traits, directly connecting person-based judgments of brands and market share. Automobile brands with greater typicality critically involved the AG, highlighting the role of semantic processing in connecting personality traits and brand recall. These findings may be useful to marketers in brand positioning in the billion-dollar automobile industry.

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P2-C-45: Identifying a signature of delay discounting using machine-learning applied to whole-brain cortical structure

Valérie Godefroy¹, Marie-Christine Simon², Bernd Weber², Leonie Koban³, Hilke Plassmann¹

¹Paris Brain Institute / INSEAD, ²University of Bonn, ³Paris Brain Institute

OBJECTIVE: Delay discounting reflects the extent to which a reward loses its subjective value when it is received with a delay. It is an individual marker of impulsive decision-making, predicting important life and health outcomes. Our aim is to identify a brain signature (i.e., a typical brain pattern) of delay discounting in adults from structural brain features. Using a multi-variate method of machine-learning applied to structural MRI data is an original way to investigate the neural mechanisms of delay discounting, more reliable and reproducible than usual univariate methods. **METHODS:** We used data collected in healthy male participants (N=117; mean age=31.9) who performed a delay discounting task consisting of 108 choices between smaller sooner and larger later monetary rewards, and computed each participant's discounting parameter ($\log(k)$). Structural MRI data were preprocessed using voxel-based morphometry to assess local grey matter density across the cortex in each participant. We applied LASSO-PCR (least absolute shrinkage and selection operator-principal component regression) to the preprocessed MRI data, to obtain a pattern of brain cortical structure that predicts $\log(k)$. The predictive accuracy of the classifier was assessed using a stratified 10-fold cross-validation procedure. Bootstrapping (5,000 samples) was used to identify the brain areas that contributed most significantly to predict $\log(k)$. We further explored the spatial similarity between the obtained brain pattern and meta-analytic maps corresponding to specific functional networks. **RESULTS:** We identified a structural brain pattern predicting $\log(k)$ (called 'structural k-marker') with a cross-validated prediction-outcome correlation of $r = 0.35$ (permutation test: $p=0.003$), a mean squared error of 3.45 (permutation test: $p = 0.003$), and a mean absolute error for predicted $\log(k)$ of 1.46 (permutation test: $p = 0.002$). Significant predictive weights of the structural k-marker were found in the lateral parietal cortex and posterior cingulate cortex (at $p < 0.05$, FDR-corrected), as well as in the orbitofrontal cortex and amygdala (at $p < 0.001$, uncorrected). Comparing with meta-analytic maps showed that the structural k-marker was mostly similar to the maps associated with valuation, emotion and conflict processing. **CONCLUSIONS:** The identified structural k-marker evidenced the preponderant role of regions (such as lateral parietal cortex) not typically associated with delay discounting in the literature. This biomarker of impulsive decision-making could be used for the early detection of individuals at risk of different health conditions, in particular neurodegenerative diseases.

P2-C-46: Revealing the time-course of Pavlovian-instrumental conflict using mouse-tracking and drift diffusion modeling

Hoyoung Doh¹, Yunseo Jeong², Harhim Park¹, Daeyeol Lee³, Woo-Young Ahn¹

¹Seoul National University, ²The Catholic University of Korea, ³Johns Hopkins University

Decisions result from the interaction between multiple decision-making systems such as Pavlovian and instrumental systems. The Pavlovian system provides preprogrammed responses to rewards and punishments, while the instrumental system learns appropriate responses to get more rewards and avoid punishments. Studies using laboratory tasks such as the orthogonalized Go/Nogo task have

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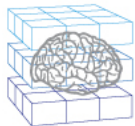
revealed that while Pavlovian and instrumental systems cooperate in many situations (Pavlovian-congruent responses), they sometimes compete with each other (Pavlovian-incongruent responses) hindering adaptive behavior (Cavanagh et al., 2013; de Boer et al., 2019; Guitart-Masip et al., 2012; Ousdal et al., 2018). While the orthogonalized Go/Nogo task has been widely used, it only yields final behavior responses but provides no information about the time-course of cooperation or competition between the two systems. To address this limitation, we developed a new version of the orthogonalized Go/Nogo task with mouse-tracking requiring an active response on every trial, with which we can track both the time-course of decision-making and final responses. We also developed a novel "change-of-mind" drift diffusion model to account for participants' mouse trajectories and final responses. We recruited 77 healthy adults and replicated the behavioral findings of the original orthogonalized go/no-go task when using the final responses. The mouse-tracking data revealed greater initial movement to Pavlovian-congruent targets compared to Pavlovian-incongruent targets ($p < 0.001$). Similarly, mouse trajectories deviated more from the shortest path to the Pavlovian-incongruent targets compared to Pavlovian-congruent targets ($p < 0.001$). Our drift diffusion model explained individual differences in human participants' initial response accuracy and directional change. This work demonstrates the utility of mouse tracking and sequential sampling models in explaining the within-trial dynamics of the cooperation and competition between multiple decision-making systems and provides novel insights into the computational mechanisms underlying Pavlovian-instrumental conflict.

P2-C-47: Continuous Tracking of Perceptual and Value-Based Evidence

Minhee Yoo¹, Giwon Bahg², Brandon Turner¹, Ian Krajbich¹

¹The Ohio State University, ²Vanderbilt University

(1) Objective. While the literature tends to focus on two-alternative forced choice, many decisions we make are based on a continuous scale and require temporal integration of incoming information. For example, how much we like a restaurant may be based on the average of prior experiences in that restaurant. Despite the abundance of these types of decisions in our daily life, the neural and computational mechanisms of such decisions has not been well studied. Our study investigated the evidence averaging process using a modified interrogation paradigm along with computational modeling, eye tracking, and fMRI. (2) Methods. The evidence averaging task had two blocks each of a perceptual task and a value-based task. In each trial, 30 pairs of square grids (perceptual task) or snack foods (value-based task) were presented in series; subjects ($N = 38$) had to judge the whiteness of the grids or the tastiness of the foods. Subjects continuously reported their estimates of the average evidence favoring left vs right (using a joystick) while we measured their brain activity and eye gaze. We modeled behavior with the Averaging Diffusion Model (ADM) (Turner et al., 2017). A temporal weighting function was added to ADM to assign differential weights to information sampled at different time points in a trial. ADM was fitted separately to each subject's perceptual and value-based data. (3) Results. Modeling results revealed that subjects had a recency bias in the evidence averaging process. The degree of this bias was very stable within an individual (Correlation between parameter estimates in the perceptual and value-based tasks: primacy: $r(36) = .57$, $p < .001$; recency: $r(36) = .63$, $p < .001$; noise: $r(36) = .84$, $p < .001$). Neuroimaging analyses revealed domain-specific brain regions for tracking instantaneous evidence (IE), the evidence favoring left vs right in a single pair of stimuli. Intraparietal



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sulcus tracked IE in the perceptual task, whereas the reward network - VMPFC, VS, PCC - tracked IE in the value-based task. We also found domain-specific brain regions for tracking average evidence (AE), the evidence favoring left vs right averaged over all the sampled stimuli in the trial. Visual cortex was involved in tracking AE in both tasks, whereas dorsolateral prefrontal cortex was selectively engaged in tracking AE in the value-based task. (4) Conclusions. Results from our study provide novel evidence on how the brain tracks average evidence over time. Despite remarkable behavioral consistency between perceptual and value-based tasks, the evaluation and integration of evidence appears to arise, at least partly, in distinct neural circuits.

P2-C-48: Neural Correlates of Emergent Prosocial Behavior During Dynamic Human Group Formation

Wojciech Zajkowski¹, Wojciech Zajkowski², Masahiko Haruno³, Rei Akaishi²

¹RIKEN Institute, ²RIKEN Center for Brain Science, ³The Center for Information and Neural Networks

OBJECTIVE: Probing the emergent changes in cognition as group sizes increase is vital for understanding the evolution of large cooperative societies. Larger group sizes often require complex self-versus-other trade-offs, as well as possibly greater mental capacity to process than smaller groups or dyads--issues which have been rarely studied in social neuroscience. Specifically, to date, there has been few studies exploring how dynamic cognitive changes associated with group size increases and decreases affect cooperation within economic decision-making experiments, as group size is typically fixed rather than modulated within-session. We deploy a novel, social network-embedded-dyad version of the classic iterative prisoner's dilemma (PD) task to study how preference for cooperation changes, within-subject, as a function of group size. **METHODS:** 87 participants (26 for fMRI) completed 240 trials of the iterative PD. Each trial consisted of a two-way PD game with one randomly chosen group member. New group members were added every ~5-10 trials in 180-trial session (up to a group size of 5 partners), but both the subject and current partner could unilaterally break ties on select trials. **RESULTS:** Being in larger groups is assumed to affect both memory and social behavior, which are examined by behavioral and neural analyses. Subjects consistently (72% of the trials) followed a well-performing decision policy (tit-for-tat, TFT), in which players imitate the prior choice of the current partner from their previous interaction, suggesting subjects could strategically track and respond to multiple partners even in larger groups and over multi-trial timescales. However, subjects became more forgiving as group size increased and the longer they haven't interacted with the current partner. Response time (RT) also increased with group size, suggesting larger group sizes required more mental capacity to process, while there was a default preference shift from faster RT for defect in dyads to faster RT for cooperate in larger groups. Larger group size was associated with deactivation in the right angular gyrus, while interaction distance was positively related to precuneus activity. Choice (e.g. TFT) and new partners each correlated with changes in the right fusiform gyrus and functional connectivity within social and salience networks. **CONCLUSIONS:** Overall, humans seem to default to more cooperative strategies partly due to intrinsic preference for larger group sizes, and this prosocial behaviour transition may be governed by the brain's social memory systems.

P2-D-49: Central EEG beta/alpha ratio predicts the population-wide efficiency of advertisements

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Neuroimaging studies have suggested the ability to use the brain activity of a group of individuals to forecast the behavior of a larger independent group at the population level. The current study aimed to forecast the outcome of the digital media campaign using electroencephalography (EEG), eye-tracking, and behavioral measurements. During two studies, participants were exposed to 10 banners, which were also used in the real digital marketing campaign of a large food retailer. We investigated the relationship between the EEG, eye-tracking, and behavioral indexes obtained during participants' visual processing of the banners and the banners' aggregated efficiency calculated based on the decisions of 291,301 Internet users. The central beta/alpha ratio--an EEG-based engagement index--significantly correlated with the aggregated efficiency of banner advertisements. Our multiple linear regression models demonstrated that a combination of EEG and eye-tracking data better explained the market-level efficiency of banner advertisements better than behavioral measurements. Overall, our results confirm those of prior studies that the brain activity of a relatively small number of individuals can forecast the aggregate choice of a larger independent group of people.

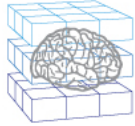
P2-D-50: Influence of Distinct Motives on the Moral Judgment of Broken Promises in the Workplace

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¹*Duke University*, ²*Columbia University*

Study's objectives. This study aimed to investigate whether and how certain motives influence how intensely people judge others' behaviors. We focused on two motives: control, which describes people's desire to manage what happens, and truth, which describes people's desire to understand what is real and right. We used a novel integrative framework that identifies different types of control-oriented (e.g. defend, protect) vs. truth-oriented activities (e.g. examine, assess) in the process of goal pursuit. For this purpose, we developed 22 workplace scenarios where a person broke a promise related to either a control- or truth-oriented activity. We explored whether the scenario motive influenced people's moral judgment intensity of that person's moral failure. Furthermore, previous studies have shown that moral failures may be judged more harshly if others perceive those actions to be more intentional. Thus, we also investigated a potential mechanism -- perceived intentionality -- through which these motives may affect moral judgment intensity. **Methods.** We presented all scenarios to participants ($n = 73$) in a randomized order and asked them to judge how morally wrong was the person's moral failure in each scenario. To measure perceived intentionality, we separately asked participants to rate how responsible the person was for breaking their promise in each scenario. **Results.** We conducted a multilevel regression analysis where moral judgment intensity was regressed on scenario motive with random intercepts of participant and scenario. We found that participants rated control-oriented (vs. truth-oriented) scenarios as more morally wrong ($p < 0.001$). To assess whether perceived intentionality mediated the association between scenario motive and moral judgment intensity, we conducted a Bayesian multilevel mediation analysis with two simultaneous regression models. In the first model, perceived intentionality was regressed on scenario motivational concern and, in the second model, moral judgment intensity was regressed on scenario motivational concern, both with random intercepts of participant and scenario. We found that perceived intentionality partially mediated the effect of

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scenario motive on moral judgment intensity ($\beta = 0.13$) such that control-oriented scenarios were perceived as more intentional ($\beta = 0.47$) and therefore judged as more morally wrong ($\beta = 0.27$). Conclusion. This study shows that distinct motives may influence how harshly people judge others' moral failures. It contributes to the moral and social psychology literatures by helping to establish the motivational determinants of moral judgments.

P2-D-51: The Effect of Ad Hoc Category Construction on Purchase Intention: An fNIRS Study

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¹Florida Atlantic University

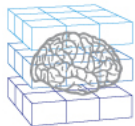
Introduction: To meet the needs of a specific context, consumers must sometimes construct an ad hoc category of brand-name products (i.e., a category that is not typically represented in one's mind). The objective of the present study was to examine the neural mechanisms underlying the construction of multiple ad hoc categories and the effect of that construction on purchase intention behavior. We hypothesized that, at study, construction of two different ad hoc categories would produce a greater hemodynamic response (HR) in left lateral prefrontal cortex (PFC) and bilateral anterior temporal (ATL) than repeated construction of the same ad hoc category. We also hypothesized that construction of two different ad hoc categories at study would produce, during a subsequent purchase intention test, reductions in HR in those same cortical regions. **Method:** Functional near-infrared spectroscopy was used to measure bilateral PFC and ATL in 48 participants. Participants studied items by constructing ad hoc categories that were the same (Same condition) or different (Different condition) across two instances. In a subsequent purchase intention test, participants were presented the studied item along with a novel item from the same product category and asked to choose which brand-name product they would purchase. **Results:** At the behavioral level, significant purchase intention priming was observed, $\eta^2 = .09$, with no significant differences across conditions. At the hemodynamic level, during study, greater HR was observed in the Different condition in left PFC, but not right PFC, $\eta^2 = .09$, and in bilateral ATL, $\eta^2 = .09$, in accord with predictions. During the purchase intention test, less HR was observed in the Different condition in left PFC but not right PFC, in accord with predictions, $\eta^2 = .07$. However, there were no significant differences in HR in bilateral ATL at test, although there was a weak trend for less HR in the Different condition in left ATL, $\eta^2 = .09$. **Conclusion:** Observed HR changes in left PFC were consistent with prior research implicating that area as the locus of semantic processing, while observed HR changes in bilateral ATL were consistent with prior research implicating that area as the locus of semantic content (Lambon Ralph et al., 2017). Given that less neural activity is indicative of the lingering presence of processing fluency and/or greater representational activation, this pattern of HR demonstrated that the category versatility or flexibility inherent in the construction of two different ad hoc categories at study was more likely to transfer processing and/or representational activation benefits to later purchase intention behavior.

P2-D-52: Gaze and choice dynamics in decisions with interacting attributes

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Objective: In multi-attribute decisions, one attribute value may influence the evaluation of another attribute. For example, in risky choice, a payoff might be weighted more (through increased sampling) if its associated probability is higher. It has been argued that this "interactive sampling" strategy is important, because otherwise paired elements do not influence each other any more than unpaired elements. In this project, we examine this sampling strategy and test its impact on choice, using eye-tracking & computational modelling in multiple choice domains. **Method:** Subjects (N = 52) in this study first rated how much they would like to consume various foods and donate to various charities. Subjects then proceeded to the four choice tasks while we tracked their eye movements. For all the tasks, each option included two pairs of elements. Subjects were told that there was a 50/50 chance that they would receive one or the other pair. The following are descriptions and examples of a single option for each task: 1) risky choice: two gambles (e.g., 70% to win \$4.50 or 45% to win \$7.00) 2) intertemporal choice: two delayed outcomes (e.g., \$10 in 1 day or \$5 in 4 days) 3) charity choice: two donations (e.g., \$10 to CARE or \$0.80 to LGBT Fund) 4) consumer choice: two foods (e.g., 10oz of chestnuts or 3oz of walnuts) **Results:** We found that attribute value is correlated with complementary attention in all the tasks. However, the strength of the association depended on the task and the attribute. For example, in the risky domain, we found both strong and positive effect for probability driving attention to payoffs ($r = 0.85$; $p < 0.01$) and for payoffs driving attention to probabilities ($r = 0.71$; $p < 0.01$). In contrast, in the food domain, we found a marginal effect of food tastiness on attention to food quantity ($r = 0.19$, $p = 0.06$), but no effect of food quantity on attention to food identity ($r = 0.15$, $p = 0.58$). Next, we tested the correspondence between interactive sampling and choice. We found this mechanism is positively correlated with the proportion of choice consistent with expected value in risky ($\beta = 0.41$, $p < 0.01$) and charity choice ($\beta = 0.37$, $p = 0.01$), but not in the consumer and intertemporal choice. **Conclusions:** In summary, we do find fairly consistent evidence for the hypothesis that gaze patterns (i.e. information sampling) depend on paired attribute values. Moreover, the strength of these tendencies predicts choice behavior in some domains. These results reveal important attentional considerations for models of multi-attribute decision making.

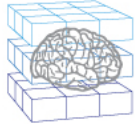
P2-D-53: The impact of overall value on preferential and perceptual choices

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¹University of Hamburg

Study objectives: There is growing empirical evidence that decisions are not only affected by value differences or perceptual discriminability but also by the overall sum of option values or by overall perceptual intensities. Specifically, people tend to make a faster decision when choosing between two very attractive/high-intensity options than choosing between two less attractive/low-intensity options. However, the underlying mechanism of these effects of overall value on the speed of decisions remains elusive. Similarly, whether and how overall value also affects choice accuracy is unclear. Accordingly, in this project we set out to address the questions of how overall value is involved in the choice process in different domains of decision making and influence other decision patterns beyond response time (RT). **Methods:** The experiment consisted of two tasks, a value-based (food) choice task, and a perceptual (brightness discrimination) task. Each task was separated into a rating and a choice stage. In the rating stage, participants (N=30) were asked to rate the subjective value/brightness of snacks/grayscale

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patches. The options were categorized into a 3-by-3 matrix of value difference levels (VD) and overall value levels (OV). In the choice stage, participants made binary decisions between food snacks/grayscale patches, with options being systematically sampled from all of the nine cells of the VD-by-OV matrix. In addition to measuring choices and RT from these binary decisions, we also asked participants to state their confidence about choosing a better option and recorded eye movement during the binary-choice tasks. Results: In line with previous work, we found significantly negative effects of OV on RT in both choice domains (perceptual: linear regression coefficient (β)=-2.83, $p=.0289$; preferential: β =-3.89, $p=.0046$), as well as positive effects on confidence ratings (perceptual: β =5.42, $p<.001$; preferential: β =9.73, $p<.001$). In contrast, the effect of OV on choice consistency/accuracy was more complicated and differed across tasks. In particular, participants tended to be more accurate when overall objective brightness was higher (β =1.95, $p=.0501$). In preferential decision, however, we found a quadratic relationship between OV and choice consistency with participants making being least consistent when OV was at a medium level (quadratic regression coefficient=4.50, $p<.001$). Conclusions: Our results demonstrate that OV strongly influences various choice processes, challenge some of the effects of OV on choice consistency reported in previous literature, indicate that OV effects are in part domain-specific.

P2-D-54: Reward-Dependent Corticostriatal Connectivity: A Meta-analysis of Psychophysiological Interactions

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¹Temple University

Objective: A host of neuroimaging studies have shown that reward processing and decision making are associated with activation in striatum and parts of the prefrontal cortex (PFC). Building on these findings, other studies have probed connectivity between the striatum and PFC during a wide array of reward processing tasks, particularly those involving anticipation, consumption, learning, and valuation. Yet, it remains unclear whether these studies are associated with consistent and specific patterns of corticostriatal connectivity. To address this problem, we conducted a meta-analysis of reward processing studies that utilized psychophysiological interactions to assess corticostriatal connectivity. **Methods:** We identified a list of 3,689 potential studies for inclusion through a database search of PubMed. Next, we screened the potential studies and identified 64 reward PPI studies, with 42 using a striatal seed and 22 using a PFC seed. Additionally, studies were organized by reward task based on whether they analyzed connectivity before (anticipation and valuation) or after (consumption and learning) receipt of reward. The meta-analysis was conducted using activation likelihood estimation (ALE) via GingerALE with a cluster-forming threshold of $p < 0.001$ and a family-wise error rate of $p = 0.05$. **Results:** Across all studies analyzing reward-dependent connectivity with the striatum, we saw consistent connectivity with the anterior cingulate cortex (ACC). A similar analysis focused on studies using PFC seed regions did not reveal consistent patterns of connectivity, possibly due to the heterogeneity of PFC seed locations across studies. In order to identify patterns of connectivity that were common and distinct between the striatum and PFC we conducted a subtraction and conjunction analysis, but revealed no significant effects. Within the set of studies using a PFC seed and reward learning paradigms, we found a consistent PPI with the amygdala. **Conclusions:** We found that ACC is a



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common feature of reward-dependent connectivity with studies using the striatum as a seed region, irrespective of reward task. And for studies using a PFC seed region during reward learning tasks, we found that the amygdala was a consistent target region. Overall, this meta-analysis can help to consolidate a body of literature exploring the corticostriatal interactions that are involved in the encoding of rewards. This information can help to motivate future research to better understand how these other regions support reward encoding within the striatum and PFC.

P2-D-56: Bayesian-Optimality of Decision-Making Behavior within Sensorimotor and Visual Search Contexts

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¹*University of Minnesota - Twin Cities*

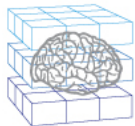
Objective: Bayesian Decision Theory has been used extensively to model human decision-making behavior, particularly within sensorimotor contexts, and has shown that human decision-making behavior quite similar to what is predicted by Bayesian-optimal behavior. But it has been less used to model decision-making behavior in conducting visual search tasks and particularly the low prevalence effect. In addition, it is not known if and how Bayesian behavior in one task relates to Bayesian behavior in a different task, which has implications for both task reliability and the putative generality of Bayesian behavior. In this present study, we use Bayesian Decision Theory to model human decision-making behavior in both a low prevalence visual search (LPVS) task and in a sensorimotor task. Our aim is to assess the extent to which behavior is Bayesian-optimal in both tasks as well as how behavior compares between the two context-distinct tasks. **Methods:** All participants (n=9 so far) completed a rubber ducky sensorimotor task and a LPVS task. In the sensorimotor task participants have to guess where a rubber ducky (a yellow dot) is going to appear in the pond (the computer monitor display), while in the LPVS task they have to indicate whether or not the target item is present on the screen. Both tasks are made up of four blocks which vary in the level of uncertainty of the prior and likelihood information. **Results:** As hypothesized, we found that participants show a difference in reliance on likelihood information depending on the uncertainty of both the prior and likelihood information in the sensorimotor task. Reliance on likelihood information is greater when there is higher prior uncertainty or lower likelihood uncertainty. Similarly, performance in the visual search task showed that the uncertainty level of prior and likelihood information influenced hit rates and false alarm rates. Average hit rates are greatest when the uncertainty of the prior is large and the uncertainty of the likelihood is large, and smallest for small prior uncertainty and small likelihood uncertainty. **Conclusions:** Although the data is preliminary, we see the expected differences in decision-making behavior according to relative uncertainties of prior and likelihood information within each context. Nevertheless, behavior comparison between the two contexts remains unclear. This study presents a first step in comparing Bayesian Behavior across tasks, and highlights both the promise and challenges that come with it.

P2-D-57: Decoupling Learning Strategies for Repeated Outcomes with Temporal Uncertainty

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Sequential outcomes can create several problems in decision-making. One such problem is identifying which decision resulted in the outcome, especially when there is a delay and other intervening decisions between the two events. In such cases, it may be possible to attribute the outcome to more than one decision. Reinforcement Learning (RL) provides a framework for testing competing theories about how people deal with this uncertainty. Feed-forward RL algorithms formalize the ability to cognitively prospect credit into the future. A second class of RL utilizes back-propagation algorithms, retrospectively assigning credit to previously experienced states. When information is limited, individuals may choose to employ a simple retrospective strategy, as there is little benefit to justify the additional computation and storage necessary for prospection. However, when additional information linking a decision to its outcome is made available by the environment, prospection could afford increased performance. The current research leverages a simple decision task to test how individuals switch between credit assignment strategies. Participants ($N = 147$) took part in two separate online sessions making repeated binary decisions between several stimuli and were paid a bonus for accuracy. Feedback for half of the stimuli was delayed two trials into the future, and was immediate for the other half. There were two experimental conditions, each completed in a separate session, with order counterbalanced across participants. The 'sum' condition gave conjoined feedback, for example, an immediate reward of 5 and a delayed reward of 3 from two trials ago resulted in the participant seeing the total reward of 8. This contrasted with the 'dual' condition, which gave dissociated immediate and delayed feedback. In line with our hypothesis, preliminary results showed that participants were more likely to perform prospective-based RL in the dual condition as compared to the sum condition. Retrospective-based RL in comparison, showed stronger effects in the sum condition with a boost to the learning rate. Temporal discounting also appeared to dramatically decrease for prospective-based RL when in the sum condition, but this effect may be a result of the combined reward resulting in a larger prediction error. Participants' willingness to increase model complexity when given additional information illustrates a type of cost-benefit evaluation about the cognitive effort required for increased compensation. Furthermore, rates of prospective discounting may be associated with working memory capacity, due to retaining values of future delayed decisions.

P2-D-58: Known probability information influences how adolescents respond to ambiguity

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¹*Fralin Biomedical Research Institute at VTC, Virginia Tech*, ²*Nanjing Audit University*, ³*Virginia Polytechnic Institute and State University*

Objective: Adolescence is a time of new experiences during which adolescents make decisions in novel situations with uncertain outcomes. Previous research suggests that adolescents' willingness to engage in health risk behaviors is more often related to tolerance of ambiguity, in which the probability of an outcome is unknown, rather than tolerance for risk, in which the probability of an outcome is known. This study seeks to identify individual biases in how known and unknown information interact to guide decision-making in ambiguous contexts. **Methods:** In this study adolescents starting at a mean age of 14 (s.d. = 0.54) participated in yearly assessments across five years. Participants underwent functional magnetic resonance imaging while making choices between two options with varying levels of risk and ambiguity. A behavioral model was adapted to estimate two behavioral parameters associated with



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ambiguity. The first captures optimism or pessimism associated with the unknown likelihood. A second parameter quantifies the influence of the known probability information on the ambiguous portion of the gamble. Results: Initially, adolescents were optimistic about the ambiguous portion of the gamble (mean = 0.71, s.d. = 0.07), but became less optimistic across time ($\beta = -0.04$, $r^2 = 0.96$). Associated neuroimaging revealed that while making a decision under ambiguity, more optimistic individuals had less activation in left middle insula ($Z = 4.51$, $p(\text{FDR}) < 0.05$). Additionally, the known likelihood of a high outcome negatively influenced the utility of the ambiguous portion of gambles (mean = -0.48, s.d. = 0.16) at age 14, and this effect waned across time ($\beta = 0.04$, $r^2 = 0.98$). Neural results revealed that individuals whose behavior was more negatively influenced by the known probability information had diminished anterior insula activity associated with the known likelihood of the high outcome ($Z = 4.00$, $p(\text{FDR}) < 0.05$). Conclusion: This study suggests that in addition to ambiguity tolerance, the known probability information of a gamble influences the utility associated with the ambiguous portion. Specifically, the probability of receiving a higher outcome diminished the utility associated with the ambiguous portion of a gamble among adolescents, particularly during early adolescence. Interestingly, individual differences in these two parameters show activation in separable regions of the left insula, a key area for decision-making under uncertainty.

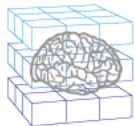
P2-E-59: Failure to capture excessive demand: A fundamental flaw that limits the applicability of neoclassical economics

John Haracz¹

¹*Indiana University*

Objective: According to price theory, supply and demand determine prices (Jaffe et al., 2019). Excess demands sum to zero when equilibrium is reached and markets clear, according to general equilibrium theory (Arrow, 1974; Debreu, 1984). Neoclassical economists address the "important and...difficult" methodological treatment of demand (Knight, 1944, p. 289) by invoking balanced "excess demand" in general equilibrium theory (Arrow, 1974, p. 266; Debreu, 1984, p. 270) and supply-demand balance in price theory (Stigler, 1990 [1942]; Friedman, 2007 [1962]). However, dynamic stochastic general equilibrium models have been widely criticized for failing to forecast the Global Financial Crisis of 2008-09 (Yellen, 2010; Guzman and Stiglitz, 2020; Vines and Wills, 2020). This and other flaws of neoclassical economics are presently proposed to arise from the failure of equilibrium-based models to capture excessive demand, which exceeds the balanced excess demand in general equilibrium theory. The present theoretical study seeks potential neuroeconomic biomarkers of excessive demands. Methods: A systematic literature review focused on neuroimaging or behavioral economics studies of tasks that elicit demands (i.e., choices) by subject groups that may be prone to show excessive demands (e.g., individuals with substance use disorders, eating disorders, or gambling disorder, as well as investors or lab-market subjects who trade excessively). The numbers of encountered studies that do or do not meet specific inclusion criteria will be presented. Results: Compared to healthy control groups, the above subject groups typically show altered neural activity in valuation-related brain areas (e.g., nucleus accumbens [NA] and ventromedial prefrontal cortex) during anticipation, choice, or outcome phases of demand-elicitation tasks. Substance abusers show behaviorally relevant results: drug cue-related NA activation predicted relapse in patients with stimulant use disorders (MacNiven et al., 2018); among

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subjects with opioid use disorder, hypothetical purchase tasks revealed that proneness to recent illicit opioid use was associated with high demand intensity for heroin and low sensitivity to heroin price (Schwartz et al., 2021). Conclusions: Neuroimaging (e.g., fMRI and near-infrared spectroscopy) research may yield biomarkers of traders' or consumers' excessive demands. A high biomarker prevalence could indicate that financial- or commodity-market demands have exceeded boundary conditions, beyond which equilibrium-oriented models are less applicable than alternatives (e.g., novel disequilibrium [Guzman and Stiglitz, 2020] or multiple equilibrium models [Vines and Wills, 2020]).

P2-E-60: Neural indices of imagination are associated with patience in intertemporal decisions on behalf of others

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Objective: How people treat others is known to depend on a multitude of factors, including others' gender, ethnicity, age, and even occupation, yet little is known about how the mind integrates this information with other aspects of the decision context to guide choices. Using a combination of behavioral experiments, computational modeling, and neuroimaging (fMRI), we investigate the possibility that, when people make decisions on behalf of others, the temporal contours of their imagination depend on the identity of the target individual, producing systematically different patterns of choice for members of different social groups. **Method:** We scanned 47 participants using fMRI while they made monetary choices between sooner-smaller and later-greater rewards on behalf of members of different social groups, each identified by a different first and last name (i.e., "Arjun Kumar"; "Claire Smith"). To identify brain regions associated with imagination, participants also completed a second task in which they rated the degree to which the same counterpart would enjoy various activities in the near and more distant future (e.g., "How much would Arjun Kumar enjoy getting up early to watch the sunrise [this weekend, on a weekend in 6 months]). **Results:** At the behavioral level, the degree to which participants imagined the near versus far future on behalf of different counterparts was related to the choices made on those counterparts' behalf, with more patient choices made on behalf of those counterparts for whom they imagined the far (relative to the near) future more vividly. At the neural level, we defined ROIs in a set of brain regions associated with imagination—including the medial prefrontal cortex (MPFC) and posterior cingulate cortex (PCC); in turn, we found that the explanatory power of a classic hyperbolic discounting model was improved significantly when we incorporated activation in these regions during decision-making for different counterparts into that model as a weight on the discounting rate. **Conclusions:** Although many decisions in life are made on behalf of others, most laboratory research in this domain makes only a coarse distinction between self and other (or sometimes ingroup and outgroup), minimizing generalizability to real-world settings in which decisions on behalf of others are often made in the context of a variety of information about others' identity. Our results suggest that people spontaneously imagine the near versus far future to different degrees during decision-making on behalf of different people, and these differences in imagination may produce different outcomes of decisions on behalf of members of different social groups.

P2-F-61: Individual differences in extrastriatal dopamine D2-like receptors shape strategic social learning

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Navigating complex social interactions requires careful monitoring of others' choices. In competitive contexts, for instance, success depends on the ability to learn from an opponent's actions and consider the actions one should have taken in the past to inform future decisions. These belief-based learning abilities recruit cortical brain regions that receive dopaminergic projections. While the role of dopamine in basic non-social learning is well established, it is unknown whether individual differences in dopamine function relate to belief learning in a social context. Here, 37 healthy adults (ages 26-79, 20 Females) performed the patent race task in which they competed with computerized opponents across 80 rounds to invest endowed money in a hypothetical product. On another visit, they underwent a PET scan with the extrastriatal D2-like receptor (D2R) radiotracer [11C]FLB-457. Receptor availability was estimated for 6 bilateral regions of interest in the frontal, temporal, and parietal cortices along with the insula, amygdala, and hippocampus. Participants' choices were examined using mixed-effects logistic regressions to identify whether variation in D2R availability shifted the weight that participants placed on regret and payoffs on their decisions to stay with versus switch their investment strategy on the subsequent round. To test whether participants used belief strategies, data were fit to an experience-weighted attraction (EWA) model. Individual differences in EWA parameters were correlated with D2R availability. All analyses controlled for age and sex. Overall, participants with higher D2R levels in each ROI except the hippocampus were less motivated by payoffs to stay rather than switch their investment strategies but also generally tended to stay with a prior round strategy overall. Conversely, those with higher hippocampal D2R levels were more motivated by payoffs to stay with a prior round strategy. Participants with higher D2R availability in each ROI except the hippocampus and amygdala were less motivated by regret to switch their strategy. D2R availability was unrelated to the EWA model degree of belief learning but was positively correlated with a discounting-like parameter for opponents' decisions and related to higher sensitivity to subjective values. These data indicate that specific aspects of complex learning depend on dopamine function and that extrastriatal D2R availability may shape strategic decision making in a social context.

P2-F-62: Self-reported intolerance of uncertainty, but not economic uncertainty tolerance, predicts COVID-related stress and resiliency

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OBJECTIVE: The COVID-19 pandemic has served as a universal stressor that has altered all aspects of life. While stress can have detrimental effects on psychological functioning, there is also evidence that certain dispositions can mitigate these effects. Given that uncertainty is a central feature of stressors, one possibility is that higher tolerance to uncertainty may predict greater resilience to stress. Here, we examined whether self-reported uncertainty tolerance in everyday life, as well as economic uncertainty tolerance, may render individuals more resilient to stressors encountered during the pandemic.

METHOD: We conducted a large-scale, smartphone app-based longitudinal study to track how self-reported intolerance to uncertainty and economic risk and ambiguity aversion predicted COVID-related stress and resilience. Participants completed the COVID Stress Assessment, a self-report survey we

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developed to identify how unpredictable, uncontrollable, and overwhelming stressors were perceived to be over the previous week, as well as the Intolerance to Uncertainty scale (IUS) and a gamified version of a well-validated economic task that measures risk and ambiguity preferences. Our analysis focused on a subset of participants ($n=208$, 79% female; mean age = 39.75, $SD=13.81$) that completed all surveys and tasks between April 2020-2021. Data were analyzed longitudinally using linear mixed-effects models in R and included both fixed and random effects. RESULTS: Higher perceived controllability, predictability, and coping all predicted lower overall COVID-related stress, suggesting these factors served a protective role during the pandemic. We thus collapsed these factors to calculate an aggregate value that represents how resilient participants were to pandemic stress. We used this value to test how self-reported and task-derived economic uncertainty tolerance predicted stress resilience. We observed that greater intolerance to uncertainty predicted lower COVID-related stress resilience ($B=-0.02$, 95% CI $[-0.03, -0.02]$, $p < .001$). In contrast, economic uncertainty tolerance was unrelated to stress resilience, and was also unrelated to IUS scores, suggesting uncertainty intolerance in psychology and in economics are not necessarily identical. CONCLUSION: Our findings provide a longitudinal account of stress resilience and uncertainty tolerance in the wake of the COVID-19 pandemic and open future avenues of research into how broader uncertainty reduction strategies can be optimized to promote stress resilience. Our results also indicate that self-reported and economic intolerance of uncertainty are two related but distinct notions of uncertainty.

P2-F-63: Sleep duration predicts risk preferences

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¹New York University

Environmental states affect our day-to-day emotions and decisions, including our choices under risk and uncertainty. Previous work has found that an unexpected positive outcome, such as a sunny day after a streak of cloudy days, can increase risk-taking (Otto, Fleming & Glimcher 2016). To extend these findings to more personal daily life activities at the within-subject level, we conducted a longitudinal examination of the correlations between a variety of daily activities and risk attitudes. We defined risk attitude using a novel PCA-based approach that allowed us to search for general patterns without relying on any one specific measure of risk-taking. Using this approach, we hoped to determine how features of daily life impact risk preferences and mood. One-hundred and twenty-three subjects were recruited in the US on Craigslist and the NYU subject recruitment systems. In total 115 subjects finished the experiments. We employed a mobile smartphone-based experimental platform (Datacubed Health: Linkt) to gather daily data about the lives, states and traits of our participants. Each participant was asked to complete a time-use diary once per week over a two-month period. The following instruments were also delivered at least once every week: a risky choice task (Levy et al. 2010), a delay discounting task (Kable & Glimcher, 2007), and the self-report positive and negative affect (Kahneman et al. 2004). In the time use diary, we asked subjects to complete a timeline detailing everything they did on that day, and we categorized these activities into Sleep, Work, Home, Leisure, and Social times. In addition, we gathered 13 personality inventories: attitude toward uncertainty, temporal discounting tendency, impulsivity, and the level of psychological distresses to better understand the individual difference of the risk attitude. Our goal was to examine how the amount of time spent on a particular activity in previous weeks



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influenced risk attitude-related variables, in a way that did not depend on any one specific measure of risk attitude. To do that, we employed a Principal Component Analysis (PCA) to define the collinearities of a suite of risk-related measurements. We then used these aggregated risk-ontologies to perform a standard Granger-style time-series autoregression. We found that Sleep-time significantly predicts a generalized risk vector and reported negative mood in the coming week. We did not find any correlation between the other activities we examined and mood and decisions. With more sleep time, subjects have less negative emotions and become more risk-tolerant. Our results indicate that simple bio-behavioral variable changes can influ

P2-F-64: Effects of Social Context on Reward-based Learning

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Objective: People readily learn associations between decisions and the outcomes that follow them through instrumental learning. How does social context affect the speed and fidelity with which people learn the likely consequences of their actions? Here, we integrate approaches from instrumental learning and social decision-making to investigate how reward distributions (across oneself and another person) and others' identity (with whom rewards are shared) influence how people learn about rewards. **Methods:** We recruited 94 online participants to perform a computerized instrumental learning task in which the monetary rewards obtained on each trial would ostensibly be split between themselves and another person (e.g., "Nurse"; "Lawyer"). On each trial in a block, one of five possible images appeared on the screen, along with information about how the reward would be split (e.g., you: 30%; Nurse: 70%); participants were obliged to quickly press 1 of 3 keys, which yielded either \$0, \$1, or \$2 (before splitting). We varied the split percentage to create either disadvantageous inequality (participant gets the smaller share) or advantageous inequality on each trial. Following the task, subjects rated the warmth and competence of each partner. We embodied two hypotheses into computational models. The naive reinforcement learning (Naive) model assumes the mind represents only the total, objective reward. The social perception reinforcement learning model (SPRL) assumes that monetary inequity and social perception dynamically shape value representations during learning. **Results:** Mixed-effect linear regressions with subject ID as the random intercept revealed that people learn faster when they gain a larger share of the reward, indicating an effect of inequity on learning ($p = 0.02$). Regression further showed that the effect of both inequity and social perception is stronger in the later stage of learning ($ps < 0.05$). Critically, we then compared our computational models using WAIC and discovered that SPRL outperformed Naive. Further, we saw SPRL outperformed more in the disadvantageous inequality condition ($p < 0.01$), suggesting that the social context has a larger effect on learning when subjects obtain a smaller share of rewards. **Conclusion:** These results suggest inequality and social perception information influence reward-based learning. These effects are especially prominent in the later stage of learning and when subjects suffer disadvantageous inequity.

P2-F-65: Heterogeneity in strategy use during arbitration between observational and experiential learning

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Caroline Charpentier¹, Seokyoung Min¹, John O'Doherty¹

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STUDY OBJECTIVE. To navigate our complex social world, it is crucial for people to deploy multiple learning strategies, such as learning from directly experiencing the outcomes of one's actions (experiential learning; EL) and learning from observing the behavior of others (observational learning; OL). Despite the prevalence of OL and EL in humans and other social animals, it remains unclear (i) how control over behavior is assigned to one strategy over the other depending on the environment, (ii) how individuals vary in their strategy use, and (iii) whether this heterogeneity is relevant for psychopathology. **METHODS.** Here, we describe an arbitration mechanism in which the prediction errors associated with each learning strategy influence their weight over behavior. We designed an online behavioral task to test our computational model, manipulating the uncertainty of each strategy, and collected two independent online studies for replication (Nstudy1=128 and Nstudy2=497). **RESULTS.** Model comparisons revealed similar and meaningful individual differences in how people solve this task. While a substantial proportion of participants relied on our proposed arbitration mechanism, four other groups were identified based on lowest individual AIC: those who use a fixed mixture between the two strategies, those who rely on a single strategy (OL or EL) and non-learners who perform an irrelevant strategy. Groups were found to differ not only on behavioral signatures of OL, EL, and their arbitration, but also on psychiatric symptom dimensions of social anxiety and autism traits. Those dimensions, typically highly comorbid in patient populations, differed significantly in two of the groups, with non-learners (N=59) showing high autistic traits and low social anxiety (Cohen's $d=0.31$, $p=0.02$) while those mixing OL and EL (N=128) exhibited high social anxiety and low in autistic traits (Cohen's $d=0.28$, $p=0.002$). **CONCLUSIONS.** Clustering participants based on each individual's preferred strategy allowed us to go beyond the traditional 'winning-model-fits-all' approach, and uniquely characterize the heterogeneity typically present in large online datasets. Overall, our findings demonstrates how the computational characterization of individual differences in social learning may help better separate and understand comorbid symptom dimensions of social dysfunction.

P2-F-66: Framing influences donation behavior by altering the process and timing of information acquisition

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Increasing charitable donations is an important goal for society. How the donation decision is framed may have an impact on the amount donated. For instance, experimental work shows that people allocate more money to charity when the decision is framed as giving their own money to the charity rather than taking money from a default allocation to charity. Rewarding or punishing this donation behavior may also influence the amount donated. For instance, if a person knows that they will be rewarded for contributing to charity, they may be more likely to donate. Here we examine how frames produce differences in donation behavior and also in other people's judgments of donation behavior. We use eye-tracking and mouse-tracking to unpack the mechanisms that underlie these differences. In our first study, subjects make willingness-to-give decisions, during which their mouse movements are recorded. Subjects are assigned either a give frame or a take frame. In the give frame, the subject has

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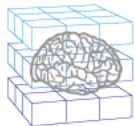
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been allocated money and decides how much to give to a charity. In the take frame, a charity has been allocated money, and the subject decides how much to take. Subjects are also assigned to one of two reward/punishment conditions. They are told that they may be punished/rewarded either before vs. after they make their decisions. In our second study, subjects decide how much to punish or reward these previous subjects. These new subjects are also assigned to a give vs. take frame, in which they are told that the previous subjects either gave or took from the charity. They then make a series of binary decisions, which are eye-tracked. The options differ on the punishment/reward amount and the cost of taking the action. We find that the subjects donate significantly more under the take frame than the give frame, \$2.91 vs. \$1.78 ($t(48.0) = 2.88, p = 0.006$). We do not find that subjects donate more when told they may be rewarded/punished; however, they do take significantly longer in making their decision ($t(48.8) = 3.86, p = 10^{-4}$). We then examine whether these subjects exhibit more conflict during their decision, which is quantified by the directness of the path to the final choice. We find that subjects take a less direct path when told they will be rewarded or punished ($t(47.9) = 2.16, p = 0.036$). This suggests that while the possibility of punishment or reward does not seem to increase donations, subjects are more conflicted when making their decision. This work provides insights into how framing and how anticipation of rewards or punishment influences donation behavior and other people's judgments of this behavior.

P2-G-67: Novelty and uncertainty differentially drive exploration across development

Kate Nussenbaum¹, Rebecca Martin¹, Sean Maulhardt¹, Yi (Jen) Yang¹, Greer Bizzell-Hatcher¹, Naiti Bhatt¹, Maximilian Scheuplein¹, Gail Rosenbaum¹, John O'Doherty², Jeffrey Cockburn², Catherine Hartley¹
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Study Objective: Across the lifespan, individuals frequently choose between exploiting known rewarding options or exploring unknown alternatives. A large body of work has suggested that children may explore more than adults. However, because novelty and reward uncertainty are often correlated, it is unclear how they differentially influence decision making across development. Here, we asked how the effects of novelty and uncertainty on exploratory choice change from middle childhood to early adulthood and lead to developmental decreases in exploration. **Methods:** To address this question, we had a large, age-continuous sample of children, adolescents, and adults (ages 8 - 27 years, $N = 122$) complete a recently developed value-guided decision-making task (Cockburn et al., 2022). Throughout the task, participants had to select between two choice options to earn reward. The task was divided into ten distinct blocks of 15 choice trials each. Within each block, participants encountered familiar choice options that they had seen in prior blocks and a novel option that they had never encountered before. Critically, however, reward probabilities were reset for all choice options at the beginning of each block. In this way, the task dissociated stimulus novelty and reward uncertainty -- at the start of each block, the options varied in their level of novelty, but all options had high reward uncertainty. **Results:** In line with prior studies, we found that with increasing age, participants were less 'exploratory' and more likely to choose higher-value options (age x expected value interaction: $X^2(1) = 9.98, p = .002$). Critically, however, participants of all ages demonstrated a similar bias to select choice options with greater novelty (age x novelty interaction: $X^2(1) = 0.98, p = .323$). Decreases in exploration with increasing age were driven by stronger aversion to reward uncertainty in older participants (age x



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uncertainty interaction: $X^2(1) = 43.4, p < .001$). Reinforcement learning modeling further revealed that children's choices were best characterized by a different algorithm relative to those of adolescents and adults. While children simply inflated the utility of more novel options, adolescents and adults used novelty to buffer the influence of reward uncertainty (Cockburn et al., 2022), such that the utility of novel options was less influenced by uncertainty aversion. Conclusions: These findings suggest that, though often correlated, distinct features of lesser-known choice options -- novelty and uncertainty -- differentially influence exploratory decision-making across development.

P2-H-68: Computations of rewards and punishments in learning and decision-making within and between individuals

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Objective: Decisions depend on evaluating the expected values of potential rewards and punishments. These value representations are typically established through reinforcement learning and must be flexible to adapt to changing conditions. Features of learning and decision-making have been studied in the context of individual differences, but less is known about their interaction within an individual. Here we disentangle properties of value, action, and learning by combining learning in the absence of decision, decision in the absence of learning, and both together. Thus, the objective of this proposal is to understand how expectations of rewards and punishments are learned, how these values guide decision-making, how they are flexibly adapted under changing contingencies, and how these processes differ within and between individuals. **Methods:** To do this, we developed a novel three-part task consisting of passive probabilistic learning, decision making, and active reversal learning to allow for learning measurements of each feature of valuation and decision-making. Participants for a pilot sample ($n = 102$) were recruited on Amazon Mechanical Turk and completed the task in addition to a series of behavioral surveys. **Results:** Our preliminary model-free analyses demonstrate associations between learning parameters and anxiety, impulsivity, and smoking status. We also use two types of reinforcement learning (RL) models for granulated analysis of learning parameters for each participant. Behavioral performance during passive learning is modeled with a RL model that learns the values of stimuli without action selection, while instrumental performance during reversal learning is modeled with RL models that incorporate action selection on the learned values, subjects' model on the reversal, as well as behavioral tendencies such as perseveration. **Conclusions:** Together, these data will provide insights into the basic processes of value computation for gains and losses and the contribution of differences within and between individuals. This will have implications for identifying a behavioral marker in both the general population and in mental health and substance use disorders where decisions are non-optimal.

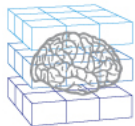
P2-H-70: Creative explanations and knowledge networks

Kara Kedrick¹, Iris Vilares¹, Paul Schrater¹

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Objective: Explanation generation is ubiquitous, and is shaped by our individual and collective knowledge about a phenomenon. Some phenomena are not easily explained by known explanations and

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require the creative recombination of existing knowledge to form original explanations (e.g., How is evolution impacted by globalization?). Other phenomena are strongly associated with known explanations, wherein connections between existing knowledge have already been established (e.g., How do species survive exceptionally harsh conditions?). However, little is known about this distinction. We hypothesized that original (compared to known) explanations will: require relatively more sense-making--manipulation of acquired information--and result in looser knowledge networks containing relatively novel recombinations or semantically dissimilar foraged-for information. Method: We recruited 64 participants, and asked them to answer questions by writing explanations that were either fully answerable (known condition) or not fully answerable (original condition) with information found on Wikipedia. To measure sense-making, we compared the semantic similarity between the text from Wikipedia searches and the text from the participants' explanations. To measure information foraging, we created knowledge networks with visited Wikipedia pages as nodes, wherein nodes were connected if they were visited by the participant within the same condition and weighted by the cosine similarity of term-frequency inverse-document frequency vector pairs. Results: We found that the average semantic similarity between explanations and Wikipedia pages was higher for the known condition than the original condition ($p < 0.001$, Effect size = -0.59). For the knowledge networks, we found that the known condition had smaller average clustering coefficients ($p < 0.001$, Effect size = -0.47) and smaller average path lengths ($p < 0.001$, Cohen's $d = -0.69$). Conclusion: Our results suggest that, as hypothesized, people engage in higher levels of sense-making in the original condition, by producing explanations that are relatively less similar to the acquired information. We also find partial support that participants in the original condition form looser-knowledge networks with relatively longer path lengths. Surprisingly, knowledge-networks in the original condition had relatively higher clustering coefficients, which may indicate that participants are visiting highly clustered, semantically dissimilar patches. Understanding these behavioral differences informs how explanation generation differs in creative versus non-creative contexts, and provides insight into the processes that underlie innovation.

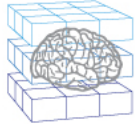
P2-I-71: Neural mechanisms of risky choice when learning from description and experience

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A critical goal of neuroeconomics research is to bridge animal and human behavioral findings to uncover the neural basis of decision making. One challenge has been the distinct paradigms used across these species. While human research often relies on description-based paradigms where choice information is explicitly communicated, non-human primate research relies on experience-based paradigms where choice information is learned via trial-by-trial feedback. Research on the description-experience (D-E) gap in humans demonstrate that risk preference and decision biases change as a function of the differing experimental paradigms. In the current study, we sought to further delineate the neural mechanisms underlying decisions from experience (E) and description (D) within the same individuals. 31 adults completed a within-subjects D-E gap paradigm while undergoing fMRI. Participants completed 36 choices in each condition (D or E), with trials divided into three separate phases (acquisition, think, and decision). In the acquisition phase, participants either sampled from two separate decks repeatedly (E) or viewed visual information about the probabilities and outcomes of the two choice alternatives (D).

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In the think phase, participants were instructed to consider which of the two options they would choose based on the information acquired. In the final decision phase, participants selected between the two available options. At the end of the study, a single trial was randomly selected, and participants received a bonus payment based on the outcome of that trial. Consistent with prior research, participants took more risks when information was learned via experience compared to description. Preliminary fMRI analyses in a subset of adult subjects ($n=24$) reveal parallel mechanisms involved with decisions from experience and description. During information acquisition, there was activation in regions including the bilateral insula and the medial temporal lobe (MTL) in D compared to E. In E during the deliberation phase (compared to D), we found increased activation in the MTL and bilateral insula. We also found a positive correlation between activation in the left hippocampus during information acquisition in D and the likelihood of making a risky choice ($p < .1$). In E, activation in the left hippocampus during the deliberation phase was negatively associated with the likelihood of making a risky choice ($p < .1$) - suggesting successful retrieval of previously encoded outcome information resulted in a decreased likelihood for risk-taking. Our results reveal that memory may play a critical role in explaining the D-E gap in humans and influence risk behavior.

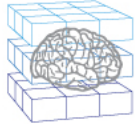
P2-I-72: Deconstructing neural predictors of risky choice: Convergent, replicable, and generalizable evidence for distinct neural circuits predicting risk seeking versus avoidant choices

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¹Stanford University

Previous Functional Magnetic Resonance Imaging (fMRI) findings on risky decision-making have raised the question of whether a single system or two distinct sets of regions contribute to risky choice. Potential reasons for these discrepant results in the literature may be analytic variability and lack of temporal staging of different components of choice including sensory/attentional, anticipatory, motor, and integrative processes involved in each stage of decision-making. To address this inconsistency, we orthogonalized sensory-motor components of choice in a risky decision-making task (Leong et al., 2016) and differentiated between neural activity occurring before and after the choice, and using only the pre-choice activation for prediction of trial-by-trial choice. We additionally used three different univariate and multivariate analysis methods and looked for convergent evidence across analysis methods. We then replicated the findings in an independent sample (total $N=107$) and tested the generalizability of our model in a distinct risky choice dataset (i.e., the Mixed Gambles Task of Tom et al., 2007). Using conventional whole-brain linear model, Region of Interest analyses, as well as a model-free classifier (i.e., Support Vector Machine with Recursive Feature Elimination), we find convergent results disentangling sensory-motor correlates of risk and activity evoked in response to gains and losses from those that more generally predict risky choices. Risk-seeking choices were predicted by increased activity in the Nucleus Accumbens and Medial Prefrontal Cortex but risk-averse choices were predicted by increased activity in Anterior Insula. Furthermore, we find that anticipatory activity in the Nucleus Accumbens specifically on positively skewed gambles consistently accounts for individual differences in risk preference. Despite differences in task, sample, and scanner in the Mixed Gambles Task dataset (Tom et al., 2007), activity from the same regions predicted risky choice with comparable effect sizes and in the same direction. Thus, neural features that predict risk-seeking choices are distinguishable

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from those that predict risk-averse choices, and each may be associated with different types of anticipatory affect. Together, these findings also further identify and refine a "risk matrix" of reliable, valid, and generalizable neural features that predict risky choice.

P2-I-73: Neurobiomarkers of Laboratory and Real-World Dietary Success

Rémi Janet¹, John-Dennis Parsons¹, Cendri Hutcherson¹, Hilke Plassmann¹, Anita Tusche¹

¹*Neuroeconomics laboratory, Queens university*

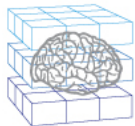
INTRODUCTION: Research has linked variance in both neuroanatomy and functional activity in vmPFC (ventromedial prefrontal cortex) and dlPFC (dorsolateral prefrontal cortex) to variance in lab-based dietary self-regulation. However, whether and how such metrics relate to complex diet-related outcomes in the real world (e.g., weight) remains unclear. **OBJECTIVE:** We sought to address two related questions: First, do the same neural markers that predict dietary choice behaviour in the laboratory predict normal variation in BMI (body mass index)? Second, do these markers generalize to predict clinical outcomes (i.e., obesity)? **METHODS:** We aggregated data from three studies (N=118, 79 females, BMI: 15.94 - 29.15) in which subjects completed a food choice task under natural and regulatory conditions in the MRI scanner. We estimated behavioral regulatory success (RS) scores for each individual and obtained their BMI. Next, we extracted grey matter volume (GMV) and task-based BOLD responses from vmPFC and dlPFC, and used them in several general linear mixed models to predict BMI and RS (controlling for age, sex, total grey matter volume, and study). Formal model comparison assessed the predictive value of neuroanatomy and activity of the vmPFC and dlPFC. Cross-validation assessed the generalizability of our findings to left-out subjects within the original sample and a group of highly obese individuals (N=19, BMI: 30.91 to 53.75). **RESULTS:** BMI and behavioral RS were uncorrelated ($p=0.38$). Variance in RS scores was best predicted by task-based activation in the vmPFC and dlPFC ($R^2_{adj}: 0.47, p=0.002$), with no added value of considering brain structure. Higher GMV in dlPFC predicted lower BMI ($R^2_{adj}: 0.15, p<0.001$). Adding task-based neural activity decreased model performance. Predictions did not generalize to morbidly obese individuals, potentially due to nonlinear links of neurobiomarkers and measures of dietary indicators in this sample. **CONCLUSION:** Our findings suggest that performance on an established dietary regulation task does not predict long-term, real-world health outcomes like BMI. Significant but independent predictors of variance in both RS and BMI showcase the predictive power of neurobiomarkers across various unrelated indicators of dietary success. Importantly, neuroanatomical markers were better predictors of long-term dietary outcomes than functional properties, which better predicted momentary dietary control in the laboratory. These results emphasize the relative importance of distinct brain features for explaining different facets of dietary success and caution against generalizing across evidence from task-based and BMI-related research.

P2-I-74: SEF encodes temptation-modulated value signals to guide behavior during intertemporal choice requiring self-control

Ka Eun Lee¹, Jaewon Hwang¹, Veit Stuphorn¹

¹*Johns Hopkins University*

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OBJECTIVE: Self-control is critical for committing to long-term goals that involve large but delayed rewards. When there is temptation to give up on the long-term goal and instead switch to a smaller but more immediate reward, high self-control would allow the individual to remain committed to the larger later reward while low self-control would lead the individual to give into temptation to switch to the suboptimal sooner reward. How an individual responds to the presence of temptation is therefore integral to successfully achieving long-term goals. Despite its behavioral significance, it remains unclear how neuronal activity guides such variance in behavior that results from varied self-control levels. Prior work identified the Supplementary Eye Field (SEF) to carry context-dependent action value signals (i.e., the subjective value of selecting an option) that are adjusted to changes in the environment to guide adaptive behavior, placing the SEF as a potential candidate to support this role. Here, we examined how the SEF represents temptation-modulated value signals that can be used to inform behavior. **METHODS:** We recorded the activity of 201 single neurons from the SEF of two male rhesus macaques performing a self-control task, a modified intertemporal choice task in which for a small proportion of trials, the monkey is presented with the temptation to switch from his initial choice to the other option. When the monkey initially chooses the larger later reward, staying with the initial choice indicates high self-control, while switching to the smaller sooner reward indicates low self-control. **RESULTS:** First, SEF neurons continue to represent value of the available options even after the initial choice is made, throughout and after the delay period. In particular, SEF activity after reward delivery was found to predict choice in the subsequent trial, suggesting that the SEF retains value information to compute evaluative signals that modulate future choice. Second, value representation in the SEF is influenced by the presence of temptation. Moreover, SEF activity predicted for how long the monkey exerts self-control to stay at his initial choice before ultimately giving into temptation, showing that SEF activity encodes value signals that reflect self-control levels that can predict the behavioral response to temptation. **CONCLUSIONS:** Collectively, our results suggest that the SEF encodes value signals that are sustained until after reward delivery and are modulated by the presence of temptation, which are used to guide current and future behavior in the context of delayed rewards.

P2-I-75: Examining the role of perspective taking in prosocial and intertemporal choices using intermittent theta-burst stimulation

Kenji Kobayashi¹, Heather Robinson¹, Victoria Halewicz¹, Hannah Long¹, Theodore Satterthwaite¹, Desmond Oathes¹, Joseph Kable¹

¹*University of Pennsylvania*

OBJECTIVE: Perspective taking is often thought to underlie a wide range of decision-making, such as social interactions (taking others' perspective to be prosocial) or intertemporal choice (taking the future self's perspective to be patient). Particularly in the social domain, perspective taking has long been associated with the right temporoparietal junction (rTPJ), but empirical evidence for the causal role of these neural mechanisms in decision-making remains limited (Soutschek et al., 2016). To bridge this gap, we tested whether intermittent theta-burst stimulation (iTBS), a putatively excitatory protocol of transcranial magnetic stimulation, applied to rTPJ enhances individuals' perspective taking and thereby makes them more prosocial and patient. **METHODS:** Across two within-subject studies (n=22 each), the participants received iTBS to either rTPJ or vertex (control; order counterbalanced) and made a series of



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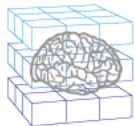
choices in the social domain (the Dictator Game) and the intertemporal domain. In the Dictator Game, the participant chose between two options on monetary allocation between themselves and an anonymous, randomly paired recipient. The payoffs for the self and recipient were manipulated across trials to enable model-based estimation of aversion to advantageous inequality (the self earning more than the recipient) and disadvantageous inequality (the self earning less than the recipient) in each session. In the intertemporal choice paradigm, the participant chose between a smaller payoff available today and a larger payoff available after a specified delay. The payoffs and the delay were parametrically manipulated across trials to estimate a hyperbolic delay discounting parameter. The two studies differed only in the number of pulses and the iTBS target location within rTPJ. RESULTS: Contrary to our hypothesis, the participants' choices were not systematically affected by iTBS. There was no difference between the rTPJ and vertex sessions in estimated advantageous inequality aversion (Bayes factor in favor of zero difference over non-zero difference [BF01] = 12.0 in study 1, 9.83 in study 2), disadvantageous inequality aversion (BF01 = 19.1, 16.6), or hyperbolic delay discounting parameter (BF01 = 38.9, 21.9; all $p > .15$, paired t-test). CONCLUSIONS: iTBS to rTPJ did not make people more prosocial or patient. While our findings do not support the causal role of perspective taking centered on the rTPJ in decision-making, future studies need to examine if it plays a more important role in social interactions (e.g., cooperation), or whether and how excitatory and inhibitory neurostimulation to rTPJ exerts asymmetric effects on decision-making.

P2-I-76: Choosing Well: Testing the Efficiency of Neural Value Coding

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¹New York University, ²University of Sydney, ³University of Tübingen and Max Planck Institute for Biological Cybernetics, ⁴New York University and NYU Shanghai

Objective The Divisive Normalization (DN) function is often viewed as a canonical neural encoding mechanism. However, DN maximizes mutual information, hence efficient, only for input stimuli coming from a long-tail multivariate Pareto distribution. Using behavioral paradigms and computational modeling, we test whether the brain uses DN for choice behavior under diverse distributions of input stimuli, or whether the encoding mechanism varies across different stimulus environments. That is, we ask whether choices are efficiency-constrained by one physiological encoding mechanism or whether the encoding mechanism adapts across different choice environments. We test these hypotheses in a biphasic risky-choice experiment, where subjects were given lotteries from different types of input distributions. **Methods** In Phase 1, subjects (N=40) reported their willingness-to-pay for participating in a lottery, using a Becker-DeGroot-Marschak (1964) auction, aimed at eliciting their risk preferences. The subject-specific risk parameters were used to generate two types of continuous distributions of subjective valuations (SVs): (1) a Uniform distribution, for which the DN encoding function is inefficient; and (2) a multivariate Pareto type-III distribution, for which the DN function is efficient. These distributions were then used in Phase 2 of the study, where subjects made 680 binary choices between pairs of lotteries, half of which were drawn from the Uniform distribution of SVs, whereas the other half were drawn from the Pareto distribution of SVs (counter-balanced across subjects). We used pooled and hierarchical maximum likelihood estimations to recover the DN functional parameters. **Results** We



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found that the normalization-weighting factor was significant across the two experimental treatments, in both the pooled and hierarchical estimations. This indicates that subjects employed normalized value encoding regardless of the distribution of the input stimuli they were facing. Nonetheless, the magnitude of the normalization-weighting factor and the curvature of the DN function varied across treatments, suggesting that subjects adapted to the different choice environments. Conclusions Our results suggest that people are obligate DN-choosers, which implies a certain degree of embedded inefficiency in choice. These findings are in line with previous empirical results, showing that many real-world naturalistic stimuli have long-tail asymmetric distributions, and perhaps imply an evolutionary origin of the neural encoding mechanism.

P2-I-77: The neurocomputational basis of ToM when the self knows more than the other

Wenning Deng¹, Giovanni Gentle², Dean Mobbs², Antonio Rangel²

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Objective. During social interactions, people make inferences about others' beliefs, feelings and preferences. These inferences are especially difficult in situations where the self has information that the other does not have, or vice versa. In this case, successful Theory of Mind (ToM) inference requires not only modeling the other's beliefs, but inhibiting the self's knowledge. The goal of this study is to understand the neurocomputational basis of ToM in this type of challenging situation. **Methods.** (N=32) We carried out an fMRI study in which subjects were shown the outcome of 2-10 coin flips generated from a coin with a $P(\text{Heads}) = 20\%, 40\%, 60\%$ or 80% . Subjects knew that another subject was shown the same data and were asked to predict the others' judgments about the coin bias. Importantly, they made this judgment in two conditions: (1) in a coin known condition, subjects knew the bias of the coin, but the other did not, (2) in a coin unknown condition, both subjects did not know the bias of the coin. **Results.** Behaviorally, we find that subject's judgments are biased towards their private knowledge in the coin known condition, although they are also predictive of the others' choices. Also, response times are longer in the coin known condition, consistent with the hypothesis that ToM in this case requires inhibiting the self's knowledge. We also find that the subjects' behavior is well explained by a computational model in which decisions in each trial are made based on a mixture of the Bayesian posteriors for an ideal agent and the subject's private information. We are currently carrying out an analysis of the fMRI data, which will be presented. Preliminary analysis shows activation of the standard circuitry at the time of decision (e.g., vmPFC, dmPFC) and more activation of areas commonly found in cognitive control in the coin known condition. **Conclusions.** Our behavioral results are consistent with the hypothesis that subjects make judgments using standard sequential integrations models of decision-making, and that the quality of their judgments depends on their ability to inhibit their private information.

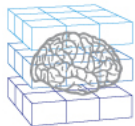
P2-I-78: Pupil size anticipates exploration and predicts disorganization in prefrontal cortex

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Objective: In uncertain environments, we balance exploitation and exploration: we generally exploit rewarding opportunities but sometimes explore uncertain alternatives that could be even better.

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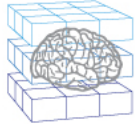
Exploration is associated with sudden disorganization of neuronal activity patterns in the prefrontal cortex. Although the mechanisms behind this disorganization remain unknown, one possibility is pupil-linked neuromodulatory systems. Yet, it is unclear whether pupil size predicts the neural signatures of exploration, much less the sudden disorganization that occurs at the onset of exploration. Methods: We simultaneously collected pupil size, a peripheral index of neuromodulatory mechanisms, under constant luminance--a peripheral index of neuromodulatory mechanisms and neuronal activity in the frontal eye fields (FEF), a prefrontal region involved in sensorimotor decision-making (574 units, 28 sessions, 2 rhesus macaques). Monkeys performed a classic explore-exploit task known as a restless k-armed bandit which consists of choosing between 3 options, whose reward value changed randomly, unpredictably, and independently over time. We modeled exploration and exploitation as the latent goal states in a hidden Markov model. Results: Consistent with previous studies, we found that pupil size was larger during exploratory choices, compared to exploitative choices (paired t-test: $p < 0.0001$, $t(27) = 4.95$, mean offset = 0.23, 95% CI = 0.13 to 0.32). Over the 10 trials before the onset of exploration, pupil size slowly ramped up and dipped down below baseline after exploration. These dynamics were not an artifact of some misalignment of the goal state labels: there was no ramping in several other behavioral measures that differed between exploration and exploitation. At the single neuron level, we found that increasing pupil size predicted flatter neuronal tuning functions for neurons in the FEF. At the population level, increasing pupil size predicted worse choice decoding accuracy from population of FEF neurons (GLM: $\beta = -0.032$, $p < 0.0001$) and more trial-by-trial variability in the FEF neuronal activity (GLM: $\beta = 0.04$, $p < 0.0001$). Conclusions: The fact that pupil size ramped up before exploration could suggest that the pupil tracks the variables that make exploration more likely, rather than predicting exploratory brain states per se. However, the pupil also predicted trial-to-trial fluctuations in the disorganized patterns of prefrontal activity that are linked to exploration, even in the absence of any overt changes in behavior. These results support the idea that pupil-linked processes drive broad alterations in neural processing.

P2-I-79: On the reliability of individual economic rationality measurements

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Study Objective: A contemporary research agenda in psychology, behavioral and neuroeconomics aims to identify individual differences and (neuro-)psychological correlates of rationality. Here, indices of revealed preference consistency, specifically, are used as an ad hoc measurement for the supposedly latent concept of rationality, that is often interpreted as a psychological construct. Empirical research on this topic has been widely received in important interdisciplinary and field outlets such as Science or the American Economic Review. However, it is unclear whether such measures also fulfil the necessary psychometric standards. The goal of this research project (forthcoming in PNAS) was therefore to probe the psychometric reliability of individual rationality measurements. Methods: Rationality was quantified via the two most prominent indices of rationality, namely Afriat's Critical Cost Efficiency Index (CCEI) and the Houtman-Maks-Index (HMI). Our empirical analyses draw from multiple original and published datasets that vary in the deployed choice domain, choice complexity, study context (lab, online), incentivization structure, study population, sample size, task structure, measurement length, as well as



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time gap between measurements. Overall, we evaluated reliability of rationality measurements in 8 datasets with, in total, over 1600 participants, including a preregistered replication. Results: We found that across datasets and for both, CCEI and HMI, the inter-method, test-retest, and split-half reliability was moderate to poor according to common standards (all ICC estimates < 0.75 ; 95% CIs exclude benchmark of 0.75). Further, using both an experimental manipulation (allowing participants to revise choices) as well as an analysis of the within-subject variance, we provide evidence that this result was not driven by large measurement error or random noise but by little inter-individual differences. In line with this explanation, most participants across all datasets descriptively behaved highly consistent, and taking individual measurements of CCEI and HMI yielded approximately two times worse predictive accuracy for another measurement within the same individual than simply assuming the population mean. Conclusions: We demonstrate that the reliability of individual rationality measurements cannot be assumed until shown otherwise. While few (perhaps none) of the relevant studies report reliability coefficients, our results suggest that reliability is modest even for more conservative study designs. This poses a challenge to the contemporary search for sociodemographic or psychological correlates.

P2-I-80: Brain mechanisms underlying metacognition in decision making

Georgia Eleni Kapetanidou¹, Marius Moisa², Christian Ruff², Philippe Tobler², Alexander Soutschek¹

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Metacognitive awareness of our preferences is an important component of rational decision making. Previous findings have established a causal link between metacognitive accuracy in value-based decision making and theta band oscillations in the frontopolar cortex (FPC) (Soutschek et al., 2021). However, little is known on which brain regions interact with FPC to facilitate the read-out of performance-related information and implement metacognition. Here we addressed this question by combining HD-tACS stimulation with concurrent functional MRI. In a within-subjects design, 41 healthy participants underwent theta (5Hz), alpha (10Hz; control frequency) or sham stimulation over the FPC (AFz position) with a 3x1 high-definition electrode set up during task performance in the fMRI scanner. Participants performed a confidence accuracy task, where they decided between smaller-sooner and larger-later monetary rewards and subsequently indicated their confidence in their decisions. High-intensity theta tACS impaired metacognitive accuracy in participants' reports of subjective uncertainty relative to sham stimulation, a finding in line with previous reports of improved metacognition following FPC disruption (Shekhar & Rahnev, 2018). Moreover, we observed that theta stimulation compared to sham resulted in altered functional connectivity between the FPC and bilateral lateral prefrontal cortex and right posterior parietal cortex, regions previously associated with tracking confidence and choice difficulty in decision making. Taken together, our results support the hypothesized causal role of theta FPC oscillations for metacognition and are consistent with an active role of FPC possibly modulating communication with other brain regions in order to metacognitively access relevant decision-related information.

P2-I-81: A normalization mechanism in human multi-attribute choice

Giulia Mezzadri¹, Silvio Ravaioli², Michael Woodford¹

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Many daily decisions, such as choosing which coffee to have at Starbucks, involve comparing options characterized by multiple attributes (Tversky, 1972). Although multi-attribute choices are ubiquitous, the way our brain compares and combines attributes to form a unitary decision is still unknown. According to normative theories, the value of an option should be independent of the choice set (Allingham, 2002). However, numerous studies have shown that preferences can vary with the context (for instance, by adding a new irrelevant option) and task framing (Tsetsos, 2012). In this work, we propose a new psychometric model that helps us explain some of the biases that have been documented in the literature. According to our model, attributes within an option are weighted as a function of their value, relative to the other attributes and options. In other words, we hypothesize that the brain performs a normalization process, while combining together multiple pieces of information. To test our model, we run an averaging task in which subjects had to compare two series of six numbers and select the series with the highest average. The distribution from which numbers were drawn (upward vs. downward), as well as the type of stimuli that was used (numbers vs. bars) and the order in which stimuli were presented (sequential vs. simultaneous vs. alternate) varied. We found that performance was better in the downward treatment, as well as on trials with a low average. Moreover, subjects were biased toward the option with the highest number of local winners, in the simultaneous and alternating orders. Our model was compared through cross-validation to the following psychometric models: the benchmark model, in which attributes are encoded with no bias; the Spitzer's model (2017), in which a non-linear transformation of the attributes is encoded; and the Tsetsos's selective integration model (2016), in which the weakest attribute is encoded less strongly than the others. Our model was the best fitting model, followed by the selective integration model. Moreover, it was the only one that could explain the difference in performance between treatments, as well as the one across trials of different averages. However, the selective integration model was the only one explaining the bias toward the option with the highest number of local winners. We conclude that the mechanism that best explains our data set is the normalization mechanism on which our model is based, but that both the normalization and selective integration mechanisms are necessary to reproduce the biases we found in the data set.

Poster Session 03

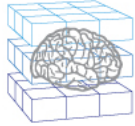
P3-A-82: Dopamine-Revealed Preference and Beliefs over Resolving Uncertainty

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¹*Max Planck Institute for Biological Cybernetics*

The risk and ambiguity inherent to many decisions tend to resolve over time as more information becomes available. How a decision maker values their options at different times, facing different information, depends on their preferences over, and beliefs about, outcomes. The canonical explanation is subjective expected utility theory (Savage 1954), but only non-expected utility theories can account for phenomena such as ambiguity aversion (Ellsberg 1961). Furthermore, new methods such as distributional reinforcement learning (Bellemare et al. 2017) show how it is readily possible to maintain more information about outcome distributions than merely their expectation. A popular proposal inspired by robust control as well as finance is that decision makers use such information to hedge against model uncertainty by optimizing for the worst case, as with robustness preferences (Hansen &

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Sargent 2000), variational preferences (Maccheroni et al. 2006), or by using convex risk measures (Föllmer & Knispel 2012) such as the Conditional Value at Risk (Gagne & Dayan 2022). Based on behavior alone it is often not possible, however, to disambiguate between ambiguity preferences and distorted beliefs. The goal of this project is to inform (and distinguish between) these models, by making theory-driven inferences about participants' preferences and beliefs from their behavior and prediction-error-related responses (as measured in BOLD signal). We introduce a theoretical framework that makes precise what these behavioral and prediction error measurements reveal about preferences and beliefs. We will also present behavioral pilot data from a lottery task in which the uncertainty about the winning odds gradually resolves. Eliciting participants' lottery valuations at different stages allows us to measure their evolution as ambiguity resolves - as a first application of the theory. Better identification of preferences and beliefs will become possible when supplementing the behavioral data with neural measurements.

P3-B-83: Inter-Individual Neural Similarity of Automobile Brands Predicts Brand Recall and Is Explained by Brand Personality

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OBJECTIVE: The mental associations consumers form with brands are crucial for marketing success. One approach to measuring these associations is to ask consumers to make person-based judgments of brand personality attributes, which have been shown to coalesce in both semantic space and patterns of brain activity (Chen, Nelson, and Hsu, 2015). A second approach probes the free recall of brands, which predicts market share in a manner consistent with prototype-based retrieval (Hutchinson, Raman, and Mantrala, 1994). Here we use fMRI and representational similarity analysis (RSA) to connect brand personality and brand recall via multivariate patterns of brain activity. **METHODS:** Participants ($n = 33$) were presented with three types of words: (1) fourteen automobile brand words (e.g., "Ford"), (2) the two product categories "car" and "computer," and (3) the control condition "nonwords." Each word was presented twelve times in each of two runs per participant. Participants were instructed to think about the meaning of each word and press a button whenever they saw a nonword. **RESULTS:** Preliminary functional localization revealed neural activation patterns for automobile brands were more similar to the pattern for the 'car' product category than to the pattern for either the 'computer' category or 'nonwords' within the angular gyrus (AG), anterior temporal lobule, and temporal pole-- regions associated with semantic processing. RSA across consumers revealed that neural similarity of automobile brands predicted brand recall within the AG ($p = .021$), parahippocampal gyrus ($p = .019$), and occipital fusiform gyrus ($p = .027$), regions associated with semantic processing, memory retrieval, and object perception, respectively. Further, brand typicality assumed to be familiar to and liked by consumers was not represented in the localized brain, ruling out these confounds. Finally, brand personality traits of aggressiveness ($b = .18$), activity ($b = .09$), and simplicity ($b = .02$) were significant predictors of brand typicality within the AG. **CONCLUSION:** Here we show that automobile brands that are more prototypical in the brains of consumers were similarly recalled and share similar personality traits, directly connecting person-based judgments of brands and market share. Automobile brands with greater typicality critically involved the AG, highlighting the role of semantic processing in connecting



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personality traits and brand recall. These findings may be useful to marketers in brand positioning in the billion-dollar automobile industry.

P3-D-84: Functional dissociations of human absolute versus relative confidence signals in ventral versus dorsal prefrontal networks during instrumental-learning

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¹University of Hamburg, ²INSERM / École Normale Supérieure, ³University of Amsterdam, ⁴Paris School of Economics

Study objectives: The feeling or the confidence about having made a correct decision plays a crucial role in decision-making and learning. However, it can be biased by the valence of the anticipated outcome (Lebreton et al., PLoS computational biology, 2019). Specifically, a growing literature has identified that confidence is higher when learning to gain rewards relative to learning to avoid losses. While the valence-induced confidence bias is robust across tasks and contexts, its neural correlates have not been addressed to date. Two candidate neural networks of interest are the ventral (vPFC) and dorsal prefrontal cortex (dPFC), whose activity has been consistently associated with the computation of confidence and uncertainty. **Methods:** In this study (N=40), we combined functional magnetic resonance imaging (fMRI) and an optimized reinforcement learning paradigm, which dissociated gain and loss contexts and isolated motor responses from option evaluation (Ting, et al. CABN 2020). **Results:** At the behavioral level, we successfully replicated the valence effect on confidence ($p < .001$), despite identical objective difficulty and learning performance (i.e., accuracy) between gain and loss contexts ($p = .967$). At the neural level, we focused our analysis on the option evaluation step. We confirmed that confidence judgments across conditions were positively and negatively correlated with BOLD activity in the vPFC and dPFC ($p < .015$), respectively. While there was no effect of valence on this confidence-related activity in either network ($p > .275$), we found a significant main effect of valence on option-evoked activity in the vPFC ($F(1,37)=9.01$, $p=.004$), but not activity in the dPFC ($F(1,37)=3.05$, $p=.089$). Using several statistical comparison methods (comparison of regression parameters, Bayesian Model Selection), we further established that vPFC encodes confidence over conditions (absolute confidence, including valence bias), while dPFC encodes the relative changes in confidence within each condition (relative confidence). **Conclusions:** Altogether, these results reveal a clear functional dissociation between the ventral versus dorsal prefrontal networks, which respectively encode absolute versus relative confidence signals during instrumental learning.

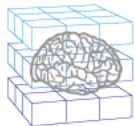
P3-D-85: Are there behavioral hallmarks of configural and elemental evaluation in multi-attribute decision-making?

Juliette Ryan-Lortie¹, Gabriel Pelletier¹, Matthew Pilgrim², Lesley Fellows¹

¹McGill University, ²The University of Southern California

Objectives. While multi-attribute decision-making underpins many everyday choices, how attribute-values are integrated to allow such choices remains unclear. Findings from our lab argue for a distinction between elemental (attribute-by-attribute) and configural (holistic) evaluation of multi-attribute options. We have shown distinct neural substrates of evaluation of complex objects under elemental and configural conditions, when value is predicted by visually distinct value-predictive attributes. Here,

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we asked if there were behavioral or gaze pattern hallmarks distinguishing these two forms of multi-attribute decision-making. Candidate behavioral outcomes were selected, informed by widely-used multi-attribute decision-making models, and compared within-subject across elemental and configural value-based decision conditions. **Methods.** 39 healthy participants were trained on the monetary values of novel pseudo-objects (fribbles) and then chose between pairs of these objects while eye movements were tracked. Value was associated with individual attributes of fribbles in the elemental condition, while value was associated only with combinations of attributes in the configural condition. Choice, reaction time, gaze fixation time on options and individual attributes, and within- and across-option gaze transitions were recorded. Linear and logistic mixed effect regression models were used for the analysis. **Results** There were systematic behavioral differences between elemental and configural conditions. Elemental trials had longer reaction times ($p=3.09e-14$, $d=0.34$), and involved more between-option transitions, yielding a significant difference in the Payne Index ($p=2e-16$, $d=0.34$), in line with attribute-based strategies. Finally, gaze-cascade related metrics revealed that the effect of last fixation location ($p=0.01030$, 1.49 odds ratio) and dwell time advantage ($p=0.00125$, 1.14 odds ratio) affected choice more in the configural condition than in the elemental condition. **Conclusions.** We report systematic differences in behavior and gaze patterns in multi-attribute value-based choices depending on how value is associated with attributes. This adds support for the claim that there are distinct modes of evaluating multi-attribute decision options analogous to (or perhaps built upon) similar distinctions in the recognition of multi-attribute complex objects. The findings suggest behavioral outcome measures that may be useful in distinguishing these elemental and configural decision-making in more naturalistic paradigms.

P3-D-86: Neuroscience study of the impact of the knowledge degree on the decision process with FITradeoff

Anderson Lucas Carneiro de Lima da Silva¹, Ana Paula Cabral Seixas Costa¹, André Marques Cavalcanti¹

¹*Universidade Federal de Pernambuco*

Decision support systems (DSS) have been widely used in organizational environments. A specific type of decision faced by such decision makers (DMs) is the multi-criteria. FITradeoff is a multi-criteria method implemented in a DSS with the characteristic of being flexible and interactive, requiring little information from the DM (DE ALMEIDA et al. 2021). Such characteristics make FITradeoff a practical method, being used by DMs with varying levels of knowledge in multi-criteria approaches. **Objective:** The present study seeks to evaluate the impact of the degree of knowledge in multi-criteria on the use of FITradeoff DSS from the perspective of neuroscience. Levels of engagement and cognitive effort of DMs were evaluated along two steps of the preference elicitation process with FITradeoff: Scale constants ordering and decomposition elicitation. **Methodology:** Two experiments were conducted using a 16-channel electroencephalography and an eye tracker. In the first experiment, a sample with advanced knowledge in multi-criteria solved specific decision problems in the DSS, while in the second, a sample with basic knowledge of multi-criteria solved a standard problem of smartphone choice. For the analyses, we considered measures of theta band power, which is related to cognitive effort (PUMA et al., 2018), frontal alpha asymmetry (FAA) that is related to engagement (REZNIK; ALLEN, 2018) and pupil size, a measure related to cognitive effort and attention (VAN DER WEL; VAN STEENBERGEN, 2018).

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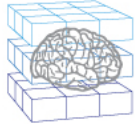
Wilcoxon and t-tests were used. Results: Pupil size and theta band data suggested greater cognitive effort in the elicitation step for both groups, while negative FAA values for the F3/F4 channels were observed for the sample with low knowledge, suggesting lower engagement. Thus, it is possible to suggest the relevance of the elicitation step in the decision process, as well as the impact of knowledge on the performance of DMs in the use of DSS, requiring greater support. It is noteworthy that the fact that the sample with less knowledge solved a standard problem may have contributed to the lower engagement. With this, it is suggested that the DM's familiarity with the problem is a relevant factor, requiring greater support. Conclusion: Thus, the study contributes towards generating recommendations for improvement for the FITradeoff DSS and others in the multi-criteria context, indicating factors and situations that require interventions either from the analyst who supports DMs in such contexts, or in changes in the DSS through the adding extra functionality.

P3-D-87: Honesty sometimes decreases cooperation in Prisoner's Dilemma games with communication

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Objective: An important role of communication is to coordinate action. Economic theory tells us, however, that communication is "cheap talk" in social interactions with compromised incentives to coordinate like the Prisoner's Dilemma (PD) game. Yet, communication regularly increases cooperation in experiments. Recent work models a two stage PD game where players believe that their counterpart is lying averse (suffering a cost when telling a lie) and characterizes the conditions that facilitate cooperation (Bahel, Ball, and Sarangi, 2022 - BBS). Our objective was first to design an experimental setting of social interaction (with communication) that varies individuals' cost of lying and, importantly, their perception of the underlying population's honesty level. Second, we applied this setting to test the predictions and comparative statics of the PD model with lying aversion and pre-play communication. **Methods:** We modify the standard PD game by 1) exogenously assigning lying costs to participants, 2) manipulating the underlying prevalence of lying costs in the population, and 3) restricting communication to sending either a conditional cooperation message (promise to cooperate) or a non-cooperative message. Participants (N=100) completed 60 rounds divided into 8 blocks that varied lying costs and the PD incentives (potential gains/losses). In each round, participant's counterpart lying cost (financial penalty incurred when not keeping one's promise) was drawn from either a uniform urn of penalties or a skewed urn where high penalties were twice as likely. **Results:** The frequency of cooperation decreased with the monetary gain of lying or loss incurred when being deceived and with lower assigned penalties. Using elicited forecasts of a counterpart's lying cost, we verify that the skewed urn significantly shifted participants beliefs about their counterpart's penalty. Surprisingly, cooperation did not necessarily increase in a more honest population. Confirming the BBS model predictions, the frequency of cooperation was instead driven by the interaction between the incentives to cooperate and the population's honesty. **Conclusion:** Our results demonstrate that the nature of communication, beliefs about one's opponent's honesty, and an individual's incentives operate in synergy in social interactions. Future modifications to our malleable experimental setting will allow us to examine how the information and neural processing changes when the level of honesty in the population is



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manipulated in social interactions. Bahel, E., Ball, S., & Sarangi, S. (2022). Communication and cooperation in Prisoner's Dilemma games. *Games and Economic Behavior*, 13

P3-D-88: Emergence of Probability Weighting in the Choice Circuit

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OBJECTIVE: Probability weighting proposed by the Prospect Theory (Kahneman and Tversky, 1992) transforms the objective probabilities into subjective probability assessment to explain the nonlinearity of human decision-making under risk. Probability distortion postulated by the weighting function exhibits underweighting of high probabilities (certainty effect) and overweighting of low probabilities (possibility effect). The effects were investigated and confirmed experimentally in numerous behavioral studies. However, the neuronal mechanism behind these effects remains unknown. The computation of categorical decisions performed in the brain through the integration-to-the-bound process is non-linear (Peixoto, Verhein, Kiani, et al., 2021). Thus, the choice circuit is a natural candidate for the potential locus of probability distortion emergence. **METHOD:** The hypothesis is investigated with computational analysis using the decision-making model based on the recurrent attractor network (Penconek, 2020). The model exhibits non-linear integration, which is consistent with neurophysiological experiments. **RESULTS:** Analysis confirms the emergence of probability distortion when computing risky choices in the gain domain. The analysis assumes no distortion of the representation of probability in the brain. It produces underweighting of high probabilities and overweighting of low probabilities with realistic parameters of the Prelec weighting function: 0.994, 0.842. Elicitation is conducted in the framework suggested by the Prospect Theory with the non-parametric method proposed by Abdullaoui (2000) with no assumptions on the shape of the weighting function. Elicitation of probability weighting in the subjective utility space requires no assumptions about the shape of the value representation function. **CONCLUSIONS:** The study provides a biophysically plausible explanation of the neuronal mechanism of probability weighting observed in behavioral studies. The analysis provides new testable predictions which can be verified in future experimental research. Abdellaoui, M. (2000). Parameter-free elicitation of utility and probability weighting functions. *Management Science*, 46(11), 1497-1512. Peixoto, D., Verhein, J.R., Kiani, R. et al. (2021). Decoding and perturbing decision states in real time. *Nature* 591, 604-609. <https://doi.org/10.1038/s41586-020-03181-9> Penconek, M. (2020). Decision making model based on attractor network with binary neurons. *Procedia Computer Science*, 176, 1930-1939. Tversky, A., & Kahneman, D. (1992). Advances in prospect theory: Cumulative representation of uncertainty. *Journal of Risk and Uncertainty*, 5(4), 297-323.

P3-D-89: Split In Probability Weights - Scarcity, Cognitive Load And Tunnelling

Suvarna Pande¹

¹*University of East Anglia*

This work presents the conceptual framework that investigates decision-attribute dependent bifurcation in preferences. We propose a process model that begins with financial scarcity, works through the cognitive load, draws attention, and controlled cognitive systems to the need at hand, thus simultaneously making those preferences rational and all other choices more biased. We focus on risk

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preferences and probability weighting. We implement the lab-in-field design with 600 people in Bwikhonge in Uganda, a predominantly rural region with a bimodal annual harvest cycle. Our design is composed of two between-within-subject treatment arms and a control group. It is spread across the naturally occurring monsoon cycle in the area. With a randomised sample in both seasons, we prime half the group with shock financial concerns, following which we introduce the cognitive load test. We use the Stroop and the digit span test to measure the role of working memory, attention, and inhibitory control. Finally, we offer two 5- prospect lists that differ only in one aspect, the decision attribute. Each subject allotted to one of the four states makes two rounds of decisions- scarcity relevance and irrelevance. At this stage, the within-subject assignment controls for all other variables. Therefore, the difference in choices is due to decision attributes alone. We also construct a psychological index from the post-experiment survey in our logistic analysis with other demographic factors. We plot and estimate the one parameter pwf on STATA for both gains and losses and find the significant role of the level of scarcity and cognitive load on splitting the pwf. Participants in the lean season and shock scarcity are most cognitively loaded with the most significant effect on attention, leading to the greatest split in the pwf. Known decision biases disappear for the scarcity relevant choices for this group. The pwf is a straight line. At the same time, all other decisions are the most biased for the group. This points to the driving role of cognitive load and scarcity relevance in guiding the neural systems to become rational decision-makers for urgent needs and affect driven for all else. The results advance the study of the psychology of poverty. This rational-bias split as a function of what matters can explain many counterintuitive behaviours like low pickup rates of preventative health or high-interest borrowing that seem self-sabotaging. To our knowledge, this is the first study to present a single phenomenon (financial scarcity) behind a variety of behaviours operating via two core neural mechanisms (bifurcation- decision neglect and cognitive load).

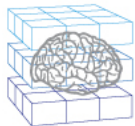
P3-D-90: The social brain: Domain-general contributions to decision making?

Claire Lugrin¹, Arkady Konovalov¹, Christian Ruff¹

¹University of Zurich

Objective. The "social brain" refers to a network of areas commonly activated during social behavior. However, many of these regions (e.g. temporo-parietal junction (TPJ), dorsolateral (dlPFC) and dorsomedial prefrontal cortex (dmPFC)) are also activated during non-social choices. We propose that the involvement of these regions in both social and non-social decisions may reflect a common function: Integrating sensory and memory inputs into salient conceptual representations, such as Gestalt representations of objects or typical social situations. To test this hypothesis, we designed a non-social paradigm that compared, for identical sensory input and motor output, integration of sensory stimuli based on salient Gestalt principles versus alternative arbitrary rules. To control for difficulty, we also compared different response rules that had different motor planning demands but did not differ in terms of stimulus integration. **Methods.** 54 subjects underwent 3T fMRI while judging which of two clouds of elements contained most items (squares and diamonds). We varied mappings in a 2x2 design (salient vs alternative, stimulus vs response): Under salient stimulus mappings (SS), subjects had to select the cloud with the largest total number of elements, whereas under alternative stimulus mappings (AS), they had to select the cloud with the largest number of specific elements. To control for

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difficulty, we also varied representation-response mappings: Under salient response mappings (SR), subjects selected the first (second) cloud by pressing the response button once (twice); under alternative response (AR) mappings, this salient correspondence was reversed. Results. Compared to the salient mappings (SS/SR accuracy = 89%, RT = 628ms), participants were indeed less accurate (AS accuracy = 82% $p < .001$, AR accuracy = 86% $p < .001$) and slower (AS RT = 711ms $p < .001$, AR RT = 718ms $p < .001$) for both alternative mappings. As hypothesized, several "social" brain regions (bilateral TPJ, dmPFC, left anterior dlPFC, precuneus, corresponding to a "social" meta-analysis map from Neurosynth) were activated for salient stimulus mappings (SS > AS). These activations did not reflect task difficulty, as alternative response mappings (AR > SR) instead led to activation in distinct cognitive control regions. Conclusion. Our results reveal an important mechanism that could lead to misinterpretation of fMRI results in studies of the "social brain". Specifically, our findings suggest that integrating sensory information onto salient conceptual representations may be a key contribution of "social" brain areas to behavior in both social and non-social situations.

P3-D-91: Conforming to generous vs. selfish group norms during charitable donations: an fMRI study of the moderating role of internalized social values

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Study's objective: Sharing behavior is known to be facilitated by social norms. Although the mechanisms underlying norm compliance are well studied, a remaining question is to what extent normative influence depends on one's own intrinsic values, and how the interaction of both jointly shape sharing behavior. We investigate how the brain deals with, and solves conflict between one's internalized values and external social norms (prosocials confronted with selfish norm and vice versa). We expect generous norms to foster sharing in prosocials, supported by increased activation in regions linked to norm compliance and/or reputation. Conversely, selfish norms require self-control mechanisms for prosocials to resist temptation and continue sharing. Methods: We used an fMRI donation task, where 50 participants (preselected by their social value orientation, SVO; decided how much to donate to 120 different charities. Social norms were manipulated by presenting the average donations (generous vs. selfish) made by others to each charity, resulting in mismatches (prosocials-selfish norm, prosocial-generous norm) and matches (prosocial-generous norm, prosocial-selfish norm). Results: Consistent with the hypotheses, whole-brain analysis (all fMRI results are FWE-corrected at $p < .05$) showed increased activation in IFG for prosocials processing a mismatch. Donation decisions parametrically modulated by the distance from the norm covaried with activation in IPL, MTG and IPFC for prosocials in a match, and prosocials in a mismatch. Conclusions: Together the data indicate so far that conforming to a generous norm is supported by a similar mechanism when it matches as well as mismatches values. However, processing a selfish norm that mismatches values (prosocials) requires additional cognitive control (IFG). We next compute ROI analyses to better differentiate how prosocials and prosocials make generous decisions in a mismatch condition.

P3-D-92: Cognitive Effort Discounting in Adolescents: Evaluating the Role of ADHD in Effort-Based Decision Making

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Objectives: While the diagnostic criterion for ADHD encompasses several heterogeneous symptoms, one symptom frequently reported by the parents and teachers of adolescents with ADHD is a diminished willingness to initiate or maintain effort with schoolwork. Unfortunately, identifying the mechanisms underlying this phenomenon has been a challenge, partly due to the lack of a systematic procedure to quantify deficits and influential variables. To address this issue, we compared adolescents with and without ADHD on two cognitive effort discounting tasks, which characterized individual preferences between small monetary rewards obtained with no effort exerted and larger monetary rewards (\$10, \$25, \$50) requiring either sustained attention or working memory to be engaged for a specific duration (1, 5, 10, 20 minutes). **Methods:** Participants were ADHD-diagnosed and healthy control participants aged 16-21 years ($n=54$). Participants performed and rated six variants of a sustained attention task and a working memory task, each with varying difficulty levels, produced by varying display rates (inter-stimuli-interval: 750 or 1000 ms and stimulus durations: 200, 400, 800 ms). A variant of each task, rated as moderately effortful, was identified for each participant. Participants subsequently completed two associated cognitive effort discounting tasks. Preferences and decision response time were recorded. Discounting was measured by calculating the area under the discounting curve (AUC). **Results:** In both cognitive effort discounting tasks, adolescents across the two groups demonstrated similar systematic cognitive effort discounting patterns. There were differences in decision response times, demonstrating that individuals with an active ADHD diagnosis invested significantly more time making choices during the working memory task ($F(1,49) = 4.27, p=.04$). This trend was also seen for the sustained attention task; however, it did not rise to the level of significance. **Conclusions:** The data from this study, while potentially in contention with research highlighting inhibition deficits in ADHD, provide evidence that although adolescents with ADHD are not more inclined to select low effort alternatives compared to healthy controls, increased decision response times are consistent with ADHD individuals experiencing higher levels of cognitive dissonance when contemplating effort-based decisions. As this research develops, we hope that we may ultimately find new targets for clinical interventions with improved insight into the cognitive barriers hindering optimal decision-making in adolescents with ADHD.

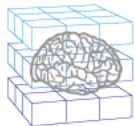
P3-D-93: Surprising sounds increase risk taking and decrease choice perseverance

Gloria Feng¹, Robb Rutledge¹

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Objective: In bustling urban environments, surprising sensory events are common. The sound of an approaching car warrants immediate action, motivating a quick change in behavior that can be critical for avoiding danger. However, most sensory events, like the sound of a nearby stranger's phone, are surprising but uninformative about future rewards or threats and thus should not influence behavior. When behaviorally irrelevant sounds are played during a risky choice task, we might anticipate no systematic influence on decision making due to those sounds. Here, we demonstrate that incidental surprising sounds systematically increase risk taking and decrease choice perseverance. **Methods:** Across six online experiments (each $n = 200$), participants made choices between risky and safe options in which each option presentation was preceded by task-irrelevant six-tone auditory sequences. **Results:**

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In two experiments (each $n=200$), "common" sequences heard before 75% of trials consisted of identical tones and "rare" sequences heard before 25% of trials ended with a novel deviant tone. Rare sequences simultaneously increased risk taking and increased switching away from the option chosen on the previous trial. Our computational model captured both changes with value-independent risk-taking and choice perseveration parameters, respectively. In two additional experiments (each $n=200$), we found that when sequence probabilities were reversed, rare sequences, which ended on common tones, still increased option switching but not risk taking. These results are consistent with deviant rare tones explaining the risk-taking effect, and rare sequences explaining the option-switching effect. Neither effect could be explained by surprising sounds increasing or decreasing the consistency of choices. In two control experiments (each $n=200$), both surprise effects were eliminated when tone sequences were presented in a balanced or fully predictable manner. Conclusions: We find evidence for two dissociable influences of sensory surprise on risky decision making. We find that surprising sounds systematically alter human behavior, identifying a previously unrecognized source of behavioral variability in everyday decision making.

P3-D-94: Effect of skewness on risky decision making in a visual performance task

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OBJECTIVES: Several studies have examined the impact of aging and skewness on risky decision making using monetary outcomes as rewards. However, there is a lack of studies investigating similar themes using alternate rewards. Thus, it remains unclear if the age effects on skewed financial decisions extend to other, non-monetary outcomes. The current study investigated how skewness affects risky decision making in the context of non-monetary outcomes. Here, we report preliminary findings from younger adults, where participants completed a visual search "cover" task and periodically made decisions that impacted the difficulty of that task. We hypothesized that the younger adults were more likely to accept positively-skewed gambles compared to other types of gambles (symmetric and negative). **METHODS:** Participants ($n = 48$, Age: $M = 20.17$, $SD = 2.15$, Range = 18-31) completed a visual object search task, with an initially low visual contrast to increase the task difficulty. They also periodically made decisions that impacted the subsequent task difficulty via adjustments to the visual contrast. Thirty, two-alternative decision trials were presented with the choice between no change in difficulty and three gambles: symmetric, positive, and negative. Symmetric gambles involved an equal probability of moderate improvement or decline (50%) in the object's visual contrast (± 5). Positively-skewed gambles paired a low probability (25%) of a large improvement in contrast (+8), together with a high probability (75%) of a small decline (-2). For negatively-skewed gambles, there was a high probability (75%) of a small improvement (+2), and low probability (25%) of a large decline (-8). **RESULTS:** Using multilevel logistic regression models, we examined participants' rate of gamble acceptance, as predicted by gamble type and the outcome of the previous decision trial. Contrary to our predictions, the acceptance rates of positively-skewed gambles were lower compared to symmetric and negatively-skewed risks combined. Additionally, compared to the "no change" outcome, risks were more likely to be taken after experiencing a loss, whereas experiencing gains in the previous trial did not alter risk acceptance rates. **CONCLUSIONS:** In contrast to prior research findings of a positivity bias in skewed financial decision



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making, our results suggest this may not be generalizable to alternative reward outcomes among younger adults. Next steps in our study include adding an older adult sample to see if the age-related positive-skew bias observed in skewed financial decision making may still extend to non-monetary rewards.

P3-D-95: Distinct Effects of Aging on Risk Tolerance and Risk-taking Behavior in Old Adults

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Objective: Older adults are often faced with making difficult decisions under risk, particularly ones involving finances and health care. However, it remains controversial how aging affects risky decision-making capabilities. While some studies report that older people tend to be more risk-averse, other studies suggest the contrary. In this study, we employed a well-validated Balloon Analog Risk Task (BART) paradigm along with computational modeling to assess both risk-taking behavior and risk tolerance changes in older adults versus younger controls. **Methods:** A total of 81 healthy participants (27 males) participated in the study, including 45 older adults (mean age = 78.9 ± 5.7 yrs, age range 69-100 yrs) and 36 younger adults (mean age = 34.6 ± 9.3 yrs, age range 21-50 yrs). All participants completed the BART, in which they were asked to inflate a virtual balloon with a monetary value that could either increase in value or burst. Each participant completed 45 balloon trials, with the maximum number of pumps for each balloon at 128. The average number of pumps participants made for the winning balloons was calculated as the index of individual risk-taking behavior. The extended Expectancy Valence model was used to model the behavioral data and characterize individual risk tolerance during the BART. This model has four free parameters, including risk tolerance (γ), prior belief of balloon not bursting (Φ), update rate, and inverse temperature. **Results:** Older and younger participants showed no difference in the average number of pumps made for the winning balloons (28.4 ± 15.0 vs. 26.5 ± 8.3 , $p > 0.2$). Computational modeling revealed significantly reduced risk tolerance γ (0.367 ± 0.288 vs. 0.572 ± 0.343 , $p = 0.004$) and increased prior belief of balloon not bursting Φ (0.994 ± 0.006 vs. 0.988 ± 0.005 , $p < 0.001$) in older participants than in younger individuals. Risk tolerance γ negatively correlated with Φ in older adults ($r = -0.44$, $p = 0.002$), but showed no correlation in younger adults ($r = -0.15$, $p > 0.3$). **Conclusion:** To the best of our knowledge, this is the first study using computational modeling with the BART paradigm to dissociate risk-taking behavior and risk tolerance changes in older adults. Compared to younger adults, older adults showed significantly lower risk tolerance, but no changes in risk-taking behavior, suggesting distinct effects of aging on risk-taking behavior and the underlying risk tolerance. Moreover, the negative correlation between prior belief of balloon not bursting and risk tolerance suggest that altered risk belief may compensate for reduced willingness to take risk in the elderly during decision-making.

P3-D-96: Linguistic markers of momentary mood dynamics during risky decision-making

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Objective: Individuals with depressive symptoms have been characterized by negative emotional vocabularies in their daily language. In a decision-making context, they also report lower momentary mood during risk-taking tasks. However, it is unknown whether linguistic features relate to affective experience during decision-making tasks. **Methods:** In this study ($n=196$), we assessed depressive symptoms using the Patient Health Questionnaire (PHQ-9) and asked participants to write text responses to nine short-answer neutrally framed questions based on the PHQ-9 (e.g., Think about your life overall. Is there anything you are particularly satisfied or dissatisfied with?). Participants also completed an established risky decision task with repeated happiness ratings as a measure of momentary mood. **Results:** Replicating previous research, depressive symptoms were negatively correlated with baseline mood parameters for the task estimated using a computational model of momentary mood dynamics ($p<0.0001$). Participants with higher depressive symptoms used fewer positive affect words (e.g., good, love) and more negative affect words (e.g., bad, wrong). We also found that baseline mood parameters were positively correlated with the use of positive affect words ($p<0.01$) and negatively correlated with the use of negative affect words ($p<0.0001$). After controlling for overall depressive symptoms, the use of positive tone words still correlated with baseline mood parameters ($p<0.01$). This finding shows the variance in individual mood dynamics not explained by depressive symptoms can be captured by their use of emotional language. **Conclusions:** We find that affective experience during a risky decision task relates not only to depressive symptoms assessed with a standard questionnaire, but also to the use of affective language. Our findings suggest that text data can provide insights into both mood disorders and mood dynamics.

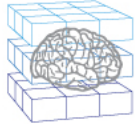
P3-E-97: Hidden Markov modeling of the cognitive process in strategic thinking

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Hidden Markov models (HMMs) are used to study language, sleep, and other processes that reflect probabilistic transitions between states that cannot be observed directly. We apply HMMs to data from experiments on visual location games. In these games, people choose a pixel from an image. They either have a common goal to match locations or have different goals in hide-seeker games. Eyetracking records where they look at a fine-grained time scale. Numerical salience of different locations is predicted, a priori, from a specialized vision science based neural network. The HMM shows the pattern of transitioning from hidden states corresponding to either high or low salience locations, using the eye-tracking and salience data. The transitions vary based on the player's strategic goal; for example, hiders transition more often to low-salience states than seekers do. The estimated HMM is then used to do two useful things. First, a continuous-time HMM (cHMM) predicts the salience level of each player's looking over the course of several seconds. The cHMM is then used to predict what would happen if the same process was truncated by time pressure choosing in two seconds instead of six, cHMM predicts seekers will match hiders 12% of the time; they actually match 15%. Second, dHMM is used to infer levels of strategic thinking from high-to-low transitions (a la Costa-Gomes et al. 2001 and others). The resulting estimates are more plausible than some maximum-likelihood procedures and models which appear to grossly underestimate strategic sophistication. Other applications of HMM in experimental economics are suggested.

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P3-E-98: Dissociation between improved performance and metacognition in observational learning

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GOAL: In some social situations involving choices among reward alternatives, agents can learn by sampling the alternatives themselves, but also by observing their peers. Deciding whether to observe likely involves metacognition: reflecting on knowledge about oneself, the potential observee and the situation. Observation should increase when agents are uncertain about which alternative has the highest value. But also when observees are experienced, and thus more likely to pick the best alternative. Moreover, when picking a bad option can have negative consequences, observing provides learning while avoiding such aversive outcomes. This study aimed at knowing how these variables shape decisions to observe along a choice sequence, how this affects choices between alternatives, and how metacognitive judgments reflect those choices. **METHOD:** 43 participants completed blocks of trials. A trial involved drawing a card from one of two decks. Both decks gave points drawn from Gaussian distributions, with one deck having higher mean reward. At the start of each trial, participants decided between choosing themselves or observing another agent choosing. This observee was a simulated choice algorithm disguised as another player. After some trials, participants judged which deck gave higher mean reward, and rated their confidence on that judgment. Across blocks, two variables were manipulated factorially. Reward could be on average high or low. In low reward blocks, choosing the lower mean reward deck incurred a high risk of receiving negative reward (losing points). The second variable was observee experience: in some blocks, the participant started choosing along with the observee, while in others the observee had already 10 trials of experience. **RESULTS:** There were more observation choices in low reward blocks, probably as a strategy to avoid losing points, as well as in experienced observee blocks, particularly on early trials. More observation in low reward blocks led to more choices of the best arm, and thus better performance. It also led to better confidence accuracy: i.e. correctly identifying the best arm to a greater extent in confidence ratings. However, absolute confidence was greater for high reward blocks. This dissociation agrees with confidence being higher when people made their own choices and when reward was overall positive. **CONCLUSIONS:** Observational learning can produce a dissociation, improving performance and confidence accuracy but reducing absolute confidence. Although novel, these results are coherent with previous reports of confidence being affected by egocentric and valence biases.

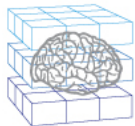
P3-E-99: Delay discounting beyond decision-making: Delay discounting steepness as a modulator in delayed-reward pursuing

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Objective: Delay discounting describes a tendency for people to choose immediate rewards over delayed rewards, and this tendency also reduces motivation for pursuing delayed rewards. However, much remains unknown about how the brain represents and computes delayed rewards beyond decision-making. We examined the neural mechanism of delayed-reward pursuing using fMRI in a modified Monetary Incentive Delay task (MID) and identified its link to the delay discounting rate

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measured in the delay discounting task (DDT). Methods: Participants ($n = 31$) in the fMRI scanner pressed a button to discriminate the color of a target circle after a cue indicating the potential of gaining the immediate- or delayed-reward (vs. no-reward) for a given trial. Response-contingent feedback was then presented, indicating whether they gained the corresponding reward. The immediate-reward was cashed out after the experiment, while the delayed-reward was paid out three months later. Moreover, we used DDT and computational modeling to characterize participants' delay discounting rates. Results: The behavioral results showed that performance was improved after a reward (vs. no-reward) cue, with a more improvement after the immediate-reward cue than after the delayed-reward cue. Neural results revealed that the orbitofrontal cortex (OFC), a region associated with valuation, was activated both in immediate- and delayed-reward anticipation compared to no-reward anticipation. Combining DDT and computational modeling, our results further revealed that the OFC signal was attenuated as a function of the delay discounting rate during delayed-reward anticipation compared to immediate-reward anticipation. The dorsal prefrontal cortex (DLPFC) and the medial temporal gyrus (MTG), dominating cognitive control and imagination separately, deactivated as the delay discounting rate increased in the delayed-reward consummatory phase. Moreover, inter-subject representational similarity analysis (IS-RSA) conducted on a 200-parcel atlas revealed that participants with similar delay discounting rates had a comparable neural representation for delayed reward in the brain regions dominating valuation and cognitive control. Conclusions: Computational and neural mechanisms of delay discounting are well-documented but largely limited in the decision-making context. Our results extend this phenomenon to reward-pursuing behavior, suggesting that computational principles and critical regions (i.e., valuation, imagination, and cognitive control networks) engaged in DDT, also dominate the anticipation and consummation of delayed rewards.

P3-F-100: On the Resource-Rationality of the Description-Experience Gap

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OBJECTIVE: When making decision based on a description of two available options (a sure thing vs. a risky gamble), people tend to be risk-seeking for low-probability gains and high-probability losses, and, conversely, risk-averse for high-probability gains and low probability losses. This well-established empirical regularity is called the fourfold pattern of risk preferences in decision from description (Kahneman & Tversky, 1979), explaining e.g. why the same people who buy lottery tickets that promise a tiny chance of winning also take out insurance against a tiny chance of damage. However, there is substantial evidence that this pattern of risk preferences reverses when decision is made based on experiential samples from available options (Hertwig & Erev, 2009). And this is referred to as the description-experience gap. But could this gap be given a resource-rational basis? That is, could it be understood in terms of the optimal use of limited cognitive resources? In this work, we provide a resource-rational basis for the description-experience gap. **METHODS:** We incorporate optimal learning from experience into a recently proposed resource-rational process model of risky choice, sample-based expected utility (SbEU; Nobandegani et al., 2018). SbEU assumes that people estimate expected utility of their options as best as they can, given their computational resources. As such, SbEU effectively implements a resource-rational variant of the normative expected utility maximization. **RESULTS:** SbEU



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simulates the fourfold of risk preferences in decision from description. Additionally, when deciding from very few experiential samples, SbEU simulates the reversed fourfold pattern of risk preferences, and, as the number of experiential samples increases, the reversed fourfold pattern of risk preferences diminishes--consistent with past empirical research (Hau et al., 2009). Together, these results provide a resource-rational basis for the description-experience gap and demonstrate that, in decision from experience, it is resource-rational to produce the reversed fourfold pattern of risk preferences when deciding from few experiential samples. CONCLUSION: The normative status of the description-experience gap has remained elusive. In this work, for the first time in the literature, we provide a resource-rational basis for this puzzling phenomenon, showing that it could be understood in terms of the optimal use of limited cognitive resources.

P3-F-101: Gender differences and heritability in reference points

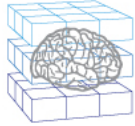
Agnieszka Tymula¹, Nathan Kettlewell², Xueting Wang³, Jonathan Levy¹

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Objective Although the reference point has been one of the most prominent concepts in behavioural economics (Kahneman and Tversky, 1979), little is known empirically about what reference point is. Behavioural economics suggested various possible rules that choosers may use as a reference point but their prevalence has not been studied in a broad population. Moreover, most of the behavioural economics research has focused on a static reference point that relates only to the choice at hand ignoring the potential impact of historical rewards. In this project, we empirically investigate what people actually use as the reference point. **Methods** We recruited 853 adults (18-67 y. o., mean 42.2, sd 14.16) from Twins Research Australia. Our sample includes 361 twin pairs out of which 269 are monozygotic. Participants made 46 decisions between two lotteries. The choice scenarios were designed to distinguish between different behavioural economics reference point rules (Baillon et al., 2019). In addition, participants completed a rich demographic and socioeconomic questionnaire. To ensure that participants respond truthfully, for each participant we randomly picked one of their decisions and implemented it for payment. We use a comprehensive model that includes different possible reference point rules and estimate which reference point is most likely using Hierarchical Bayesian Modelling. **Results** Most common reference point rules are maxmin (23%), the prospect itself (22%), and expected value (20%). The least likely used rule is status quo (9%) suggesting that reference point changes from trial to trial and depends on the choice set. We analyse whether the demographic, socioeconomic, and genetic associations between willingness to take risk are driven by differences in reference points. Finally, we contrast the behavioural economics reference point with a neuroeconomic model in which reference point is derived from the neurobiological capacity constraints of the nervous system, rather than being a simplistic rule. **Conclusions** Our project reveals that most do not use a status quo as a reference point and that it is necessary to account for individual differences in reference points to adequately capture behaviour. We provide the first heterogeneity analysis of the reference point as a source of individual differences in risk taking behaviour in a large (n=853) and demographically and socioeconomically diverse sample. Using data from dizygotic and monozygotic twins we can assess the relative impact of the genetic and environmental factors on an individual's reference point.

P3-F-102: Uncertainty aversion predicts the neural expansion of semantic representations

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Disambiguating a word's meaning when it is uncertain requires activating the appropriate semantic representation. One way to reduce this uncertainty is to differentiate each semantic representation as much as possible, thereby expanding the semantic space. In three experiments, we test this semantic-expansion hypothesis, finding that individuals who are uncertainty intolerant exhibit increasingly differentiated and distal semantic representations. This effect is mirrored at the neural level, where uncertainty aversion predicts greater distances between activity patterns in the left inferior frontal gyrus when reading, and enhanced sensitivity to the semantic ambiguity of these words in the ventromedial prefrontal cortex. A direct test of this semantic-expansion hypothesis further reveals that uncertainty averse individuals exhibit reduced semantic interference during a memory test. Together, these findings demonstrate that the internal structure of our semantic representations is shaped in a principled manner: aversion to uncertainty acts as an organizing principle to make the world more identifiable.

P3-F-104: Examining the associations between past and present socioeconomic status and social, temporal, and risky decisions

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Objective: There has been a recent interest in understanding how socioeconomic status (SES) affects adult decision-making processes. Multiple theoretical models propose different underlying mechanisms by which socioeconomic factors shape our preferred choices and actions, specifically within social, risk, and time domains. However, the evidence for these models is mixed. For example, some find that individuals from lower-status backgrounds are less prosocial, more risk-seeking, and more present-oriented (Griskevicius et al., 2011; Korndörfer et al 2015). Others, however, have found the opposite for risk and prosocial preferences (Amir et al., 2018). The current study is a preregistered replication study on the role of SES in shaping choice preferences. Here we aim to (1) quantify SES across multiple different methods (i.e., education, occupation, income, and subjective status) (2) take a model-based approach to estimating choice preferences, (3) dissociate generosity and inequity aversion within social choices, and (4) examine possible mediators (i.e., empathy, selfishness, and early adverse experiences). **Methods:** In this study, we asked 1008 online participants to complete three economic tasks that measure social, risk, and time preferences (i.e., Dictator Game, Risk Choice Task, Intertemporal Choice Task). We also collected various childhood/parental and current socioeconomic demographics. **Results:** Replicating previous findings, we found that both lower current ($\beta = -0.138$, $p = 0.001$) and lower childhood ($\beta = -0.089$, $p = .013$) SES were predictive of preferences for immediate rewards, with current SES being a stronger predictor. In contrast to previous studies, however, we found SES was not a significant predictor of social and risk preferences. Instead, we found that trait-levels of affective empathy ($\beta = 0.178$, $p < 0.001$) and selfishness ($\beta = -0.271$, $p < 0.001$) were important predictors of inequity aversion, and selfishness was associated with current SES ($\beta = 0.117$, $p < 0.001$). **Conclusion:** Our results suggest that the association between SES and time preference is robust, while those between risk and social are not. Furthermore, current SES is more strongly related to time preferences,



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which constrains explanations of this relationship (i.e., time preferences are not learned during childhood). Keywords: socioeconomic status, childhood, decision-making

P3-F-105: Ventromedial prefrontal cortex lesions disrupt learning to gain prosocial rewards

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Background. The ventromedial prefrontal cortex (vmPFC) has long been associated with learning and decision-making as well as social cognition. Human neuroimaging studies have repeatedly shown that the vmPFC encodes computational parameters relevant for self-benefitting learning, including value, prediction errors, and learning rates. A separate line of research suggests that the vmPFC is linked to social processing, with damage to this area associated with abnormal social behaviours including greater utilitarianism. However, neuroimaging studies cannot show a causal role of this region in learning and decision-making, and studies of vmPFC damage have so far often relied on small samples or patients with diffuse damage. **Objective.** The current study aimed to test whether vmPFC damage affected learning to help oneself (self-benefitting learning), learning to help another person (prosocial learning), or learning in the absence of reward (learning for neither individual, control condition). **Methods.** The sample comprised a large cohort of adults with localised vmPFC damage ($n=28$) and a carefully age- and gender-matched healthy control group ($n=152$). All participants completed a probabilistic reinforcement-learning task in which they learned to obtain rewards in three conditions: for themselves, for another person, or for neither individual where outcomes were associated with points but no monetary rewards for either self or other. This allowed us to separately assess the influence of vmPFC lesions on self-benefitting learning, prosocial learning, and learning when neither person benefits, akin to work in non-human primates. **Results.** Compared to healthy controls, patients with vmPFC lesions showed deficits in learning to obtain rewards for another person. They were unable to learn significantly above chance in the prosocial condition but were able to learn above chance to benefit themselves or neither individual. When compared to healthy controls, we also observed significant reductions in learning for others compared to neither (group-by-recipient interaction for No one versus Other $OR = .76$, 95% CI [.63, 0.91], $Z = -2.91$, $p = .004$) and for oneself compared to neither (group-by-recipient interaction for No one versus Self $OR = .82$, 95% CI [.68, 0.99], $Z = -2.03$, $p = .04$). **Conclusion.** These results suggest that vmPFC is particularly involved in prosocial learning and to a lesser extent in self-benefitting learning. Crucially, vmPFC damage preserves learning in the absence of reward. These findings suggest a causal role for vmPFC in reward learning and prosocial learning, but damage may in fact preserve learning in certain contexts.

P3-F-106: A computational view on the gender differences of self-other moral conflict

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Objective This study seeks to investigate the role of gender on conflictual moral decision-making where one's own monetary benefits are pitted against someone else's harm. We explore the effect of gender of the decision-maker (the self) and of the other person receiving the consequences of these choices

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(the other). **Methods** Leveraging computational modeling in a reinforcement learning paradigm, we explore latent mechanistic processes underlying moral behavior. Participants (N=235) learned probabilistic associations of abstract symbols and outcome representations. One symbol led to high self-monetary gain and high other-painful shock stimulation, and the other to low self-payout and low other-pain. Short movies depicted shocks in the dorsum of someone's hand and facial expressions represented the amount of pain. A between-subjects design was used to manipulate the gender of the other: a male or a female. The model was fitted using a hierarchical Bayesian approach with RStan package. Two separate learning rates kept track of money for the self (λ Money) and shock for the other (λ Shock). The individual variability on preferences was captured with a weighting factor (wf), and the stochasticity of choices with the tau parameter (τ). **Results** Our results provide compelling evidence for the effect of gender of both the decision-maker and the other. Specifically, women make more prosocial choices than men ($p < 0.01$, $BF_{10} = 5$), yet the gender of the shock-recipient does not influence the proportion of prosocial choices ($p > .05$, $BF_{10} < 1/3$). Additionally, women decision-makers show lower λ and higher τ (λ Money: $p < .001$, $BF_{10} > 1000$; λ Shock: $p < .001$, $BF_{10} > 1000$; τ : ($p < .01$, $BF_{10} = 10$). Notably, those observing the pain of a female also show higher λ (Money: $p < .001$, $BF_{10} > 1000$; Shock: $p < .001$, $BF_{10} = 5$) and lower τ ($p < .001$, $BF_{10} > 1000$). Furthermore, women and those observing the pain of a female make slower decisions ($p < .05$). This effect becomes stronger as individuals learn, since differences in subjective values between options is associated with slower responses for prosocial choices when the other is a female ($p < .05$). Prosociality is associated with self-reported probabilities for shock and monetary symbols when the other is female ($p < .05$), but only with recall for monetary symbols for male others ($p < .01$). **Conclusions** Women show more prosocial behavior than men by making more pain-reducing choices, and model parameters and reaction times indicate a more cautious behavior. When considering the pain of a female, learning parameters and response times also point towards more cautious behavior, although no differences arise on the proportion of prosocial decisions themselves.

P3-F-107: Deciding when to help others depends on the expected value of the environment

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Study objectives In everyday life, decisions are not presented as binary options between choices. Instead, ongoing behaviours are interrupted with alternatives, such as being asked to cook dinner while watching TV. However, current experimental paradigms rarely capture these types of context-dependent decisions that our brains evolved to solve. Computational accounts across several fields highlight that deciding when to act depends on such 'ecological' influences. Yet, the mechanisms that drive when people decide to help others are unknown. Here we examined when people will interrupt their ongoing behaviour to help themselves or another person when placed in "rich" or "poor" environments based on the average rate of reward. **Methods** We collected data from a large group of participants online (n = 324, age 18-35, 161 female). Participants encountered opportunities to make effortful actions in order to receive rewards for themselves or another person, while watching a movie. Effortful actions were thresholded to participants' own ability and were effortful yet achievable (60% of maximum threshold). Critically, participants made decisions to interrupt the movie to help themselves



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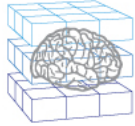
or others in two different environments: in poor environments where, on average, opportunities were lower reward and lower probability, or in rich environments where opportunities were generally higher reward and higher probability. The quality of the environment was signalled to participants at the beginning of each block. Results When people decided to help others was more strongly influenced by the richness of the environment compared to making decisions to help oneself (three-way interaction between recipient, environment, and expected value, $\beta(\text{SE}) = -0.40(0.12)$, $z = 3.30$, $p < .001$). Specifically, as the expected value of the reward increased, people became more likely to help others in a poor environment compared to a rich one. We also found, consistent with prior work, that overall for matched offers, people were more likely to accept effort for reward in a poor environment, relative to a rich one ($\beta(\text{SE}) = -3.07(0.15)$, $z = 20.04$, $p < .001$), and that people were more likely to interrupt the movie when it benefitted themselves relative to another person ($\beta(\text{SE}) = 0.77(0.15)$, $z = 5.03$, $p < .001$). Conclusions A previously reported ecological mechanism whereby people accept worse options in poorly rewarded environments is enhanced when deciding whether to help others out. These findings could have important implications for understanding prosocial and self-benefitting behaviours as environments change, and ultimately for increasing prosociality.

P3-F-108: Assessing social forward planning reliably across in-person, web-based, and mobile app-based platforms

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It is estimated that over 6 billion people in the world currently use smartphones. This provides an unparalleled opportunity for scientists to conduct large-scale research on mobile platforms, which has revolutionized the cognitive and behavioral sciences (Brown et al., 2014; Gillan et al., 2016; Teki et al., 2016; Palan and Schitter, 2018). However, due to lack of monetary incentives or user engagement tracking, it remains elusive how reliable mobile-based data collection is, especially for the study of complex, higher-order social cognition. In the present study, we examined a particular form of complex social cognition--social forward planning--across three different data collection platforms: in-person ($N=48$), online via a web-interface (i.e., Prolific.co; $N=1342$), and online via a novel mobile application (i.e., the Social Brain App; $N=110$, data collection ongoing). Participants completed a social controllability task (Na, Chung et al, 2021) in which they were able to influence partners' proposals of monetary offers in the future (Controllable) or not (Uncontrollable). Across all platforms, participants successfully influenced their partners' offers in the Controllable condition on average (In-person: $t(47)=3.42$, $p=0.001$; Web-based: $t(1341)=20.29$, $p<0.0001$; Mobile app: $t(109)=5.18$, $p<0.0001$) and reported having greater influence in the Controllable versus Uncontrollable condition on average (In-person: $t(39)=3.56$, $p<0.001$; Web-based: $t(1341)=26.60$, $p<0.0001$; Mobile app: $t(100)=3.43$, $p<0.001$). Furthermore, choice behavior in the Controllable condition was also consistently best characterized by computational models that captured participants' forward planning of future actions to affect subsequent offers from partners. Key model parameter estimates did not significantly differ on average, including a parameter indexing participants' expected influence, which reflects the amount by which participants simulated the offers changing based on their choices (δ ; $F(2, 1497)=2.38$, $p=0.79$) and a parameter indexing participants' sensitivity to norm violations (α ; $F(2, 1497)=0.19$, $p=0.83$). Across three different platforms, we



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replicated that individuals were able to exert influence on others when given the opportunity by simulating how current choices might affect subsequent social interactions. These findings demonstrate that mobile apps can be leveraged to collect high quality, reliable behavioral data even in complex social contexts, which can eventually enable large-scale investigation of the mental health relevance and socioeconomic correlates of these behaviors.

P3-G-109: Disentangling the Motivation to Exert Cognitive Control in Depression

Mahalia Prater Fahey¹, Laura Bustamante², Ivan Grahek¹, Johanne Solis³, Temitope Oshinowo², Elizabeth Tong², Jeremy Lee², Allison Burton², Anna Konova³, Nathaniel Daw², Jonathan Cohen², Amitai Shenhav¹
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Objective: Depression is characteristically associated with impaired cognitive performance, and recent work suggests this reflects diminished motivation rather than only diminished capacity. The motivation to exert mental effort is determined both by the amount of reward expected for performing well, and the extent to which this reward is determined by one's performance versus factors outside of their control (the 'efficacy' of control). Variability in mental effort allocation across people can therefore reflect differences in how people evaluate expected reward, expected efficacy, or their interaction (the overall expected value of control). Here we examine which of these might account for differences in mental effort exerted between people with and without depression. **Methods:** As part of an ongoing study, 66 participants (47 MDD patients and 19 healthy controls) performed self-paced intervals (6-9s each) of an incentivized Stroop task. Across the session, we varied whether the amount of reward at stake for an interval was small or large, and whether those rewards were more likely to be determined based on their performance ('high efficacy') or at random ('low efficacy'). **Results:** Replicating previous findings in healthy adults (Frömer et al., 2021), effort exertion by healthy controls was determined by an interaction between reward and efficacy: they completed the most correct trials per second when both reward and efficacy were high ($p=0.006$), which reflected faster responding under these conditions ($p=0.004$) without any change in accuracy. By contrast, response rate for MDD patients only varied as a function of efficacy level ($p=0.004$) and not its interaction with reward. Unlike controls, performance differences in patients primarily reflected changes in accuracy, with patients responding less accurately on low efficacy trials ($p<0.001$). Ongoing analyses are using the hierarchical drift diffusion model to differentiate between distinct control strategies that these groups may have engaged in response to these incentives. **Conclusions:** We find preliminary evidence that reductions in mental effort observed in depression may reflect differences in how depressed individuals process the incentives for mental effort. Specifically, whereas healthy participants adjusted their effort by integrating information about both expected reward and efficacy, participants were more selectively sensitive to efficacy alone.

P3-H-110: Evidence for distinct and opposing value normalization circuits in human BOLD signals

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¹*New York University*

Objective: Contextual value coding has been shown in both neural activity and context-dependent behavior. However, the precise form of contextual coding is controversial, with proposed models including divisive normalization, range adaptation, and subtractive competition. Here we developed a

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novel mathematical tool to differentiate predictions of different theories and examined fMRI activity in a pilot sample of human subjects performing a contextual economic choice task. **Methods:** Human subjects ($n=10$) were scanned in a two-stage evaluation and choice task (258 trials). In the first step of choice trials, the participant viewed one, two, or three consumer product(s) presented on the screen for 4s. In the second step, the items were withdrawn for .3 - 8s. In the third step, two items were presented -, one old item and another new item (under 1- and 2-item trials) or two old items (under 3-item trials) and the participant chose one within 2.5s. The steps were designed to elicit value representation, working memory, and action selection signals in a manner that dissociates value signals from choice probability signals. **Results:** From the behavior, we found that the choice accuracy between two items changes with contextual value (the value of the extinguished item in 3-item trials) as a 'U' shape - initially decreasing but rebounding at high levels of contextual value, consistent with previous findings and the prediction of divisive normalization. Mathematically, we show that the cross 2nd derivative (X-D2) of BOLD over direct input value and contextual value differentiates existing theories: zero X-D2 in range adaptation and subtractive inhibition, and negative X-D2 in divisive normalization. We approximate the effect of X-D2 by contrasting the parametric modulations of the item value between high and low values of the other two. Under a liberal threshold, we identified negative X-D2 in insula and VS during representation, and STG and M1 during memory, suggesting a contextual suppression consistent with divisive normalization. Surprisingly, we also observed positive X-D2 in distinct areas including pMTG and PM during representation, and insula and VS during memory, suggesting non-linear contextual enhancement in these areas, which may reflect attention, salience, or contrast effects. **Conclusion:** We identify distinct value-related circuits for both contextual suppression and contextual enhancement in human value coding. Together, these results reinforce the canonical nature of normalization in neural computation and emphasize the importance of a strict mathematical analysis in brain-wide disambiguation of alternative decision-making models.

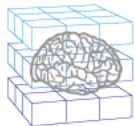
P3-H-111: Distinct contributions of perceptual and reward processes to choice errors and decision confidence

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Objective: Disruptions in perceptual and reward-based decision-making have been widely identified in neuropsychiatric illness. However, due to the complex relationship between these processes, their independent contributions to behavior and their respective involvement in pathophysiology are unclear. Thus, behavioral paradigms and modeling frameworks that can dissociate perceptual and reward computations underlying decisions are needed. **Methods:** We designed a novel auditory signal detection task in which signal base-rate and reward probabilities were orthogonally manipulated across blocks. Each trial, participants ($N = 65$) reported if they heard a tone and their perceptual and reward confidence. To evaluate participant behavior, we developed a computational model which updates both perceptual and reward expectations based on experience and integrates these expectations with current sensory evidence to determine if a signal was present or absent on each trial. Furthermore, this model computes perceptual confidence as the posterior probability of a signal and reward confidence as the prior probability of reward. Reported p-values correspond to mixed-effects regressions. **Results:** Our

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model predicts that errors can be driven by either perceptual or reward expectations and that the relative contributions of these expectations to individual decisions can be dissociated using confidence reports and across task blocks. Consistent with these predictions, we found that participants made errors that tracked with both perceptual ($p = 4.82 \times 10^{-4}$) and reward ($p = 9.94 \times 10^{-4}$) contingencies. Furthermore, we found that perceptual confidence reports scaled with perceptual difficulty ($p = 5.17 \times 10^{-45}$) and perceptual ($p = 2.38 \times 10^{-15}$) but not reward ($p = 0.921$) contingencies. In contrast, reward confidence reports scaled with reward contingencies ($p = 6.75 \times 10^{-29}$) but with neither perceptual contingencies ($p = 0.138$) nor perceptual difficulty ($p = 0.318$). Finally, we found that perceptual ($p = 2.61 \times 10^{-20}$) and reward ($p = 1.20 \times 10^{-3}$) confidence reports explained unique variance in choice errors. Conclusions: Here, we developed a novel paradigm that elicits perceptual and reward learning and a computational model that accounts for human choice and confidence behavior. In agreement with our model, choice and confidence data showed that participants simultaneously tracked perceptual and reward contingencies and integrated them into their decision processes. Furthermore, trial-by-trial confidence reports reflect independent contributions of perceptual and reward expectations to decisions, potentially allowing for more detailed dissections of choice processes in health and disease.

P3-I-112: Influence of imagining the future on time discounting across the adult lifespan

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¹Duke University

As the population ages and retirement savings are left for individuals to manage, promoting patient savings behavior is important for the well-being of older adults. Previous studies have shown that in younger adults, but not older adults, imagining the future during intertemporal choices can promote more patient choices. In the present study, after repeated rehearsal of hypothetical imagined future events, younger adults and older adults ($N=35$, ages 25-80, $M=54.40$, $SD=18.11$) made choices between larger-later and smaller-sooner monetary rewards. Some of the trials included a cue that invoked the imagined future event whereas other trials did not include a cue. Younger adults were more likely to choose larger, delayed monetary rewards on trials where the imagined future event was cued compared to trials without a cue. However, older adults did not show an effect of cued imagination (age*trial-type interaction: $b=0.0008$, 95% CI [0.0004, 0.001]). Across age groups, functional neuroimaging data revealed that trials with an imagination cue elicited greater engagement of regions that are part of the default mode network including the posterior cingulate cortex, angular gyrus, and medial prefrontal cortex. This network is commonly engaged during thinking about past memories as well as imagining the future in many studies that did not focus on decision making. Interestingly, this difference in neural activity did not vary across age groups even though the behavioral effect of the cue was limited to younger adults. We replicate the age difference in the expression of the effect of imagining the future on intertemporal choice. Further, we do not find evidence that repeated rehearsal to promote semanticization of events is an effective strategy for promoting more patient financial choice.

P3-I-113: Representing and Predicting Individual Variations in Third-Party Intervention in Injustice with Endogenous Neural Patterns

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Introduction When confronted with injustice, other-regarding third parties often intervene to restore justice by punishing perpetrators or helping victims, even at their own costs. Surprisingly, little is known about how endogenous neural patterns are associated with individual differences in third-party intervention and how these associations vary between specific types of intervention. Here, we addressed these questions by combining a novel behavioral paradigm, resting-state fMRI (r-fMRI) with multivariate analysis. **Methods** Fifty-four healthy participants (30 f; 22.2 ± 1.6 yrs) underwent r-fMRI scanning and performed a third-party intervention task. On each trial, they were presented with an unequal monetary split made by a proposer and decided whether to accept an intervention proposal to help the disadvantaged recipient (the Help condition) or to punish the proposer (the Punish condition) at a specific cost. We performed an inter-subject representational similarity analysis (IS-RSA) to associate multidimensional behavioral measures with a geometric representation of resting-state functional connectivity (rFc) across individuals. We focused on a costly punishment network that comprised a total of 18 nodes covering the salience, default mode, and central executive networks. For each node, we constructed a neural representational dissimilarity matrix (RDM) by calculating the pairwise Euclidean distance of node-specific rFc patterns between each pair of participants. Similarly, we built three behavioral RDMs to capture dissimilarity in acceptance rate for each condition (two 1d vectors) and both conditions (a 2d space; indicating a general tendency). Then, we computed Spearman's rank-order correlation between neural and behavioral RDMs. We further implemented the elastic net regression to explore whether the rFc in nodes in IS-RSA analyses could predict the acceptance rate across individuals. **Results** Inter-subject variations in general intervention tendency were positively associated with those in rFc patterns of dACC, vmPFC, dmPFC, dlPFC, and PPC, covering all the three networks. Acceptance rate patterns were more similar to rFc patterns of the TPJ and dlPFC in the Help condition than to rFc patterns of the dmPFC in the Punish condition (all pspermutation < 0.05, FDR-corrected). Follow-up prediction analyses showed that rFc in nodes representing the similarity of general intervention tendency predicted the overall acceptance rate of both conditions and the rate for each condition. **Conclusion** Our findings provide novel evidence for the endogenous neural bases of individual variations in costly third-party intervention.

P3-I-114: Challenges in fMRI-based Lie Detection: Heterogeneous Neural Correlates

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Can we detect lies using fMRI? Previous studies have used instructed lying paradigms to identify neural correlates of deception, which involved heightened activity in the insula, inferior parietal lobule, middle frontal gyri, etc. Here we sought to extend these findings in a more naturalistic setting where participants were incentivized, but not instructed, to lie. We used a messaging task in which the participants play the role of the 'signaler' who sends a message to the 'recipient' about which monetary outcomes the recipient should pick (e.g., much like the role of a financial advisor advising the client which option to choose). In the preference condition, participants tell the recipient that they would

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'prefer the recipient choose option A/B', while in the deception condition, participants tell the recipient that 'option A/B will earn you more money'. Hence, a selfish message in the preference condition does not involve a lie but a selfish message in the deception condition does. Using meta-analysis ROIs from previous instructed lying studies, we were able to predict whether the participants were lying or not on a given trial, but only for those participants who showed aversion to lying. Regions such as the insula showed increased activity to lying only if the participants were averse to lying, while participants who were comfortable with lying showed dampened activity in these regions. Furthermore, those who were comfortable with lying showed neural responses in the deception condition that were similar to their responses in the preference condition.

P3-I-115: Changing the Incentive Structure of Social Media Platforms to Halt the Spread of Misinformation

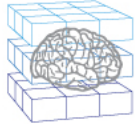
Laura Globig¹, Nora Holtz², Tali Sharot¹

¹University College London, ²Humboldt University of Berlin

Objective: The spread of misinformation has skyrocketed in recent years, causing polarization, racism and resistance to climate action and vaccines. We argue that this spread is facilitated by the incentive structure of social media platforms, where rewards (in the form of 'likes' and 'shares') are dissociated from accuracy. To halt the spread, an incentive structure is needed where 'carrots' and 'sticks' are associated with reliability. Here, we test such a possible structure. Specifically, we capitalize on reputation as an evolutionary adaptive incentive mechanism to improve discernment by adding metrics of trustworthiness. **Methods:** Over four experiments participants (total N=400) engaged in simulated social media platforms similar to Twitter where they encountered true and false information. However, in some platforms in addition to the existing reaction options (e.g., 'like', 'dislike', 'share') we added 'trust' and 'distrust' buttons. The rationale was that these reactions would naturally be used to indicate reliability and thus provide a reward structure contingent on accuracy. We then examined if participants (i) would use the trust/distrust options to discern accurate from inaccurate posts; (ii) thus to obtain more 'trusts' and less 'distrusts', they would share more accurate posts; and (iii) the process would increase belief accuracy. **Results:** Subjects used the (dis)trust buttons in a way that discerned accurate from inaccurate posts more so than they used (dis)like buttons ($F(1, 98)=63.77, p<0.001$). As a result, on platforms that included the (dis)trust options, the proportion of shared accurate to inaccurate posts was greater ($t(96)=2.628; p=0.01$). Participants who engaged in a platform that included (dis)trust reactions formed more accurate beliefs at the end of the study relative to the other participants ($t(94)=3.715, p<0.001$). These effects were contingent on genuine interactions with real users, and were reduced significantly when we provided participants with random reactions generated by a computer but believed to be generated by other participants ($t(93)=2.32, p=0.02$). **Conclusions:** We created an incentive structure where rewards are contingent on accuracy by introducing a slight modification to the reaction options. The new structure reduced the spread of misinformation and increased accurate beliefs. An intriguing possibility is that this simple intervention could markedly improve the veracity of information sharing online.

P3-I-117: Older and Wiser? Young Adults and Seniors Respond Differently to Social Context in an Ultimatum Game

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Objective: Prior work has implicated areas within the default mode network (DMN) and executive control network (ECN) in scenarios where economic decision-making is contextualized by social information. One example is in financial negotiations, where a partner's fairness in making offers may influence acceptance decisions. Early evidence suggests that neural and behavioral responses in such scenarios vary in adults as a function of age, with specific noted differences in dorsolateral prefrontal cortex (DLPFC) and anterior cingulate cortex (ACC) activity. In the present study, we replicate and extend these findings by asking if responses also vary based on characteristics of the partner. Here, younger and older adults considered offers from a computer, similar, and dissimilar human partners, and we use novel analyses to detect differences in their responses. **Methods:** 26 young adults (age 18-34) and 24 senior adults (64-80) underwent neuroimaging while playing an ultimatum game, and accepted or rejected a partner's offer to split a financial endowment between them. Participants made decisions on 144 total trials presented in blocks of more-fair and more-unfair offers. Social context via partner type was visually cued at the start of each block and randomized; partners were a) a computer, b) an anonymous young adult, and c) an anonymous senior adult. Imaging analyses were corrected for multiple comparisons across the whole brain using a cluster-forming threshold of $z > 3.1$ and a family-wise error rate of $p < 0.05$. **Results:** Preliminary neural results revealed distinct, yet complimentary, patterns of responses to those previously reported. While prior studies saw age-related activation in the DLPFC specific to unfair offers, we find that older adults had greater activation in DLPFC when receiving fair offers from a human partner. Additional analyses found that older adults showed enhanced connectivity between the ECN and the insula during trials with human partners, and with the DMN and the dACC during fair offers from other older adults. **Conclusions:** Our results complement prior work finding age-related differences in neural responses to economic decision-making within varying social contexts. Seniors showed greater activation in and connectivity to areas previously implicated while considering fair offers made by other humans. These results may relate to recent work suggesting that functional and structural differences in older adults relates to risk for interpersonal financial exploitation (e.g. Spreng et al., 2017). Additional planned analyses include multilevel modeling and single-trial approaches to better illuminate age-related differences in responses.

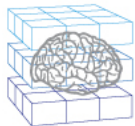
P3-I-118: Constrained representations of numerical magnitudes

Arthur Prat-Carrabin¹, Michael Woodford¹

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Objective: How people perceive numerical magnitudes is an important and far-reaching question in economics and cognitive neuroscience. Both fields have noted the variability in human estimates of numerical magnitudes, when people are asked to estimate the "numerosity" of an array of items, but also in tasks involving Arabic numerals. A prominent hypothesis is that the brain operates under cognitive constraints, resulting in imprecision in its representations of magnitudes. The nature of these constraints, however, remain unclear. Several hypotheses, founded on statistical, neurobiological, or information-theoretic arguments, are proposed in the literature. If the imprecise representations are optimal under the brain's constraints, they should be adapted to the prior distribution of the

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magnitudes they represent, in ways that depend on the nature of the assumed constraint. For instance, range normalization models predict that the variance of numerical estimates should scale with the square of the range of numbers used in an experiment. At the same time, a different tradition would predict that the variance should scale with the square of the number to be estimated, in the spirit of the Weber-Fechner law. Methods: To investigate the imprecision of the brain's representations, we design two tasks: one in which subjects ($N=36$) are asked to estimate the numerosity of clouds of dots presented to them, and one in which subjects ($N=63$) are asked to compare the averages of two series of numbers presented as Arabic numerals. In both tasks the numbers are sampled from uniform prior distributions, and we manipulate across blocks of trials the widths of these priors. Results: In the estimation task, clouds of dots with the same numerosity are perceived with different variabilities depending on the width of the prior. Specifically, the variance of estimates is a linear function of the width of the prior, rather than the square of this width. This implies that subjects are relatively more precise with wider priors. Consistently, in the average-comparison task the subjects perform better with the wide prior. The behavioral data in the two tasks are best captured by the same model, in which the same formula specifies the brain's resource constraint. Conclusions: We find that the brain's representations of numerical magnitudes seem to be adapted to the distribution of these magnitudes. Our findings are consistent across experimental modalities (clouds of dots and Arabic numerals). By showing how the subjects' imprecision varies with the prior width, our results shed light on the nature of cognitive constraints.

P3-I-119: Using Neurocognitive Mediation Analysis to Investigate Spectral Dynamics of Evidence Accumulation Across Domains

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¹The Ohio State University, ²University of Amsterdam

Background: Decisions can be classified along two dimensions: subjective versus objective criteria, and evaluation based on stimulus versus representation. Research using EEG and sequential sampling models (SSM) has provided evidence for different spatial and frequency-specific patterns of activation during choice. Yet no work has studied how EEG markers vary along these two dimensions. In our EEG study, participants made decisions in four tasks, one for each combination of dimensions. Our goals were (1) to investigate which EEG markers mediate the relation between stimulus value and drift rate; (2) to examine whether these EEG markers differentiate between tasks. To do so, we developed a neurocognitive mediation model to jointly capture EEG, choice, and response times. Methods: In the main part of the study, participants chose which of two foods they preferred to eat, which of two food images they preferred, which of two foods took up a greater proportion of the screen, and which of two foods weighed more. Each task used the same images and responses. In the model, drift rates were regressed onto stimulus values and the principal components (PC) extracted from the time-frequency representations of power, which was, in turn, regressed onto the stimulus values. Results: We have pilot data from 10 subjects. Averaged across conditions, stimulus values predicted drift rates $\beta = 8.731$, CI 95% [1.5661;18.0895]. Higher stimulus values also predicted PC's of the EEG signal $\beta = 0.137$, CI 95% [-6.8957; 6.9193] However, the PC's did not predict drift rates, $\beta = 0.0000124$, CI 95% [-0.00020; 0.00022]. In addition, we found evidence for a negligible indirect effect of stimulus value on drift rates that was

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mediated by our PC's $\beta = -0.0000073$, CI 95% [-0.00078; 0.00068]. Conclusions: By jointly modeling neural and behavioral data, we were able to test the assumption that neural activity mediates the relationship between stimulus value and evidence accumulation. However, in our pilot data we found little evidence for frequency-specific activity that mediates the relationship between stimulus value and drift rate. We failed to find evidence in either beta or gamma bands, which prior work has found to reflect drift rate. This research is ongoing.

P3-I-120: Neurocomputational determinants of dietary behavior in obesity

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¹ETHZ, ²University Hospital and University of Bern

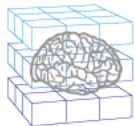
Objective: There is growing evidence that obesity is associated with alterations in dietary decision-making. However, a comprehensive description of these alterations is lacking. These alterations may be linked to the valuation process or to modulations of this process through attention. Attention can lead to modulation of valuation in different ways. A first way is linked to saliency; saliency can attract attention and therefore lead to preferences for salient options. A second way is linked to attentional discounting; the value of options that are not attended to are discounted compared to the attended option. We investigate whether the valuation process or attentional modulation are linked to the alterations of decision making in obesity. We further investigate if the attentional differences are linked to saliency or attentional discounting. **Methods:** We recruited 20 obese patients (mean [SD] age, 43.5 [12.0] years; 14F) and 18 lean controls (mean [SD] age, 40.7 [12.2] years; 10F). The participants rated their willingness to eat different food items during functional MRI scans. Then, they estimated different nutritional attributes of the items (fat, protein, added sugar content and healthiness). Finally, they performed a choice task in which they chose between two food items on each trial while eye-tracking measurements were performed. **Results:** We investigated the computational determinants that could explain the food choices. Subjective attribute estimations explained choices better than objective attributes ($\Delta\text{LOOIC} = -99$). Combining subjective attributes estimations with willingness to eat ratings provided a better description than subjective attributes estimations alone ($\Delta\text{LOOIC} = -455$) and willingness to eat ratings alone ($\Delta\text{LOOIC} = -449$). Adding the relative fixation times improved the model further ($\Delta\text{LOOIC} = -882$) and revealed that obese individuals were more likely to choose the items that they looked at longer (PMCMC = 0.011). We investigated if this effect was linked to saliency or attentional discounting. We found no difference in the effect of saliency between the two groups, however we found differences in attentional discounting (PMCMC = 0.024) indicating that the obese group discounts the value of the item that they do not look at more than lean controls. **Conclusions:** These results indicate that the valuation process is differently modulated by attention for obese and lean participants. In particular, attentional discounting and not saliency modulation is altered in dietary behavior in obesity.

P3-J-121: Momentary happiness depends on state-value prediction errors during learning

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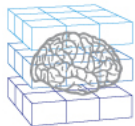
Objective: The function of mood is unclear, but one recent proposal is that mood represents the momentum of rewards in an environment, whether the environment is getting better or worse. In reinforcement learning tasks, momentary happiness is associated with prediction errors that depend on the value of chosen options (Blain & Rutledge, 2020). Environments in the real world usually include multiple states but it is unclear how different states influence momentary happiness. In an environment with multiple states, we tested whether happiness is better explained by prediction errors that depend on the value of chosen options or instead by prediction errors that depend on the value of the current state. **Methods:** In a reinforcement learning task, we tested participants ($n=200$) with a high state-value pair (reward probabilities of 80% and 50%) and a low state-value pair (reward probabilities of 50% and 20%). Pairs were randomly ordered, and feedback was revealed for chosen options. Participants periodically reported momentary happiness. **Results:** A model including state values and state-value prediction errors can explain momentary happiness (mean $r^2=0.42$). We calculated state values as the average of action values of the two options in a pair. Consistent with previous findings, lower baseline mood parameters were associated with greater depressive symptoms ($\rho=-0.27$, $p<0.001$). Parameters for state values ($p<0.001$) and state-value prediction errors ($p<0.001$) captured the dynamic of momentary happiness. As either increases, momentary happiness increases. Additionally, we compared the performance of this model with a model including action values and action-value prediction errors, which is a commonly used model in past studies. A model including state values and state-value prediction errors outperformed a model including action values and action-value prediction errors. **Conclusions:** These results show that in environments with multiple states, happiness is associated with prediction errors that depend not just on the value of the chosen option but also depend on the value of the current state.

P3-L-122: Cost or confidence: why do we avoid making decisions for others?

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Study objective: In our daily life, we often need to make decisions under responsibility for others. There is great variability in how averse individuals are to responsibility, and how well they perform under responsibility. Previous work has suggested that responsibility aversion during ambiguous monetary gambles is related to an increased demand for certainty about the best choice when taking responsibility for others. Here, we aim to further investigate responsibility aversion in simple perceptual choices through the lens of metacognition. To test the underlying mechanisms for responsibility aversion, we generated several hypotheses according to a normative computational framework of metacognition. Specifically, we hypothesized that people who are responsibility-averse when making decisions for others may, 1. have lower confidence in themselves; 2. have higher confidence in others; 3. have a subjectively higher cost/lower benefit for making decisions for others. **Methods:** We developed perceptual experiments in which individuals make decisions affecting themselves or others. In one task phase, participants ($n=49$) have to make the decisions, while in another phase, they can choose whether to take this responsibility or defer to the group majority opinion. We analyzed the choices affecting self and others using a normative computational model of metacognition in control. **Results:** First, we find that responsibility aversion generalizes to basic perceptual choices, i.e., participants are more likely to



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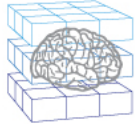
defer to the group majority when making decisions affecting others (t -statistic=2.544, p -value=0.007). In addition, our data suggest that responsibility aversion is best explained by an internal cost of taking responsibility, and not by a change in confidence. This framework can also be used to explain the general frequency of choosing to take responsibility and the accuracy when taking responsibility for others, and how it is affected by metacognitive properties (for example, metacognitive bias).
Conclusions: These results characterize the hitherto unexplained cognitive and computational mechanism for individual differences in decision making under responsibility for others, especially with connections to metacognition.

P3-I-123: Distinct neural dynamics underpin competing subjective experiences of value-based choice

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Objective– Decisions can give rise to an array of competing experiences, like excitement about a fantastic set of options, anxiety about choosing one of them, and confidence in the ultimate choice. We have shown that appraising one's options elicits distinct neural correlates from choosing among them (Frömer et al, 2022, BioRxiv), but the dynamics of the latter and how they relate to anxiety and confidence remain opaque. Here, we combine EEG and a novel choice paradigm to zoom in on the decision process, and distinguish processing of information about an item's motivational salience (here, strength of momentary evidence to choose/avoid) from subsequent integration of that information to inform the pending choice. We hypothesized that more persistent salience signaling throughout a trial would connote greater conflict between one's options and be associated with greater choice anxiety, whereas more consistent updating would connote greater support for one's choice and be associated with greater choice confidence. – **Method**– We recorded EEG from 39 participants choosing from pairs of consumer items. Choice sets varied in relative and overall value of the options based on prior single item ratings. Crucially, options in a choice pair were presented one at a time in alternation, with variable presentation duration, until participants made a choice or 5s had elapsed. This allowed us to control which items could be considered and for how long, and afforded us precise time-logging to the onset of each item presentation. Participants then retroactively rated how anxious they felt making each choice, how confident they were in their decision, and how much they liked the items as a set. We extracted the LPP component (indexing affective salience) to choice-trial onset, and the P3a (indexing motivational salience) and P3b (indexing choice-updating) components related to each stimulus onset within a trial, and tested how each predicted subjective experience ratings. – **Results**– In line with our previous findings, and consistent with its role in task-independent affective evaluations of stimuli, trial-locked LPP predicted set appraisal. Importantly, we found the expected dissociation in item-based neural signatures, whereby P3a amplitude uniquely predicted choice anxiety (consistent with its role in signaling motivational salience) and P3b uniquely predicted choice confidence (consistent with its role in choice updating). – **Conclusion**– Our choices elicit a range of sometimes competing experiences. Here we



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show how these dissociable experiences arise from our brain's distinct computations and in doing so offer a richer understanding of the dynamics underlying our choices.