NINTH INTERNATIONAL SYMPOSIUM ON BIOLOGY OF DECISION MAKING

SBDM 2019

May 27-29

Oxford, United-Kingdom

PARTNERS AND FUNDERS

University of Oxford

Sorbonne Université (SU)
(formerly UPMC)

Ecole Normale Supérieure (ENS)

Okinawa Institute of Science and Technology (OIST)

Université de Bordeaux

Institut du Cerveau et de la Moelle Epinière (ICM)

Team *Motivation, Brain, and Behavior* (MBB)

AI and Brain Science Project

Institut des Maladies Neurodégénératives

Institut des Systèmes Intelligents et de Robotique

CONTENTS

Partners and funders 2

Contents 3

Part 1 – General Information 4

- Introduction 5
- Daily Programs 9
- Venues 12
- Poster schedule 16
- Visiting Oxford 25

Part 2 – Talk abstracts 26

- Monday 27 May 27
- Tuesday 28 May 36
- Wednesday 29 May 41

Part 3 – Poster abstracts 47

- Session 1: Monday 27 May, 12:15 – 14:15 (posters 1-44) 48
- Session 2: Tuesday 28 May, 12:45 – 14:45 (posters 45-86) 98
- Session 3: Wednesday 29 May, 12:15 – 14:15 (posters 87-127) 141

PART 1 – GENERAL INFORMATION

INTRODUCTION

The *Symposium on Biology of Decision-Making* (SBDM) is an international conference annually held in Paris or Bordeaux in France. This is the first time it is organized in Oxford and we hope it will become one of the regular venue of the symposium. The objective of this three-day symposium is to gather people from different research fields with different approaches (psychology, economics, ethology, psychiatry, neural, behavioral, computational and robotics approaches) to decision making.
The conference will include 6 sessions:

1. Neural circuits for decisions about if and when to act (chair: Mark Walton).
2. Social decision-making (chair: Patricia Lockwood)
3. Exploration and information-seeking (chair: Nils Kolling)
4. Optimizing information processing for the decision context (chair: Jill O'Reilly)
5. Mood, emotion and decision-making (chair: Miriam Klein-Flügge)
6. Memory and inference (chair: Andrew Bell)

We are also delighted to welcome 126 poster presenters, distributed over 3 poster sessions to be held on at lunch time. Poster presenters are encouraged to display their poster during the whole day of their session.
The symposium will take place at The Maths Institute, Andrew Wiles Building, in the Radcliffe Observatory Quarter. During all days, lunch as well as warm and soft drinks will be provided. On Tuesday evening, there is a social event at the Cherwell Boat House. During this event, drinks and dinner will be provided.

ORGANIZERS

The **scientific committee** hosting the speakers consists of:

Andrew Bell (University of Oxford, UK)
Thomas Boraud (CNRS / Univ. Bordeaux, France)
Kenji Doya (Okinawa Institute of Science and Technology, Japan)
Mehdi Khamassi (CNRS / Sorbonne Université, Paris, France)
Miriam Klein-Flügge (University of Oxford, UK)
Etienne Koechlin (CNRS / Ecole Normale Supérieure, Paris, France)
Nils Kolling (University of Oxford, UK)
Patricia Lockwood (University of Oxford, UK)
Jill O'Reilly (University of Oxford, UK)
Mathias Pessiglione (INSERM / ICM, Paris, France)
Matthew Rushworth (Univ. Oxford, UK)
Jérôme Sallet (Univ. Oxford, UK)
Chris Summerfield (Univ. Oxford / Google Deepmind, Oxford/London, UK)
Mark Walton (University of Oxford, UK)

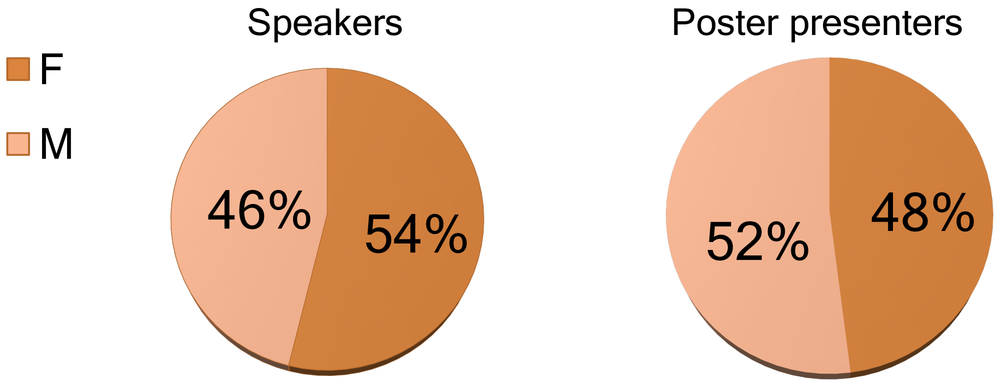
The **local organizers** responsible for the event are:

Dan Bang (University College London, UK)
Alexander Bongioanni (University of Oxford, UK)
Neil Garrett (University of Oxford, UK)
Alizée Lopez-Persem (University of Oxford, UK)
Matthew Rushworth (Univ. Oxford, UK)
Jérôme Sallet (Univ. Oxford, UK)
Hannah Sheahan (University of Oxford, UK)
Chris Summerfield (Univ. Oxford / Google Deepmind, Oxford/London, UK)
Marco Wittman (University of Oxford, UK)

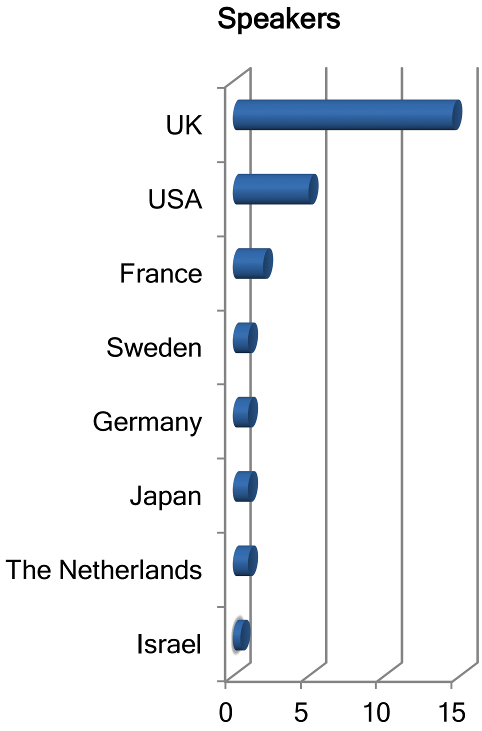
PARTICIPANT STATISTICS

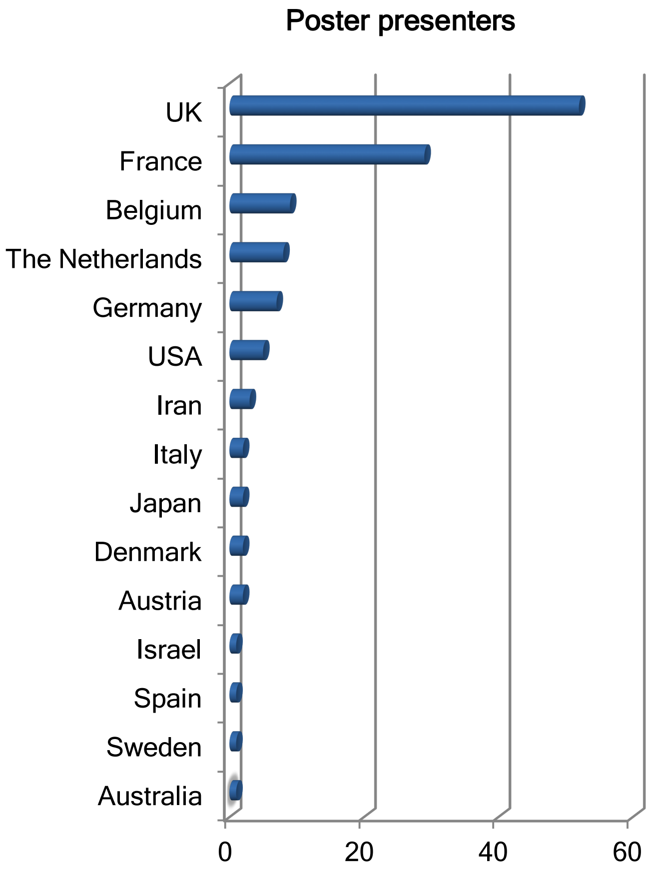
Since we all love data, here are some statistics about SBDM participants:

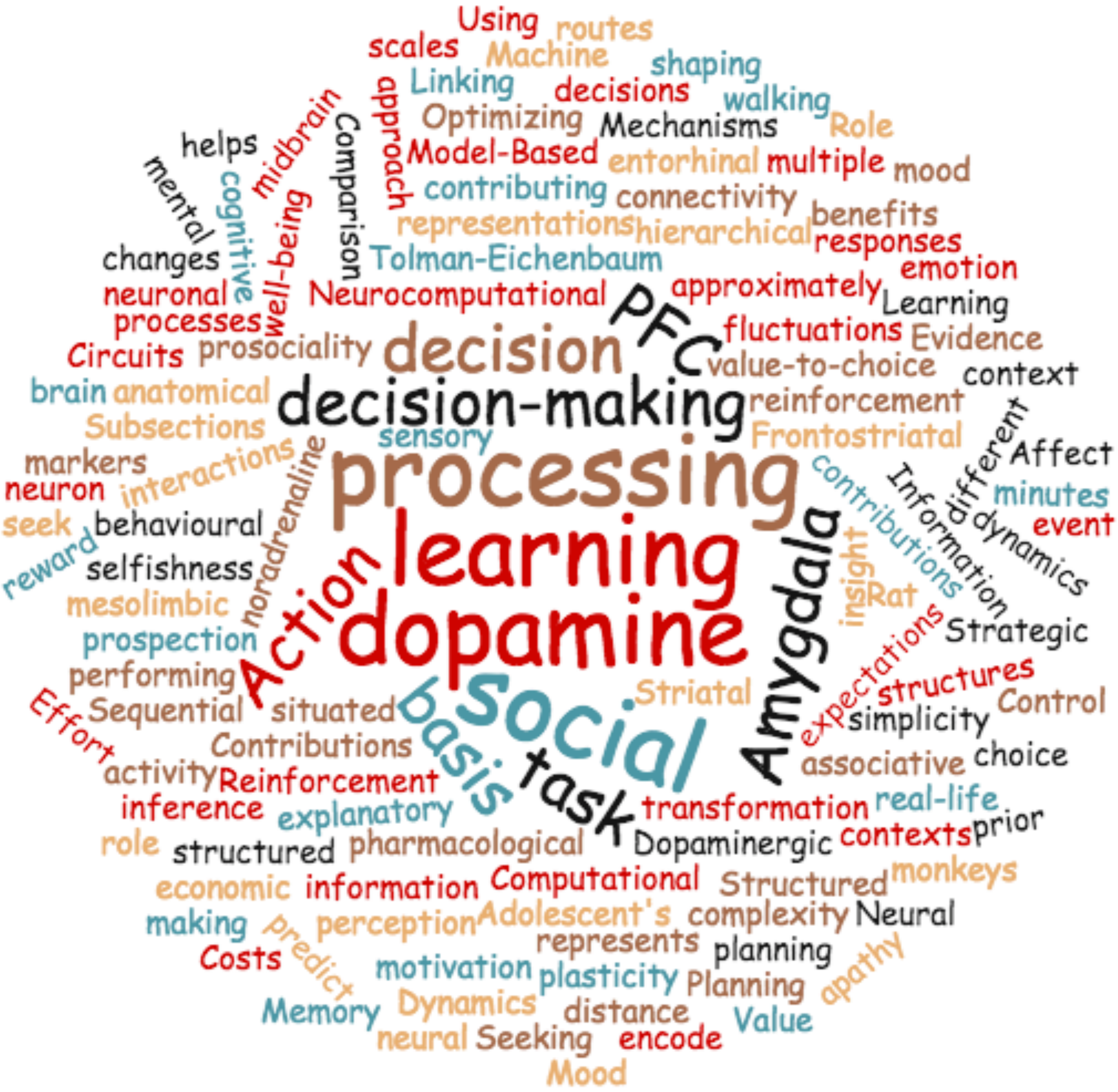
Gender



Countries







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[1] Wordcloud created from www.wordclouds.com, all words of the talk titles were included.

Daily Programs

Monday, 27 May (venue: Maths Institute)

Registration opens at 08:00

Neural circuits for decisions about if and when to act (chair: Mark Walton)

09:00 - 09:30	Laura Grima Action and reward interactions in mesolimbic dopamine
09:35 - 10:05	Masuyuki Matsumoto Dynamics of dopamine neuron activity represents value-to-choice transformation in monkeys performing an economic decision-making task
10:10 - 10:40	Sebastien Bouret Effort processing: what is it that noradrenaline does and dopamine does not do?
10:40 - 11:05	Coffee Break
11:10 - 11:40	Tobias Hauser Dopaminergic midbrain contributions to decision making
11:45 - 12:15	Ilka Diester The Role of PFC Subsections and Frontostriatal Circuits in Action Control
12:15 - 12:45	Emilio Salinas How perception informs urgent saccadic choices: halting, acceleration, and deceleration

Lunch and Poster Session (posters 1-44): 12:45 - 14:45

Social decision-making (chair: Patricia Lockwood)

14:45 - 15:15	Patricia Lockwood Neurocomputational basis of prosociality and selfishness: a reinforcement learning approach
15:20 - 15:55	Michael Platt Monkey Business: Modeling the Neurobiology of Strategic Human Social Interactions
16:00 - 16:30	Ana van Duijvenvoorde Adolescent's learning in social contexts
16:30 - 16:55	Coffee Break
17:00 - 17:30	Andreas Olsson Social learning and decision-making under threat
17:35 - 18:05	Matt Apps Costs, benefits and apathy: Computational, anatomical and pharmacological basis of behavioural and social motivation

TUESDAY, 28 MAY (VENUE: MATHS INSTITUTE)

Exploration and information-seeking (chair: Nils Kolling)

09:35 - 10:05	Tali Sharot Affect and Information Seeking
10:10 - 10:40	Emmanuel Procyk Evidence at multiple scales of neural dynamics contributing to decisions
10:40 - 11:05	Coffee Break
11:10 - 11:40	Alla Karpova Using structured task complexity to seek explanatory simplicity
11:45 - 12:15	Jacquie Scholl Sequential choice, prospection and insight

Lunch and Poster Session (posters 45-86): 12:15 – 14:15

Optimizing information processing for the decision context (chair: Jill O'Reilly)

14:15 - 14:45	Jill O'Reilly Control of uncertainty in internal models
14:50 - 15:20	Marlene Cohen Linking cognitive changes in neuronal responses to perception
15:20 - 15:50	Coffee Break
15:55 - 16:25	Peter Kok The role of prior expectations in sensory processing
16:30 - 17:00	Zoe Kourtzi Strategic brain routes for learning and plasticity

17:30 – 23:30 Social Event at the Cherwell Boat House
The social event is situated at approximately 20 minutes' walking distance from the Maths Institute.

Wednesday, 29 May (venue: Maths Institute)

Mood, emotion and decision-making (chair: Miriam Klein-Flügge)

09:30 - 10:00	Miriam Klein-Flugge Amygdala and PFC encode different associative structures and their connectivity helps predict markers of mental well-being
10:05 - 10:35	Vincent Costa A Comparison of Amygdala and Striatal Contributions to Reinforcement Learning
10:35 - 11:05	Coffee Break
11:10 - 11:40	Eran Eldar Value learning processes shaping real-life mood fluctuations
11:45 - 12:15	Hannah Clarke Cost-benefit decision making - the PFC and emotional dysfunction

Lunch and Poster Session (posters 87-127): 12:15 - 14:15

Memory and inference (chair: Andrew Bell)

14:15 - 14:45	Carlos Brody Neural circuit mechanisms underlying cognition in rats
14:50 - 15:20	Kevin Miller Neural Mechanisms of Model-Based Planning in the Rat
15:20 - 15:50	Coffee Break
15:55 - 16:25	Tim Behrens The Tolman-Eichenbaum Machine
16:30 - 17:00	Kim Stachenfeld Structured entorhinal representations for hierarchical learning and planning

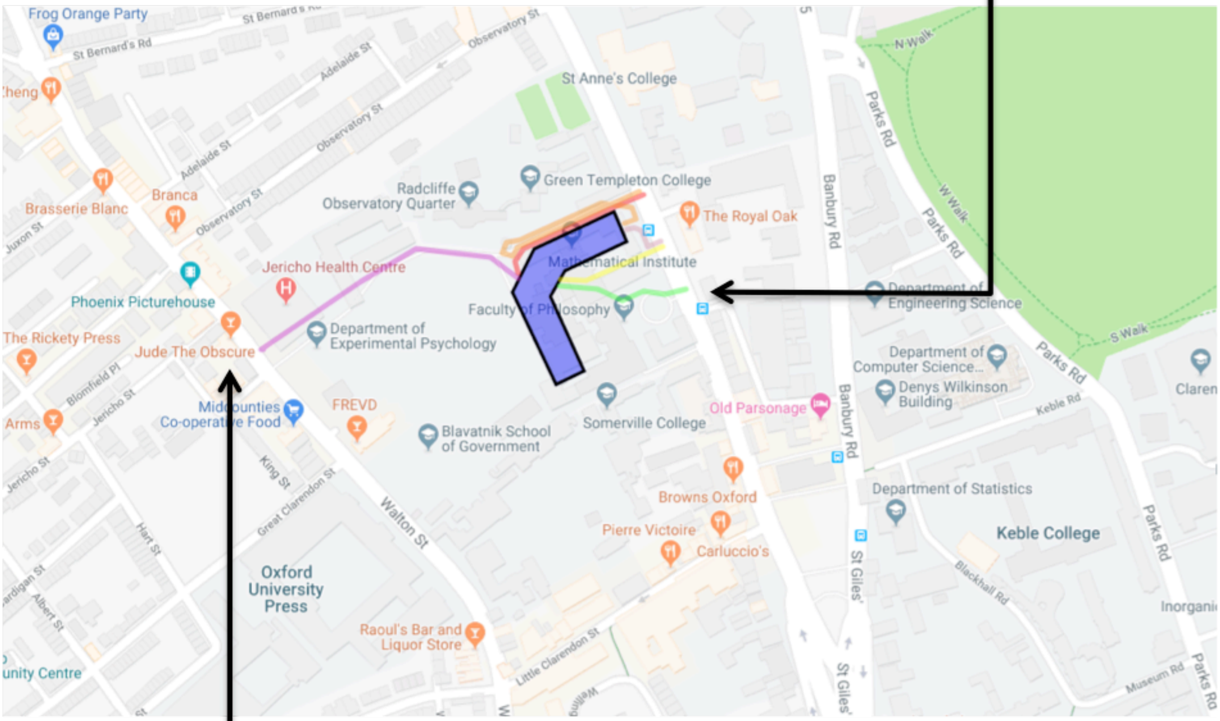
VENUES

THE MATHS INSTITUTE, UNIVERSITY OF OXFORD

SBDM takes place in the Maths Institute, located in Andrew Wiles Builing, in the Radcliffe Observatory Quarter. You can enter this quarter through one of two entries:

- From 7 **Woodstock Road**
- From **48 Walton Street**

7 Woodstock road entry



48 Walton Street entry

THE CHERWELL BOAT HOUSE (SOCIAL EVENT)

On Tuesday evening, a social event takes place at at the Cherwell Boat House.

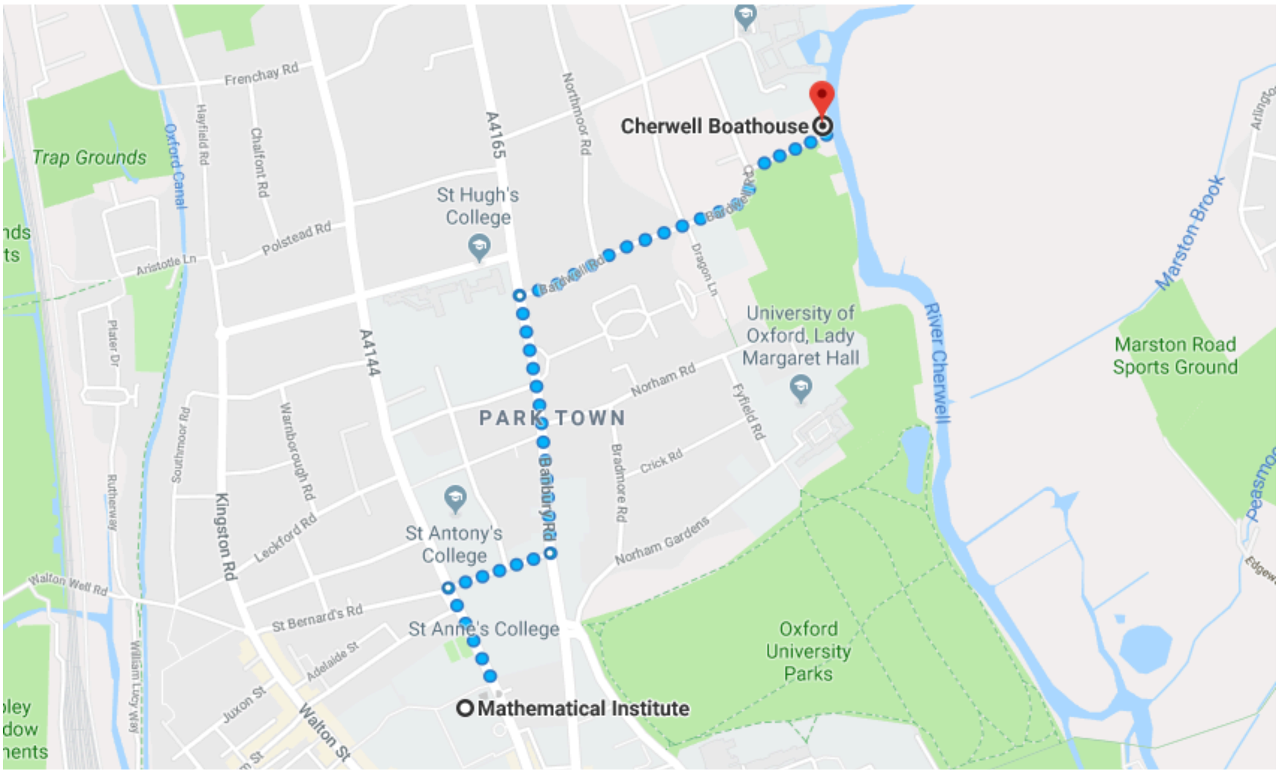
The venue is situated at a 20-minute walking distance from the Maths Institute.

We will start with a **light reception** with Pimm's and canapés.

From 6 to 7pm, enjoy a typical Oxon experience by **punting on the river**. Note that you will be able to sign up to form groups of 5-6 people during the previous afternoon break.

The **barbecue** will start at 8pm. Beyond soft drinks and wine (half a bottle per person) and coffee, people will have right to 1 free drink at the bar. Note that further drinks will be charged.

Music will stop at 11pm and everyone needs to leave before midnight.



ACCESSING INTERNET ON SITE

Wi-Fi is available throughout the building via The Cloud. Eduroam is also available.
If you don't have an eduroam access, here are the steps to connect to the Cloud WifFi:

1. Switch on your smartphone, tablet or laptop and check that WiFi is enabled.
2. Select '_The Cloud' from the available network list.
3. Open your internet browser - the venue landing page will appear. If it does not, type in bbc.co.uk to prompt the browser to load the landing page.
4. If it is your first time using The Cloud WiFi network, follow the simple one-time registration process by sharing some simple details.
5. Once registered you can access the internet via The Cloud.

VENUES ACCESSIBILITY

In the conference building, access to the restrooms and lecture theatres can be completely step-free, and is accessible for those in wheelchairs. However, some of the areas on the step-free access routes require a key-card to access them. If you require step-free access, we would be grateful to be told in advance so that we can brief our facilities team and reception team, and so that we can consider how to make your attendance as easy as possible, such as giving you a temporary access card.

The Cherwell boathouse is completely accessible for those in wheelchairs.

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[2] Wordcloud created from www.wordclouds.com, all words of the poster titles were included.

POSTER SCHEDULE

SESSION 1: POSTERS 1-44 (MONDAY 27 MAY, 12:45 – 14:45)

	Name	Title
1	Manuela Sellitto, Adam Schweda, Bernd Weber, Tobias Kalenscher	The neural mechanisms of the framing effect on social discounting
2	Trevor Chong, Sara McGuigan	Dopamine restores cognitive motivation in Parkinson's disease
3	Bianca Westhoff, L. Molleman, E. Viding, W. van den Bos, A.C.K. van Duijvenvoorde	Learning from social interactions: Development of adaptive social learning across adolescence
4	A.Abdurahman, D. Drew, M.Tamm, M.Husain, M. A. J. Apps, P. L. Lockwood	Computational basis of prosocial motivation in ageing
5	Maaike Van Swieten, Rafal Bogacz	Framework for modelling the effects of motivational state on choice and learning in the basal ganglia
6	Luis Contreras Huerta, Patricia L. Lockwood, Matthew J. Apps, Molly J. Crockett	Affective traits are the key drivers of prosocial choices: a transdiagnostic study
7	A. Gabay, M. J. Kempton, J. Gilleen, M. A. Mehta	MDMA Increases Cooperation and Recruitment of Social Brain Areas When Playing Trustworthy Players in an Iterated Prisoner's Dilemma
8	N Khalighinejad, A Bongioanni, L Verhagen, D Folloni, J Sallet, MFS Rushworth	A basal forebrain-cingulate circuit in macaques decides whether and when to act
9	Irene Cogliati Dezza, X.Noel, A. Cleeremans, A. J. Yu	Impaired reward and information processing in addictive disorders
10	Caroline Quoilin, Philippe de Timary, Julie Duque	Using virtual reality to assess the impact of craving on physiological motor inhibition in alcohol dependence.
11	Samuel Ereira, Tobias Hauser, Ray Dolan, Zeb Kurth-Nelson	Neurocomputational plasticity of Self-Other distinction
12	Marwa El Zein, Bahador Bahrami	Protective role of group majority in costly decisions
13	Daniel Murphy, Catherine Harmer, Michael Browning, Erdem Pulcu*	An interaction between social affective biases and monetary offer amounts in human interpersonal negotiations
14	Fanny Fievez, Ignasi Cos, Gerard Derosiere, Caroline Quoilin, Julien Lambert, Julie Duque	Action Preparation: an integrated Perspective of Choice and Motor Control
15	Pauline Bornert, Sebastien Bouret	Locus coeruleus neurons encode the subjective cost of triggering an action
16	Jules Brochard, Jean Daunizeau	The impact of biological constraints on the detection of cognitive computation
17	J W de Gee, Z Mridha, Y Shi, H Ramsaywak, A Banta, W Zhang, J. McGinley	Neural Circuits and Pupil Readouts of Motivated Shifts in Attentional Effort

18	T.Thiery, A.-L. Saive, E. Combrisson, A.Dehgan, J. Bastin, P. Kahane, A. Berthoz, J.-P.Lachaux, K.Jerbi	Decoding the neural dynamics of Free Choice
19	E. Wilhelm, C. Quoilin, G. Derosière, A. Jeanjean, J. Duque	The role of Dopamine in Preparatory Inhibition: What can we learn from Parkinson’s disease?
20	Jorien van Hoorn, Tycho Dekkers, Neeltje E. Blankenstein, Eveline A Crone, Elke Weber, Arne Popma, Hilde Huizenga, Bernd Figner, Anna C.K. van Duijvenvoorde	Risk Taking, Perceived Risks, and Perceived Benefits in Adolescents with and without ADHD: A Domain-Specific Risk-Return Approach
21	Zoe Jaekel, Stefanie Hardung, Brice de la Crompe, Ilka Diester	Viral Strategies to Target Fronto-Striatal Circuits for the Investigation of Action Control
22	Quentin Feltgen, Christiane Schreiweis, Eric Burguière, Jean Daunizeau	Spending effort to purchase confidence: a cost-benefit arbitrage framework of resource allocation in perceptual decision-making
23	Emmanuelle Bioud, Corentin Tasu, Mathias Pessiglione	No sweat, no sweet? How monetary incentives inflate anticipated effort cost
24	Masakazu Taira, K.W. Miyazaki, K. Miyazaki, K. Doya	The effects of optogenetic serotonergic stimulation on motor actions for future rewards in mice
25	Lei Zhang, Jan P. Gläscher	The causal role of temporoparietal junction in computing social influence in human decision-making
26	Lukas Lengersdorff, Isabella Wagner, and Claus Lamm	Neurocomputational bases of learning to avoid harm to others
27	A.Losecaat Vermeer, R.Ligneul, G. Bellucci, R.Janet, R.Lanzenberger, S. Park, J.-C. Dreher, C. Eisenegger, C.Lamm	Testosterone affects learning of implicit social dominance relationships from competitive interactions
28	R. Janet, A. Losecaat Vermeer, G. Bellucci, S. Park, R. Ligneul, Christoph Eisenegger, JC. Dreher	Relationships between serotonin transporter rate and brain activity associated with learning of social ranks: a simultaneous TEP([11C]-DASB)-fMRI study in humans
29	Marlou Nadine Perqui, Aline Bompas	Temporal structures in reaction time correlate to performance but not to self-assessed attentional state or personality traits
30	Eoin Travers, Patrick Haggard	The Readiness Potential reflects endogenicity, not uncertainty
31	L. Roumazeilles, M. Schurz, L. Verhagen, R. B Mars, J.Sallet	Functional comparison of the social brain in macaques and humans
32	Sara Ershadmanesh, , S. Fleming, D. Bang	Counterfactual learning supports context-dependent social behaviour
33	Charles Findling, Vasilisa Skvortsova, and Valentin Wyart	A role for the noradrenergic system in the precision of reward-guided learning
34	Koen Frolichs, Benjamin J. Kuper-Smith, Jan Gläscher, Gabriela Rosenblau, Christoph Korn*	Employment of conceptual relations for social learning and cooperative decision-making
35	Uri Hertz	Dynamics of Adaptation to Social Norms
36	Raphael Le Bouc, Mathias Pessiglione	Why not reading this abstract tomorrow? A procrastination model based on how the brain discounts effort and reward with time

37	Simon Nougaret, Lorenzo Ferrucci, Richard C. Saunders, Aldo Genovesio	The “social pole”: frontal pole activity of macaque monkeys differently reflects the social and nonsocial agent in an interactive task
38	Gabriele Chierchia, , Blanca Piera Pi-Sunyer, Sarah-Jayne Blakemore	Prosocial influence in decision making is amplified in adolescents relative to adults
39	Aurelien Weiss, Lindsay Rondot, Luc Mallet, Philippe Domenech, Valentin Wyart	Impaired learning from conflicting action outcomes in obsessive-compulsive disorder
40	Gabriela Rosenblau, Christoph W. Korn, Abigail Dutton, Daeyeol Lee, Kevin A. Pelphrey	Social learning relies on distinct cognitive mechanisms in adolescents with and without autism
41	Andrea Pisauro, Fouragnan E.F., Apps M., Philiastides M.G.	The neural trade-off between social cooperation and competition in the Space Dilemma.
42	Romane Cecchi, Philippe Kahane, Nica Anca, Jiri Hammer, Agnès Trebuchon, Jean-Philippe Lachaux, Emmanuel Barbeau, Bruno Rossion, Mathias Pessiglione, Julien Bastin	How pre-choice neural activity influence value-based choices: an intracerebral investigation
43	Rémi Philippe, K Khalvati, R Rao, JC. Dreher	Understanding social decision-making mechanisms using Markov Decision Processes
44	Ili Ma, Bianca Westhoff, Anna C. K. van Duijvenvoorde	Social Uncertainty Tolerance Changes During Adolescence

Session 2: Posters 45-86 (Tuesday 28 May, 12:15 – 14:15)

	Name	Title
45	Eric Schulz, Nicholas T. Franklin, Samuel J. Gershman	Finding structure in multi-armed bandits
46	C. Barre, J.B Masson, C. Vestergaard, F. Laurent	Generative Bayesian modeling for causal inference between neural activity and behavior in Drosophila larva
47	Gerard Derosiere, David Thura, Paul Cisek, Julie Duque	Urgency tunes center-surround inhibition in the motor system during action selection
48	Elodie Levy, Estelle Chavret Reculon, Sebatien Bouret	Neurophysiological correlates of engagement in the task vs option selection in the monkey ventro-medial prefrontal cortex
49	M. Scheuplein, J. Westbrook, M. Rickard,L. Chan, M. P. Noonan	Contingency learning and value-guided decision-making in adolescents
50	Paula Kaanders, Hamed Nili, Laurence Hunt	Linking neural representations for decision-making between monkey and human cortex
51	Rani Moran, Mehdi Keramati, Raymond J. Dolan	Know Thyself! Model Based Planners Reflect on their Model-Free Propensities
52	Marion Rouault, Stephen M. Fleming	A neural basis for the formation of global self-beliefs
53	Tarryn Balsdon, Pascal Mamassian, Valentin Wyart	Dissociable pupillary correlates of decision confidence and decision bound-crossing
54	Julie Drevet, Valentin Wyart	Growing influence of priors on reversal learning across the encoding-decoding information trade-off
55	Iris Koele, Marieke Jepma, Wouter van den Bos, Anna C.K. van Duijvenvoorde	Exploration and development: Sensitivity to exploration costs emerges in adolescence
56	Pierre Petitet, Bahaaeddin Attaallah, Sanjay Manohar, Masud Husain	Active foraging for information in dynamic decision-making is influenced by both apathy and impulsivity
57	Lieke van Lieshout, Iris J. Traast, Floris P. de Lange, Roshan Cools	Role of uncertainty in curiosity about wins versus losses
58	Joshua Calder-Travis, Lucie Charles, Rafal Bogacz, Nick Yeung	Normative decisions and normative confidence: A unified account
59	Nadescha Trudel, Marco K Wittmann, Jacqueline Scholl, Miriam Klein-Flügge, Elsa Fouragnan, Lev Tankelevitch, Matthew FS Rushworth	Polarity of subjective uncertainty in ventromedial prefrontal cortex changes with behavioural adaptation across time
60	Sophie Bavard, Stefano Palminteri	The construction and deconstruction of suboptimal preferences through reinforcement learning
61	Fabien Cerrotti, V. Skvortsova, V. Wyart, S. Palminteri	The experience-description gap in the human brain
62	Clemence Almeras, Valérian Chambon, Valentin Wyart	Opposing cognitive pressures on human exploration in the absence of trade-off with exploitation
63	Annika Boldt, Sam Gilbert	Metacognitive knowledge controls cognitive offloading decisions

64	John Grogan, Timothy R. Sandhu, Joyce M.G. Vromen, Sanjay G. Manohar	Reinforcement learning with different reward identities
65	Antonius Wiehler, Bastien Blain, Francesca Branzoli, Isaac Adanyeguh, Fanny Mochel,Donata Marra, and Mathias Pessiglione	How executive fatigue arises and affects decision making
66	Dimitrie Markovic, Andrea M.F. Reiter, Stefan J. Kiebel	Exploratory choices reveal human sensitivity to the temporal structure of changes
67	Pi Vassiliadis, G Derosiere, C Dubuc, F Crevecoeur, J Duque	Impact of reinforcement on action selection, initiation and execution during motor skill learning
68	Tsvetomira Dumbalska, Hannah Smithson, Christopher Summerfield	Gain control explains the effects of distraction during perceptual decision-making
69	Anna Marzecova, Eva Van den Bussche, Tom Verguts	Phasic pupil dilation tracks expected and unexpected uncertainty during attentional orienting
70	Sara Ershadmanesh, Mostafa Miandari , Abdol-Hossein Vahabi, Majid Nili Ahmadabadi	The Impact of Meta-cognitive Ability on Habitual Learning; The Over Confident Learning Strategy
71	Aline Bompas, Marlou Nadine Perquin	Correlating mind wandering and behavioural variability to preceeding oscillatory power - a MEG study
72	Laura Viñales, Delphine Autran-Clavagnier, Emmanuel Procyk	Neural dynamics in human frontal cortex during performance monitoring and decisions to check
73	Fabrice Luyckx, Clemens Teupe, Christopher Summerfield	Representing numbers in a sequential numerical comparison task
74	Vasilisa Skvortsova, Charles Findling, Rémi Dromnelle, Stefano Palminteri, Valentin Wyart	Bounded adaptability of reward-guided learning to the correlation structure of volatile environments
75	Robert Hardwick, Alexander D Forrence, John W Krakauer, Adrian M Haith	Time-dependent Competition Between Goal-directed and Habitual Response Selection
76	Tom Marshall, Maria Ruesseler, Laurence Hunt, Jill O’Reilly	Stable and Competitive Dynamics in Attention Allocation
77	Pete Trimmer, John M McNamara, Sean M Ehlman, Andrew Sih	Sequential Signal Detection Theory: Reversing Old Beliefs
78	Elise Lesage, Robert M. Hardwick, Tom Verguts	Inducing habit formation in humans through extended overtraining
79	Patricia Romero Verdugo, Lieke L. F. van Lieshout, Floris P. de Lange, Roshan Cools	Choice increases curiosity in a lottery task
80	Queirazza F., Andrea Pisauro*, Philiastides MG	The role of confidence during perceptual learning with and without feedback
81	Hrvoje Stojic, Jacob L. Orquin, Peter Dayan, Raymond Dolan, Maarten Speekenbrink	Rewards and uncertainty jointly drive the attention dynamics in reinforcement learning
82	Alexandre Hyafil, Travis Stewart, Vincent Adam	Generalized Nonlinear Models, a flexible and interpretable tool for behavioral and neural analysis

83	Nadege Bault, Stefano Palminteri, Virginia Aglieri, Giorgio Coricelli	Reduced value contextualization impairs punishment avoidance learning during aging
84	Pantelis Pipergias Analytis, Charley M. Wu, Alexandros Gelastopoulos	Make-or-break: chasing risky goals or settling for safe reward
85	Wojciech Zajkowski, Dominik Krzeminski, Jiaxiang Zhang	Slope between N100 and P300 ERP components predicts trial-by-trial accumulation drift-rate in certainty-based choice task
86	Naomi Carlebac, Nick Yeung	Learning about advice: Confidence guides information sampling flexibly

SESSION 3: POSTERS 87-127 (WEDNESDAY 29 MAY, 12:15-14:15)

	Name	Title
87	Tanja Müller, Campbell Le Heron, Miriam C. Klein-Flügge, Masud Husain, Matthew A. J. Apps	Tired of working: Neurocomputational mechanisms of moment-to-moment fatigue and its effect on effort-based decisions
88	Douglas Lee, Jean Daunizeau	Motivational Control during Multi-Option Decision Making
89	Max Rollwage, T. U. Hauser, A. Loosen ,R. Moran, R. J. Dolan, S. M. Fleming	The influence of confidence on post-decision evidence processing
90	Aiqing Ling, Stijn Massar, Michael Chee, Hilke Plassmann	Disruption of Affect Integration on Aesthetic Evaluation Following Sleep Deprivation
91	Nicolas Clairis, Mathias Pessiglione	Neural correlates of deliberation across rating, choice and learning tasks
92	Iris Duif,Joost B. Wegman, Cees de Graaf,Paul A. Smeets, Esther Aarts	Distraction-induced rIFG decreases relate to reduced goal-directed effort for food reward after satiation
93	Florent Meyniel	Brain dynamics for adaptive learning
94	Damiano Azzalini, Palminteri Stefano, Tallon-Baudry Catherine	Neural encoding of subjective values for cultural goods depends on cardiac monitoring in vmPFC
95	Maria Maio, Robert Udale, Sean James Fallon, Younes A. Tabi, Sanjay Manohar, Masud Husain	A decision model for information retrieval from visual working-memory
96	Anita Keshmirian, Bahador Bahrami, Ophelia Deroy, Fiery Cushman	Do people punish you less when you belong to a group? The role of intention and outcome in third-party punishment for collective harm
97	Shirley Mark, , Thomas Parr, Steve Kennerley, Tim Behrens	A mechanistic account of transferring structural knowledge across cognitive maps
98	Alessandro Bongioanni, Miriam Klein-Flügge, Davide Folloni, Lennart Verhagen, Jérôme Sallet, Matthew Rushworth	Novel choices in macaques: activation and disruption of a neural mechanism for value integration
99	Thomas Thiery, Pierre Rainville, Paul Cisek, Karim Jerbi	The neural dynamics of decisions in changing conditions in humans: A MEG study
100	Moritz Moeller, Jan Grohn, Sanjay Manohar, Rafal Bogacz	Differences in reward variability induce value-depended biases in a learning task
101	Felix Klaassen, Leslie Held, Bernd Figner, Floris Klumpers, & Karin Roelofs	The relationship between freezing and passive vs. active approach/avoid decisions under acute threat
102	Maria Ruesseler, Tom Marshall, Jill O'Reilly, Laurence Hunt	Towards single-subject neural markers of decision formation at clinically relevant timescales

103	Joshua Bolam, R. Ince, S. Boyle, I. Delis	A Neurally-Informed Modelling Approach for Investigating Cross-Modal Associations in Perceptual Decision-Making
104	Giuseppe Castegnetti, Mariana Zurita, Benedetto De Martino	The geometry of flexible goal-dependent representations for value-based choice
105	R. H. Martinez, E. Warnberg	A neural circuit for graph-search in internal world models
106	David Folloni, Elsa Fouragnan, Marco Wittman, Lea Roumazeilles, Lev Tankelevitch, Lennart Verhagen, JérômeSallet, Matthew F.S. Rushworth	Causal role of the lateral orbitofrontal cortex in credit assignment
107	P. Domenech, M. Laquitaine*, D. Benis, M. Polosan, S. Chabardès, J. Bastin	Task switching increases beta and theta osciillations in the human subthalmic nucleus
108	Joao Peixoto, Michele Veldsman, Henrique Fernandes, Campbell Le Heron, Morten Kringelbach, Masud Husain	Static and dynamic brain functional connectivity changes associated with effort-based decision-making in clinical apathy
109	Alex Pike, Vincent Valton, Oliver J. Robinson	A simulation meta-analysis of the role of reinforcement-learning in mood and anxiety disorders
110	Veronika Samborska, Thomas Akam, James L. Butler,Mark E. Walton, Timothy E. Behrens	Generalisation of structural knowledge in hippocampal - prefrontal circuits
111	Thomas Ringstrom, Paul R. Schrater	An architectural theory for efficient planning
112	Alexandra Vlassova, Roshan Cools, Floris de Lange	The effect of risk and ambiguity on curiosity
113	Hannah Sheahan, Christopher Summerfield	One-shot generalisation of learned hierarchical reward structure
114	Leonie Glitz*, Neil Garrett, Keno Jüchems, Christopher Summerfield	Computational mechanisms of structure learning: how humans update relational knowledge
115	Hossein Rafipoor, AbdolHossein Vahabie, Babak Nadjar Araabi, Alireza Soltani	From Meta-Plasticity to Meta-Learning
116	Rachel Newey, Richard Ramsey, Kami Koldewyn	The influence of varied gaze-cue validity on social perception
117	Ron Dekker, Christopher Summerfield	Curriculum learning for human categorisation of naturalistic stimuli
118	Chen Hu, Mathias Pessiglione	Order matters: how the sequence of information disclosure affects multi-attribute choice
119	Elena Zamfir, P. Dayan	The dynamical interaction between attribution and belief: Evidence from a novel task
120	Hrvoje Stojic, Eric Schulz, Pantelis P. Analytis*, Maarten Speekenbrink	It's new, but is it good? How generalization and uncertainty guide the exploration of novel options
121	Ariel Zylberberg, Akram Bakkour, Michael N. Shadlen, Daphna Shohamy	Sequential dependencies in value-based decisions

122	Roeland Heerema, Jean Daunizeau, Mathias Pessiglione	How emotional states incidentally affect economic decisions
123	Sijia Zhao, Fred Dick, Peter Dayan, Shigeto Furukawa, Hsin-I Liao, Maria Chait	Phasic norepinephrine is a neural interrupt signal for unexpected events in rapidly unfolding sensory sequences – evidence from pupillometry
124	Marco Wittmann, Elsa Fouragnan, Davide Folloni, Bolton Chau, Mehdi Khamassi, Matthew F S Rushworth	Multiple memory traces of choice and reward in macaque frontal cortex
125	Bianca Sieveritz, Marianela Garcia-Munoz and Gordon W. Arbuthnott	Ventral motor thalamic input to prelimbic cortex is involved in cost-benefit decision-making
126	Karsten Olsen, Andreas Roepstorff, Dan Bang	Knowing whom to learn from: Individual differences in metacognition and weighting of social information
127	Youssuf Saleh, Campbell Le Heron, Michele Veldsman, Sanjay Manohar, Masud Husain	Mechanisms underlying apathy in neurological disorders: A multimodal investigation
128	Bastien Blain, Robb Rutledge	Interaction between mood and adaptive learning and choice under uncertainty

VISITING OXFORD

Oxford is a beautiful city of stunning architecture, history and culture. You'll find ancient and modern colleges, fascinating museums and galleries, and plenty of parks, gardens and green spaces in which to relax. Plus, the city centre is small enough to cover on foot, and only a few minutes walk from the main rail and coach stations.

PUBLIC TRANSPORT

For detailed information about your journey to and from the airport, see this page on the SBDM website.

You can move around in Oxford using buses, self-serive bikes (Oxonbike, Ofo, Mobike), or on foot. To plan your trip, simply use Google Maps or the official public transportation website.

SIGHTSEEING

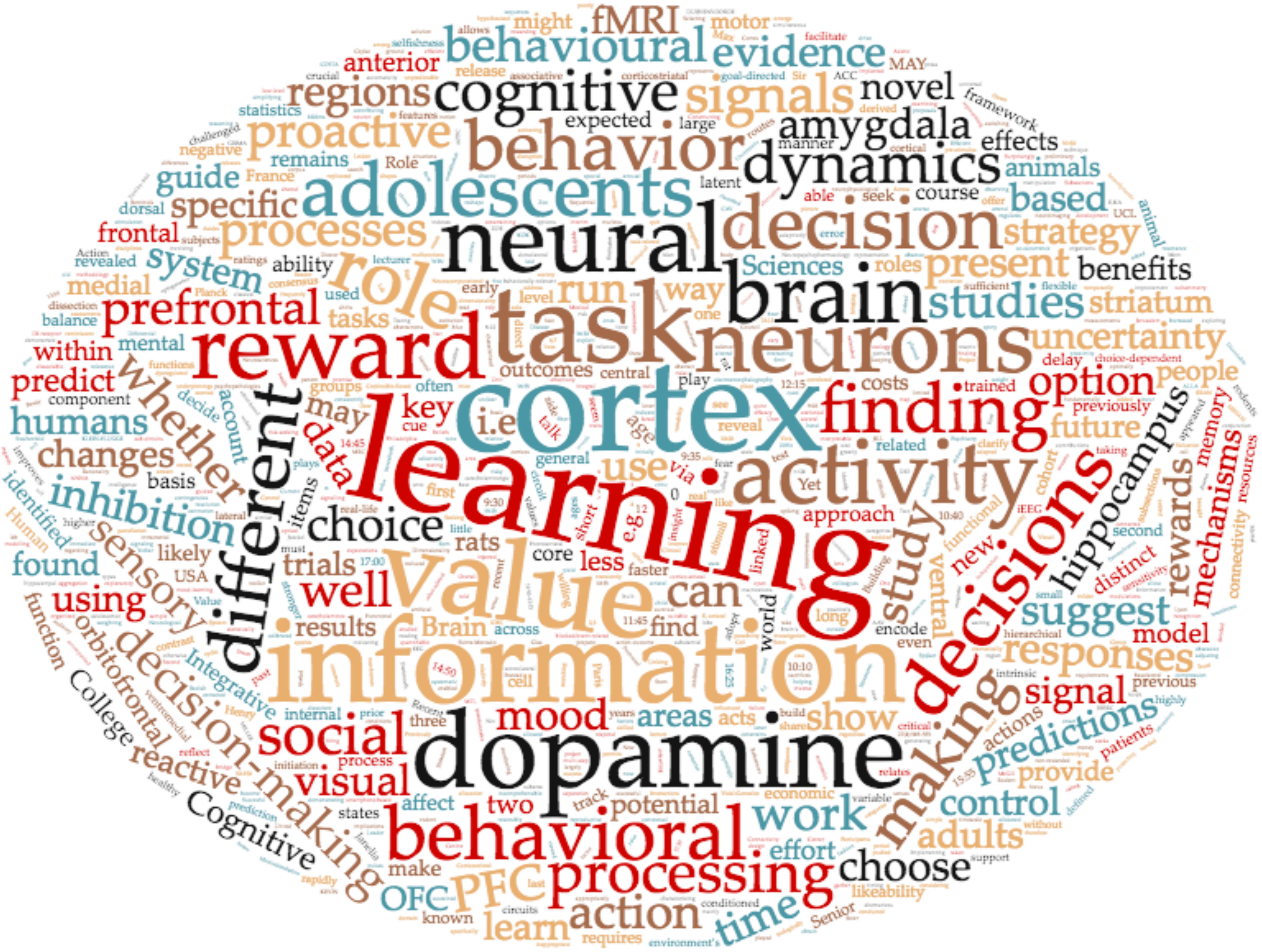
There's a broad range of things to do in Oxford. They include discovering the history and heritage of a city that is home to 1,500 listed buildings from every major period of British architectural history from the 11th century onwards. The centre looks like an enchanted fairytale city - no wonder Oxford is a firm favourite of filmmakers from all over the world and has inspired countless famous writers over the centuries.

Oxford is flat and compact, with many of its major attractions, such as the University of Oxford and its 38 colleges; Bodleian Library, the museums, and Oxford Castle & Prison right in the centre - perfect to explore on foot. If you are interested in learning more about Oxford, the Oxford Preservation Trust hosts a range of events throughout the year from visits, to talks and walks getting behind closed doors to explore Oxford's rich heritage. Also, climb the 99 steps of Carfax Tower to experience a bird's eye view of Oxford's "dreaming spires."

Just a little out of the centre, you can find large green spaces like Christ Church Meadows (with excellent views of Oxford's spires), University Parks, the riverbanks and Port Meadow.

Oxford is a favourite filming location for many famous TV shows, such as Inspector Morse and movies filmed in the city. You can also retrace the steps of Harry Potter in Oxford if you are a fan. See the Tudor dining hall at Christ Church that inspired the Hogwarts Great Hall, as well as the staircase that was used several times during the films. Even though neither of the Alice in Wonderland films were ever made in Oxfordshire, Oxford was where author Lewis Carol met little Alice and where the whole story began!

PART 2 – TALK ABSTRACTS



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[3] Wordcloud created from www.wordclouds.com, all words of the “Talk abstracts” section were included. Post-hoc removals of the following words due to an over-representation: University, also, Professor, Centre, Research, May.

MONDAY 27 MAY

LAURA GRIMA (9:00 – 9:30)

Post-doctoral researcher, Department of Experimental Psychology and Wellcome Trust Centre for Integrative Neuroimaging (WIN), University of Oxford

Action and reward interactions in mesolimbic dopamine

There is broad consensus that the activity of midbrain dopaminergic neurons and downstream dopamine release in the nucleus accumbens (NAc core) correlate with a reward prediction error. Yet there is also evidence that mesolimbic dopamine release and the activation of dopaminergic receptors on ventral striatal medium spiny neurons may play a causal role in the initiation of goal-directed action. To understand how action and reward interacts in the mesolimbic dopamine system, I have used fast-scan cyclic voltammetry and targeted pharmacological manipulations in conjunction with a novel behavioural task that varies both action requirements and reward size on offer. I will discuss findings that demonstrate a role for action initiation in canonical prediction error signalling, as well as the importance of dopamine D1-receptor activation in the NAc core for in cue-driven action.

MASUYUKI MATSUMOTO (9:35 – 10:05)

Lab. Cognitive and Behavioral Neuroscience, Faculty of Medicine, University of Tsukuba, Japan

Dynamics of dopamine neuron activity represents value-to-choice transformation in monkeys performing an economic decision-making task

In economic decision-making, individuals decide to choose or not to choose an option based on its value. To identify the neural mechanism underlying this behavior, it is critical to understand how the brain transforms value information into a choice command. Although previous studies have focused on the roles of prefrontal regions (e.g., the orbitofrontal cortex, OFC) in the value-to-choice transformation, the global picture of the neural mechanism underlying the transformation remains unclear. In the present study, we investigated whether and how midbrain dopamine neurons, a subcortical center for reward processing, contribute to value-to-choice transformation. We designed an economic decision-making task in which monkeys needed to decide to choose or not to choose an option based on its value immediately after the option was offered, and recorded single-unit activities from dopamine neurons as well as OFC neurons, for comparison, in the animal performing the task. We found that dopamine neurons represented diverse signals related not only to the option's value but also to the animal's choice behavior; some dopamine neurons represented the value of the offered option, some represented whether the animal would choose or not choose the option, and some represented the combination of the value and choice behavior, i.e., these neurons represented the value only when the monkey decided to choose the option (we henceforth call this signal "choice-dependent value"). We next analyzed the time course of these dopamine signals, and found that these signals were observed at different timing. Shortly after the onset of the option, the value signal rapidly appeared, followed by the choice-dependent signal. The choice signal arose at last. This time course of the three signals is well consistent with the time course of value-to-choice transformation, and we also observed the same time course in the OFC. Notably, the last choice signal appeared before the monkey executed a motor action to choose the option in both dopamine neurons and the OFC. Our findings show that dopamine neurons and OFC neurons share the same signal dynamics corresponding to the value-to-choice transformation, and provide evidence suggesting that not only prefrontal regions but also the subcortical dopamine system regulates the value-based choice formation.

SÉBASTIEN BOURET (10:10 – 10:40)

Researcher, Brain and Spine Institute, CNRS, Paris, France

Effort processing: what is it that noradrenaline does and dopamine does not do?

The balance between potential costs and benefits is crucial for decision making, and catecholamines are essential for adjusting that balance appropriately. There is a general consensus regarding the role of dopamine in incentive processing, i.e. in mediating the positive influence of upcoming rewards (potential benefits) on behavior. By contrast, its implication in effort, i.e. how potential energetic costs affect behavior, remains debated. Based on a series of neurophysiological and pharmacological data in monkeys, I will show that noradrenaline plays a stronger role than dopamine in effort, when it can be dissociated from reward or force production. Altogether, this should clarify the relative contribution of the two catecholaminergic systems in regulating how and when to act as a function of potential effort costs and reward benefits.

TOBIAS HAUSER (11:10 – 11:40)

Sir Henry Dale Wellcome Fellow, University College London, London, UK

Dopaminergic midbrain contributions to decision making

The dopamine-rich midbrain structures, encompassing substantia nigra and ventral tegmental area (SN/VTA), are known to be critical in simple reward-related learning. However, what is the SN/VTAs role when humans face complex decision making and learning challenges? In my talk, I will present two studies investigating the role of SN/VTA. In the first, we explored the role of SN/VTA in the context of simultaneous learning about multiple choice attributes (reward, effort) and show a functional dissociations of mesolimbic and mesocortical pathways. In the second study, we investigate the role of endogenous SN/VTA fluctuations and show that they directly impact risky decision making. My talk will show that the dopamine-rich midbrain is critical for complex learning and its activity directly affects human behaviour.

ILKA DIESTER (11:45-12:15)

Professor, Optophysiology Lab, University of Freiburg, Freiburg, Germany

The Role of PFC Subsections and Frontostriatal Circuits in Action Control

Selecting appropriate actions while inhibiting inappropriate ones is crucial to successful interaction with the environment. The inhibition of action can be classified into proactive (i.e. based on a subject's internal processes) and reactive (i.e. based on an external cue) components. Previously, we have identified the PFC as a critical structure in action control, with the subsections prelimbic (PL) and infralimbic (IL) cortex as well as ventrolateral orbitofrontal cortex (VO) exerting different effects on proactive and reactive motor control [1]. In this study, rats had been involved in a response preparation task in which they were required to press a lever and release it after a short (300ms) or long (1000ms) delay period cued by an auditory signal. While PL supported correctly timed responses in the long delay condition, IL pushed towards early releases, confirming the previously suggested opposing roles of these two subsections [2,3]. VO, on the other hand, was mainly involved in reactive responses in the short delay condition.

We now asked whether excitation of a subarea of the PFC will result in an opposing effect to the inhibition. For this we trained a new cohort of animals (n=3), injected a ChR2 carrying viral vector and implanted an optical fiber into PL. Surprisingly (given the artificial nature of the stimulation (2 ms light pulses, 20Hz)), blue light showed opposing effects to the inhibition of PL populations, i.e., an improvement of the waiting ability.

Asides from interconnectivity within PFC subregions [4,5], the PFC is also densely connected with subcortical structures [6,7] such as the striatum, which is also hypothesized to play a role in motor inhibition [8]. In addition to reversibly silencing or activating defined areas in awake behaving animals, optogenetics also allows the targeting of cells in a projection specific manner. We employed this latter approach and tested the efficacy of the combination of a Cre/double-floxed inverse open reading frame (DIO) system with retroAAV-Cre (adeno associated virus - AAV) and CAV-Cre (Canine Adeno virus - CAV) for targeting cell populations of the PFC which project to the striatum during a behavioral task (see poster by Zoe Jaeckel).

When applying the projection specific targeting to a trained cohort of rats, we found similar effects of inhibition of PL- and IL-striatal projecting populations (PL to striatum n = 6; IL to striatum n = 3) on performance in the behavioral paradigm as for the direct inhibition of PL and IL populations. This suggests that the previously identified roles of PL and IL in proactive inhibition dependent on these fronto-striatal projections. These findings support a role of the fronto-striatal circuit for proactive motor inhibition.

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[2] Sierra-Mercado D, Padilla-Coreano N, Quirk GJ (2011) Dissociable roles of prelimbic and infralimbic cortices, ventral hippocampus, and basolateral amygdala in the expression and extinction of conditioned fear. Neuropsychopharmacology 36:529-538.
[3] Vidal-Gonzalez I (2006) Microstimulation reveals opposing influences of prelimbic and infralimbic cortex on the expression of conditioned fear. Learn Mem 13:728-733.
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[7] Riga, D., Matos, M. R., Glas, A., Smit, A. B., Spijker, S., Oever, V. d., and C, M. (2014). Optogenetic dissection of medial prefrontal cortex circuitry. Frontiers in Systems Neuroscience, 8.
PLOS ONE, 5(11).

EMILIO SALINAS (12:15 – 12:45)

Associate Professor, Department of Neurobiology and Anatomy, Wake Forest School of Medicine, Winston-Salem, USA

How perception informs urgent saccadic choices: halting, acceleration, and deceleration

The choice of where to look next is guided by current perceptual information as well as internal factors such as motivation, current goals, prior experience, etc. I will discuss the development and testing of a mechanistic framework that describes how perceptual and motor-planning processes dynamically interact and give rise to saccadic choices. In traditional studies of choice behavior, a decision based on sensory information is made first and is then followed by a motor report. Choices conceived in such a serial fashion progress slowly (hundreds of ms) --- but under natural viewing conditions the median time between gaze fixations is short (200--250 ms), and the next saccade is always being planned. Our approach is to manipulate time pressure to reveal how perception and attention guide saccadic choices under more temporally realistic conditions, i.e., when the perceptual evaluation occurs rapidly (< 50 ms) and informs oculomotor plans that are already ongoing. By combining behavioral, neurophysiological, and theoretical work, we have developed a modeling framework that (1) is applicable to a wide range of urgent-choice tasks, (2) replicates rich psychophysical data in great detail, and (3) is firmly consistent with activity recorded in the frontal eye field (FEF). In this framework, perception influences ongoing target selection by halting, accelerating, or decelerating developing motor activity. These three forms of dynamical interaction explain in quantitative detail the rapid temporal variations in psychometric performance observed in our urgent tasks; for example, how exogenous (saliency-driven) and endogenous (rule-driven) influences compete when the goal is to look away from a salient stimulus.

PATRICIA LOCKWOOD (14:45 – 15:15)

MRC Fellow and Junior Research Fellow, University of Oxford, UK

Neurocomputational basis of prosociality and selfishness: a reinforcement learning approach

The question of whether humans are fundamentally selfish or prosocial has intrigued many disciplines from philosophy to economics for centuries. From small acts of kindness to major sacrifices, just how willing are humans to help others? Here I will use models derived from reinforcement learning to understand 'prosocial learning' namely, how people are able to learn which of their actions help others. I will then discuss how basic associative learning processes might also underlie our tendency to be biased towards self rather than other-related information. Neurally I will show how distinct portions of medial prefrontal cortex reflect social computations related to selfishness and prosociality, whereas classical areas implicated in reinforcement learning such as ventral striatum track domain general learning signals regardless of the social context. These findings could have important implications for understanding everyday social learning and decision-making and its disruption in disorders of social behaviour.

MICHAEL PLATT (15:20 – 15:50)

James S. Riepe University Professor, Departments of Neuroscience, Psychology, and Marketing, University of Pennsylvania

Monkey Business: Modeling the Neurobiology of Strategic Human Social Interactions

Social factors both complicate and enable our economic behavior. Despite its importance, our understanding of the fundamental neural mechanisms mediating strategic social interaction remains incomplete, due in part to the difficulty of modeling these behaviors in animal models. In this talk I will discuss our recent work modeling complex strategic social interactions in monkeys. Both monkeys and humans played two different games–one based on the classic economic game “chicken” and a second based on penalty kicks in soccer–while we monitored behavior, tracked gaze, and measured pupil size. In monkeys, we recorded neuronal activity in two brain areas, the temporo-parietal junction (TPJ) and anterior cingulate gyrus (ACCg) which have been implicated in theory of mind and empathy, respectively. Despite the multidimensional nature of both games, humans and monkeys played in a remarkably similar fashion, and their patterns of gaze and pupillary responses–a measure of arousal and attention–were virtually indistinguishable. These data suggest similar underlying mechanisms mediate these strategic social interactions in both species. We found that neurons in the putative primate homolog of TPJ signaled information about social context, goals and intentions, reward outcomes for self and other, strategy, and predictions about whether the other player would cooperate based on prior interactions. By contrast, neurons in ACCg only signaled information about payoffs for self and other. Together, these findings indicate neurons in TPJ multiplex information underlying complex strategic social interactions. The presence of these neurons in monkeys belies the notion that these processes that are so fundamental to human behavior and economics are uniquely human.

ANNA VAN DUIJVENVOORDE (15:55 – 16:25)

Assistant Professor, Developmental and Educational Psychology, Institute of Psychology, Leiden University, Netherlands

Adolescent's learning in social contexts

Everyday behavior is strongly shaped by the example of others, but this impact may vary across age. For instance, adolescence is a period of pronounced change in social- and affective sensitivity, which may result in greater risk taking, social influenceability, but possibly also alter learning processes. Here, I will discuss a set of studies testing the developmental changes in adolescent learning in various social contexts including learning from, for, and about others. By combining behavioral, computational, and neural measures this work aims to facilitate a more mechanistic understanding on how social learning changes from childhood to adulthood.

ANDREAS OLSSON (17:00 – 17:30)

Senior lecturer, Division of Psychology, Department of Clinical Neuroscience, Karolinska Institute, Stockholm, Sweden

Social learning and decision-making under threat

In rapidly changing environments, humans and other animals often glean information about the value of objects and behaviors through social learning. In contrast to learning from direct, personal, experiences, little is known about the mechanisms underlying social transmission of information, and how such learning affects decision-making. Here, I will discuss research using behavioral and brain imaging techniques examining social threat learning and its transfer to decision-making. Consistent with research across species, our results show that social and direct learning draw on partially overlapping mechanisms. In addition, social learning depends on processing of social information that biases the outcome in predictable ways. The study of the impact of social learning on decision-making is fundamental to our understanding of the spread of both adaptive and non-adaptive emotional information between individuals, in real life, as well as in virtual networks.

MATTHEW APPS (17:35 – 18:05)

BBSRC Fellow, University Research Lecturer, Department of Experimental Psychology, Wellcome Centre for Integrative Neuroimaging, University of Oxford, UK

Costs, benefits and apathy: Computational, anatomical and pharmacological basis of behavioural and social motivation

Apathy - a quantifiable reduction in goal-directed behaviour - is one of the most common symptoms in Neurology, particularly in Parkinson's Disease (PD), coming at a major cost to society, patients and carers. Apathy is also present in a milder form in the healthy population and is comprised of three independent dimensions: behavioural, social and emotional. Previous work has suggested that behavioural apathy is associated with both a reduced sensitivity to rewards (e.g. money) and a heightened sensitivity to effort, with more apathetic people less willing to incur costs to obtain themselves benefits - functions linked to the brain's dopaminergic systems. However, the mechanisms underlying the different dimensions of apathy are poorly understood.

Is social apathy linked to the effort required for social acts? Is behavioural apathy linked to dopaminergic dysfunction? Here, using foraging and effort-based decision-making tasks, brain imaging, pharmacological manipulations and testing in PD patients, I will provide some answers to these questions. In doing so, I will put forward an account of the neural and computational basis of the different dimensions of motivation.

TUESDAY 28 MAY

TALI SHAROT (9:35 – 10:05)

Professor of Cognitive Neuroscience, Department of Experimental Psychology, University College, London, UK

Affect and Information Seeking

The ability to use information to adaptively guide behavior is central to intelligence. In this talk I will present our recent research characterizing the influence of affect on how humans gather, and use, information to make predictions. First, I will present a framework for understanding how people decide whether to seek information. One key component is whether the information is likely to produce a positive or negative affective response. This influence of valence on information-seeking is captured by brain regions along the dopamine reward pathway. The findings yield predictions about information-seeking behavior in disorders in which the dopamine system malfunctions. We have begun to test these predictions, aiming to use measures of information-seeking to facilitate early detection, monitoring and treatment selection for psychopathology. Second, I will show that learning in response to positive and negative information involves distinct mechanisms. This segregation of function allows for flexibility in how positive and negative information influence beliefs and actions in different environments, for instance as a function of the level of threat.

EMMANUEL PROCYK (10:10 – 10:40)

Professor at the Stem Cell and Brain Research Institute, INSERM, Lyon, France

Evidence at multiple scales of neural dynamics contributing to decisions

Decisions to temporarily quit an ongoing task to seek information can be based on multiple drives built over short or long timescales. Such decisions are accompanied by particular neural activity in the frontal cortex. This presentation will review the neural markers and dynamics that dissociate midcingulate from lateral frontal cortex contributions to these decisions. This concerns selectivity of information coding across trials, as well as intrinsic timescales of different cell types spiking activity. In the midcingulate cortex these intrinsic properties seems to contribute to certain aspects of information processing devoted to exploratory decisions.

ALLA KARPOVA (11:10 – 11:40)

Senior Group Leader, Janelia Research Campus, Ashburn, USA

Using structured task complexity to seek explanatory simplicity

Our work over the past five years has laid the technical, behavioral and conceptual foundation for identifying simplifying principles underlying higher cognition using rats as a model system. Recent evidence suggests that rats' reliance on abstraction of environmental structure may share fundamental principles with hierarchical reasoning central to human cognition. Building on the intuition that animals approach complex environments by attempting to create models of the environment's latent structure, we record and perturb ensemble activity in tasks with carefully engineered complexity. Our behavioral framework permits us to tune task complexity up and down, to build in hierarchical structured relationships and to ascertain whether an animal's solution captures the added complexity and latent structure. Our early explorations within this framework of the neural dynamics in the anterior cingulate cortex (ACC) – an area implicated in keeping track of higher order abstractions, but with what previously seemed like only modestly task-related responses – have revealed surprisingly interpretable activity patterns. Using novel circuit dissection tools that we have developed with our colleagues at Janelia, we have been able to provide causal evidence for the behavioral relevance of these dynamics, and have begun to map them onto specific interacting sub-circuits within the ACC. Our findings support the notion that stronger and more organized dynamics are likely to emerge in challenging behavioral environments and suggest that it will be possible to ground even abstract cognitive computations in mechanistic insight. Going forward, we will continue to examine, in a systematic fashion, how task complexity constrains neural dynamics in the frontal cortical areas, with a particular emphasis on the *neural dynamics that accompany the learning and use of structured relationships in behavioral tasks*.

JACQUIE SCHOLL (11:45 – 12:15)

Post-doctoral researcher, Wellcome Centre for Integrative Neuroimaging, University of Oxford, UK

Sequential choice, prospection and insight

Many real-world decisions have benefits occurring only in the future and dependent on additional decisions taken in the interim. We combined computational modelling with FMRI (n=24) to investigate this in a novel decision-making task in humans. Modeling revealed that participants computed the prospective value of decisions: they planned their future behavior taking into account how their decisions might affect which states they would encounter and how they themselves might respond in these states. They considered their own likely future behavioral biases (e.g., failure to adapt to changes in prospective value) and avoided situations in which they might be prone to such biases. Analysis of the neural data revealed a key role for a network including dorsal anterior cingulate cortex in representing the value of exploring alternatives and planning. I will also show data from a large sample (n=400) collected over the internet. This allowed me to link distinct individual differences in obsessive compulsive and apathetic traits to distinct computational processes related to habitual behaviours and motivation.

JILL O'REILLY (14:15 – 14:45)

Associate Professor, Department of Experimental Psychology, Universtity of Oxford, UK

Control of uncertainty in internal models

TBA

MARLENE COHEN (14:50 – 15:20)

Associate Professor, Department of Neuroscience, University of Pittsburgh, USA

Linking cognitive changes in neuronal responses to perception

Visual attention dramatically improves subjects' ability to see and also modulates the responses of visual and oculomotor neurons. Despite hundreds of studies demonstrating the co-occurrence of behavioral and neuronal effects of attention, the relationship between neuronal modulations and improved performance remains unknown. Two dominant hypotheses have guided previous work: that attention 1) improves visual information coding or 2) changes the way visual information is read out by downstream areas involved in decision-making. By recording from groups of neurons at multiple stages of visuomotor processing, we showed that neither of these hypotheses account for observed perceptual improvements. Instead, our data suggest a novel hypothesis: that the well known effects of attention on firing rates and shared response variability in visual cortex reshape the representation of attended stimuli such that they more effectively drive downstream neurons and guide decisions without explicitly changing the weights relating sensory responses to downstream neurons or behavior. Implementing behavioral flexibility by changing the activity in visual cortex is very different than how computational models implement flexibility (e.g. by changing weights relating different nodes of the network or by reducing noise). This mechanism may be a biologically simple way to implement flexibility, and our preliminary experiments suggest that it is at work in other cognitive processes like arousal and task switching. In general, our work shows that constraining our analyses by the animals' behavior and the simultaneous recordings from multiple brain areas can greatly clarify the relationship between attention, neuronal responses and behavior.

PETER KOK (15:55 – 16:25)

Researcher, Wellcome Centre fpr Human Neuroimaging, University College London, UK

The role of prior expectations in sensory processing

Our senses are constantly bombarded with noisy and ambiguous sensory information. It has been suggested that we use prior knowledge to constrain sensory processing, resulting in a best possible guess of what's out there in the world. However, the neural mechanisms by which the brain achieves this are largely unknown. In this talk, I will discuss how predictions of both low-level features and complex shapes affect processing in the visual cortex. Furthermore, I will discuss the potential role of the hippocampus in generating such stimulus predictions. Together, this body of work suggests that memory and sensory systems constantly interact to optimise sensory processing.

ZOE KOURTZI (16:30 – 17:00)

Professor of Experimental Psychology, Department of Psychology, University of Cambridge, UK

Strategic brain routes for learning and plasticity

When immersed in a new environment we are challenged to make sense of initially incomprehensible event streams. Yet, quite rapidly, the brain is able to find meaningful structures, helping us to predict and prepare for future actions. We combine behavioural and brain imaging measurements with computational modeling, to understand the dynamics of learning complex structures. We show that individuals adapt to changes in the environment's statistics and extract predictive structures. Importantly, extracting complex structures relates to individual decision strategy: faster learning relates to selecting the most probable outcomes and is implemented by interactions in fronto-striatal circuits, while learning the exact stimulus statistics is implemented by visual cortico-striatal circuits. Our findings provide evidence for alternate brain routes to learning of behaviorally-relevant statistics that facilitate our ability to predict future events in variable environments.

WEDNESDAY 29 MAY

MIRIAM KLEIN-FLUGGE (9:30 – 10:00)

Sir Henry Wellcome Fellow, Department of Experimental Psychology, University of Oxford, UK

Amygdala and PFC encode different associative structures and their connectivity helps predict markers of mental well-being

To guide flexible decision making, humans and animals learn from reward but also from observing statistical relationships in the world. While much is known about the neural encoding of updating signals during learning, there is relatively little knowledge on where and how learnt representations are stored. The first study explores such neural representations using human fMRI and asks whether different learning mechanisms may guide the formation of representations in subcortical regions such as the amygdala and ventral striatum, compared with frontal cortical regions. We find that knowledge encoded via model-free RL is dissociable from the encoding of statistically learnt relationships in PFC, and that the amygdala holds information about spatial proximity to reward.

Mental health disorders often impair decision making and are also associated with abnormal amygdala metabolism. In the second study, I will focus on the amygdala and its connections to PFC and brainstem in a large cohort of healthy participants from the Human Connectome Project. We examined whether measures of functional coupling of specific amygdala nuclei can predict markers of mental well-being, in the absence of a decision task, at rest. We performed a detailed amygdala parcellation and extracted markers of mental well-being using a factor analysis on questionnaire scores. We find that a small number of specific amygdala connections is sufficient to predict these markers of mental well-being which captured problems frequently encountered in mood disorders.

VINCENT COSTA (10:05 – 10:35)

Assistant Professor, Department of Behavioral Neuroscience, Oregon Health & Science University, USA

A Comparison of Amygdala and Striatal Contributions to Reinforcement Learning

Traditional views of reinforcement learning emphasize the central role of the ventral striatum in integrating dopaminergic signals to facilitate learning, but only ascribe the amygdala a minor, modulatory role. I will discuss a series of experiments in non-human primates that overturn this view. These experiments combine computational modeling of choice behavior in multi-arm bandit tasks with excitotoxic lesions and neurophysiological recordings to discern the relative contributions of the amygdala and ventral striatum to reinforcement learning during reversal learning and explore-exploit tradeoffs. Overall, these data provide strong evidence that both conceptual and computational models of reinforcement learning should be revised to incorporate a more prominent role for the amygdala and its interaction with the ventral striatum.

ERAN ELDAR (11:10 – 11:40)

Senior lecturer, Psychology and Cognitive Sciences Department, Hebrew University of Jerusalem, Israel; Honorary research associate, Max Planck UCL Centre for Computational Psychiatry and Ageing Research, London, UK

Value learning processes shaping real-life mood fluctuations

Despite the ubiquity and substantial impact of mood fluctuations in our lives, we often find it difficult to explain even with regards to our own mood why it fluctuates the way it does. Recent findings suggest that such mood fluctuations, which may otherwise seem chaotic, could in fact reflect tractable processes of value learning. Studying this possibility, however, requires new methodology capable of examining people’s learning processes and real-life mood fluctuations side by side on an appropriate timescale. For this purpose, we developed a novel smartphone-based platform - the first to allow frequent behavioral and physiological experimental assessments in individual participants over extended periods. I will present results from a week-long experiment conducted using the platform, and show that changes in physiological value learning signals predict subsequent corresponding changes in mood. The findings contribute to an emerging conception of mood as an integral component of ongoing value learning processes, and offer an effective way to study how mood-learning interactions unfold over time.

HANNAH CLARKE (11:45-12:15)

Lecturer and MRC Fellow, Department of Physiology, Development and Neuroscience, University of Cambridge, UK

Cost-benefit decision making - the PFC and emotional dysfunction

Affective disorders such as depression and anxiety are associated with an increased sensitivity to negative feedback that adversely influences day-to-day decision making. Although correlative human neuroimaging studies of these disorders reveal dysregulation throughout the prefrontal cortex (PFC; including the orbitofrontal cortex, ventrolateral PFC, cingulate areas 25 and 32), and the anterior hippocampus, the causal involvement of these structures in such symptoms is unknown. Furthermore, uncertainty over the functional homologues of these areas in rodents and the lack of relevant behavioral tasks hinders cross-species translation. In this talk I therefore describe the development of a novel approach-avoidance decision making task in marmoset monkeys and the selective, causal, pharmacological manipulations we have employed to dissect out the specific contributions of these PFC regions and their associated circuits to the control of negative-biases during decision making. In doing so, I will also consider the implications of these findings with respect to back-translation to the rodent literature and forwards translation into the clinic.

CARLOS BRODY (14:15 – 14:45)

Professor in neuroscience, Princeton Neuroscience Institute, USA

Neural circuit mechanisms underlying cognition in rats

I will describe studies of the neural bases of cognitive processes. Rodents, mostly rats, are trained to perform behaviors that lend themselves to quantitative modeling that can help identify and assess specific cognitive processes, such as decision-making, short-term memory, planning, and executive control. With these well-quantified behaviors in hand, we then use electrophysiological recordings, optogenetic perturbations, and computational modeling. We aim to understand the neural architecture underlying cognition, across multiple levels, from local neural circuits, to interactions between brain regions, to overall behavior. I will focus on decision-making and working memory. Gradual accumulation of evidence for or against different decision options has been proposed to be a core component of many different types of decision-making. I will describe our efforts over the past few years to identify the relative roles of cortical and subcortical regions in supporting this process.

KEVIN MILLER (14:50 – 15:20)

Post-doctoral researcher, Cortexlab, University College London, UK

Neural Mechanisms of Model-Based Planning in the Rat

Planning can be defined as use of an internal model, containing knowledge of action-outcome contingencies, to guide action selection. Recently, we adapted for rodents a multi-step decision task widely used to study planning in human subjects, allowing the experimental toolkit available for rodents to be brought to bear on this problem in a new way. We found that rats adopt a strategy of model-based planning to solve the task, and that silencing neural activity in either the orbitofrontal cortex or the dorsal hippocampus was sufficient to impair this strategy (Miller, Botvinick, & Brody, 2017). Here, I will describe data from new experiments designed to reveal the computational role in model-based cognition played by each region. In the orbitofrontal cortex, neurons encode information about expected outcomes in a manner specifically suitable for a role in model-based learning, but not for a role in model-based choice. Trial-by-trial optogenetic inactivations similarly reveal a pattern of impairment that is consistent with impaired learning, but not with impaired decision-making. These data suggest that rodent OFC acts as a "model-based critic" (Schoenbaum, et al., 2009), signaling expected outcomes to a process which updates choice mechanisms residing elsewhere in the brain. In the dorsal hippocampus, neural activity does not seem to encode information about expected outcomes, but instead indexes the various behavioral states of the task in a manner reminiscent of “place cell” coding. Ongoing work seeks to test computational proposals that hippocampal activity supports planning via predictive coding (Stachenfeld, et al., 2017), via representations of latent environmental state (Gershman & Niv, 2010), or via prospective activity during either theta sequences (Johnson & Redish, 2007) or sharp-wave ripple events (Mattar & Daw, 2018).

TIM BEHRENS (15:55 – 16:25)

Professor of computational neuroscience, University of Oxford.UK
Honorary lecturer, University College London, UK

The Tolman-Eichenbaum Machine

Flexibly generalising knowledge from one task to another is a hallmark of intelligent behaviour but is notoriously difficult to achieve in artificial neural networks. The hippocampal-entorhinal system is essential for generalisation in both spatial and non-spatial tasks. Famously, in space, cells in these regions display a buffet of distinct bespoke firing patterns thought useful for representing maps. Existing theories extend some of these representations to non-spatial situations within a single task. These frameworks, however, do not explain generalisation, and account for only a subset of recorded cell types. Here we provide a mechanistic understanding of the hippocampal role in generalisation, and a unifying principle underlying many different entorhinal and hippocampal cell-types. We propose medial entorhinal cells form a basis for describing structural knowledge, and hippocampal cells-types reflect conjunctions of this basis with sensory knowledge. Adopting these principles, we introduce the Tolman-Eichenbaum machine (TEM), a model that learns and generalises abstract structural knowledge. After learning, TEM entorhinal cells display diverse properties resembling apparently bespoke cell types, such as grid cells, band cells, border cells and object vector cells. TEM hippocampal cells resemble place cells and landmark cells and remap between environments. TEM predicts, however, that hippocampal remapping is not random as previously believed. Rather structural knowledge is preserved across environments. We demonstrate this structural transfer over remapping empirically in simultaneously recorded place and grid cells.

KIM STACHENFELD (16:30 – 17:00)

Research scientist, DeepMind's Neuroscience team, London, UK

Structured entorhinal representations for hierarchical learning and planning

Humans and animals seem to be capable of using prior knowledge about environmental structure for to learn and plan over large, complex environments. In this talk, we will present our recent theoretical efforts to make sense of the hippocampal/entorhinal cognitive map using a "representation learning" approach: that is, by considering how place and grid cells support efficient downstream reinforcement learning processes. First, we will overview some ideas from representation learning theory about what constitutes a good representation. We use this to motivate a "spectral model" of grid cells. These grid cells have a number of desirable properties. They are sensitive to task topology, meaning they will capture not just spatial constraints but also bottlenecks, boundaries, and clusters. This allows them to be useful for denoising place cells and "filling in the gaps" of a partially explored room in a way that respects environmental constraints. Furthermore, the population can support inferences about multiple timescales in parallel and can be flexibly modulated to attend to a timescale of interest, permitting hierarchical learning and planning. They can also be used to generate sequences at a range of spatiotemporal scales in dynamical modes that differently support exploration and consolidation. In addition to discussing these normative considerations, we will compare our simulations to recent data on sequences recorded from hippocampus and show how our model explains some of its surprising characteristics.

PART 3 – POSTER ABSTRACTS

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[4] Wordcloud created from www.wordclouds.com, all words of the “Poster abstracts” section were included.

SESSION 1: MONDAY 27 MAY, 12:15 – 14:15 (POSTERS 1-44)

[POSTER 1]

The neural mechanisms of the framing effect on social discounting

Manuela Sellitto* (1), Adam Schweda (1), Bernd Weber (2), Tobias Kalenscher (1)

(1) Comparative Psychology Department, Heinrich-Heine University Düsseldorf, Germany
(2) Department of NeuroCognition/Imaging, Life&Brain Research Center, Bonn, Germany

Being generous and sacrificing part of one's own resources for the benefit of others is modulated by the perceived social distance from the other persons (i.e., social discounting [1]). The activity of the temporoparietal junction (TPJ) has been found to modulate the activity of the ventromedial prefrontal cortex (VMPFC), promoting generous choice [2]. One powerful drive of human behaviour is the prospect of loss, as humans are usually twice as sensitive to a potential loss than to a potential gain (i.e., framing effect [3]). In the present study we show how framing decisions in terms of gains and losses can drive human generosity. Participants made a series of binary monetary choices involving persons from their social environment (i.e., from very close to strangers). In the gain frame, participants chose between a selfish option higher in amount —gain for themselves and no gain for the other person— and a generous option lower in amount —same gain for themselves and the other person. In the loss frame the same options were presented but, in spite of equivalent expected payoff values across frames for both the participant and the other person, choosing the selfish option here entailed the loss of an initial endowment for the other person. As main behavioural finding, the loss frame increased generosity significantly, especially toward persons at large social distances, as measured by applying the hyperbolic discounting model. At the neural level, besides replicating findings on TPJ and VMPFC [2] we observed activity in the posterior insula and the amygdala —regions commonly associated with loss encoding— specifically during generous choices in the loss frame. Additional physiophysiological interaction (ϕPI) analyses will be presented. Possible cognitive mechanisms underlying these findings and neural signals will be discussed.

[1] Jones, B., & Rachlin, H. (2006). Social discounting. Psychological Science, 17(4), 283-286.
[2] Strombach, T., Weber, B., Hangebrauk, Z., Kenning, P., Karipidis, I. I., Tobler, P. N., & Kalenscher, T. (2015). Social discounting involves modulation of neural value signals by temporoparietal junction. Proceedings of the National Academy of Sciences, 112(5), 1619-1624.
[3] Tversky, A., & Kahneman, D. (1981). The Framing of Decisions and the Psychology of Choice. Science, New Series, 211(4481), 453-458.

[POSTER 2]

Dopamine restores cognitive motivation in Parkinson's disease

Trevor T.-J. Chong*, Sara McGuigan

Monash Institute of Cognitive and Clinical Neuroscience, Monash University, Victoria 3800 Australia

Disorders of motivation, such as apathy, are common in Parkinson's disease (PD), and a key feature of such disorders is a greater aversion to effort. In humans, the experience of cognitive effort is ubiquitous, and cognitive apathy has traditionally been considered distinct and separable from other subtypes. Surprisingly, however, the neurobiology of cognitive motivation is poorly understood. In particular, although dopamine has a well-characterised role in incentivising physically effortful behaviour, a critical, unresolved issue is whether its facilitatory role generalises to other domains.

Here, we asked how dopamine modulates the willingness of patients with PD to invest cognitive effort in return for reward. We tested 20 patients with idiopathic PD across two counterbalanced sessions - ON and OFF their usual dopaminergic medication - and compared their performance to 20 healthy age-matched controls. We applied a novel task in which we manipulated cognitive effort as the number of rapid serial visual presentation streams to which participants had to attend. After training participants to ceiling performance, we then asked them to choose between a low-effort/low-reward baseline option, and higher-effort/higher-reward offer.

Computational models of choice behaviour revealed four key results. First, patients OFF medication were significantly less cognitively motivated than controls, as manifest by steeper cognitive effort discounting functions in the former group. Second, dopaminergic therapy improved this deficit, such that choices in patients ON medication were indistinguishable from controls. Third, differences in motivation were also accompanied by independent changes in the stochasticity of individuals' decisions, such that dopamine reduced the variability in choice behaviour. Finally, choices on our task correlated uniquely with the subscale of the Dimensional Apathy Scale that specifically indexes cognitive motivation, which suggests a close relationship between our laboratory measure of cognitive effort discounting and subjective reports of day-to-day cognitive apathy. Importantly, participants' choices were not confounded by temporal discounting, probability discounting, physical demand, or varying task performance.

These results are the first to reveal the central role of dopamine in overcoming cognitive effort costs. They provide an insight into the computational mechanisms underlying cognitive apathy in PD, and demonstrate its amenability to dopaminergic therapy. More broadly, they offer important empirical support for prominent frameworks proposing a domain-general role for dopamine in value-based decision-making, and provide a critical link between dopamine and multidimensional theories of apathy.

[POSTER 3]

Learning from social interactions: Development of adaptive social learning across adolescence

B. Westhoff* (1), L. Molleman (2), E. Viding (3), W. van den Bos (2), A.C.K. van Duijvenvoorde (1)

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(2) Center for Adaptive Rationality, Max Planck Institute for Human Development, Lentzeallee 94, 14195 Berlin, Germany
(3) Division of Psychology and Language Sciences, University College London, London WC1H 6BT, United Kingdom

Humans live in a highly social environment, thus the ability to quickly adjust to social situations is a critical skill. For decision making in social situations, we need to incorporate and anticipate other people's choices as well as outcomes, and additionally flexibly adapt our own behavior across contexts. Little is known, however, about the developmental trajectories and the mechanisms of such adaptive social decision making. Here, we assessed social decision making and learning in adolescents and young adults between 8 and 26 years (*N*=252, 59.5% female), using an incentivized social decision making task. Participants played two computerized social economic games, each composed of several single-shot games with anonymous opponent players that had been assigned to either a cooperative or a competitive community. Over the course of the experiment, participants could learn to adjust their response adaptively to each community they interacted with. As a control condition we included a simple non-social decision game with two communities of computer opponents. Preliminary results showed that all age groups are able to learn and adjust choice behavior in the non-social condition. However, the ability to adjust to different social groups increased across adolescence. Particularly, learning to trust and cooperate with a cooperative community increased with age. Moreover, social preferences such as inequality aversion and prior expectations explained individual differences in adolescents' tendency to trust or cooperate. Together, these results provide new insights on the changing influence of others in young adolescents' social decision making and learning.

Computational basis of prosocial motivation in ageing

Ayat Abdurahman* (1,2), Dan Drew (3), Marin Tamm (1), Masud Husain (1,2,3),
Matthew A. J. Apps (1,2), Patricia L. Lockwood (1,2)

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(2) Wellcome Centre for Integrative Neuroimaging, University of Oxford, United Kingdom
(3) Nuffield Department of Clinical Neurosciences, University of Oxford, United Kingdom

A fundamental aspect of human social and moral behaviour is our willingness to help others. Existing research has largely focused on testing prosociality in children and young adults and therefore how prosocial behaviour changes as we get older is poorly understood. Studies using social economic games have reported both greater prosocial behaviours (financial generosity) in older adults[1] and no age-related differences [2]. However, everyday prosocial acts typically do not come at a financial cost, instead they require physical effort. Moreover, economic games do not show whether specifically prosocial preferences are changing with age or whether both self and other preferences are changing, which may explain some of the inconsistencies in previous findings.

We examined prosocial motivation in ninety-five young and ninety-two elderly adults using a physical effort-based task that quantified people's willingness to choose to exert effort, that benefitted either themselves or another person. We replicated our previous findings showing that people are often prosocially apathetic, demonstrating reduced willingness to choose to initiate highly effortful acts that benefit others compared with those benefitting themselves[3].

Intriguingly, prosocial apathy also interacted with age, with older adults choosing to exert higher levels of effort for another person compared to younger adults. Moreover, older adults also showed a domain general effect of greater reward sensitivity for both self and other.

Computational modeling of choice behaviour showed that a parabolic model containing separate discounting parameters for self and other, and separate β noise parameters best explained behaviour in both groups. We also found that the discounting parameter was higher for other compared with self, consistent with the behavioural findings of prosocial apathy. However, as with the choice behaviour, there was a difference between groups in the rate at which they devalued rewards for other people, indexing greater prosocial effort. Overall our findings suggest that older adults are more willing to exert physical effort to help others compared to younger adults and devalue rewards by effort for others at a slower rate. These findings could have important implications for everyday prosociality and theoretical accounts of healthy ageing.

[1] Sze, J. A., Gyurak, A., Goodkind, M. S. & Levenson, R. W., "Greater emotional empathy and prosocial behavior in late life", *Emotion*, Vol. 12, No. 5, 2012, pp. 1129-1140.

[2] Beadle, J. N., Paradiso, S., Kovach, C., Polgreen, L., Denburg, N. L., & Tranel, D., "Effects of age-related differences in empathy on social economic decision-making", International Psychogeriatric, Vol, 24, No. 5, 2012, pp. 822-833.

[3] Lockwood, P. L., Hamonet, M., Zhang, S. H., Ratnavel, A., Salmony, F. U., Husain, M., & Apps, M. A. J., "Prosocial apathy for helping others when effort is required", *Nature Human Behaviour*, Vol. 1, No. 4, 2017, pp. 0131.

[POSTER 5]

Framework for modelling the effects of motivational state on choice and learning in the basal ganglia

Maaike MH van Swieten* (1), Rafal Bogacz (2)

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(2) Nuffield Department of Clinical Neuroscience, University of Oxford, John Radcliffe Hospital, Oxford

Decision-making relies on adequately evaluating the consequences of actions, a process in which the basal ganglia plays a key role. Neural activity and plasticity in the basal ganglia are modulated by dopaminergic signalling from the midbrain. Internal physiological factors, such as hunger, scale dopamine levels and the reward prediction error. Consequently, they alter the motivation for taking actions and learning about the consequences of actions. However, to our knowledge, no formal mathematical formulation exists for how a physiological state affects learning and action selection in the basal ganglia. We developed a framework for modelling the effect of motivational state on choice and learning. During action selection, the model evaluates the utility of all available options by weighting the positive and negative consequences of each action according to a physiological state. We defined the value function of the physiological state as a concave function, because it is more important to act when you are in a low physiological state, compared to a near optimal state. We also proposed a mapping of the computation of the utility onto the basal ganglia network, in which the motivation is encoded by dopamine. Reinforcement learning models typically define the reward prediction error as the difference between a reinforcement and an estimate of the expected reinforcement. This definition of the reward prediction error, encoded by dopamine, was recently experimentally challenged by Cone et al [1]. These data show that after conditioning, the physiological state of the animal modulates the reward prediction error encoded in dopaminergic activity. Therefore, we defined a state-dependent reward prediction error in which the motivational level scales both the reward and the expected value. Such modified definition allows the model to explain a large body of experimental data. In summary, we have developed a biologically relevant, mathematical framework for choice and learning in a state-dependent manner. We have brought together models of learning in the basal ganglia with the incentive salience theory in a single simple framework. This work provides mechanistic insight into how decision processes in the basal ganglia are modulated by certain factors and can serve as a building block for extending this to different contexts.

[1] Cone, JJ, Fortin, SM, McHenry, JA, Stuber, GD, McCutcheon, JE, and Roitman, MF. “Physiological state gates acquisition and expression of mesolimbic reward prediction signals,” *PNAS* Vol. 113, No. 7, 2016, pp. 1943-1948.

Affective traits are the key drivers of prosocial choices: a transdiagnostic study

L. Sebastian Contreras-Huerta* (1,2), Patricia L. Lockwood (1,2), Matthew J. Apps^{x} (1,2), Molly J. Crockett^{x} (1,3)

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(3) Department of Psychology, Yale University, New Haven, CT, 06511, USA
^{x} These authors contributed equally to this work

Prosocial behaviours - actions that benefit others at some personal cost- lie at the core of healthy social relationships and are a key facilitator of social cohesion and group bonding. For someone to be considered a highly altruistic individual, they need to be prosocial in multiple contexts i.e. they need to be both highly averse to harming others but also very willing to put in effort to obtain rewards for others. However, whether such 'domain-general' prosociality exists, and whether people who are very averse to others harm are also very motivated to put in effort to benefit others is unknown. Furthermore, although many psychological traits are correlated with prosocial behaviours, either obstructing (e.g. psychopathy, alexithymia and apathy) or facilitating (e.g. empathy) them, it is unclear which traits are the most strongly linked to being prosocial across different contexts.

Here, we use computational modelling of two decision-making tasks that measure people's aversion to other people's pain [1], and their willingness to put in effort to obtain rewards for others [2], and use transdiagnostic statistical techniques (canonical correlation analyses [CCA]) to address two questions: (i) Is prosocial behaviour domain-general, with the people more averse to others harm also those who are more willing to put effort in for others? And (ii) which traits - of 18 that are commonly linked to prosocial behaviours and psychiatric disease - are the key drivers of being prosocial across contexts? Across two online studies (n = 325), we show that people are more averse to others harm than their own, but are less willing to invest effort to obtain rewards for others than themselves. However, despite these different patterns of behaviour, parameters measuring people's aversion to others' harm and willingness to invest effort for others were correlated. In line with our hypothesis, people who were more motivated to exert effort for others, gave up more money to prevent harm them. Furthermore, we found that a constellation of traits associated to empathy, apathy, and alexithymia are the most predictive of being highly prosocial in both tasks. Here, by using this computational, transdiagnostic approach, we show that people who are highly altruistic do so no matter whether they are making a moral decision or they need to be motivated. Moreover, we show that being prosocial across different contexts is underpinned by a constellation of predominantly affective traits, providing a key link for future investigations of the neural mechanisms underlying altruism and their disruption in psychiatric and neurological disorders.

[1] Crockett, M. J., Kurth-Nelson, Z., Siegel, J. Z., Dayan, P., & Dolan, R. J., "Harm to others outweighs harm to self in moral decision making," *Proceedings of the National Academy of Sciences.*, vol. 111, no. 48, 2014, pp. 17320-17325.

[2] Lockwood, P. L., Hamonet, M., Zhang, S. H., Ratnavel, A., Salmony, F. U., Husain, M., & Apps, M. A., "Prosocial apathy for helping others when effort is required," *Nature Human Behaviour.*, vol. 1, no. 7, 2017, pp.0131

[POSTER 7]

MDMA Increases Cooperation and Recruitment of Social Brain Areas When Playing Trustworthy Players in an Iterated Prisoner's Dilemma

Anthony S. Gabay* (1), Matthew J. Kempton (2), James Gilleen(3), Mitul A. Mehta (1)

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(2) Department of Psychosis Studies, King's College London
(3) Department of Psychology, University of Roehampton

Social decision-making is fundamental for successful functioning and can be affected in psychiatric illness and by serotoninergic modulation. The Prisoner's Dilemma is the archetypal paradigm to model cooperation and trust. However, the effect of serotonergic enhancement is poorly characterized, and its influence on the effect of variations in opponent behavior unknown. To address this, we conducted a study investigating how the serotonergic enhancer 3,4-methylenedioxy-methamphetamine (MDMA) modulates behavior and its neural correlates during an iterated Prisoner's Dilemma with both trustworthy and untrustworthy opponents. We administered 100 mg MDMA or placebo to 20 male participants in a double-blind, placebo-controlled, crossover study. While being scanned, participants played repeated rounds with opponents who differed in levels of cooperation. On each round, participants chose to compete or cooperate and were asked to rate their trust in the other player. Cooperation with trustworthy, but not untrustworthy, opponents was enhanced following MDMA but not placebo (respectively: odds ratio = 2.01; 95% CI, 1.42-2.84, $p < 0.001$; odds ratio = 1.37; 95% CI, 0.78-2.30, not significant). Specifically, MDMA enhanced recovery from, but not the impact of, breaches in cooperation. During trial outcome, MDMA increased activation of four clusters incorporating precentral and supramarginal gyri, superior temporal cortex, central operculum/posterior insula, and supplementary motor area. There was a treatment × opponent interaction in right anterior insula and dorsal caudate. Trust ratings did not change across treatment sessions. MDMA increased cooperative behavior when playing trustworthy opponents. Underlying this was a change in brain activity of regions linked to social cognition. Our findings highlight the context-specific nature of MDMA's effect on social decision-making.

A basal forebrain-cingulate circuit in macaques decides whether and when to act

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Wellcome Centre for Integrative Neuroimaging, Department of Experimental Psychology, University of Oxford, Oxford, UK

Decision-making studies often focus on neural mechanisms for selecting between goals or actions giving less attention to determining *when* and *whether* to act in the first place. Medial frontal cortex has been linked to voluntary action but an explanation of why decisions to act emerge at particular points in time has been lacking. We introduced a new paradigm to investigate in the macaque how contextual factors and internal state, shaped by present and past environment- for example, respectively, cues indicating the current average rate of reward and recent previous voluntary action decisions, are integrated to determine when to act. Behavioural analyses showed that identifiable features of the internal and external environment relating to both current context and the recent past context, such as recent rewards and the timing of recent previous decisions, influenced how soon the next action will be made. A deterministic component of decision time could be deduced from the present and past context, explaining a significant proportion of variance in decision time. We used functional imaging (fMRI) to identify two areas -- anterior cingulate cortex (ACC) and basal forebrain (BF) – that encoded decision time to act. The relationship between expected reward and decision time was mediated by ACC, while BF mediated the combined effect of contextual factors on decisions about when to act. Finally, we showed that alteration of ACC and BF activity with Transcranial Focused Ultrasound Stimulation (TUS) changes decisions about whether and when to act in distinct ways.

[POSTER 9]

Impaired reward and information processing in addictive disorders

I. Cogliati Dezza* (1), X. Noel (2), A. Cleeremans (1), A. J. Yu (3)

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Addiction is a complex psychiatric condition manifested as a loss of control over drug usage, or certain non-drug behaviours, despite harmful consequences. In this study, we attempt to gain insight into this disorder and its underlying mechanism by investigating the way addicted individuals negotiate the trade-off between exploration and exploitation in a sequential decision-making task, in comparison to healthy controls.

In this study, we focus on problem gamblers, who are addicted to a certain type of harmful behaviour i.e., gambling, but whose behavioural pathology does not suffer from the confounding effects of consuming illicit drugs. We adopt a computational model, previously validated in a healthy sample, to study the nature of pathology in gamblers.

Our results show that problem gamblers, in comparison to healthy controls, employ a decision policy that under-explores uncertain elements of the environment. Additional analyses also reveal that problem gamblers exhibit altered temporal dynamics of the representation of reward and information whose underlying mechanisms have been associated with adaptive and flexible behaviours in “neurotypical” subjects. By espousing the exploration-exploitation framework in the context of the study of addictive behaviours, our study opens up new ways of investigating addiction while embracing the complexity of this disorder and of interpreting its main symptoms within a more reliable biological framework.

[POSTER 10]

Using virtual reality to assess the impact of craving on physiological motor inhibition in alcohol dependence.

Caroline Quoilin*, Philippe de Timary, Julie Duque

Institute of Neuroscience, Université Catholique de Louvain, 1200 Brussels, Belgium.

Converging lines of evidence suggest that both alcohol craving and impaired inhibitory control contribute to the maintenance and relapse of alcohol dependence. However, whether craving worsens inhibitory performance is still unclear. Here, we aimed at studying whether the induction of craving, by means of 360° immersive videos (bar compared to library), alters the strength of motor inhibition in alcohol-dependent (AD) patients. Motor inhibition was evaluated using a standard procedure consisting in measuring motor-evoked potentials elicited by single-pulse transcranial magnetic stimulation over primary motor cortex during a choice reaction time task. Our data indicate a strong shortage of motor inhibition in AD patients relative to control subjects, consistent with an inhibitory deficit. Importantly, this deficit was comparable following videos placing patients in a bar or in a library. Accordingly, we found that the former video did not induce craving in the patients. This result is surprising given that we previously demonstrated that the same video was effective in eliciting alcohol craving in young social drinkers. Interestingly, the level of presence experienced during the immersion was lower in patients compared to controls and social drinkers, which may indicate that patients deployed some strategies to avoid being impacted by the immersive videos.

[POSTER 11]

Neurocomputational plasticity of Self-Other distinction

Sam Ereira* (1), Tobias Hauser (1), Ray Dolan (1), Zeb Kurth-Nelson (1,2)

(1) Max Planck UCL Centre for Computational Psychiatry and Ageing Research/Wellcome Centre for Human Neuroimaging, UCL
(2) DeepMind

Humans have a remarkable ability to distinguish their own beliefs from another person's beliefs. Our research aims to explain how the human brain can selectively attribute a predictive model of the world to 'self' or to 'other'. To this end, we recently applied computational neuroimaging to healthy adults engaged in a novel Theory-of-Mind task. We found sensory prediction error (PE) signals in distinct, agent-specific neural patterns. Variability in the agent-specificity of these signals predicted the extent of subclinical psychopathological traits [1].

In the present study we explore the source of this variability by testing whether self-other distinction is susceptible to experience-dependent plasticity. 47 healthy adults were trained on a probabilistic false belief task, with two different agents, in a within-subjects design. Subjects were required to attribute belief updates to self and other at the same time when playing with agent 1, but not at the same time when playing with agent 2. We then tested subjects on this task, with no difference between agent 1 and agent 2, whilst they underwent functional magnetic resonance imaging (fMRI). We also tested participants on a visual perspective-taking task with the same two agents. In the test session, subjects could better distinguish their own beliefs from another agent's beliefs

when playing with agent 2 versus agent 1. This training transferred to the visual perspective-taking task. Pattern-based fMRI measures showed a neural self-other distinction, in learning signals, that was modulated by agent-identity.
In summary, we show that healthy adults can identify the agent to whom a predictive model of the world belongs, using agent-specific neural learning signals. The degree of agent-specificity of these signals can itself be learned through cognitive training in a general manner that transfers to different cognitive domains.

1. Ereira, S., R.J. Dolan, and Z. Kurth-Nelson, *Agent-specific learning signals for self-other distinction during mentalising.* PLoS Biol, 2018. **16**(4): p. e2004752.

[POSTER 12]

Protective role of group majority in costly decisions

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(2) Center for Adaptive Rationality, Max Planck Institute for Human Development, Berlin, Germany

Past research on collective decisions focused on their accuracy benefits when compared to individual ones, but there is a lack in empirical studies addressing the individual motivations to engage or not in group decisions [1]. Here, we investigate how outcome valence interacts with people's tendency to play alone or in group in a gambling decision-making task.
In an online experiment on Amazon's Mechanical Turk, 125 participants (aged 19-57, mean age=31.72±7.31, 88 males) had to choose between two gambles with different probabilities of winning and losing. This validated gambling decision-making task was designed to elicit regret in participants through the presence of counterfactual outcomes, and allows to compute the influence of both expected value and anticipated regret on choices [2]. Importantly, in our adapted version of the task, participants were given the choice on a trial-by-trial basis to play alone or in a group of 5 people following a majority rule.
Both expected value and anticipated regret influenced decision-making about gambles replicating previous results [2] and confirming that participants were playing in an environment with possibly high negative costs (loss and regret). When participants were playing in group, the influence of both these parameters was decreased, reflecting a decrease in motivation and/or responsibility in the decision when belonging to a group. Importantly here, using computational modelling, we show that outcome valence (from a combination of factual and counterfactual outcomes) changed individuals' propensity to play alone or in group. When playing alone, the higher negative outcome experience, the more participants joined the group on the next round. When playing in group, being in a group minority vs. majority differentially influenced participants' behaviour: when belonging to a group minority, negative experience led to abstaining from joining the group on the next round while positive experience encouraged joining the group. When belonging to a group majority however, outcome valence did not have any impact on choosing to play alone or in group.
Our results thus suggest that belonging to a group majority renders people unresponsive to outcomes and counteracts behaviours based on experiencing negative outcomes, that were observed when playing alone or in a group minority. This is possibly because making

(consensual) decisions with others allows to share responsibility for decision outcomes, thereby protecting against the influence of negative emotions [1].

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[POSTER 13]

An interaction between social affective biases and monetary offer amounts in human interpersonal negotiations

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Negotiating the distribution of finite resources between parties who might have competing interests is an important part of human social interactions. Two key cognitive processes relevant to these social interactions are: (i) how people perceive their share of the resource distributions proposed by others, and (ii) the degree to which social affective biases (e.g. perceiving others' facial emotions more negatively than they actually are) influence these valuation mechanisms. We investigated the interaction between social affective biases and social monetary rewards in a novel Ultimatum Game design. Participants (N=43) first completed a brief facial emotion recognition task (bFERT) and rated various affective faces on a 9-point Likert scale (i.e. from negative to positive), allowing an assessment of social affective biases. Participants then interacted with human confederates or a computerised opponent in a novel social interactive decision-making game which incorporates opponents' facial emotions, while undergoing pupillometry. All participants completed questionnaire measures of mood and social value orientation (e.g. Quick Inventory of Depressive Symptoms, Social Value Orientation Slider Measure). Affective biases were evaluated by fitting a 2-parameter weighting function to participant ratings in the bFERT. Participant choice behaviour was analysed using an ordinary least squares (OLS) regression model (e.g. regressors: opponent's facial emotion, offer amount, interaction term) as well as fitting formal computational models of the negotiation process. Pearson's correlation was used to evaluate linear relationships between psychological questionnaire scores and decision-making parameters. Regression analysis of acceptance probabilities suggested that unfair offers coming from proposers with positive facial emotions were more likely to be accepted (based on Bonferroni corrected t-tests on regression coefficients, all t>3.508, all p<.001). Model-based analysis suggested that social affective biases accounting for how people perceive others' emotional states are represented nonlinearly. Decision values, which guide participants' probability of accepting a condition in the negotiation game, are influenced by both the offer amount and an inequality term (i.e. difference between self and other's reward), which is further modulated by social affective biases. Pupillometry results suggested that pupil size encodes opponent's affective states and surprise associated with offers (all t> 2.01, p<.05). Taken together, our results describe a computational model accounting for human social interactive decision-making and we show evidence to suggest that central arousal systems (i.e. pupillometry indexing the firing of the central norepinephrine system) encode

key elements of social interactive decision-making that influence participant choice behaviour.

[POSTER 14]

Action Preparation: an integrated Perspective of Choice and Motor Control

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Adaptive sensorimotor interaction requires fine movement preparation[1]. By applying transcranial magnetic stimulation (TMS) over the primary motor cortex (M1) to elicit motor evoked potentials (MEPs) in muscles of the contralateral hand[2], many studies have shown that action preparation is associated with a transient decrease in the excitability of the corticospinal pathway; this phenomenon has been referred to as preparatory inhibition[3]. Intriguingly, while a growing number of studies support the extreme robustness of this effect, the role of such preparatory inhibition remains fundamentally unclear.

Our long-term goal is to test the hypothesis that preparatory inhibition reflects the operation of processes that assist action preparation at the level of both choice and motor control. In the context of choice, preparatory inhibition would serve to regulate a speed-accuracy tradeoff (SAT), with more inhibition favoring accuracy over speed. Furthermore, in the context of motor control, preparatory inhibition would facilitate the fine-tuning of muscle activity, with stronger inhibition increasing the gain of motor commands. To test these hypotheses, we recently developed a new experimental task that combines the Tokens Task[5,6] and some features of the Pac-Man video-game[7]. In brief, at each trial of this task, called the "Tok-Man" Task, tokens jump one-by-one from a central circle to one of two lateral circles. Subjects must then foresee which of both circles will receive more tokens by the end of the trial, and report it by pressing a button on a keyboard with their left or right index finger. Subjects may respond whenever they feel confident to make a choice, but necessarily before the last token jump. Once their choice is made, the motor control part of the trial initiates, by showing a Pac-Man on the screen. Subjects have to perform tapping movements with the chosen index finger to move the Pac-Man towards the chosen circle, while grabbing additional tokens on its way. In summary, the SAT in this task is manipulated by requiring subjects to make either fast or slow (accurate) choices, while motor tuning requirements are manipulated by requiring subjects to prepare faster or slower tapping movements. Importantly, these requirements are manipulated independently of each other, thus crossing choice and motor control instructions in four different block types.

The goal here is to report preliminary behavioral data acquired on healthy subjects with this new Tok-Man Task (n=10). Our data indicates that participants adjusted their SAT according to the choice instruction: when the emphasis was on decision speed over accuracy, subjects made faster and less accurate choices. Moreover, subjects were able to change the speed of their tapping movements according to the motor control instruction, and were able to do so regardless of the SAT requirement. Hence, participants were globally able to follow choice and motor control instructions separately.

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[POSTER 15]

Locus coeruleus neurons encode the subjective cost of triggering an action

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The noradrenergic nucleus *locus coeruleus* (LC) is thought to contribute to motivation by mobilizing cognitive resources to face upcoming challenges. To further understand this role, we recorded 75 LC units in monkeys performing a delay-discounting task. Monkeys were trained to release a bar after a go signal (green point) to obtain a reward (1, 2 or 4 drops of juice) after a variable delay (400 to 600ms; 3000 to 4200ms or 6000 to 8400ms). Trials started with a visual cue indicating the upcoming reward and delay levels.

LC neurons were activated at cue onset (population analysis: t(74)=6.80; p<0.001; 81±18.17ms latency); action initiation (t(74)=11.26; p<0.001; -197±10.73 ms latency) and reward delivery (t(74)=10.8367; p<0.001; 55.67±12.13ms latency). Responses to cues were modulated positively by the expected reward (t(75)=7.98; p<0.001) and negatively by the delay (t(75)=-2.21; p=0.03), but their response did not correlate with WTW when correcting for the joint influence of task parameters. Action initiation related behavior only exhibited a significant effect of delay, which was positive on reaction time (RT) and negative on action-related lipping. LC neurons positively encoded delay (t(75)=4.04; p<0.002) and RT, even after correction for the joint influence of task parameters (t(63)=11.43; p<0.001).

In sum, LC responses to cues only reflect information about the outcome, but action-related activity encodes the subjective cost of triggering the action. LC activation might reflect the effort to overcome this cost and promote action monitoring.

The impact of biological constraints on the detection of cognitive computation

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How are incoming stimuli or cues transformed into over behavior? Model-based fMRI addresses this sort of question by looking for brain correlates of computational variables that capture intermediate steps of stimulus processing (e.g., prediction error in a learning context). This approach has proven very successful in identifying the specific functional contribution of brain regions involved in learning and/or decision making. However, it neglects potentially relevant biological constraints and cannot be used in an exploratory manner. We address these two issues using Artificial Neural Network (ANN) modeling.

In brief, ANN model stimuli-response transformations in terms of compositions of stereotyped neural input-output transformations. When fitted to behavioral responses, ANNs thus predict patterns of computational unit activity that can be compared to multivariate patterns of neuroimaging data. The objective here is to identify brain regions that are involved in the stimulus-response transformation, by introducing simple biological realism constraints in the analysis, in particular, recurrent computations with bounded activation range.

We performed numerical simulations to test the robustness of our approach to anticipated potential confounding factors (in particular: inter-individual differences in spatial and computational aspects of stimuli-response transformations). We then demonstrated it on an fMRI study of gambling behavior (Tom 07).

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[POSTER 17]

Neural Circuits and Pupil Readouts of Motivated Shifts in Attentional Effort

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Humans and other animals constantly adapt their allocation of cognitive resources to changes in the environment. In sensory domains, the brain is capable of enhancing the processing of difficult-to-perceive stimuli when they are important (Kahneman, 1973). The neural circuit mechanisms that implement such adaptive changes in sensory processing are poorly understood. Key candidate mechanisms are direct neuromodulation of sensory cortex (Aston-Jones & Cohen, 2005), and bi-directional interactions of sensory cortex with frontal brain regions (Miller & Cohen, 2001). To dissect the detailed circuit mechanisms of adapting attention to momentary environmental conditions, we have developed an attentional effort (AE) task for head-fixed mice.

In the AE task, mice are trained to lick for sugar-water reward to report detection of the unpredictable emergence of temporal coherence in an ongoing tone-cloud. This acoustic signal is analogous to coherent motion in common visual tasks. Perceptual difficulty was parametrically and unpredictably varied on a trial-by-trail basis, through partial degradation of temporal coherence. In order to detect all of the weak-coherence signals, mice would need to sustain an infeasibly high level of attentional effort across the 90-minute sessions. To manipulate attentional effort, we shifted its momentary value by switching back and forth between a large and small magnitude reward (droplet volume) in blocks of 60 trials. Thus, mice were motivated to expend more attentional effort in blocks of large reward.

Here, we report behavioral and physiological signatures of flexible effort allocation in 22 mice. First, increased attentional effort in high reward blocks manifested as improved detection of the weak signals. Specifically, in high-reward blocks, mice increased their sensitivity (d' from signal detection theory) to detect coherence in noise (2-way repeated measures ANOVA $F_{1,21} = 38{,}48$; $p < 0.0001$), particularly for the weak-coherence targets, as indicated by the ANOVA interaction ($F_{2,42} = 11{,}70$; $p = 0.0001$). Second, mice exhibited at least 5 attentional effort shifts within a single session, which were tightly time-locked to the switches in reward context (e.g. within a small # of trials). Third, contrary to the trivial prediction that higher rewards increase general arousal, we found that mice actually *decreased* their arousal in high reward blocks, apparent in the baseline pupil diameter ($p = 0.002$). This indicates that the brain stabilizes in a moderate-arousal state that is more optimal for detecting weak signals. Fourth, the feedback-related pupil response reflected multiple learning signals across blocks, including correctness, reward context, and prediction errors, which might be used to flexibly regulate attentional effort.

In sum, we find that mice adapt their allocation of cognitive resources to changes in the environment. In ongoing GCaMP 2-photon imaging work, we are determining the roles of frontal-sensory interactions and neuromodulatory signals in mediating these shifts in overt behavior.

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[POSTER 18]

Decoding the neural dynamics of Free Choice

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How does the human brain decide what to do when we face competing alternatives that we are free to choose between? Deciding where to look to explore the visual world and select available alternatives is a crucial aspect of our everyday interactions with the environment, and studies of eye movement control provide a promising approach for learning about sensorimotor and cognitive aspects of voluntary action planning. According to neurophysiological accounts of decision making, planning a movement to select an alternative appears to be simultaneously represented in a collection of parietal and frontal areas[1]. In humans, several neuroimaging studies have identified a set of neural networks of brain areas located in parietal, frontal, and motor cortex functioning together for many aspects of saccade planning, execution, and decision making[2,3,4,5,6]. However, little is known about the spatiotemporal brain dynamics that give rise to motor decisions in humans. We address this question with unprecedented resolution thanks to intracerebral EEG recordings from 778 sites across six medically intractable epilepsy patients while they performed a delayed oculomotor task. We use a data-driven approach to identify temporal, spatial, and spectral signatures of human cortical networks engaged in active and intrinsically motivated viewing behavior at the single-trial level. We find that sustained high gamma (HG) activity (60-140 Hz) in fronto-parietal areas reflect the intrinsically driven process of selection among competing behavioral alternatives during free choice. Furthermore, we show that instructed saccade planning is characterized by an early transient increase in HG activity, accompanied by a suppression of β oscillations (16-30 Hz), thus leading to a fast encoding of a motor plan. During saccade execution, HG activity was tightly coupled to reaction times and action selection processes during the planning phase.

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[POSTER 19]

The role of Dopamine in Preparatory Inhibition: What can we learn from Parkinson's disease?

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By measuring the amplitude of motor-evoked potentials (MEPs) elicited by transcranial magnetic stimulation (TMS) over the primary motor cortex during choice reaction time (RT) tasks, many studies have revealed a strong suppression of corticospinal excitability when preparing an action [1-4]. This phenomenon - called "preparatory inhibition" - still remains a matter of investigation and debate: neither its functional role as part of action preparation nor the neural structures at its basis have been clearly elucidated yet [5-9]. Furthermore, this phenomenon has never been investigated in Parkinson's disease (PD). Yet, it would allow addressing the role of basal ganglia and dopamine in the generation of preparatory inhibition [10].

In the present study, preparatory inhibition was probed on two consecutive days in 11 right-handed PD patients (ON and OFF dopamine replacement therapy [DRT]; randomized order) and 11 matched healthy subjects. Participants performed an instructed-delay choice RT task, in which they had to choose between a left or right index finger response based on the position of a preparatory cue, but had to wait until the onset of an imperative signal to release their movement [11]. Single-pulse TMS was applied concurrently over both primary motor cortices at rest and during the preparatory delay, eliciting MEPs in both hands [12-14]. Preparatory inhibition was assessed by expressing MEP amplitudes obtained during the preparatory delay relatively to those obtained at rest.

Our preliminary results showed that PD patients with a relatively short disease duration (4 ± 1.3 y) exhibited MEP suppression during action preparation, similarly to healthy subjects. However, preparatory inhibition was less obvious in PD patients with a long disease duration (12.3 ± 2.3 y). In fact, in those patients, MEPs were only suppressed when the finger was not selected for the response. Interestingly, the lack of suppression found in the selected finger was even worse in the presence of DRT, especially in the dominant hand, where MEPs became facilitated.

Taken together, those results confirm the presence of preparatory inhibition in healthy subjects, as previously shown in the literature. This phenomenon is also evident in PD patients, but seems to decline throughout the disease. Most importantly, DRT medication appears to decrease the strength of preparatory inhibition, especially in the dominant hand, suggesting a role of dopamine in the mechanisms at the very basis of preparatory inhibition.

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[POSTER 20]

Risk Taking, Perceived Risks, and Perceived Benefits in Adolescents with and without ADHD: A Domain-Specific Risk-Return Approach

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Risk-taking behaviors such as risky driving and unsafe sex peak during late adolescence, compared to childhood and adulthood. Such behaviors–although partly considered normative–are associated with substantial individual and societal costs. Despite strong research interest, little is known about contextual factors and underlying mechanisms leading to the increase in risk taking behavior in adolescence compared to childhood and adulthood[1,2]. Youth with behavioral disorders, such as attention-deficit/hyperactivity disorder (ADHD), are particularly prone to risk taking. However, the domain-specificity and underlying mechanisms are hardly studied in youth with ADHD. Here, we used the newly developed adolescent version of the Domain-Specific Risk-Taking (DOSPERT) scale[3] to investigate the likelihood of risk taking, perceived risks, perceived benefits, and their tradeoff in two cohorts of youth with and without ADHD. The first cohort was a typically developing sample from an accelerated longitudinal study. Three-hundred forty-four 12-25-year-olds filled in the DOSPERT for 1 up to 3 times with varying time intervals (2 years and 6 months). A second cross-sectional cohort of 12-19-year old boys diagnosed with ADHD (*N*=81), and a sex, IQ, and age-matched control group (*N*=99) also filled in the DOSPERT. In the cohort of typically developing adolescents, results showed that internal consistency of the DOSPERT was satisfactory and comparable to the adult DOSPERT. Using mixed-effects models, we mainly found curvilinear age effects with a peak in likelihood of risk taking in mid-late adolescence in the ethical, health/safety, and social domains of risk taking, with similar curvilinear patterns in perceived benefits and perceived risks. In both cohorts, perceived risks and benefits were significant predictors of risk taking in all domains, with benefits typically showing stronger effects than perceived risks. In addition, results in the second cohort yielded limited group differences in overall likelihood of risk taking, risk perception, and benefit perception between the ADHD and matched-control group, except for the social domain. ADHD-youth displayed a particularly heightened likelihood of risk-taking behavior in the social domain compared to typically developing adolescents. Taken together, our results replicate the developmental inverted-U in risk taking observed in real-life with age and our results highlight the role of perceived benefits in risk taking in this age range. Moreover, these findings indicate a domain-specific risk-taking sensitivity in ADHD youth, in which heightened risk taking may occur specifically in the social domain. Together, these findings provide promising entry points for possible intervention and prevention efforts.

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[POSTER 21]

Viral Strategies to Target Fronto-Striatal Circuits for the Investigation of Action Control

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Selecting appropriate actions while inhibiting inappropriate ones is crucial to successful interaction with one’s environment. The inhibition or stopping of action can be classified into proactive (i.e. based on a subject’s internal processes) and reactive (i.e. based on an external cue) components. Previously, we identified the prefrontal cortex (PFC) as a critical structure in action control, with the subsections prelimbic (PL) and infralimbic (IL) cortex, as well as ventrolateral orbitofrontal cortex (VO) exerting different effects on proactive and reactive motor control [1]. Here, rats performed in a response preparation task where they were required to press a lever and then release it after a short (300ms) or long (1000ms) delay period cued by an auditory signal. While PL supported correctly timed responses in the long delay condition, IL facilitated early releases, confirming the previously suggested opposing roles of these two subsections [2,3]. VO, on the other hand, was mainly involved in reactive responses in the short delay condition.
Asides from interconnectivity within PFC subregions [4,5], the PFC is also densely connected with subcortical structures [6,7], such as the striatum, which is also hypothesized to play a role in motor inhibition [8]. In addition to reversibly silencing or activating defined areas in awake behaving animals, optogenetics also allows the targeting of cells in a projection specific manner. We employed this latter approach and tested the efficacy of the combination of a cre/double-floxed inverse open reading frame (DIO) system with a recombinant adeno associated retrograde virus expressing cre recombinase (rAAV2-retro-cre) versus a canine adenovirus expressing cre recombinase (CAV2-cre) for targeting varying circuits. While the two viral constructs showed similar expression patterns for cortico-striatal pathways, we found differing expression patterns while comparing to other circuits; in the cortico-thalamic circuit, CAV2-cre infected mostly layer VI cells, while rAAV2-retro-cre mainly targeted layer V cells in the PFC, confirming previous findings [9]. Furthermore, while CAV2-cre was sufficient for targeting the thalamo-cortical circuit, rAAV2-retro-cre was not effective for this pathway. In the response preparation task, we observed similar effects on performance with both viral constructs: an

increase in early releases in long delay trials while inhibiting PL-striatal projecting cells, and an increase in late releases in short delay trials while inhibiting IL-striatal projecting cells. However, when rAAV2-retro-cre was used for inhibition of PL-striatal projecting cells during the behavioral response task, the percent change in the performance was greater and more significant, than that found from inhibition with CAV2-cre. Thus, rAAV2-retro-cre seems better suited for targeting the cortico-striatal pathway, while CAV2-cre may be more appropriate for other circuits, such as the thalamo-cortical pathway.

When applying this projection specific targeting to a trained cohort of rats (n=3), we found similar effects of inhibition of PL- and IL-striatal projecting populations on performance in the behavioral paradigm as for the inhibition of PL and IL populations. This suggests that the previously identified roles of PL and IL in proactive inhibition depend on these fronto-striatal projections. These findings indicate the relevance of the fronto-striatal circuit for proactive motor inhibition.

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[POSTER 22]

Spending effort to purchase confidence: A cost-benefit arbitrage framework of resource allocation in perceptual decision-making

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Decision making, as a cognitive process, entails the mobilization of a resource [1], be it time [2], computational power [3], working memory [4], information processing channels [5], or metabolic [6]. Assumedly, the allocation of this resource drives the decision process and constrains it, for instance by setting thresholds over the decision variables which, when reached, would prompt the choice, in the spirit of the DDM family of models [7]. The Expected Value of Control (EVC) framework [8] describes the allocation of that resource as an optimization of a cost-benefit trade-off over the cognitive effort exerted. Here we extend this framework to perceptual decision making, in which behaviorally-relevant evidence is accumulated over time. Maximizing EVC in this context reduces to finding the response time that optimally balances choice confidence with the cost of information processing, given the reward at stake.

This model predicts that the relationship between response time (assuming a stable rate of sampling) and difficulty is non-monotonic. The optimal response time ramps up with low difficulties to ensure a satisfying level of choice confidence, and decreases once the difficulty compromises the estimated efficiency of information processing. This latter ‘disengagement’ regime cannot be predicted by established decision models, which are grounded on a threshold function set prior to stimulus processing. Conversely, the stopping criterion of the EVC depends upon the current (dynamically updated) stimulus representation, allowing for a more severe criterion whenever the stimulus is deemed too poorly informative.

To test the model, we performed an experiment with mice, based on a perceptual discrimination task in which difficulty and reward attached to the correct response are systematically varied. The set-up of the task is such that mice are continuously immersed within the task for weeks: they can freely initiate a trial at any time, and get rewarded with food, which is not provided to them otherwise. This allows for robust within-subject data acquisition of thousands of trials per individual.

In agreement with the EVC model of resource allocation, the mice spend more time processing the stimulus in the high reward condition. We also find an enhancement of their performance when incentivized with a higher reward. Additionally, the response time decreases with difficulty, which corresponds to the ‘disengagement’ regime predicted by the EVC model. Furthermore, we can reconstruct the whole non-monotonic relationship between difficulty and response time by accounting for inter-individual variability in information processing efficiency.

In conclusion, the theoretical frame of the EVC cohesively explains the non-trivial effects of both incentives and task difficulty on performance and response time. This gives empirical support to the idea that decision processes are shaped by a motivated allocation of cognitive resources. Future investigations will explore how lesions in the ACC, assumed to be responsible for the cost-benefit arbitrage, translate into decision-making deficiencies.

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[POSTER 23]

No sweat, no sweet? How monetary incentives inflate anticipated effort cost.

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Should you walk to the nearest bakery or cycle to your favourite one?

According to modern theories of value-based decision-making, when individuals ponder whether to incur an energetic expense in order to reach a desired state (a goal), they discount the subjective value of that goal by some function of the expense. These theories still make the implicit assumption that judgments about goal value and effort cost are made separately before being integrated into a decision variable computation. Yet, it has been decades since the first reports of an interplay between these judgments have appeared in the psychology literature. For instance, healthy people exhibit an 'effort justification' bias, i.e. they tend to value more the outcome of their more effortful actions. However, all reported interferences were so far only observed once effort was *already* expended. Here, we investigate whether, and how, effort cost judgments might be modulated by goal value *prospectively*.

For this, we devised a novel experimental paradigm in which healthy volunteers prospectively appraised the energetic cost of various action sequences leading to a more or less valuable outcome. Specifically, a monetary incentive (ranging from 1c to 10€) was displayed at the onset of each trial, followed by an animation depicting a cartoon character running along a more or less effortful multi-segment route on a treadmill (varying in slope and speed). Participants were then required to anticipate the energetic cost of that route. We ensured that cost judgments and incentives had personal significance to the participants by having them systematically choose between the displayed high-effort high-value option and a default low-effort low-value one, and then randomly implementing some of these choices in reality.

In a first experiment, although monetary incentive and real energetic cost were orthogonal to each other by design, we found a *positive* impact of incentive on prospective cost estimates. Three main psychological mechanisms could be put forth to account for this dependency: 1) a 'Belief' scenario where individuals incorporate information about goal value as a cue about effort cost, due to an implicit or explicit belief in a positive correlation between these two variables, 2) an 'Affect' scenario, in which affective states are modulated (along their valence or arousal dimension) by prospective rewards or losses, and in turn inform prospective effort cost judgments, 3) a 'Cost-Benefit' scenario, in which these judgments are partly "contaminated" by cost-benefit evaluations related to effort investment. In the latter scenario, participants automatically estimate the maximal effort they are willing to invest for the proposed outcome, or the optimal effort they should invest to secure this outcome. We extended our experimental paradigm and performed a second experiment in order to arbitrate between these mechanisms. Behavioural model-free and model-based results contradicted the predictions of the 'Belief' and 'Affect' scenarios, but were in support of the 'Cost-Benefit' hypothesis.

Overall, we identified a positive distortion of anticipated effort cost by goal incentive value, which was best explained by a contamination from the product of a cost-benefit analysis prescribing the energetic expense to invest.

The effects of optogenetic serotonergic stimulation on motor actions for future rewards in mice

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Serotonin (5-HT) is an important neuromodulator regulating behavioral, affective, and cognitive functions. Recent studies showed that the optogenetic activation of 5-HT neurons promotes waiting for future rewards [1, 2]. However, it remains unclear through what internal process activation of 5-HT promotes waiting - by increasing patience for delayed rewards, inhibiting motor actions, or both of them? To examine these processes separately, we trained Tph2-ChR2 transgenic mice (n=4) to perform the lever-pressing task, in which active motor behavior for future rewards rather than inhibition of motor action is required, and tested the effect of optogenetic activation of 5-HT neurons in the dorsal raphe nucleus (DRN).

In the lever-pressing task, mice could initiate a trial by poking their nose to a hole, which was followed by tone signal and presentation of a lever. Mice could obtain a food reward by pressing the lever required times, which was randomly chosen from 8, 16, 32, 64 and infinity (reward omission) every trial. A trial was ended either when mice could successfully press the lever and get the reward or when they abandoned a trial by a nose poke to a hole. From the first lever-press till the end of a trial, DRN 5-HT neurons were optogenetically activated by blue light in random half of the trials and not activated with yellow light in the other half.

Mice could almost successfully obtain rewards in 8, 16, and 32 presses trials, but the success rate decreased to about 80 % in 64 presses trials. Optogenetic activation did not change the success rate in 64 presses trials (85.3 ± 10.1 % and 82.9 ± 11.7 % with blue and yellow, respectively). In the reward omission trials, optogenetic activation did not change the number of lever-presses (99.2 ± 8.0 and 98.8 ± 11.9) and the time from the first lever-press to the last lever-press (56.9 ± 7.3 sec and 53.1 ± 7.6 sec). The inter-press intervals (IPIs), the durations between two neighboring lever-presses, showed the tendency to increase toward the end of an omission trial, but 5-HT neuron activation did not affect IPIs (0.58 ± 0.12 sec and 0.54 ±0.11 sec). These results indicate optogenetic activation neither enhances nor inhibits motor actions.

To verify the effectiveness of our stimulation protocol on mice behaviors, we also trained the mice for reward delay task and optogenetically activated DRN 5-HT neuron in half of the trials as in our previous studies [1, 2]. Consistently with the previous studies, optogenetic activation significantly increased waiting duration in omission trials (18.7 ± 0.8 sec and 16.1 ± 0.2 sec with blue and yellow, respectively, $p = 0.0214$ with paired t-test), indicating our optogenetic stimulation was sufficient to induce behavioral changes.

In conclusion, optogenetic activation of DRN serotonergic neurons does not inhibit or enhance motor actions for future rewards, while it enhances stationary waiting. This may be due to different neural substrates responsible for delay-based and effort-based behaviors [3] modulated differentially by 5-HT.

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[POSTER 25]

The causal role of temporoparietal junction in computing social influence in human decision-making

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Decision-making in social contexts is commonly driven by two major sources of social influence [1]: normative influence (i.e., leading to public compliance) and informational influence (i.e. overwriting private beliefs). Our previous work has established a comprehensive neurocomputational account of social influence in human decision-making using a novel experimental paradigm [2]. Crucially, we have dissociated these two types of social influence, and have identified that bilateral temporoparietal junction (TPJ) encodes normative influence. However, it remains unclear whether the effect of normative influence causally depends on activity in the TPJ. Here, we present a transcranial magnetic stimulation (TMS) study (N = 40) using a similar paradigm as previously [2] with slight modification. The core of this paradigm is a probabilistic reversal learning task [3]. Participants on each trial were first required to choose between two stimuli, after they have seen the choices from four other co-players, they had the opportunity to adjust their choices. Probabilistic reward was then delivered given their second choice. Notably, participants were instructed that they would play this game with four "intelligent computers," and choices from those computers were in fact generated from our winning model and the associated posterior parameters [2], such that they matched with actual human behavior. We ran 3 TMS sessions in a within-subject design. At the beginning of each TMS session, we administered theta-burst repetitive TMS [4] over right TPJ, left TPJ, or vertex of each participant with a counter-balanced order. To increase ecological validity, we used human faces to indicate each computer. Behavioral results indicate that disrupting activity in the left TPJ resulted in reduced choice switch probability (i.e., less influenced by the social information), relative to the right TPJ and vertex conditions. No significant difference was observed between the right TPJ condition and the vertex condition, and behavioral patterns from both conditions were comparable with previous findings [2]. Computational modeling with hierarchical Bayesian parameter estimation [5,6] suggests that the corresponding parameter quantifying normative influence significantly decreased in the left TPJ condition, as compared to the right TPJ and vertex conditions. However, the extent to which informational influence (i.e., social learning) was integrated into individuals' valuation processes was comparable in all three conditions. Together, our results provide evidence for the causal role of left TPJ in computing normative social influence in human decision-making, whereas the integration of informative social influence in value computation remains intact. These results corroborate our previous findings showing distinct neurocomputational networks for normative influence and informational influence.

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[POSTER 26]

Neurocomputational bases of learning to avoid harm to others

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Adapting behavior to avoid harm is a deeply engrained skill of all mammals [1]. However, in social contexts, our actions might also harm others. It is currently unclear whether learning to avoid harm to others is functionally similar to learning to avoid self-harm, and whether these two types of learning are supported by similar neural processes. Recent research indicates a central role of empathy in reward-based learning for others [2] and observational fear learning [3]. We therefore hypothesized that learning to avoid others' harm depends on individual empathic abilities. To investigate the neurocomputational bases of other-oriented learning, we conducted a functional magnetic resonance (fMRI) study in combination with computational modeling.

Seventy male volunteers (age range 18 - 40) were recruited, and paired with a male confederate. To test punishment-based learning for self and other, we used a two-alternative forced-choice learning task, where one choice option was associated with a high probability (70%) of a painful shock, and the other with a low probability (30%). Crucially, the recipient of the resulting shocks differed between experimental conditions. In the *Self* condition, participants received the shocks themselves, while in the *Other* condition, the shocks were delivered to the confederate. Additionally, participants completed a paradigm designed to elicit empathic responses to the other's pain [4].

Computational modeling showed that participants' choices were best accounted for by a reinforcement learning model involving separate learning rates for positive and negative outcomes, but with no differences in computational mechanisms between self- and other-oriented learning. FMRI data analyses revealed significant activations of the nucleus accumbens during positive feedback for both recipients, while negative feedback was associated with activations of the anterior midcingulate cortex (aMCC) and bilateral anterior insula (AI). Moreover, generalized psychophysiological interaction analyses (gPPI [5]) showed increased connectivity between the aMCC and the right supramarginal gyrus (rSMG) during other-related feedback. Lastly, increased activation of the aMCC and AI during the perception of the other's pain predicted the number of correct choices for the other. This activation increase was also significantly correlated with activity in the right temporal pole during other-related positive feedback in the learning task.

These findings provide evidence that learning to avoid self- and others' harm is implemented by partially overlapping neural processes, as indicated by activation changes in nucleus accumbens, aMCC and AI for both self- and other-related feedback. However, our results also point towards specific contributions of areas related to social cognition during other-oriented learning: activity in the aMCC and AI during the perception of the other's pain was positively correlated with task performance while learning for the other, supporting our hypothesis that other-oriented learning depends on empathy-related processes. Moreover, participants with higher other-pain related activity in aMCC/AI also exhibited higher activation during other-related feedback in the right temporal pole, possibly indicating an increased recruitment of theory of mind [6]. Finally, increased connectivity between aMCC and rSMG during other-related feedback implies the involvement of self-other distinction in this learning modality, indicating a putative shift of attention from self- to other-directed consequences [7].

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[POSTER 27]

Testosterone affects learning of implicit social dominance relationships from competitive interactions

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Social dominance hierarchies play a prominent role in our daily lives (e.g., in our social network). Attaining high social dominance (i.e. status) provides access to limited resources and rewards. Therefore, learning one's position and that of others within a social dominance hierarchy is vital for survival and successful social interactions. A key neurobiological substrate associated with dominance and status-relevant behaviour is the androgen testosterone [1], which has been found to correlate with monitoring social threats [2], as well as reduced threat and punishment sensitivity [3]. Relatively little is known about testosterone's role in learning social dominance hierarchies, and how this may affect decisions in dynamic social interactions. Previous research has shown that areas that contain androgen receptors [4], such as the medial prefrontal cortex (mPFC), amygdala and striatum, underlie monitoring and learning of dominance relationships [5,6]. Here, we examined how exogenous testosterone influences learning of social dominance hierarchies.

Forty-five males (M_{Age} = 25.2 years, SD = 3.64) partook in a cross-over double-blind placebo-controlled paradigm. Participants learnt an implicit dominance hierarchy while playing a competitive task against three opponents of different skills (which was used as a proxy for their dominance ranks). Each round, participants had to decide whom they wanted to compete against, and received feedback whether they won or lost. As a non-social control, participants played a reinforcement learning task in which they had to track reward contingencies of different fractals. Learning was assessed by using a selection of reinforcement-learning models based on prior research [5], and a softmax decision rule to translate opponent-specific dominance values into choice probabilities.

Participants learnt the opponents' dominance ranks as shown by an increased choice preference for the lower ranked (i.e. weaker) opponent of each pair (p<.001). Testosterone did not influence choice behaviour for specific opponents as compared with placebo, but affected the learning of their dominance ranks as shown by model comparison (p<.05). A dual-learning rate model which allowed for different learning rates for victories and defeats in the update of the dominance value of the specific opponent showed that testosterone (vs. placebo) reduced the learning rate for defeats over victories (p<.01). Importantly, testosterone did not influence learning during the non-social learning task as compared with placebo (p>.05). Subsequent analysis revealed that testosterone influenced competitive decisions depending on the personality trait of behavioural inhibition (BIS scale [7]), such that testosterone (vs. placebo) increased choosing the lower ranked opponent in competition among individuals with higher BIS (reflecting more subordinate personality profiles).

Together, testosterone enhanced the asymmetry of learning from victories and defeats while learning the dominance ranks of their opponents. These preliminary findings suggest that testosterone likely reduces sensitivity to threat and negative outcomes when upregulating one's own dominance rank. This, in turn, may reduce avoiding to re-challenge an opponent while forming new dominance hierarchies in dynamic interactions. Future fMRI analysis should reveal whether testosterone affect learning via moderating the functional connectivity between amygdala and mPFC, a key network involved in monitoring dominance ranks and threat perception [7,8].

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Relationships between serotonin transporter rate and brain activity associated with learning of social ranks: a simultaneous TEP([11C]-DASB)-fMRI study in humans

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Dominance hierarchies are ubiquitous in the animal kingdom. Knowing one’s own rank in a group is crucial to have access to resources and to avoid harmful social interactions. Serotonin may play an important role in the regulation of social dominance hierarchies in animals. It is still unclear what the precise role of serotonin is in the neurobiological mechanisms supporting learning of social hierarchies in humans. Stress originating from competitive social interactions is implicated in various mental disorders (e.g., anxiety and depression [1]). Moreover, personality traits such as trait anxiety, have been related to serotonergic neurotransmission and sensitivity to stress, and specifically to the serotonin transporter binding potential [2]. Yet, little is known about the relationship between inter-individual differences in brain responses to learning social hierarchies (from experiencing social victories and defeats), serotonergic function during competitive interactions and personality traits related to stress and anxiety. To investigate these relationships, here, we examined the role of serotonin transmission during learning of social ranks in men, using a combined PET-fMRI scanner.

Participant (30 males; M age 24 ± 4 y.o) were scanned in a simultaneous PET- 3T fMRI scanner using the serotonin reuptake transporter (SERT) with the [11C]-DASB tracer. In a Social Dominance Learning task (SDL), participants had to learn their social ranks by competing against other individuals within a group of four. As control condition, participants performed a classical non-social reinforcement learning task (RL) in which they had to learn how to maximize their payoff by choosing between two probabilistically rewarded fractals. After scanning, participants completed questionnaires (State and Trait Anxiety Questionnaire (STAI), Beck Depression Inventory (BDI), Social Dominance Orientation (SDO) and Self-esteem questionnaires).

The behavioral results revealed that participant learned both the RL and SDL tasks. We found a positive correlation between STAI anxiety temperament and Dominance indices scores (obtained by adding both Social Dominance Orientation and self-esteem assessment). At the brain system level, the ventromedial prefrontal cortex (vmPFC) tracked both positive and negative prediction errors during the social learning task, but not during the non-social control RL task. PET analyses are on-going. Understanding how vulnerability to stress - determined by personality traits - modulates the interaction between serotonin transporter activity and brain responses to learning dominance hierarchies, will have implications for our understanding of the neural mechanisms underlying the effects of social stress on social interactions, mental disorders and health in general.

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[POSTER 29]

Temporal structures in reaction time correlate to performance but not to self-assessed attentional state or personality traits

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Human performance shows substantial endogenous variability over time. Such variability has been known to show temporal structures: Performance from action to action is not independent, but shows correlation with itself over time. Two recent studies have linked temporal structures to individual differences in behaviour, but with contrasting results - with one study finding a positive correlation between temporal dependency and good performance in a Go/No-Go task [1], and the second finding a negative correlation in a Continuous Temporal Expectations Task [2]. In spite of these differences, both studies interpret their findings as evidence for the critical brain hypothesis. However, measures of performance on such tasks are not straightforward, because they are partly depended on individual strategies. More generally, these temporal structures are highly difficult to interpret, as their properties remain largely unknown. In the current study, we aim to investigate the intra-individual repeatability (25 participants, tested in two sessions ~45 minutes apart) of the temporal structures. Furthermore, we were interested in the inter-individual correlates (83 participants), specifically looking at links with objective task performance, subjective attentional state, and self-assessed ADHD tendencies, mind wandering, and impulsivity. Participants completed the Metronome Task [3] - in which they press in synchrony with a metronome tone. This task is particularly suited for capturing endogenous fluctuations in performance. Occasionally, participants are presented with a thought probe, and are asked to rate their current attentional state. Results indicate that autocorrelations at lag 1, Power Spectra Density slopes, and Detrended Fluctuation Analysis slopes all show good intra-individual repeatability over time, but ARFIMA(1,d,1) parameters did not. Furthermore, the three reliable temporal dependency measures show between-subject correlations to performance- such that good performance was associated with lower temporal structures. However, we found evidence against correlations with the subjective attentional state ratings as well as with self-assessed personality traits. Overall, while the temporal structure measures thus show good reliability, their use for studying individual differences appears to be limited so far. Future research may focus on the extent to which the temporal dependency measures can be influenced by experimental manipulations, to find out if it captures any neural-cognitive mechanisms.

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[POSTER 30]

The Readiness Potential reflects endogenicity, not uncertainty

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Voluntary actions are preceded by the Readiness Potential (RP), a slow EEG component generated in supplementary motor area. The RP is usually thought to reflect motor preparation after a decision to act has been made. Recent work suggests instead that it may reflect the evidence accumulation process underlying the decision itself, with weak noisy evidence. To test this account, we recorded EEG in a task where participants decided to act or withhold action to accept or reject gambles. We contrasted three kinds of gamble. Some decisions had clearly postive or negative expected value, and were consistently accepted or rejected (*choices*). Others had approximately neutral expected value, and were sometimes accepted and sometimes rejected (*picks*). On other gambles again, participants had to decide whether or not to gamble without knowing the odds and possible outcomes (*guesses*). Choices are driven by strong external cues, picks by weak external cues, and guesses by weak endogenous cues.

We used a Laplacian filter and PCA to isolate a preperatory motor analagous to the RP. We found that this component ramped up slowly prior to actions for guesses, but not for choices or picks. We conclude that the RP precedes decisions to act based on endogenous cues, rather than weak cues. These findings can be accommodated by evidence accumulation models of voluntary action, but only with substantial modifications.

[POSTER 31]

Functional comparison of the social brain in macaques and humans

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The Temporo-Parietal junction (TPJ) in humans has been associated with the ability to attribute thoughts and beliefs to others, a key ability to support complex social decision-making and often thought to be uniquely human. Despite the reorganisation of the temporal cortex that has occurred in humans since the last common ancestor with macaques[1], comparative neuroanatomical studies have identified the middle Superior Temporal Sulcus (mid-STS) in macaques as a potential homolog to the human TPJ[2]. However, the computations supported by the mid-STS remains unknown, therefore we aimed to assess in this project the functions associated with the mid-STS in macaques.

We used a set of three free-viewing fMRI tasks in fourteen macaques and corresponding tasks from the Human Connectome Project (HCP). We first used a standard face localizer task to test the sensitivity of the macaque STS to low-level social information. We identified reliably across individuals five face patches reported previously in the STS[3], the middle fundus (MF) and lateral (ML), the anterior fundus (AF) and lateral (AL) and the anterior medial (AM). We also identified face-patches in the human temporal cortex, including the TPJ. We established the connectivity profiles of this face patches using a seed-based correlation analysis on the resting-state data of each macaque and were able to perform a similar analysis on the resting-state data from the HCP. Our results confirm the connectivity similarly between macaque middle STS and human TPJ[2]. Indeed, ML, MF, AL, AF show strong connectivity to midline regions such as the medial prefrontal cortex and the posterior cingulate cortex[4], as do the TPJ. Next, we addressed the question of the coding of a social prediction error because it is thought to be the core computation at the basis of Theory of Mind abilities in humans and involves the TPJ[5]. We presented videos showing macaques involved in social interactions that were either predictable or contained an unpredictable social event. We had similar videos with objects instead of monkeys as controls. We revealed regions corresponding to MF and AF in macaques which show more activity for the unpredicted condition than for the predicted condition. Interestingly, the activation for the same contrast in the object condition was restricted to the ventral bank of the mid-STS, therefore not overlapping with the dorsal bank of MF and AF. Finally, we also conducted a task consisting of cartoon of geometric shapes moving either randomly or socially. It has been shown that humans are able to detect the difference with an increased activation in the TPJ for the social condition[6]. In macaques, we could not find any difference in brain activation for the social versus the random interaction. This result can have multiple interpretation, from the macaques not being able to infer sociality to abstract shape to a more parsimonious interpretation related to the cultural differences.

Overall, this study shows that a region in mid-STS previously identified based on its connectivity profile similarity with the human TPJ also shares some social functions, such as face responsiveness and social prediction error.

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[POSTER 32]

Counterfactual learning supports context-dependent social behaviour

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A core aspect of healthy social function is the ability to map private states onto public actions according to the current social context. For example, it may be socially appropriate to express gratitude for a gift we do not want, or remorse for an action we do not regret. Here, we studied how people learn such context-dependent private-public mappings, using a social interaction task which required subjects to adapt how they reported their confidence about a perceptual decision according to the social context. For example, one context required subjects to publicly overstate what they privately thought in order to maximise reward. Computational modelling revealed that the learning of such context-dependent private-public mappings was supported by two distinct processes: an evaluation of the outcome associated with the chosen mapping from a private state onto a public action (reward prediction error; e.g., I felt ‘unsure’ and said ‘unsure’ but the outcome was negative) and an evaluation of the outcome that could have been obtained had another mapping been chosen (counterfactual prediction error; e.g. the outcome could have been positive had I said ‘sure’). Our study is consistent with recent work on counterfactual learning in non-social domains and highlights that an appropriate balance between factual and counterfactual processes is essential for healthy social function.

A role for the noradrenergic system in the precision of reward-guided learning

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When learning the value of actions in volatile environments, humans make a sizable fraction of 'non-greedy' decisions which do not maximize expected payoff. In a recent study [1], we have shown that a significant proportion of these decisions is driven by computational noise in the sequential update of action values rather than by choice stochasticity. In other words, learning noise triggers variability in the update of action values, which leads to seemingly non-greedy decisions - thereby providing a computationally inexpensive source of exploration.

Based on neural and pupillary correlates of learning noise [1], we have proposed that the locus coeruleus-norepinephrine (LC-NE) system controls the precision of learning. This prediction contrasts with the dominant theory of the LC-NE system which postulates that tonic increases in NE result in task disengagement and exploratory behavior [2] - despite inconclusive experimental evidence [3,4]. In a recent study [4], Jepma and colleagues performed a pharmacological manipulation of the LC-NE system in a double-blind controlled experiment. Healthy adult subjects played a four-armed restless bandit task [5] under one of three conditions. $N = 18$ played the task under reboxetine, a selective NE reuptake inhibitor, $N = 16$ under citalopram, a selective serotonin reuptake inhibitor, and $N = 17$ under placebo. Computational modeling of behavior using standard models without learning noise showed no increase in choice stochasticity under reboxetine.

We hypothesized that tonic increases in NE would generate learning noise rather than choice stochasticity. With permission from the authors, we reanalyzed their dataset using our computational framework [1] which postulates the existence of learning noise. First, Bayesian model comparisons revealed the presence of learning noise in all three conditions ($BF > 10^{40}$). Second, participants under reboxetine featured *more* learning noise than participants in the two other conditions (reboxetine vs. placebo, $p < 0.01$, reboxetine vs. citalopram, $p < 0.001$). Importantly, citalopram and placebo conditions showed no difference in learning noise ($p > 0.2$). Surprisingly, participants under reboxetine showed *less* choice stochasticity than participants under placebo ($p < 0.001$). These opposite effects of reboxetine on learning noise and choice stochasticity explain previously inconclusive results [4], obtained using models confounding these two sources of behavioral variability.

Together, these findings indicate an important, yet previously unsuspected role for the noradrenergic system in the precision of reward-guided learning.

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[POSTER 34]

Employment of conceptual relations for social learning and cooperative decision-making

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Everyday social interactions vary substantially. Therefore, humans often need to abstract away from the interaction at hand and employ generalized concepts for similar persons and situations. Humans tend to describe persons in terms of abstract character traits and situations in terms of generalized decision rules. That is, humans learn continuously about the traits of persons they interact with (e.g., how polite, helpful, and diligent is another person?). These traits are conceptually related (e.g., polite persons tend to be helpful but not necessarily diligent). Analogously, decision rules tend to be refined over time and related across different cooperative situations (e.g., if possible, let's both sidestep to the right to avoid bumping into each other). The first aim of the to-be-presented work was to use behavioural modelling to assess whether the relations between character traits guide learning. The second aim was to provide evidence for a representation of the relations between these traits in fMRI signals within the medial prefrontal cortex, a region commonly involved in social cognition and in abstract representations. The third aim was to test whether humans follow optimal decision rules in cooperative games with different spatial layouts.

To address the first aim, we devised two behavioural studies, in which participants (n=36; n=41) predicted how four other persons had previously rated themselves on a series of character traits. Participants received veridical feedback. Conceptual relations of these traits were derived from self-ratings of independent samples (n=835). For the second aim, we applied representational similarity analyses in two fMRI studies, in which participants (n=27; n=30) were asked to rate themselves on various character traits. To address the third aim, we tested pairs of participants (n=30) in a behavioural task, in which cooperation could be achieved via multiple–a priori–optimal paths through a "grid world."

Behavioural model comparisons showed that participants learned about the character traits of other persons by employing the conceptual relations between traits in a reinforcement learning framework. Representational similarity analyses of fMRI data in a non-learning task indicated that these conceptual relations between traits were reflected within the medial prefrontal cortex. Analyses of decisions paths suggested that participants managed to find optimal decision rules in most "grid worlds."

Overall, our work specifies how humans harness different types of conceptual relations that are relevant for learning and decision-making in social interactions. We will further investigate how such conceptual relations could be represented in the medial prefrontal cortex.

[POSTER 35]

Dynamics of Adaptation to Social Norms

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Different social groups solve PD-like (prisoner-dilemma) scenarios in different ways [1-3]. Some scenarios are solved by cooperation and prosocial behaviour, while other groups and scenarios are set on competition between group members. When most players behave in a similar manner most of the time, it is to each player's advantage to follow the current norm governing others' behaviour - either behave prosaically and cooperate or compete with others. This entails tracking other's behaviour and adapting one's own behaviour accordingly. In four experiments I examined the learning process underlying adaptation to social norms. To this end I adapted a sequential social dilemma paradigm [4] to form a grid-world game. In this game multiple players moved about a 2D grid, collected stars and could send each other to a time-out zone by sacrificing a move and zapping them. The participants played with three other players, which were preprogramed to be either competitive, zapping players that stand between them and a star, or prosocial, moving out of the way and harvesting their own corner of the grid. The first experiment examined participants' zapping behaviour as they moved from one social norm to the other. The results showed that participants adapted to the social norms around them, by increasing and decreasing their zapping behaviour. Adaptation was attenuated when moving from competitive to prosocial norms, compared with moving from prosocial to competitive norms. In a second experiment the valance of the zaps was flipped, and they conveyed a positive outcome of increased score to the affected player. Prosocial behaviour was now associated with zaps, and competitive behaviour with zap avoidance. A series of reinforcement learning models were fitted to the zapping behaviour, revealing that learning was more affected by observing and experiencing active zaps compared with passive zap avoidance. In addition, participants were found to generalize from one player's actions to others. An overall gender effect was found, in which females were less likely to follow competitive norms and more likely to follow prosocial norms, regardless of the active/passive nature of the norms. In two additional experiments different aspects of social learning predicted by the models were examined. In experiment 3, participants were shown to differentiate between competitive and polite players, and zapped the polite player less than the competitive player. In experiment 4 participants treated differently than other players - they were 'singled out'. The other players either avoided zapping them while zapping each other, or zapped the participant while avoiding zapping each other. In both conditions participants zapped less than in the competitive social norm of experiment 1, and more than in the prosocial norm. Overall these results indicate that people incorporate different levels of learning about new social norms and social settings. People can generalise from observation of others' interactions, learning in a 'group level'. When the players in the group show distinct patterns of behaviour 'person level' learning takes place. In addition, learning is affected by the nature of the observed actions, 'action level' learning, in which action's saliency (active/passive) affects learning.

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[POSTER 36]

Why not reading this abstract tomorrow? A procrastination model based on how the brain discounts effort and reward with time

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Why do we put off things that we know we should do? Humans frequently procrastinate despite being aware about potential adverse consequences. Yet, the cognitive and the neural underpinnings of procrastination remain poorly understood. Here, we combined computational modeling with functional Magnetic Resonance Imaging (fMRI) to predict the behavior of participants deciding when and whether to perform effortful incentivized tasks. Participants (n=45) first performed two separate intertemporal choice tasks, opposing immediate and delayed rewards on the one hand, immediate and delayed efforts on the other hand. Time discounting factors varied a lot across individuals, with procrastinators exhibiting steeper discounting of effort, relative to reward, than non-procrastinators. This differential time preference was reflected in the neural activity of the ventromedial prefrontal cortex, anterior insula, and dorsal anterior cingulate cortex. We then modeled the choice of when to perform an effortful task as a series of momentary decisions between doing it now or later. When informed about individual time discounting factors, this computational model provided a reasonable account for choices made by participants between performing a task now or tomorrow. Moreover, the model predicted a significant amount of variance in the time participants took to complete and send the administrative forms that were mandatory for receiving their payoff. Our findings therefore suggest that recurrent procrastination arises from the brain discounting effort more than reward with time, which exerts a repeated bias on the decision about doing it now or later.

The “social pole”: frontal pole activity of macaque monkeys differently reflects the social and nonsocial agent in an interactive task

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The Frontal Pole (FP) also known as Broadmann’s area 10 represents the most anterior part of the frontal cortex in primates and contributes in many aspects of cognition. Human imaging studies suggest that the FP largely contributes to complex reasoning and problem-solving and that its position among the neighboring prefrontal regions enables a flexible control of decision-making [1]. To date, the only electrophysiological study available highlights the importance of the FP in the encoding of monkey’s decision at feedback time [2]. The present work aims to study the contribution of the FP in the monitoring and the evaluation of goals achieved through self-generated decisions and other agent’s decisions. With this purpose, we recorded the activity from three 96-channels arrays implanted on the frontal pole of two monkeys while they performed two different versions of a Non-Match-To-Goal task. In this task, monkeys had to make their current choice based on the choice they previously made, selecting the target object not chosen in the precedent trial. Following the same Non-Match-To-Goal rule, the monkeys performed the task in two different conditions, interacting with a human or a computer agent. Both monkeys showed high performance in both tasks. They were able to keep in mind not only their own previous choice but also the human’s or the computer’s choice to subsequently make their own choice in their following trial. We recorded the single-unit activity of 319 cells to investigate whether and how FP neurons encoded the agent identity. As reported before [2], the greatest modulation was found around feedback time. Of 319 cells, 109 (34%) cells were modulated at feedback time depending on who performed the trial, either the monkey or the human partner. In the same way but to a less extent, 62/319 cells (19%) showed a significant difference in their activity at feedback time between monkey and computer trials. This finding indicates that the FP distinguishes agents, monitoring differently self-generated and others agent’s behaviors. The higher number of cells encoding the agent in the human interaction condition compared to the computer interaction condition (34% vs 19%, $p < .001$) indicates that the FP also differentiates real physical agent from computer and plays a key role in social cognition.

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[POSTER 38]

Prosocial influence in decision making is amplified in adolescents relative to adults

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Adolescence, defined as the period of life between puberty and adulthood, is associated with heightened social influence, especially by peers (Blakemore, 2018). Existing studies on peer influence in adolescence have tended to focus on social influence on risky decision making and risk perception (Reniers et al., 2017). Here, we focus on prosocial decisions, specifically, decisions that are costly to oneself but beneficial to others. We investigate whether social influence is affected by the age of participants, the age of the influencer, and the direction of influence, namely, whether the behavior of influencers is more or less prosocial than that of the participants.

220 participants (106 females) aged 11-35 years were divided into three age groups for comparability with previous research: young adolescents (11-14), mid-adolescents (15-18) and adults (23-35). We also investigate age as a continuous variable. To measure prosocial behaviour, we combined a charitable donation task (Harbaugh, Mayr, & Burghart, 2007) and a norm-compliance task (Izuma, 2013): in a first phase, participants were allotted 50 tokens with real monetary value and asked to decide how many, if any, they wished to donate to a number of charities. In a second phase they were shown how many tokens others (i.e., either teenagers, adults or a computer) donated to the same charities and were then asked to donate once more. We measure prosocial influence as the probability of changing donation in the direction of the influencer.

We found that for all ages prosocial influence was more likely when the influencers were other people as opposed to a computer. This speaks against non-social influence effects, such as anchoring. We also found that prosocial influence was more likely for young adolescents than adults, while we observed that all ages were equally influenced by adults and teenagers. Finally, we found that age effects of prosocial influence interacted with the direction of influence: adults were more likely to be influenced towards selfish behavior than prosocial behavior, whereas adolescents were equally likely to be influenced in both directions. This was additionally reflected in response times: under prosocial influence, age linearly decreased response times of *non-conforming* decisions, suggesting that age reduces prosocial influence. Conversely, under selfish influence, age quadratically affected response times of *conforming* decisions, peaking during mid adolescence. This suggests that mid adolescents are especially reluctant to conform with social influence that promotes selfish decisions.

These results demonstrate that prosocial influence is age dependent, and is specifically higher in young adolescents relative to adults. Previous studies observed similar findings in the domains of risk and self-reported prosocial behavior. These results extend those to incentivized prosocial decisions. Furthermore, relative to adolescents, adults display a heightened directional bias in prosocial influence, preferentially adapting their decisions to selfish rather than prosocial behavior. Taken together, these results highlight the potential for interventions that harness social influence to foster adolescent prosocial behavior in real world settings (Paluck, Shepherd, & Aronow, 2016).

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[POSTER 39]

Impaired learning from conflicting action outcomes in obsessive-compulsive disorder

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Obsessive-compulsive disorder (OCD), a prominent psychiatric condition characterized by repetitive, stereotyped and maladaptive behavior, is often described as a 'doubting disease'. In agreement with this view, OCD patients show elevated decision thresholds when categorizing ambiguous stimuli and have difficulty adapting to the statistics of volatile environments [1-3]. While these past studies consistently point toward an inflated perception of uncertainty in OCD, they have failed to distinguish between two different forms of uncertainty at the heart of two classes of decisions: uncertainty about the external cause of observations as in perceptual decisions, or uncertainty about the outcome of one's actions as in reward-guided decisions. We hypothesized that OCD patients should show increased difficulty learning from outcomes of their actions than from cues independent of their actions. To test this hypothesis, we relied on a recently developed reversal learning task and a computational framework [4,5] which affords to contrast cue- and outcome-based inference in tightly matched conditions. Quantitative analyses of behavior revealed that OCD patients (*N* = 17) perceived uncertain environments as more volatile than matched healthy controls (*N* = 23) across cue- and outcome-based conditions, in agreement with previous findings. However, in agreement with our hypothesis, OCD patients also showed a selective impairment in outcome-based inference relative to healthy controls. Multivariate pattern analyses of magnetoencephalographic (MEG) signals recorded in OCD patients explained this behavioral impairment by a degraded neural coding of conflicting evidence in the outcome-based condition, an effect absent from the cue-based condition despite matched levels of uncertainty. This impaired processing of action consequences is consistent with a decreased 'sense of agency' (perceived degree of control) in OCD patients. Together, these findings urge to reconsider OCD as a disorder of doubt regarding the consequences of one's own actions.

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[POSTER 40]

Social learning relies on distinct cognitive mechanisms in adolescents with and without autism

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Many of our efforts in social interactions are dedicated to learning about of others' preferences, mental states, and behaviors, an ability referred to as Theory of Mind (ToM). ToM abilities continue to develop throughout adolescence and are associated with both positive peer relationships and emotional wellbeing. Adolescents with ASD show core deficits in ToM, which have been a main focus in social skill trainings and interventions for this age group. Despite the large body of research specifying ToM deficits and intervention outcomes of adolescents with ASD, a mechanistic understanding of how individuals integrate environmental cues to learn about others is lacking.

Here, we aim to reveal the cognitive mechanisms underlying learning about others' preferences in adolescents with ASD using a computational modeling approach. In a next step, we will explore the neural implementation of these cognitive mechanisms.

We devised a novel preference task, in which TD adolescents (N=26), and adolescents with ASD (N=20) rated how much three peers liked a variety of items (e.g. activities, fashion items and food) in the MR scanner. After each rating they received trial-by-trial feedback about the peer's actual preference ratings. Participants could improve their predictions about a new item by integrating feedback about past similar items into their judgements. After they completed this learning task, they had to rate their own preferences for the same items outside the scanner.

The preference profiles used in the learning task were those of real adolescents who participated in an online preference survey. In total, we obtained 103 preference profiles. Three profiles were selected for the learning task and the remaining 100 were used to compute priors for learning (e.g. an individual's prior knowledge about their peers' preferences).

Mean prediction errors, the differences between participants' judgements and feedback they received on a trial-by-trial basis, did not differ between groups. To test finer-grained group differences in learning strategies, we devised various computational models: non-learning regression models and reinforcement learning (RL) models that describe participants' judgements over time based on previous feedback alone, or based on a combination of feedback and either own preferences or priors. We also tested more sophisticated models that assume participants represent relationships between item preferences for their peer group as a generic preference matrix, which is updated over

time to represent unique preference relationships for the peer in question (henceforth SWEEP-RL model). Bayesian model comparison revealed that preference ratings of TD adolescents relied on a combination of SWEEP-RL and participants' own preferences. In contrast, preferences of ASD adolescents were best described by a non-learning model that relied on simple priors (i.e. peers' average preference ratings) for each item.

We show that computational models are well suited to differentiate between social learning strategies of TD and ASD samples. In a next step, we will explore how parameters derived from the winning model for either group are implemented in brain activity. This will provide biological validity for the models and help specify differences in the underlying neural mechanisms of social learning in adolescents with ASD.

[POSTER 41]

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

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Competition and cooperation are two fundamental orientations in social cognition that can either hamper or facilitate group or individual achievements. In everyday life, our interactions with others entail different motivational goals eliciting both cooperative and competitive states of mind. For example, organizing a trip with a friend involves a cooperative behaviour whereas in a game played during the trip, the same friend can become a competitor. Therefore, an optimal behaviour during the whole trip requires the brain to be able to quickly adapt to the social context to adjust decision making. However the precise neurological rules governing this trade-off are unknown.

To investigate the behavioural and neural trade-off between competition and cooperation and how it is modulated by social context, we collected fMRI data while participants played a novel social economic game, which we named the Space Dilemma (SD). The SD game was designed to provide a continuous, dynamical and probabilistic generalization of the Prisoner's Dilemma.

Without deception in the task, 25 couples of unfamiliar players (with one participant inside the scanner and the other outside) made a prediction about the location of a random target on a linear space and were rewarded according to the precision of their prediction (i.e. proximity to target) and that of the other player. Each trial was won by the player closer to the target. Players chose the middle of the linear space (the position closer to the random target, on average) or moved away from it to the left or to the right, thus trading a higher chance of winning (competitive strategy) against a higher reward in case of a win (cooperative strategy), respectively. The continuous nature of the task allowed for a precise parametrisation of the level of cooperation of each player in any trial. To manipulate the social context, we instructed the participants about different reward distributions implicitly informing them about the risk associated with defecting cooperation. Participants player the Space Dilemma in three conditions, a cooperative one (where the rewards was shared 50-50 irrespective of the winner), a competitive one (where the loser incurred in a penalty) and an intermediate one. Validating our new approach, participants played more competitively when the risk associated with defected cooperation was high, whereas they exhibit cooperative behaviours when that risk is absent. The extent of this contextual modulation was reflected in the variability in the activation and in the functional coupling of a network of areas implicated in decision making, evaluation and theory of mind. This network included the striatum, ventromedial, dorsomedial and ventrolateral prefrontal cortex, temporal parietal junction and anterior and middle cingulate cortex and encoded both players' and opponents' choices and rewards.

Taken together, this combination of game theory and fMRI measurements allowed us to compare directly a competitive and a cooperative scenario and provided primary evidence that the brain continuously encodes the current social context to set the behavioural and neural trade-off between cooperation and competition.

[POSTER 42]

How pre-choice neural activity influence value-based choices: an intracerebral investigation

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Choosing to do something because the perceived gain outweighs the estimated loss is something people do routinely. Contemporary principles of decision theory assume that gain-loss integration processes can be modelled as a gradual accumulation of the net difference between gains and losses over time. However, the neural mechanisms underlying this type of decision remain unclear. Whereas fMRI in humans have suggested that separate cortical areas represent gains and losses respectively, animal electrophysiological recordings have indicated that integration of both dimensions may be possible at the single-cell level [1].

Another important issue in the literature is that the variability of ongoing brain activity (baseline) is often considered as biological “noise” and is usually eliminated to optimize task-related brain responses. Yet, recent evidences established that such pre-stimulus neural activity actually play a critical role during the subjective evaluation of either gains or losses [2]-[3].

In particular, a recent fMRI study relied on the well-known phenomenon that mood influences choice to demonstrate that mood fluctuations, induced by positive and negative feedback, were expressed in the baseline activity of two critical regions of the valuation network, ventro-medial prefrontal cortex (vmPFC) and anterior insula, which in turn biased how gain and loss prospects were weighted when making a decision [4]. However, choice happens quickly and reflects the rapid dynamical structure of neural networks. Thus, the temporal resolution that fMRI can provide is not ideal for studying this kind of phenomena.

To clarify these issues, we then recorded intracerebral electroencephalography from 30 epileptic patients while they performed a task combining a mood induction procedure, so as to manipulate ongoing neural activity, followed by a choice task. We found that baseline activity of two key regions in decision-making, vmPFC and anterior insula, respectively increase and decrease with mood level, while the probability of accepting the choice was affected by mood at the behavioral level. These results suggest that the baseline activity of the valuation networks, affected by mood fluctuations, plays a critical role in decision-making.

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[POSTER 43]

Understanding social decision-making mechanisms using Markov Decision Processes

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When decisions are made in a social context, the degree of uncertainty about the possible outcomes may increase exponentially because the behavior of other human beings can be much more difficult to predict than the physics of the environment. Partially Observable Markov Decision Processes (POMDP) is a framework for sequential decision making based on probabilistic reasoning about the hidden state of the environment. A POMDP agent develops a belief (posterior probability distribution) over the current state of the environment based on its observations and chooses an action that maximizes the expected total reward. It can adapt in a lot of situations like tracking intention of others but it is greedy in computation. The current proposal takes such POMDP approach to model social decision making. We compare inter-individual variability in a social behavioral task and a non-social reversal learning task. We hypothesize that the ability to catch the switch in the reversal learning task correlates the ability to catch a switch in the intention of others when alternating between a cooperative and a competitive situation.
19 volunteers (aged 22-40, M = 31, SD = 6.19) underwent a new social decision making task, consisting of a sequential repeated economic game in which participants played against an artificial agent who unpredictably changed its behavior between a cooperative (matching penny task) and a competitive game (Hide and seek task). Participants were led to believe that they were playing against other participants, then they were explicitly told that they will play a game against a computer. The second task was a reversal learning task. Each task consisted of 163 trials. For the social decision making task, the player had to choose from one red or one black card king displayed on a screen. To win, participants had to guess which color card their opponent had chosen and pick the same one. The computer algorithm exploited the bias of participants both in the competitive and

cooperative situations. For the non-social task, participants had to choose between two fractal images and the switches of the good target (rewarded around 90% of the time) were the same than switches between the cooperative and competitive modes of the social task.

All participants succeeded to infer the intentions of their opponents in the social condition with no more information than their behavior and their own rewards (loss or win). Participant succeeded the task much better in a non-social framework because of the 'good image' was consistently rewarded. Our fitting method implied mainly Q-learning for a model-free approach, Partially Observable Markov Decision Process models (POMDP) for the model-based method and k-Tom model to model theory of mind. We compared the different models with log-likelihood and variational Bayes methods. We observed that it was much easier to fit the behavior of participant in the non-social context than in the social one (mean log-likelihood across all models -93,7 in non-social against -117,9 in social context). Influence model – in which an agent computes the other's prediction error and thus knows the influence of his actions on the other's actions – is the best to explain the social behavior (mean log likelihood = -105.9854 std 12.7724). POMDP explained both the human social and non-social behavior (mean social log-likelihood -122.7710 std 9.6376 and non-social -74.9262 std 19.6309) but a descriptive model Win/Stay-Lose/Switch was the best to explain non-social behavior (mean log likelihood -72.2331 std 19.6712). To conclude, in a social context influence model are more efficient to take into account the influence of our own actions on future actions of others.

[POSTER 44]

Social Uncertainty Tolerance Changes During Adolescence

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Social reorientation and risky behavior are characteristics of adolescence [1, 2]. Adolescents are more susceptible to peer-influence when taking risks than children or adults [3]. Adolescents are also more uncertainty tolerant than adults [4] and gather less information prior to a risky decision [5]. Trust is a social form of decision making under uncertainty, as the outcome (reciprocation or betrayal) depends solely on the decision process of the trustee. Trusting comes with social uncertainty, as people usually have incomplete information about the trustworthiness of the trustee. Therefore, it is typically beneficial to gather information about the trustee's past behavior before deciding whether or not to trust. However, how adolescents decrease social uncertainty is unknown. We used an information sampling trust game to investigate the extent of adolescents' information search as a function of the trustworthiness (i.e., reciprocation probability) of the trustee. Participants (*n* = 149, 10-24 years) had the opportunity to sequentially sample information about a trustee's reciprocation history before they decided whether or not to trust. At all ages, subjects gathered more information when sample outcomes are inconclusive compared with when outcomes are conclusive. Importantly, this effect of sample outcome conclusiveness was less pronounced in young adolescents compared with older adolescents. Young adolescents sampled more than older adolescents when the reciprocation probability was deterministic. In addition, mid adolescents sampled most, which contrasts previous findings of uncertainty tolerance in non-social tasks. Comparing several computational models revealed that a heuristic model with Bayesian beliefs about trustworthiness fitted best across all ages, consistent with previous findings in adults [6]. The winning model further suggests that the complex developmental patterns in behavior can be explained by gradual age-related changes in the underlying parameter estimates. Our findings may fit with the social reorientation that happens at this age. As early adolescents need to learn about others in order to meet the demands of the increasing complexity of their social environment.

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SESSION 2: TUESDAY 28 MAY, 12:45 – 14:45 (POSTERS 45-86)

[POSTER 45]

Finding structure in multi-armed bandits

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How do humans search for rewards? This question is commonly studied using multi-armed bandit tasks, which require participants to trade off exploration and exploitation. Standard multi-armed bandits assume that each option has an independent reward distribution. However, learning about options independently is unrealistic, since in the real world options often share an underlying structure. We introduce a class of structured bandit tasks, which we use to probe how generalization guides exploration. In a structured multi-armed bandit, options have a correlation structure dictated by a latent function. We focus on bandits in which rewards are linear functions of an option's spatial position. Across 5 experiments, we find evidence that participants utilize functional structure to guide their exploration, and also exhibit a learning-to-learn effect across rounds, becoming progressively faster at identifying the latent function. The experiments rule out several heuristic explanations, and show that the same findings obtain with non-linear functions. Comparing several models of learning and decision making, we find that the best model of human behavior in our tasks combines three computational mechanisms: (1) function learning, (2) clustering of reward distributions across rounds, and (3) uncertainty-guided exploration. Our results suggest that human reinforcement learning can utilize latent structure in sophisticated ways to improve efficiency.

[POSTER 46]

Generative Bayesian modeling for causal inference between neural activity and behavior in Drosophila larva

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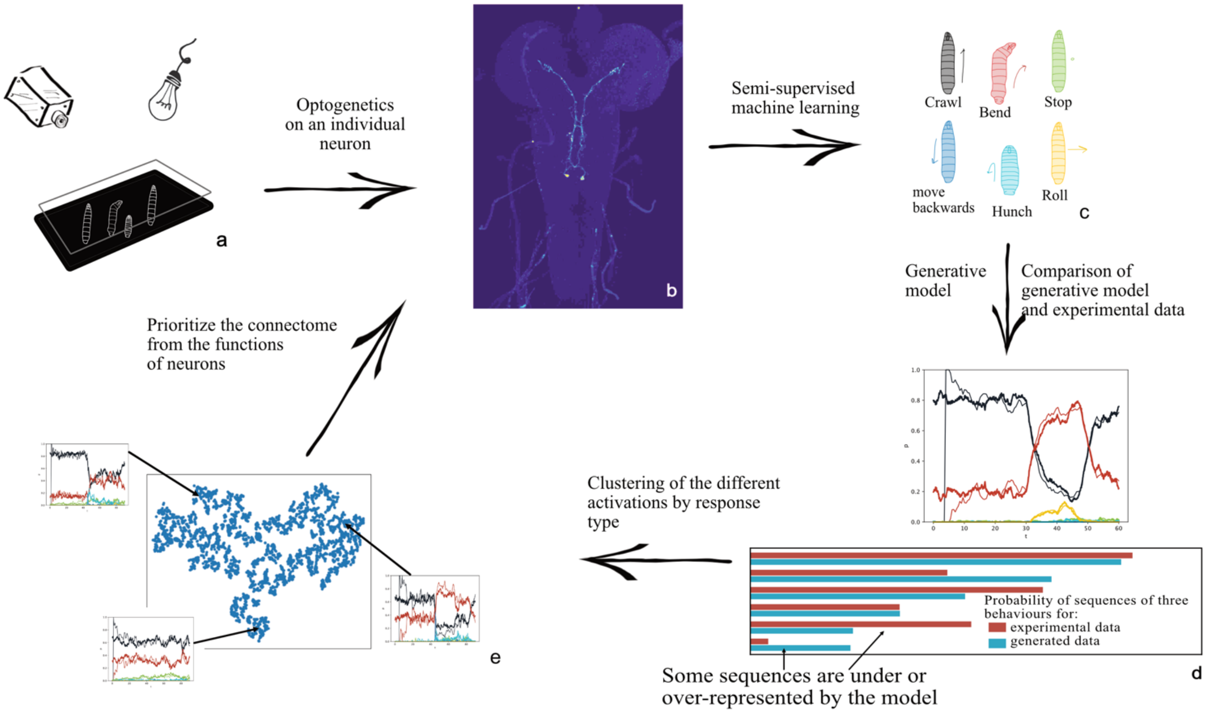
A fundamental property of the central nervous system is its ability to select appropriate behavioral patterns or sequences of behavioral patterns in response to sensory cues, but what are the biological mechanisms underlying decision making? The Drosophila larva is an ideal animal model for reverse-engineering the neural processes underlying behavior. The full connectome of the Drosophila larva brain has been imaged at the individual-synapse level using electron microscopy. The host of genetic techniques available for Drosophila allows us to optogenetically manipulate over 1,500 of its roughly 12,000 neurons individually in freely behaving larvae. This enables us to establish causal relationships between neural activity, brain connectivity, and behavior at the fundamental level of individual neurons and neural connections, Fig. (a) and (b). We have access to video record of the individual behavior of ~3,000,000 larvae. We have identified six stereotypical behavioral patterns using a combination of supervised and unsupervised machine learning (Fig. (c)).



Each realization of a behavioral pattern is characterized by a different duration, amplitude, and velocity. Here we present a generative model that extracts the behavior of wildtype larvae using Bayesian inference, and interprets behavioral changes following neuron activation or inactivation from large-scale experimental screens. Figure (d)-top shows the average behavior of $10 000$ larvae over time in a screen where a single neuron is activated at t = 30 s. A clear change in behavior is seen following activation is seen which is well captured by the model, illustrating its accuracy. The generative model enables us to robustly detect behavioral modifications as significant deviations of the patterns in the larvae's sequence of activities from their equilibrium behavior, not only for evident cases but also for much smaller behavioral modifications, Fig. (d)-bottom. These virtual larvae have made it possible to separate neural responses between those causing simple and immediate actions and those generating complex behaviours characterized by unpredictability or strong temporal correlations. He is possible to group neurons in terms of response by data partitioning techniques on inferred parameters, Fig. (e).

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[POSTER 47]

Urgency tunes center-surround inhibition in the motor system during action selection

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Action selection involves a tight balance between the competing demands of decision speed and accuracy. Recent work suggests that this balance is regulated by a context-dependent urgency signal, operating as a gain modulator of task-related activity: when decision between reaching movements are made under time pressure, activity in motor areas involved in arm movements is amplified. An open question relates to the generalization of this gain modulation in the motor system. Here, we investigated the impact of urgency on the excitability of different task-related and task-unrelated motor representations in humans by applying transcranial magnetic stimulation (TMS) over the primary motor cortex.
Subjects performed a modified version of the tokens task [1, 2]. In each trial, 15 tokens jumped one-by-one every 200 ms from a central circle to one of two lateral target circles; participants had to guess which of those two targets would ultimately receive the majority of the tokens, and to report their decision on a keyboard with either the left or right index finger. Importantly, the reward provided for correct choices was proportional to the number of tokens remaining in the central circle at the time of the response. Hence, because this number decreased as time elapsed during the trial, the urge to act grew accordingly. More critically, we manipulated the overall level of urgency by providing a different penalty for incorrect responses in two separate

block types. The use of a low penalty encouraged the subjects to make hasty choices, thus ensuring a high urgency in a category of blocks, called $\text{Urgency}_{\text{High}}$. Other blocks were associated with a low urgency (called $\text{Urgency}_{\text{Low}}$) as they involved a higher penalty, promoting accurate choices at the cost of speed. We exploited TMS to elicit motor evoked potentials (MEPs) at different times during the token jumps, in muscles that were either involved in the task (i.e. an index finger "task-related" muscle) or in surrounding muscles that were not involved (*i.e.*, thumb and pinky "task-unrelated" muscles). MEP amplitudes obtained from these muscles provided us with a muscle-specific assay of corticospinal excitability at the time of stimulation in $\text{Urgency}_{\text{High}}$ and $\text{Urgency}_{\text{Low}}$ blocks.

MEP amplitudes in task-related muscles became larger over time when elicited in a selected muscle. In contrast, MEPs obtained from task-unrelated muscles showed a progressive decrease in their amplitude. Interestingly both of these effects were stronger in the $\text{Urgency}_{\text{High}}$ than in the $\text{Urgency}_{\text{Low}}$ blocks. That is, higher urgency concomitantly increased facilitation of selected task-related muscles and suppression of surrounding task-unrelated muscles, a mechanism reminiscent of center-surround inhibition.

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[POSTER 48]

Neurophysiological correlates of engagement in the task vs option selection in the monkey ventro-medial prefrontal cortex

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All species adjust their behaviors by optimizing the ratio between costs and benefits. Value based decision making is a cognitive process that involves a cost and benefit evaluation to make choices. It is supposed to rely upon the prefrontal cortex, which is particularly developed in primates. More specifically, recent studies in humans and monkeys have identified the ventromedial prefrontal cortex (VMPFC) as a key node for value-based decision making, with a neuronal activity related to the the subjective encoding of value and the continuous encoding of the willingness to engage in goal directed behavior. But the specific relation between evaluation, engagement, choices and neuronal activity remains unclear.

Here, we used an electrophysiological approach in behaving monkeys to understand this dynamic relation. We trained one monkey to perform a sequential cost-benefit choice task involving sequences of actions. This task enables us to dissociate the influence of expected value upon engagement from its influence on choices.

We conducted a preliminary analysis on 72 single VMPFC units (Brodman area 14). In agreement with previous studies, most VMPFC neurons (n=49, 68%) encoded the monkey's willingness to perform the task. The relation between VMPFC firing and engagement in the task encompassed several trials, reflecting a slow state function rather than an event-related function. By comparison, a lower proportion of VMPFC neurons encoded the monkey's choices between 2 options (n=5, 7%) or the objective value of each option.

This preliminary analysis indicates that VMPFC activity is more strongly related to the engagement than to value-based choices. Further analysis will provide greater insight into the relation between VMPFC activity and the engagement and choices interaction.

[POSTER 49]

Contingency learning and value-guided decision-making in adolescents

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Objective: Learning the causal relationships between choice and outcome and making fine-grained value comparison judgments rely on distinct subregions of the orbitofrontal cortex (OFC) [1]. When these brain regions are damaged in the adult choices appear irrational with the decision maker adopting alternative decision strategies [2]. Here we investigated whether the underdeveloped state of these brain regions in adolescence result in the adoption of similar alternative decision strategies [3]. We focused on two learning mechanisms: "Credit assignment" and "Spread of effect". The former mechanism describes how normal behaviour is guided by precise predictions of causality between choices and outcomes while the latter spreads the reinforcing properties of the outcome to all temporally proximate choices, including choices that did not actually cause the outcome.

Methods: Participants aged 11 to 35 performed an online probabilistic 3-choice decision-making task in which the expected value of each option varied and reversed over the course of the task and could be learned through trial-and-error. In addition to age and gender, we collected impulsivity and risk-taking metrics with the impulsivity scale for children and RT18 risk-taking questionnaire.

Results: Multiple logistic regression analysis revealed that, relative to adults (aged 24-35), older adolescents (aged 18-23) showed an expected reduction in the influence of credit assignment mechanisms on choice. Non-contingent learning mechanisms are also altered in this age group, with some evidence of enhanced influence of spread of effect. In addition, impulsivity scores correlated with age, risk-taking, and key learning and decision variables, including credit assignment.

Conclusion: This study provides evidence that compared to adults, older adolescents' behaviour is erroneously less guided by the causal relationship between choice and reward suggesting an age-dependent shift towards a credit assignment mechanism. Understanding the behavioural impact of OFC development in distinct decision contexts is key in explaining age-dependent decision-making.

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[POSTER 50]

Linking neural representations for decision-making between monkey and human cortex

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Neuroscience has struggled to link animal models to human brain functioning. Hunt et al. [1] identified a triple functional dissociation in prefrontal cortex (PFC) using single-cell recordings from macaque during an information gathering task. We attempt to find a similar dissociation in the human brain using functional magnetic resonance imaging (fMRI) during a similar task using two approaches: mass univariate analysis and representational similarity analysis (RSA). In a mass univariate analysis, we find evidence of a belief confirmation signal in anterior cingulate cortex (ACC), consistent with that identified in single cell recordings in the same task. Furthermore, we find evidence of an interaction between value and attention in orbitofrontal cortex (OFC). Using ROI-based RSA, we successfully produced clear representational geometries in primary visual cortex and the fusiform gyrus for spatial location and cue type (face/house) respectively. However, we found no clear relationships between RSA matrices in anatomical regions of interest for dlPFC, OFC or ACC in an ROI-based analysis, in contrast to what was found in the macaque data. Using searchlight RSA across the whole brain, on the other hand, revealed some areas in human PFC with similar representations to those found in the macaque study. These findings are not conclusive on the utility of RSA as a means of mapping animal and human data to a common space in PFC, as there is still much scope for further exploration of the data.

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Know Thyself! Model Based Planners Reflect on their Model-Free Propensities

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Dual-reinforcement learning theories propose that behaviour is mutually controlled by two separate and systems: a retrospective value-caching, model-free (MF) and a prospective-planning, model-based (MB) system. This control architecture raises a question as to whether a MB system takes account of its MF-dispositions and their potential future effects on behaviour. In contrast to extant reinforcement learning theories, which assume that goal-directed planners disregard their very own MF tendencies, we show this is not always the case. We present a novel theory of a sophisticated self-reflective MB planning, wherein a planner incorporates a model of the self that anticipates the likely influence its MF-propensities exert on its planned future actions. In support of this theory, we show that when subjects engaged in a bespoke bandit task were periodically allowed to design their environment by assigning which of two bandits could be more, and which less, rewarding the assignments reflected a consideration of their own MF-proclivities. We highlight two importnat charachteristics of a self-reflective planning process : First, self-reflective planners do not aim for Bellman optimality but rather they form action plans that are robust to the suboptimal influences of their own MF propensities. Second- self-reflective planners prefer to act in environments wherein their goals cohere rather than conflict with momentarily MF propensities. Our findings extend existing knowledge regarding interactions between MB and MF reinforcement learning systems and have implications for a range of decision domains including drug abuse, pre-commitment, and a tension between short and long-term decision horizons in economics.

[POSTER 52]

A neural basis for the formation of global self-beliefs

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Optimal decision-making requires integrating expectations about external outcomes - positive and negative - with current internal states. However for many real-life decisions, we do not receive external feedback or rewards, and have to estimate our successes or failures based on internal evaluations alone. In series of behavioural and neuroimaging studies, we examined whether metacognition, the ability to internally monitor and evaluate our own decisions, can act as a learning signal in the absence of external feedback.

We developed a paradigm to investigate whether local fluctuations in decision confidence contribute to the formation of global self-performance estimates (SPEs) when external feedback is unavailable. In three behavioural experiments, human subjects played mini blocks with two interleaved perceptual tasks. At the end of each block, they were asked to choose the task on which they think they performed best. These task choices provided a simple behavioural assay of global SPEs. We found that human subjects incorporated local decision confidence to form global SPEs over time, while also pervasively underestimating their performance in the absence of feedback [1]. We examined confidence-related activity under functional magnetic resonance imaging (fMRI) to delineate a neural basis for the formation of global SPEs based on local confidence. Unpacking a generic confidence signal, we sorted trials according to whether they were congruent or incongruent with end-of-block task choices, allowing us to test whether trial-by-trial confidence representations are 'tagged' according to the global task SPE with which they are associated. We found that activity in ventral striatum was related to shifts in overall global confidence. In contrast, we observed a double-dissociation in prefrontal cortex (PFC) as a function of global SPEs, with confidence-related activity in ventromedial PFC (respectively bilateral PFC) selective for trials incongruent (respectively congruent) with end-of-block task choice, suggesting that these PFC areas track trial-by-trial confidence in a frame of reference determined by existing global SPEs.

Our findings provide initial evidence that the human brain incorporates local confidence when forming global SPEs, and support a functional role for confidence in higher-order behavioural control. These findings lay the groundwork for understanding how this process might go awry in psychiatric disorders characterised by the maintenance of inappropriate global self-beliefs [2].

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Dissociable pupillary correlates of decision confidence and decision bound-crossing

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Pupil dilation provides a non-invasive window onto cognitive processes via the noradrenergic system [1,2]. There has been recent interest in understanding how decision confidence might be reflected in pupillary responses to ambiguous sensory stimuli. However, decision confidence is often correlated with the amount of accumulated sensory evidence, which could also drive differences in pupil dilation. In this study, we monitored pupil dilation whilst human observers categorised sequences of ambiguous sensory stimuli. On each trial, we presented observers with a sequence of oriented Gabor patterns. The orientations were chosen from one of two overlapping circular Gaussian distributions centred on orthogonal orientations. The observer was asked to categorise which distribution the patterns were drawn from. As the distributions overlap, observers must accumulate evidence over a number of stimuli in order to make accurate decisions, with each orientation offering a specific amount of evidence for making a decision [3]. Observers completed three variants of the task. In the first variant of the task, we asked them to accumulate evidence until they reached a target performance level (70%, 85% or 90% correct). Pupil dilation showed a phasic increase as the decision bound was crossed, irrespective of the target performance level (which determined the bound). In the second task, we measured observers' default bound, by asking them to accumulate evidence until they felt ready to respond. In the third task, we probed performance and confidence relative to this default bound, by presenting either less or more evidence than needed for the observer to cross his/her default bound. We obtained behavioural modelling evidence that, on some trials, the decision bound was crossed before the end of stimulus presentation. On these trials, pupil dilation showed a phasic increase well before the end of the sequence. Interestingly, decision confidence had a markedly different effect on pupil dilation: high confidence was associated with more pupil constriction well after the response - i.e., much later than the effect triggered by crossing the decision bound. This evidence indicates that decision confidence and decision bound-crossing have dissociable signatures in pupil dilation, and thus may be associated with distinct activations of the noradrenergic system.

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Growing influence of priors on reversal learning across the encoding-decoding information trade-off

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In volatile environments, efficient decision-making requires an adequate balance between prior knowledge and incoming evidence. This prior-evidence balance is at the heart of Bayesian inference, a statistical process which has been proposed and used to model human reasoning and decision-making under uncertainty [1,2]. Such inference process has been studied across a wide range of vastly different paradigms, from discriminating ambiguous stimuli [3] to choosing among stochastic reward sources [4]. A fundamental, yet uncontrolled source of variability across these different paradigms concerns the nature of uncertainty being elicited: from low encoding precision during perceptual decisions (i.e., the information provided by the sensory representation of a stimulus), to low decoding capacity during reward-guided decisions (i.e., the information provided by a single reward about the mean value of its source). A recent study [5] has described this distinction between encoding and decoding uncertainty in terms of a 'sensory-category information trade-off', and compared their effects on the temporal accumulation of sensory evidence during *isolated* decisions. Here we sought to compare the balance between priors and evidence at the extremes of this information trade-off during *sequential* decision-making, using a novel reversal learning task divided in two uncertainty-matched conditions. Healthy participants (N = 30) were asked to track the bag (light or dark) from which presented marbles were drawn. In low encoding precision blocks, the luminance of presented marbles was spatially scrambled to reach 20% of misperceived marbles. In low decoding capacity blocks, presented marbles were unambiguously light or dark but 20% of them did not belong to the active bag. Despite matched levels of uncertainty, behavioral analyses revealed slower reversal learning in the low decoding capacity condition, modelled by a larger influence of priors on the underlying inference process. Complementary analyses of phasic pupil dilation supported this interpretation by predicting changes-of-mind before the onset of incoming evidence in the low decoding capacity condition, but not in the low encoding precision condition. Decisions based on large priors (and more constricted pupils) were associated with a lower weight of evidence than decisions based on small priors (and more dilated pupils), suggesting that pupillary fluctuations track trial-to-trial variations in the balance between priors and evidence within each condition. Together, these findings demonstrate distinct adjustments of human probabilistic reasoning to internal and external sources of uncertainty.

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[POSTER 55]

Exploration and development: Sensitivity to exploration costs emerges in adolescence

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Adolescent decision dilemmas may require weighing the value of an unknown option against options that are better known. For instance, shall I invite a new classmate or an old friend for a night out; shall I try a new drug or drink a known beer? These dilemmas are examples of typical explore-exploit problems, in which we have to choose between predictable rewarding options (exploitation), or obtaining new information on possible rewards (exploration) [1]. The relative emphasis on exploration versus exploitation shifts rapidly across adolescence, with adolescents engaging in more -and less strategic- exploration than adults[2,3]. However, it is yet unknown how adolescent's exploration is influenced by cost-benefit tradeoffs. Here, we examined whether developmental changes in explorative behavior are influenced by sensitivity to exploration costs. We merged computational decision-making and developmental approaches to characterize age-related shifts in exploration behavior from adolescence to young adulthood. Participants were 147 11-25-year-olds who completed a multi-armed bandit task, in which participants had to learn by sampling from three fishing ponds which pond was most profitable. This task manipulated exploration costs by varying travel distance -and thereby sampling opportunity- between ponds. Results showed that adolescents became increasingly sensitive to exploration costs, which decreased explorative behavior into adulthood. Next, all participants performed a foraging task with multiple ponds in an environment with high (far ponds) and low (close ponds) exploration costs. In each condition, the rate of returns declined with increased sampling from one pond. This design allowed us to calculate an optimal point of switching according to the marginal value theorem[4]. We observed that adolescent's sensitivity to exploration costs presented a slight advantage compared to adults when foraging rewards in a high-cost environment, yet a slight disadvantage compared to adults when foraging rewards in a low-cost environment. Taken together, these findings offer a framework to study the underlying mechanisms of exploratory behavior in adolescents. They highlight that adolescents are increasingly influenced by the potential costs of exploration. These developmental changes may lead to higher levels of exploration in early adolescence particularly in costly or challenging environments. Heightened exploration in these contexts may be adaptive for adolescents in seeking out new learning opportunities and potential rewards.

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[POSTER 56]

Active foraging for information in dynamic decision-making is influenced by both apathy and impulsivity

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When acting towards a goal (e.g. getting a haircut), individuals often deal with incomplete information about task-relevant variables (e.g. the skills of the hairdresser), which can result in deviations from the intended outcome (e.g. a bad haircut). In many cases, behavioural outcomes can be improved by making better informed decisions, i.e. by gathering more information prior to committing to a decision (e.g. checking online customer reviews prior to deciding which salon to go to). However, this often comes at the expense of search-related costs in terms of time, money, effort and opportunity loss. Optimal behaviour therefore requires agents to weigh information-related benefits against search-related costs when deciding how much information to gather. Here, we developed a novel experimental paradigm to 1) investigate the process of “foraging for information” dynamically in healthy individuals, and 2) study its interaction with motivational traits such as apathy and impulsivity. In this task participants were rewarded as a function of how accurately they could localise a hidden circle on a screen. Their localisation accuracy could be improved by actively sampling information about whether particular locations on the screen fell within the hidden circle or not. However, this information came at a cost: participants lost monetary credits for every sample acquired. The task therefore required participants to weigh information-related accuracy benefits against search-related costs. We used a two-by-two design in which reward availability (high or low) and sampling cost (high or low) was systematically modulated to create four different cost-benefit environments.

Consistent with previous reports [1], [2], individuals adapted the extent of their search to the cost-benefit structure of the environment. That is, both lower sampling cost and greater reward availability led to more extended searches. Crucially, the latter effect (incentivisation by reward availability) was blunted by apathy but enhanced by impulsivity.

We reasoned that this result might reflect metacognitive differences in the perceived utility of information: more apathetic individuals might underestimate the positive effect of information on task performance (localisation accuracy), while more impulsive individuals might over-estimate it. We tested and confirmed this hypothesis in a passive version of the task that required participants to report how accurately they thought they could localise the hidden circle under various, experimentally manipulated, levels of uncertainty.

In this passive version of the task, confidence ratings were followed by an offer asking whether participants wanted to play, given the current level of information and reward availability. By systematically exploring the stake-uncertainty space, these choice data allowed us to infer the contribution of reward availability and amount of information to the

decision-making process when uncertainty was fixed and irreducible. Under such conditions, impulsivity and apathy did not interact with the weight given to information. Instead both enhanced the contribution of reward availability to the computation of a subjective value.
Taken together, these results highlight differences in the management of uncertainty between a situation in which information is delivered passively versus a more ecologically valid situation in which individuals have to actively forage for it, at a cost.

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[POSTER 57]

Role of uncertainty in curiosity about wins versus losses.

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Curiosity is a basic biological drive, but little is known about its behavioral and neural mechanisms. Previous studies have demonstrated that curiosity is a function of information uncertainty: We are particularly curious when information provides us with a substantial update of what we know, even when such an update does not help us improve performance or maximize rewards [1]. Recent evidence indicates that the drive to seek information might reflect a preference for positive (versus negative) belief updating [2]. In the current studies, we assessed whether the effect of information uncertainty on curiosity is modulated by the positive versus negative valence of information. To this end, we designed a lottery task in which the uncertainty of trial outcomes, and reward context (win versus loss) were manipulated independently. Thus the lottery was associated with more or less uncertain wins or losses. In every trial, participants were asked to indicate how curious they were about the outcome of a presented lottery, in terms of self-report ratings and in terms of willingness-to-wait decisions. If the drive to seek information reflects a preference for positive versus negative beliefs, then any effect of outcome uncertainty should be a function of win versus loss context. Results replicated a main effect of outcome uncertainty, demonstrating that curiosity increased with outcome uncertainty in both the win as well as in the loss context. In addition, there was a main effect of reward context, such that curiosity was overall higher for the win context compared with the loss context. However, there was no interaction between outcome uncertainty and reward context, indicating that these two factors have distinct effects on curiosity. These results suggest that curiosity is monotonically related to the uncertainty about one's current world model and that people are driven to improve this model, regardless of reward context. In addition, there is a (perhaps Pavlovian approach) bias towards information gain about positive compared with negative information, which operates independently from information uncertainty. These findings provide novel insights into the psychological mechanisms of curiosity.

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[POSTER 58]

Normative decisions and normative confidence: A unified account

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There is substantial agreement that the drift diffusion model (DDM) accounts well for the speed and accuracy of two-alternative perceptual decisions [1]. In this model, deliberation involves tracking the difference in evidence between alternatives until this difference crosses a fixed threshold. It has been shown that tracking the difference in evidence between two alternatives is a feature of optimal decision making in a range of environments [2, 3], and this makes intuitive sense: Evidence for one alternative is evidence against the other.

In contrast to response times and choices, the drift diffusion model struggles to explain variability in confidence reports. This is because, according to the model, decisions are made when the difference in evidence between the alternatives reaches a specific value, hence all decisions are made with the same balance-of-evidence between the chosen and unchosen alternatives [4]. In a variant of the DDM, decision thresholds are allowed to vary with deliberation time, such that as deliberation time increases, the balance-of-evidence required to trigger a response decreases. These time dependent thresholds may be optimal in a variety of settings [5, 6]. Alternatively, an optimal observer who uses a fixed threshold should reduce their confidence over time if they are unsure about the difficulty of the task they are performing [7]. We compare these competing explanations for human confidence reports via computational modelling, with the aim of showing that the normative diffusion mechanism, when coupled with normative confidence read-outs, can explain quantitative and qualitative patterns observed in decisions, response times and confidence.

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[POSTER 59]

Polarity of subjective uncertainty in ventromedial prefrontal cortex changes with behavioural adaptation across time.

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Environments typically furnish multiple information sources which might be used to make predictions about subsequent events of importance such as rewards. How do we select predictors that are useful? Here we describe this process at behavioural and neural levels. First, we show that during early encounters with potential predictors, participants' selections were explorative and directed towards uncertain predictors. This is particularly the case when the time horizon is long and many future opportunities remain to exploit the knowledge that is gained. However, a preference for accurate predictors increased over time, as did a tendency to pick certain predictors. We then describe how this transition is governed by representations of belief uncertainty in ventromedial prefrontal cortex (vmPFC) using Bayesian modelling and functional magnetic resonance imaging. Activity in vmPFC was sensitive to participants' (un)certainty in their beliefs about predictors but the polarity of uncertainty representations (positive or negative encoding of uncertainty) changed with the behavioural mode: an uncertainty decision signal was present during exploration, while activity in the same region signalled certainty during exploitation. Although the dichotomy between exploration and exploitation has often been treated as binary, we show that periods of uncertainty and certainty representation in vmPFC are separated by a transitional period in which beliefs about predictors' accuracy predominate in their impact on vmPFC activity. These findings suggest vmPFC carries information about a multiplicity of decision variables, the strength and polarity of which vary according to their relevance for the current context.

The construction and deconstruction of suboptimal preferences through reinforcement learning

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Wealth of evidence in behavioral economics and affective neuroscience suggests that option values are highly dependent of the context in which the options are presented. Building on an analogy with perceptual psychophysics and neuroscience, option valuation seems to be affected by both the *spatial* (i.e., what is the value of the simultaneously presented options?) and *temporal* (i.e., which options were presented in the recent past?) contexts. In a series of recent papers, we demonstrated that contextual adjustments also occur in reinforcement learning [1,2]. However, the exact algorithmic implementation of context-dependence and how this process is affected by modulating feedback information, still remains unclear. To fill these gaps, we implemented 4 new variants of an instrumental learning task where we orthogonally manipulated outcome magnitude and feedback information, resulting in systematic variations in reward ranges. In a first phase of the task (learning test), participants had to determine by trial-and-error the most favorable option (in terms of received points) in 4 fixed pairs of options. In a second phase (transfer test), the original pairs were remodeled to investigate the choice preference between options extrapolated from their original context [3]. We ran 5 experiments (one in the laboratory: N=40; and four online N=400). In all experiments, subjects learn above chance level. Of note, lab results were qualitatively well replicated in the corresponding online experiment. We replicate results found in previous studies indicating partial range adaptation in the learning test and context-induced suboptimal preferences in the transfer test. We found that increasing feedback information (by showing both the obtained and the forgone outcome: complete feedback) in the learning test increases the context-induced suboptimal preferences, as measured at the first trial of the transfer test, compared to the partial feedback case (showing the obtained outcome only). Further analysis of trial-by-trial dynamics during the transfer test showed that, while complete feedback redresses suboptimal preferences, partial feedback does the opposite. In complement to choice rate analysis, we developed a computational model that implements normalization by tracking the range of each decision context and adapting the perceived reward accordingly. Model simulations show that this model best explains subjects' behavior, capturing both the partial adaptation during the learning test and the context-induced suboptimal preferences in the transfer test. Model comparison indicates that the new RANGE model performs better compared to a simple Q-learning model and a previously proposed descriptive model, featuring normalization as a weighted average of absolute and relative outcomes. To conclude, we provide definitive evidence of context-dependent reinforcement learning in humans and concomitantly propose a more satisfactory computational model to explain these processes. Between-task comparison indicates that increasing feedback information has somehow counter-intuitive results, since it decreases optimization in the transfer test.

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[POSTER 61]

The experience-description gap in the human brain

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Neuroeconomics investigates how decision variables are computed and represented in the brain in order to make decisions maximizing expected values (EVs). EVs are generally calculated as the product between the magnitude of an outcome and its probability. In real life as well as in laboratory experiments, the values of the decision variables (outcome probability and magnitude) can come from two very different sources. Classical behavioural economics literature consider EVs built upon described decision variables, i.e., outcome probabilities and magnitudes are explicitly communicated through a symbolic system (lotteries) [1]. In the neuroscience and reinforcement learning traditions, EVs are experience-based, i.e., learnt via trial-and-error. In the present study we aim at comparing the neural representations of decision variables derived from description or experience.

We designed a two-armed bandit task where we controlled the options' outcome probabilities and magnitudes. The task featured a 2x2 factorial design where we orthogonally manipulated which decision variable (probability or magnitude) was explicitly described or to be inferred by trial-by-trial feedback. Over two experiments (N=20 and N=30), subjects performed 396 trials (96 per condition); subjects in the second experiment underwent fMRI scanning.

Statistical analysis of aggregate accuracy revealed a main effect of both described probability and magnitude. Crucially, we found accuracy to be significant above chance level in the condition where both probability and magnitude were implicit. We further performed a trial-by-trial regression analysis, where we explained choice at trial *t* as a function of the probability at trial *t*, the magnitude at trial *t* and the obtained outcome at trial *t-1*. By doing so we were able to ascertain that for each condition, probability and magnitude significantly predicted choices. Crucially this was true also in the conditions where the variables were implicit, thus demonstrating experience-based learning. The *t-1* outcome regression coefficient was also significant, and, as expected, bigger in the condition where both variables were implicit. These model-free results were confirmed by a model-based analysis showing that data were better accounted by a model assuming decision based on both learned and described values (XP=1.0).

The initial fMRI analysis was aimed at generating the regions of interest (ROI), and consisted in regressing against the choice and the outcome onsets the EV of the chosen option and the obtained outcome. We identified very robust and significant clusters in the value-based decision-making network (vmPFC, dmPFC, Ventral Striatum, Insula). Then, we tested whether the neural activities of these areas were specific of magnitude vs. probability or description vs. experience and found that vmPFC was specifically representing decision-variables. Moreover, the dPFC, were preferentially modulated by description based decision-making and probability encoding. Finally, striatum activity was specific of outcome encoding and did not encode any decision-related variable at choice onset. To conclude, we provide behavioural evidence that experience and description-based variables, despite their different sources, can integrate to provide adaptive behaviour. Neurally, the representation of these variables at decision time is partially dissociable, thus proving a possible substrate for the behavioural experience-description gap of risky choices. Finally, we confirm the striatum as mainly concerned by experienced (rather than expected) utility.

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[POSTER 62]

Opposing cognitive pressures on human exploration in the absence of trade-off with exploitation

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Human exploration has been studied in a range of reward-guided learning tasks, where agents seek to maximize their payoff through arbitration between the exploitation of a more rewarding action and the exploration of more uncertain alternatives. However, by design, these paradigms conflate the behavioral characteristics of exploration with those of this 'exploration-exploitation' trade-off. It is thus possible that previously reported correlates of exploration in brain activity [1-3] and behavior [4,5] reflect trade-off adjustments rather than exploration *per se*.

We thus compared the behavioral characteristics of human exploration in uncertain environments, between a standard condition in which participants seek to maximize reward, and another condition in which the same participants freely sample their environment to learn its causal structure in the absence of immediate rewards. For this purpose, we designed a novel sequential sampling task in which participants (N = 30) chose repeatedly between two options (shapes), each drawing color samples ranging from orange to blue from a distribution centered either on orange or blue. In the regular, 'directed sampling' condition, participants were asked to draw a rewarded color, counterbalanced across blocks. In the other, 'open sampling' condition, participants could draw freely from the two shapes to learn their associated colors, probed at the end of the block.

We modeled sampling decisions in both conditions based on a shared learning model tracking the mean color mixtures associated with each option. The choice process was modeled using a standard softmax policy, biased toward repeating the previous decision and overridden with probability p by the continued sampling of the previous option if it has been sampled less than n times.

Quantitative analyses revealed two constraints on human exploration in the open sampling condition, which were absent in the directed sampling condition. Exploration in the first trials of each block was bounded by a minimum number n of samples to be drawn from one option before moving to the other option. Subsequent exploration was also limited by a stronger bias toward repeating the previous decision in the open sampling condition. These findings delineate opposing cognitive pressures on human exploration in the absence of trade-off with exploitation: the continued sampling of a current source (hypothesis testing), and the acquisition of information about other sources (information seeking).

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[POSTER 63]

Metacognitive knowledge controls cognitive offloading decisions

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Metacognition is the act of reflecting on one's own mental states, often for the purpose of cognitive control [1,2]. Previous research has shown that people are capable of reporting their confidence in for example their own decisions and memories. Research has also investigated how these metacognitive signals are generated, and which brain networks encode them. However, we are only just beginning to understand how such *metacognitive knowledge* can then be used to optimise behaviour (*metacognitive control*).

In the present fMRI study, we are asking whether metacognitive knowledge and metacognitive control rely on similar neural mechanisms in the context of cognitive offloading decisions. Cognitive offloading is the use of physical action to reduce the cognitive demands of a task [3]. Everyday memory relies heavily on this practice, for example when we write down to-be-remembered information or use diaries, alerts, and reminders to trigger delayed intentions. Previous research has identified metacognitive knowledge as one of the key drivers that guide people's decision to offload: If people are less confident that they will remember to do something in the future they have a higher propensity to choose an offloading strategy, such as setting a reminder [4-6].

We used a computerized task in which people had to press a button when a target colour appeared on screen whilst completing an ongoing shape discrimination task. From time to time, people were allowed to set reminders, that is the to-be-remembered colour remained on screen throughout the block. Critically, there were two key conditions: In the *Metacognitive Knowledge* condition people rated their confidence in remembering the delayed intention. In the *Metacognitive Control* condition they were asked to rate how much they would like to set a reminder. Twenty-two healthy adult participants underwent 1.5T fMRI whilst completing this task. Here we show both similarities and differences in the networks that encode metacognitive knowledge and control, centred on lateral and medial prefrontal cortex, and using a combination of both univariate and multivariate analyses.

Our results have important implications for the study of how the brain utilises internal feedback signals to optimise future decision making in the absence of external feedback.

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[POSTER 64]

Reinforcement learning with different reward identities

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Learning depends not only on the value of the outcomes elicited by actions, but also the *identity* of the outcome, such as currency of money or type of food received [1], [2]. It is unclear how outcomes of equal value but different identity are computed and compared for learning and action selection. We used probabilistic reversal learning tasks with different reward types to assess how non-value outcome information affects reward learning. Stimuli were associated with two tokens of different colours, and with 80% probability of reward or no-reward. Participants were instructed that these two colours represented different *currencies*: tokens which accumulated in different "bank" accounts, but of ultimately equal monetary value. We aimed to see how the consistency of outcome type (i.e. whether each stimulus always received the same colour of reward) affects learning. When the stimulus-colour mapping was consistent, participants learned well. However, when the mapping was *in*consistent (i.e. each stimulus received either colour reward with 50% probability), learning was worse despite the unchanged value information. We replicated this effect in a second experiment, showing that this effect was due to inconsistent colour outcomes impairing learning rather than consistent outcomes improving it (relative to single-colour outcomes). Inconsistent outcomes lead to lower accuracy after a reward reversal and a slower learning over the subsequent trials. As the reward values were the same across conditions, we showed that received reward *identity* modulated learning. Such reward identities might be represented in different ways, such as through identity prediction errors, multi-dimensional prediction errors (including reward and identity), or outcome-state prediction. We compare and evaluate the predictions of these computational models in our behavioural data.

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[POSTER 65]

How executive fatigue arises and affects decision making

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Executive control is a critical ability for educational and professional success, because it enables tolerating delay and effort in the pursuit of important goals. It relies on regions of the lateral prefrontal cortex (lPFC) that are the latest to reach functional maturity during both evolution and development. In a previous fMRI study [1], we showed that executive control is susceptible to fatigue: after one day of hard cognitive work, left lPFC activity was reduced during economic choice, which led to more impulsive decisions favoring immediate rewards. We therefore suggested the concept of executive fatigue as a neural state imposing an excessive cost on control exertion. Here, we report three studies that bring biological, behavioral and computational evidence to this concept, casting light on both the origins and consequences of executive fatigue.

First, we tested whether executive fatigue could be induced by some real-life activities and not just cognitive tasks known to recruit executive control in the laboratory. Students in medical school (n=26) were invited to a 7-hour revision day, during which they had to memorize a biology course. Between sessions, they performed inter-temporal choices and a mock exam with multiple-choice questions. Choices became significantly more impulsive with the number of revision sessions, but scores at the medical exam remained stable. This replication in more ecological settings suggests that control ability is not lost with hard cognitive work, but only recruited when it matters most, as if control cost was increased.

Second, we looked for metabolic changes that could explain the increase in control cost, using magnetic resonance spectroscopy (MRS). Participants were asked to perform cognitive tasks (N-back and N-switch) for a total of 6.25 hours. They were divided into two groups, one (n=16) performing the easy version and one (n=24) performing the hard version of the cognitive tasks. Executive fatigue was accompanied by an increase in glutamate level observed within the test voxel placed on the left lPFC, but not in a control voxel placed on the visual cortex, with a significant interaction between group and session. Thus, the increase in control cost could be the result of a regulation process whose purpose would be to limit glutamate accumulation beyond clearance capacity.

Third, we specified the effects of executive fatigue on decision making by including effort and risk discounting tasks in addition to delay discounting tasks, and by using computational models to capture the cost/benefit trade-off in all tasks. Executive fatigue in the group performing hard cognitive tasks (n=24) only affected choices when options were requesting executive control (delay and effort, but not risk discounting). Furthermore, these effects were dissociated from those of time pressure, which were tested in a separate group (n=27) performing the same choice tasks. While time pressure effects were best captured by a global increase in choice stochasticity, executive fatigue effects were best captured by an additive bonus for short-delay and low-effort options. This double dissociation suggests that executive fatigue does not affect the decision-making process itself, but increases the preference for low-cost options.

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[POSTER 66]

Exploratory choices reveal human sensitivity to the temporal structure of changes

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The human ability to represent complex temporal structure of our everyday environment and to generate complex actions and plans based on this representation are central to all aspects of our behaviour. Hence, understanding how the brain represents temporal structure over multiple time scales [1] and uses these representations for making decisions [2] is essential for understanding human adaptive behaviour and the functional role of involved brain networks [3].

Here we investigate how temporal representations modulate human exploratory behaviour. For this purpose we have modified a standard reversal learning task to include exploratory (epistemic) choices. The exploratory choices require that participants forgo any reward or punishment, and instead ask for reliable information about the correct choice on the current trial. Importantly, we hypothesised that if participants are sensitive to the temporal structure of reversals this will be reflected in their exploratory choices, in the sense that if participants expect reversals to be regular (predictable) their exploratory choices will also be largely regular.

To test this, we use a between subject-design where two groups of subjects where exposed to a different temporal structure of reversals. One group was exposed to a long sequence (800 trials) of regular (predictable) reversals and a short sequence of irregular reversals (200 trials) and another group to the reversed order, a long sequence of irregular reversals and a short sequence of regular reversals. We used the group level mean probability of exploratory choices per trial to identify distinct characteristic behaviour as a function of our reversal regularity manipulation. The distinction is reflected in higher probability of selecting exploratory choice just after the moment of reversal in the group exposed to the long sequence of regular reversals; suggesting subjects' sensitivity to the temporal structure of reversals.

Importantly, we demonstrate that these behavioural patterns are reproducible with an active inference model [5] embedded with the representation of temporal structure of reversals [2], hence illustrating computational mechanisms that underlie adaptive behaviour in dynamic environments. The decision making model is embedded with prior beliefs about the temporal structure of changes. These temporal priors allow the agent to form beliefs about the future moment of change given the inferred elapsed time since the last change. We have previously demonstrated using a standard probabilistic reversal learning task [4] that humans are using such temporal predictions when deciding whether or not to change their choices. Here we additionally show that exploratory choices are also driven by such representations, and that exploratory choices match moments of high subjective uncertainty.

We believe that these results provide novel insights into mechanism underlying human ability to learn hidden temporal structure of the environment and the computational principles they utilise for making decisions based on temporal representations.

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[POSTER 67]

Impact of reinforcement on action selection, initiation and execution during motor skill learning

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The ability to learn motor skills is a fundamental feature of human behavior, which relies both on sensory and on reinforcement feedbacks (*i.e.*, reward and punishment, [1-3]). How such reinforcements lead to improved performance during motor skill learning remains an open question. In fact, skill learning can result from improvements at several levels of control, including action selection, initiation or execution. Here, we tested the impact of reinforcement on these different levels during motor skill learning [4].

After 2 short practice blocks, subjects performed 10 blocks (360 trials in total) of a modified version of a force-tracking task [5, 6]. Each trial started with a cursor appearing at the bottom of the screen and subjects were asked to squeeze a pinch-grip sensor to bring the cursor at the center of a fixed target and maintain it there for the rest of the trial. To reach the target, subjects had to exert a force ($\text{Target}_{\text{Force}}$) corresponding to 10 % of the individual maximal voluntary contraction. On most trials, the cursor disappeared shortly after the beginning of the trial. Hence, subjects had to learn to approximate the $\text{Target}_{\text{Force}}$ in the absence of visual cursor. A trial was classified as successful if the mean of the difference between the actual force and the $\text{Target}_{\text{Force}}$ was under an individualized threshold. At the end of each trial, subjects received a reinforcement feedback based on their performance (*i.e.*, Success or Failure). In this task, success depended on force control at the level of action selection (*i.e.*, $\text{Force}_{\text{Sel}}$; the closer the mean of the selected force was to $\text{Target}_{\text{Force}}$, the higher the chances of success), at the level of initiation (*i.e.*, the faster the onset [$\text{Force}_{\text{Start}}$] and the steeper the rate [$\text{Force}_{\text{Rate}}$] of force production, the better) and execution (*i.e.*, $\text{Force}_{\text{Exe}}$; the lower the force variability during the tonic phase, the better). Moreover, we analyzed the evolution of the different force variables at the three levels of control, as well as the impact of reinforcement (*i.e.,* Success or Failure) on performance in the next trial across training.

As expected, the proportion of successful trials increased over training, indicating that subjects learned the motor skill. Moreover, we found that skill learning occurred at the level of action selection ($\text{Force}_{\text{Sel}}$ closer to $\text{Target}_{\text{Force}}$), initiation (earlier $\text{Force}_{\text{Start}}$ and steeper $\text{Force}_{\text{Rate}}$) and execution (reduced $\text{Force}_{\text{Exe}}$). Interestingly, subjects improved at all levels of control in trials following a Failure, while they exhibited the opposite pattern following a Success. However, importantly, this effect of reinforcement changed over the course of learning. In fact, the beneficial effect of Failure increased across training while the detrimental effect of Success decreased. It remains to be determined whether these effects would vary with a reinforcement involving an actual monetary loss or gain.

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Gain control explains the effects of distraction during perceptual decision-making

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Perceptual decisions are often made in the context of irrelevant information. The computational mechanisms by which decisions are biased by distracting information remain controversial. Here, we used a novel approach, combining psychophysical reverse correlation and computational modelling, to elucidate the mechanisms of distraction. Participants viewed two noisy gratings placed left and right of fixation and were asked to judge the tilt of a cued target with respect to a reference orientation, ignoring the distractor. Reverse correlation allowed us to estimate decision kernels that quantified the relationship between fluctuations in signal energy and participant choices. Surprisingly, we found that distractor energy had little direct influence on choices. However, distractor signals mediated the influence of targets on choice, such that signal orientations that were consistent with the distractor had more impact in driving decisions, as revealed by higher amplitude decision kernels for trials where the target and distractor were more similar in orientation or of congruent sign. We replicated this finding in a second experiment for which the left and right gratings were discriminated relative to orthogonal references, indicating that this modulation occurs at the decision and not the sensory level. We built a computational model in which orientation information was linearly decoded from a population of neurons with Gaussian tuning curves. The model assumes that the width of the tuning for each orientation, which in turn determines the encoding gain, was inversely proportional to the contextual information provided by the distractor, i.e. target tilt was modulated by a gain control process that depended on the distractor. This model recreated both the influence of target energy on choices and its modulation by irrelevant information. We argue that the effect of distraction is a multiplicative process, in which contextual signals determine the gain with which targets are evaluated.

Phasic pupil dilation tracks expected and unexpected uncertainty during attentional orienting

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Attentional orienting can be considered as probabilistic inference about which spatial locations are likely to be relevant in the near future. Bayesian principles can be applied to estimate uncertainty of such beliefs. Computational modelling work proposes that the attentional system relies on two forms of uncertainty estimates, which are linked to distinct neuromodulatory brainstem systems [1]. *Expected uncertainty*, associated with acetylcholine (ACh) levels, tracks the unreliability of predictive relationships within a familiar context. *Unexpected uncertainty*, likely triggered by noradrenaline (NE) release, signals sudden changes of the environmental context. In the current study, we aimed to characterise how the attentional system relies on these distinct uncertainty estimates during spatial orienting. To probe the link between uncertainty estimates and neuromodulatory brainstem responses, we capitalised on the fact that the latter are reflected by different measures of phasic pupil dilation - the pupil diameter and its temporal derivative. Recent evidence shows links between pupil diameter and ACh levels, and pupil derivative and NE levels [2]. Based on this, we hypothesised that pupil diameter following the target presentation is sensitive to expected uncertainty, while pupil derivative fluctuates with levels of unexpected uncertainty. Participants performed a novel spatial cueing task, in which two spatial cues were presented. Participants' task was to efficiently respond to low-contrast grating stimuli following the cue and to infer which of the presented spatial cues correctly predicts gratings' spatial location. A computational model estimating participants' beliefs about cue validity (expected uncertainty) and beliefs about the currently relevant cue (unexpected uncertainty) was fit to response times (RT). RT increased with increasing levels of both expected and unexpected uncertainty. Importantly, Bayesian model comparison showed more reliable evidence for the effect of unexpected uncertainty. We then analysed how uncertainty estimates (fit to behavioural data) are reflected in phasic pupil dilation measures. Initial findings showed that specifically on invalid trials (i.e., trials in which stimulus location was incorrectly predicted by the currently relevant cue), pupil diameter following the target presentation increased with lower levels of expected uncertainty. This result is consistent with the previous evidence showing that pupil diameter reflects surprise [3]. On the other hand, the pupil temporal derivative increased with increasing unexpected uncertainty, and this relationship was specifically present under low expected uncertainty. The interactive modulation by expected and unexpected uncertainty is in line with the predictions of the computational model. In conclusion, we propose that attentional orienting relies on estimates of expected and unexpected uncertainty in the environment. These two forms of uncertainty are differentially reflected in fluctuations of pupil diameter and its derivative – likely proxies for ACh and NE responses, respectively.

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[POSTER 70]

The Impact of Meta-cognitive Ability on Habitual Learning; The Over Confident Learning Strategy

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Learning is crucial for animal and human life in environmental changes. There are behavioral and neuroimaging evidence for the existence of two major learning systems which collaborate or compete with each other to evaluate decisions in the process of learning. One of them is the goal-directed system which utilize the model of environment to make decisions and the other one is the habitual system which makes decisions only based on the history of reward. These two learning systems are named model-based and model-free learning systems. On the base of previous studies, people use different weights of these systems in decision-making. However, it is not clear which cognitive abilities are related to individual differences in learning style. Especially, this question seems to be more complicated in non-stationary conditions which two systems have the same level of performance and speed of learning. We showed that in these conditions difference between options' values, confidence correlates, is exaggerated in the model-free system relative to the model-based system. We know that confidence is the common measure of meta-cognitive ability which is the ability to evaluate decisions. Thus it is expected that people with a higher level of meta-cognitive ability rely less on a learning style with exaggerated confidence about decisions. We measured meta-cognitive ability and learning style in two different tasks and we saw meta-cognitive ability was negatively correlated with model-free learning-style while it had not any significant correlation with model-free learning-style. These results confirmed previous studies, which showed meta-cognitive ability was inconsistent with over-confidence in decisions.

[POSTER 71]

Correlating mind wandering and behavioural variability to preceding oscillatory power – a MEG study

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Whatever task we are performing, our attention on it is never stable over time, but instead fluctuates between on-task and off-task focus - a phenomenon often described as 'mind wandering'. On a behavioural level, subjective reports of mind wandering have been positively associated with reaction time variability. However, effect sizes are typically weak, and the exact link between mind wandering and behavioural variability remains unclear. While some previous EEG studies have investigated oscillatory power preceding mind wandering, these studies: 1) have largely scattered methodologies and findings, 2) have not examined the neural processes of behaviour, and 3) have not distinguished mind wandering from other forms of inattention, such as fatigue. Furthermore, because of their subjective nature, the ratings may not just reflect mind wandering, but a mixture of metacognitive experiences. The current research is the first MEG study to investigate the neural processes of mind wandering. Specifically, we examined whether behavioural variability and subjective ratings of attentional state and performance can be predicted from preceding oscillatory power. Twenty-one participants took part in a two-session study. In both sessions, they performed the Metronome Task, in which they press a button every three seconds [1]. Subjective attentional states and performance were measured with quasi-randomly presented probes. The subjective ratings were found to correlate highly to each other, and showed positive but weak associations with task performance. Next, correlational synthetic aperture magnetometry analyses were conducted to correlate average oscillatory power on each trial with performance and subjective ratings. On the group level, attentional state ratings (but not perfomance ratings) correlated positively to alpha power in the right temporal gyri and frontal gamma power in the dorsolateral prefrontal cortex. Exploratory analyses suggested these patterns were similar for mind wandering and mind blanking. However, we found large differences in activity between individuals. Our findings shed light on the difficulties of investigating neural correlates of subjective states, particularly highlighting the proneness to large individual differences.

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[POSTER 72]

Neural dynamics in human frontal cortex during performance monitoring and decisions to check

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In human beings, information seeking is one major behavioral activity. For instance, verification or checking potentially increase efficiency of decisions and reduce uncertainty about outcomes. The neurobiological bases of decisions to check rely in part on the frontal cortex which might have a role in controlling and regulating the impulse to check.

The present study addresses the question of the neural bases of decisions to check for information, and in particular the neural dynamics that relate to these decisions. We performed EEG recordings in young and healthy human subjects in an experimental task that challenges the checking process using positive and negative reinforcements. In each trial subjects can freely decide either to perform a visual categorization task to win points (task with cue guided decisions), or to check how close (based on a visual gauge that change size with proximity to the bonus) a bonus of points will be available (Condition 1). In the second condition, the subject have to check to avoid losing the equivalent amount of points. The protocol leaves freedom to subjects to create their own strategy to solve the task.

We present preliminary behavioral and electrophysiological analyses with 26 subjects. The behavioral analyses suggest that subjects resort to either one of two strategies to complete the task, which might reveal two different motivations or type for checking decisions: getting information about the task (speed of the gauge), or information about the outcome (bonus delivery, avoidance of loss).

We analyzed EEG data using Current Source Density (CSD) estimates, through the Surface Laplacian computation. The CSD at the time of choice between check or play show modulations depending on the previous trial outcome and the gauge size (how close is the bonus). A time/frequency analysis revealed different levels of frontal alpha and theta oscillations before decisions to check compared to decisions to do the main task. We also compare EEG signals between decisions to check/play and decision in the categorization to extract specificity of neural dynamics during decisions to check.

[POSTER 73]

Representing numbers in a sequential numerical comparison task

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Numerical cognition, despite being considered a higher cognitive function, can resemble sensory perception by being susceptible to characteristic psychophysical effects, such as diminishing discriminability between increasing quantities (Weber-Fechner law). The same property of such logarithmic transformation has also been found to describe neural tuning in humans and animals [1,2]. However, recent work using electroencephalography (EEG) has shown that in a numerical integration task - as opposed to the classic numerical comparison task - the number line followed a convex exponential shape, with *increasing* distance between increasing quantities [3,4]. Our study aimed to bring together these conflicting findings using a paradigm that combined features of both sequential integration and numerical comparison. Specifically, we asked what the shape of the number line would be under a sequential design and whether the neural representation of the number line could change under different conditions.

We designed a new sequential numerical comparison task that could probe the representation of numbers, both when their numerical value was the key decision variable and when only the visual similarity mattered. Participants (n = 28) viewed a continuous fast-paced stream of symbolic two-digit numbers between 25 and 40. The stream would alternate between a coloured target number and a string of white filler numbers. For the coloured numbers, participants performed a numerical comparison task judging whether the current number was higher or lower than the previous coloured number. During white numbers, participants performed a template matching task, responding when a white number matched the last coloured number. We recorded brain scalp activity using EEG while participants viewed a total of 2880 numbers.

In the numerical comparison task, participants' accuracy and reaction times were significantly explained not only by the difference between the two numbers (i.e. the decision variable of interest) but also by their sum. Simulations further showed that such a pattern indicated participants on average exhibited a small, but convex shape of their number line. Neurally, we found that centro-parietal signals scaled with numerical magnitude, but only in the numerical comparison task. Surprisingly, in contrast to previous work with single-digit numbers [3,4], signal amplitude decreased with numerical magnitude. Multivariate analyses further confirmed the presence of a numerical magnitude representation.

Our preliminary results suggest that a logarithmic representation of numbers is not set but depends on the task at hand. Furthermore, in contrast to previous findings [1], number representation does not appear to arise automatically, but only becomes decodable from neural signals when the task requires numerical cognition.

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Bounded adaptability of reward-guided learning to the correlation structure of volatile environments

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Learning the value of actions in volatile environments represents an important challenge for human and artificial agents alike. It requires an efficient arbitration during choice between exploiting a currently well-valued action vs. exploring more uncertain, possibly better-valued actions - known as the 'exploration-exploitation' trade-off. However, the learning process itself can be made more efficient by adapting to structural properties of volatile environments, such as the degree of correlation between rewards associated with different actions. Here we studied the extent to which humans adapt their learning scheme and choice policy to the correlation structure of volatile environments in a restless two-armed bandit task. In half of the blocks, the mean payoffs associated with the two shapes drifted independently from each other (*uncorrelated* condition). In the other half, the mean payoffs drifted in opposite directions throughout the block (*correlated* condition). The presence or absence of correlation between mean payoffs was either cued explicitly at the beginning of each block (*N* = 30, experiment 1), or not cued (*N* = 29, experiment 2).

To characterize choice behavior in the two experiments, we applied a recently developed reinforcement learning (RL) framework which dissociates overt exploration from computational noise in the update of action values [1]. On each trial the expected value Q_t associated with the chosen action a_{t-1} is updated based on the 'prediction error' (PE) between obtained and expected reward $(r_t - Q_{t-1})$ at a learning rate α [2,3]. We modified this canonical learning rule by corrupting it with additive random noise ε_t whose standard deviation equals to a fraction ζ of the magnitude of the PE [1]:

$$Q_t(a_{t-1}) = Q_{t-1}(a_{t-1}) + \alpha \cdot \left(r_t - Q_{t-1}(a_{t-1})\right) + \varepsilon_t$$

We compared three learning schemes for updating the expected value associated with the unchosen action $\tilde{a}_{t-1}$: (1) no update, (2) a counterfactual update where the foregone reward $\tilde{r}_{t-1}$ is inferred as $100 - r_{t-1}$, and (3) a decaying update where the expected value is regressed toward its long-term mean (50 points in every block). We modeled the choice process using a 'softmax' action selection policy, controlled by an inverse temperature β. RL models were fitted to behavior using particle filtering [4,5] and compared using Bayesian model selection (BMS). When the degree of correlation was cued, BMS indicated increased reliance on the counterfactual learning scheme in the correlated condition ($p_{\text{exc}} > 0.999$, adaptability $d' = 1.25 \pm 0.35$). This adaptability rode on top of a strong idiosyncratic preference for either learning scheme. By contrast, when the degree of correlation was not cued, participants' learning did not adapt ($p_{\text{exc}} = 0.826$, adaptability $d' = 0.37 \pm 0.39$) and relied dominantly on the counterfactual learning (preference $c = 0.99 \pm 0.20$). Interestingly, participants made fewer exploratory choices in correlated than uncorrelated environments, whether cued or not (cued: $p = 0.009$, uncued: $p = 0.002$).

Together, this pattern of findings delineates a bounded adaptability of human reward-guided learning, constrained by the reliance on a default, counterfactual learning scheme.

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[POSTER 75]

Time-dependent Competition Between Goal-directed and Habitual Response Selection

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Converging evidence indicates that separate goal-directed and habitual systems compete to control behaviour [1]. The goal-directed system compares available actions and chooses the response most likely to produce a desirable outcome. This comparison process is computationally intensive and slow, but is highly accurate and can flexibly adjust to changes in the environment. By comparison, the habitual system bypasses extensive computations by simply selecting responses that have previously been successful. This has the advantage of being much faster, but the drawback of being inflexible; the habitual system will persist in selecting the same responses even when they no longer lead to desired outcomes.

While computational, neurobiological, and behavioural evidence indicate that these two systems compete to control behaviour in animals, laboratory experiments have failed to reliably induce habitual behaviour in human participants [2-4]. We reasoned this may be because the participants in previous experiments did form habits, but were able to mask them by waiting for longer periods before initiating responses.

Here we show that latent habits can be unmasked by limiting the time participants have to respond to a stimulus. Participants trained for 4 days on a visuomotor association task, after which specific stimulus-response associations were remapped. By continuously varying the time allowed to prepare responses, we found that the probability of expressing a learned habit followed a stereotyped time course, peaking 300-600ms after stimulus presentation. This time course was captured by a computational model of response preparation in which habitual responses are automatically prepared at short latency, but are replaced by goal-directed responses at longer latency. A more extensive period of practice (20 days) led to increased habit expression.

These findings refine our understanding of habits, and show that practice can influence habitual behaviour in distinct ways: by promoting habit formation, and by modulating the likelihood of habit expression.

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[POSTER 76]

Stable and Competitive Dynamics in Attention Allocation

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How does *what you know* influence *where you direct your attention?* In a complex world, humans must maximise information gain by exploring and learning the regularities of the environment (active sampling). This requires two distinct neural representations; of current attentional focus, and of past experience. In this study we combined biophysical modelling and MEG to uncover the neural mechanisms of each process.

In a novel adaptation of the random-dot motion task, participants had to concurrently resolve competition *within* a trial by judging dominant motion direction (left vs right), and integrate information *across* trials by tracking unpredictable changes in the underlying probability distribution from which trials were drawn. We modelled the neural dynamics of within-trial competition using a mean field model with two self-excitatory, mutually-inhibitory neural pools. Across-trial evidence integration was modelled using a Bayesian learning model that computed a prior belief over the set of motion directions.

Behavioural data indicate that participants' prior beliefs about the visual stimulus - before they observed it - biased subsequent evidence accumulation. MEG results indicate a pattern of temporal dynamics consistent with the biophysical model predictions, namely an early effect of the level of coherent motion, and a later effect of level of competition between choice options. Pre-stimulus activity tracked the Bayesian model, indicating that prior belief may bias current decision-making by altering the initial state of the decision-making system. Ongoing analysis seeks to determine whether these neural mechanisms share a common substrate or can be localised to different brain regions within an integrated neural circuit.

[POSTER 77]

Sequential Signal Detection Theory: Reversing Old Beliefs

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Signal detection theory has influenced many aspects of the behavioural sciences (psychology, behavioural ecology, immunology, animal welfare, etc) for over 50 years. The theory makes numerous basic predictions, such as that prey should be less bold if predators are more common. We have recently developed a new technique, state-dependent detection theory (SDDT) which allows us to look at the detection of signals over a series of decisions [1-4], and how these alter with an animal's state (including feedback effects). In contrast with the standard theory, we find that, in numerous biological scenarios, the standard results of signal detection theory do not apply; more predators can result in prey being more bold. This occurs when the change in risk applies not just to the current decision but to future decisions, because running away (and thus not gaining food) would mean that even greater risks may be required in the future. This can have far-reaching effects in each of the sciences that involve decision-making.

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[POSTER 78]

Inducing habit formation in humans through extended overtraining

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The dichotomy between habitual and goal-directed choice behaviour has received significant attention in recent decades [1]. Habit formation is classically demonstrated in rodents. Animals trained on an operant task to a high level of performance can flexibly adjust their responses in the face of changing reward contingencies, indicating goal-directed behaviour. By contrast, those who have extensively trained *past* this level of performance become unable to change behaviour as contingencies change; they become insensitive to devaluation [2]. This devaluation-insensitivity is the hallmark of habitual choice. However, inducing insensitivity to devaluation through overtraining in human subjects has proven difficult [3]. Here, we introduce a novel overtraining task using extensive training over several days to induce devaluation-insensitivity. In addition, participants performed two tasks to assess constructs related to habit formation: the development of attentional capture throughout overtraining [4], and model-based versus model-free learning in a modified two-step task [5,6].

139 participants were divided into a criterion-trained group, an overtrained group, and a third group that was overtrained on an irrelevant stimulus set. Participants learned to select the highest-yielding stimulus out of a pair. Two stimulus pairs were trained. Within each pair, one stimulus yielded 4 and one stimulus yielded 2 points, each with 80% probability. All groups were trained until they reached a criterion of five consecutive correct choices on each pair. Then, the overtrained groups trained for a further 1280 trials per stimulus pair, spread over three days. Following this training, one stimulus from each pair was devalued, such that the optimal choice changed for one of the stimulus pairs (devalued pair) but remained the same for the other (valued pair).

Results show devaluation-insensitivity in the overtrained group, with the criterion-trained group less impaired by the rule-change. That is, the difference in performance between the valued and the devalued pairs was greater for the overtrained group than for the criterion trained group. Throughout the course of overtraining, accuracy increased while reaction times and the variability of reaction times decreased, consistent with the development of automaticity. Using our extended training paradigm, we were able to induce habit formation through overtraining in human subjects.

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Choice increases curiosity in a lottery task.

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Curiosity and information consumption are pervasive in our connected era. We own smart devices that allow us to access a vast amount of information at the push of a button (or the touch of a screen), and we spend significant time and effort seeking and consuming information. However, our time and (cognitive) resources are limited, and faced with this infinite pool of information, selection is inevitable. Often, we choose which information we seek, but on occasion the selection is made for us (e.g., in a classroom or other group setting). Hence, understanding whether and how choice shapes our curiosity is a key question.

In prior work we have demonstrated that curiosity is a function of the uncertainty as well as expected value of information [1]. However, t is unclear if and how these effects interact with having the opportunity to choose an information source. To assess the impact of choice on curiosity, we designed a lottery task in which participants saw two lotteries on each trial, which were closely matched in terms of outcome uncertainty and expected value. On some trials, participants chose which lottery would be played. On other trials, the lottery would be selected for them. Participants were then asked to indicate their curiosity about the outcome of the played lottery in terms of self-report ratings (Experiment 1) or willingness to wait decisions (Experiment 2). Furthermore, to assess whether choice interacted with uncertainty and/or expected value, we sampled lotteries within a range of these parameters.

Our findings showed that participants exhibited higher levels of curiosity for lotteries they had chosen than for lotteries that had been selected for them (controlling for initial preference). Furthermore, we found that curiosity increased as a function of outcome uncertainty, replicating previous findings [1]. Curiosity also increased with the expected value of lottery outcomes.

These findings demonstrate that choice boosts curiosity. These findings might be leveraged for boosting cognitive engagement, for example, in education. In future work, we will address the neural mechanisms underlying this effect of choice on curiosity.

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[POSTER 80]

The role of confidence during perceptual learning with and without feedback.

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Choice confidence represents the belief, or probability, that a choice is correct (*1*). Little is known about how confidence shapes choice behaviour and is encoded in the brain. Within the theoretical framework of reinforcement learning it is postulated that a greater sense of confidence in the choices made will strengthen such choices (*2, 3*). Here, using model-based fMRI we first illuminate the cognitive mechanisms by which confidence contributes to perceptual learning and subsequently uncover its functional neuroanatomy. More specifically, we first test the hypothesis that in the absence of external feedback (and thus of the reward prediction error (RPE)) confidence acts as a teaching signal that updates choice value. Subsequently we test the additional hypothesis that even in the presence of external feedback confidence is integrated with the RPE to update choice value.

We employed a random-dot motion discrimination paradigm and adjusted stimulus difficulty subject- and block-wise to maintain a constant performance (~65% accuracy) throughout the experiment. To elicit choice confidence we used a post-decision wagering manipulation (i.e. betting on the decision to double the payout/penalty in case of success/error) and randomly interleaved trials with and without feedback.

We recruited twenty-five participants and performed tasked-based fMRI. At the behavioural level we show robust learning effects as indicated by a systematic increase in stimulus difficulty during the experiment. Moreover, confidence effects are evidenced by greater accuracy and faster responses on betting (i.e. high confidence) compared to non-betting (i.e. low confidence) trials.

At the computational level we show that the model providing the best fit to the observed choice behaviour on Bayesian model comparison supports the hypothesis that confidence contributes to the updating of choice value both in the presence and absence of feedback. In this model a decision variable (DV) denotes the trial-by-trial strength of the perceptual evidence available and is modulated by stimulus specific perceptual weights characterising the learned sensory contingencies (*4, 5*). Confidence is computed as the normal cumulative distribution function of the magnitude of DV and is updated according to a conventional delta rule. The prediction error used to update perceptual weights is estimated as a convex combination of confidence and RPE estimates.

To further test the validity of our model, we used mixed effects linear models accounting for between-subjects heterogeneity to show that model derived confidence estimates significantly and positively correlate with observed betting behaviour. Additionally, we demonstrate that model derived choice value estimates significantly and positively correlate with observed accuracy of choice behaviour. Crucially, using the model fits we show that the variance of the cumulative distribution function denoting the subject specific overall confidence throughout the task is negatively and significantly correlated with overall individual betting behaviour.

Taken together, these results are consistent with the proposal that confidence signals play a crucial role in driving choice behaviour during perceptual learning both in the presence and absence of feedback.

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[POSTER 81]

Rewards and uncertainty jointly drive the attention dynamics in reinforcement learning

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Aim: The nature of attention, and how it interacts with learning and choice processes in the context of reinforcement learning, is still unclear. Probabilistic accounts of associative learning, as well as approximately optimal solutions of the exploration-exploitation dilemma, suggest that both learned value and uncertainty about those values (i.e. reducible or estimation uncertainty) are important for learning and choice. This implies that both factors should jointly guide attention. Our main goal was to test this prediction. Our secondary goal was to examine whether the relation between attention and reinforcement learning is bidirectional, whether attention also influences or biases what we learn and how we choose. There are some tests of this direction of influence; however, the role of estimation uncertainty has not previously been addressed.

Method: Participants (N=36) completed two games in which they repeatedly chose between six options. Each game was a multi-armed bandit task where rewards for each option were drawn from Gaussian distributions, differing in both their means and variances. The participants' goal was to maximize the cumulative sum of rewards in each game. To do this, they needed to explore the options in the choice set in order to learn which option had the highest average reward, and subsequently exploit this knowledge. We monitored participants' attention using eye tracking while they performed the tasks, operationalizing attention as the proportion of time spent fixating on each of the options before making a choice.

Results: We relied on computational modeling to garner evidence for our two questions. To address our main question, we modeled attention with a combination of a Bayesian (Kalman filter) learning component and two types of choice rules: one that relies only on learned value (softmax) and one that additionally uses estimation uncertainty to assign an "exploration bonus" to the options (upper confidence bound rule). Model evidence showed that Kalman filter learning with the exploration bonus described overt attention best, providing evidence that trial-by-trial learned values and estimation uncertainty jointly guide visual attention. For our secondary question, we used the same models to model choices, but allowing measured attention to affect the choice process by increasing the probability of choosing attended options and decreasing it for unattended options. Attention was also allowed to modulate the magnitude of updates in the learning process. Again, we found that Kalman filter learning with exploration bonus was the best model, showing that estimation uncertainty plays an independent role in determining choice, over and above its effect on attention.

Conclusions: In summary, the interaction between attention, learning, and decision making, extends further than previously found. Our results provide support for probabilistic associative learning accounts that ground attention in efficient computations rather than constraints, and establish a relation with approximately optimal resolutions of the exploration-exploitation trade-off.

[POSTER 82]

Generalized Nonlinear Models, a flexible and interpretable tool for behavioral and neural analysis

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Generalized Linear Model (GLMs) analysis is a popular tool in psychophysics and neuroscience for inferring the relative influence of various experimental factors onto choices, reaction times, neural activity and other observables. However, GLMs are intrinsically limited by their linearity assumption, and can lead to severe misattribution errors when (correlated) regressors contribute nonlinearly to the observed response. Here we show how this framework can be expanded to capture nonlinear functions. First, Generalized Additive Models (GAMs) allow to capture a nonlinear contribution for each regressor. We show that a Gaussian Processes (GP) treatment of GAMs allows to recover the posterior distribution for each nonlinear mapping [1], [2]. Second, as neuroscience is often interested in the interaction of cognitive factors, we present Generalized Multilinear Models (GMMs) that permits to capture multilinear interactions between different sets of regressors. GMMs can be applied for example when capturing the modulation of sensory processing by additional factors such as attention factors. Merging the frameworks of GAMs and GMMs yield Generalized Nonlinear Models (GNMs), a highly versatile and interpretable environment to capture cognitive determinants of behavior and neural activity. Crucially, these models can be efficiently estimated, even with limited dataset (typically hundreds of observations); Bayesian techniques can be applied to test which model is best supported by data. We illustrate GNMs on human choices in a perceptual accumulation task with oriented stimuli [3]: GNMs showed modulation of perceptual processing by previous trial outcome (error correction) and block position (learning and fatigue effects). GNMs also revealed that subjects used a near optimal mapping from sensory (orientation) to perceptual space. A Matlab toolbox will be available to allow for rapid, flexible usage of GNMs for cognitive psychology, neuroscience and other disciplines.

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[POSTER 83]

Reduced value contextualization impairs punishment avoidance learning during aging

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The ability to adapt to new decision environments and to learn from feedback declines with age, resulting in sub-optimal decision-making in elderly. There has been much debate on whether elderly lose their ability to learn from negative feedback. We propose that rather than a specific deficit in punishment vs. reward processing, older adults might be impaired in value normalization. During learning in a specific context, the reward system tunes to adapt to the range of rewards or punishments previously encountered in that context. This value normalization theoretically allows for better discriminating between the values of currently available options. We tested a model of choice that embeds separate modules for value contextualization and learning from counterfactual information. We hypothesized that such sophisticated computations are affected by aging.

A group of 22 elderly (age range 63-86) and a group of 24 young participants (age range 18-53) performed a probabilistic instrumental learning task and a post-learning test. The learning task was designed to manipulate both outcome valence (Reward vs. Punishment) and feedback type (Partial vs. Complete). In Partial feedback contexts, participants were presented with only the outcome of the chosen cue while in Complete feedback contexts, the outcomes of both the chosen and unchosen cues were displayed. Four fixed pairs of cues were used; each corresponding to one of four stable choice context.

Receiving a complete feedback rather than a partial feedback equally improved correct choice rate in the young and elderly groups. However, compared to young people, elderly had significantly reduced correct choice rate during learning in the punishment context. Whereas the pattern of post-learning choices was consistent with the value-contextualization in the young group (value inversion in the complete feedback trials), this effect was absent in elderly people. Computational model estimations confirmed that elderly were able to use the counterfactual information but failed to contextualize values during learning. The choices of young adults were best explained by a model containing both learning modules.

During learning from negative feedback, when the best action - which yields to a neutral outcome - is consistently chosen, values are not updated. Therefore learning cannot be sustained. A solution to this problem consists in considering outcomes relative to the context in which they are delivered. The decline in the ability to use value-contextualization with age can explain the associated selective impairment in learning from negative feedback.

[POSTER 84]

Make-or-break: chasing risky goals or settling for safe rewards

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Some of the most important decisions in life may be defined by how one chooses to allocate limited resources between make-or-break tasks—with potentially life changing outcomes—and “safe” alternatives, where outcomes are a more predictable function of performance. How should you divide your time between chasing a challenging goal and investing in safer occupations? What is the optimal allocation strategy, and how does it compare to simpler, but computationally less expensive strategies? What behaviors do the different strategies produce across decision-making settings?

In this paper we study two variants of the problem of make-or-break settings. In the one-shot allocation problem, the decision maker receives feedback about performance only at the very end of the task, after all available time has been allocated. Performance is unobservable during the allocation phase, as is the case when preparing a grant application. In the dynamic allocation problem, the decision maker receives immediate feedback on their current output and—like a PhD candidate toiling to fulfill graduation requirements before funding runs out—can dynamically adapt their allocation strategies at any point in time, either continuing to pursue the make-or-break goal or dropping out in favor of a safe alternative.

We introduce the optimal solution for the dynamic version of the problem. We mathematically prove that optimally solving the dynamic allocation problem implies prioritizing investment in the make-or-break task over the safe rewards task and switching unidirectionally to the safe alternative only when performance falls below a “giving-up” threshold or when success has been reached. We show that acting optimally implies using an increasingly tolerant giving-up threshold as uncertainty in the environment increases. The optimal strategy provides insights into the nature of the decision-making environment. Yet it is inaccessible to humans, due to its exorbitant computational costs. This raises the question of what strategies are available to boundedly rational decision-makers.

We proceed by formulating three boundedly rational strategies and analyzing their performance in relation to the optimal solution across decision-making environments. First, we define a myopic giving-up strategy, which is based on the optimal solution to the one-shot allocation problem. The myopic solution implies giving up earlier than the fully optimal strategy and it becomes more conservative relative to the optimal strategy as uncertainty increases, yielding a distinct pattern of risk-aversion. Second, we examine the play-to-win heuristic, a simple heuristic strategy that only decides whether or not to invest in the make-or-break task and then stubbornly perseveres until success or failure occurs. When contrasted with optimal giving-up, this strategy produces risk-seeking behavior that is consistent with the

sunk cost fallacy. Finally, we define the control points strategy, a generalization of the above two strategies, which considers giving-up at a fixed number of time points. Holding all other factors constant, we find that an increase of uncertainty in the environment improves the relative performance of the play-to-win and control points strategies, which despite disregarding most information, almost always outperform the myopic giving-up strategy and can approximate the performance of the optimal solution.

[POSTER 85]

Slope between N100 and P300 ERP components predicts trial-by-trial accumulation drift-rate in certainty-based choice task

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Certainty of outcome is one of the major factors influencing choices. A major driving force of such choices is the difference in magnitude: given two options of varying probability of reward, we tend to choose the one associated with greater chance of success. However, little is known about the effects of absolute certainty magnitude on choice: is choosing between events with highly probable positive outcomes in any way different from choosing between two unlikely ones?

Here, we test this by focusing on choices between options associated with identical probabilities of reward. The task required participants to learn an association between 6 abstract symbols and 3 reward probability levels (100%, 80% and 20%; two symbols representing each level) and perform a series of 2-alternative and 1-alternative (forced) choices between the symbols.

We find a very strong effect of certainty on decision speed, where higher degree of certainty is associated with faster responses, both in two-alternative and forced choices. Additionally, we show that people develop a systematic preference for one of the symbols at each probability level. Using sequential sampling framework to understand the generative process of these phenomena, we show that differences in certainty and preference are associated with the speed of evidence accumulation, but not with visual encoding or motor execution.

Finally, we decomposed the EEG signal using Single Value Decomposition to obtain single trial estimates of Event-Related Potentials and use them as drift-rate regressors in the Linear Ballistic Accumulator model. Using this method, we show that model-derived speed of evidence accumulation is linearly predicted by the slope of ERP signal amplitude from the negative peak of N100 component (signalling end of visual encoding) to the peak of P300 component (a prominent signature of evidence accumulation), on a trial-by-trial basis. Signal weight analysis indicates the signal was most strongly influenced by centro-parietal region activity, previously associated with evidence accumulation [1].

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Learning about advice: Confidence guides information sampling flexibly

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Upon making a decision we typically have a sense of the likelihood that the decision we reached was a good one, i.e. a degree of confidence in our decision. Usually, people are highly accurate at evaluating their performance, with reported confidence ratings strongly reflecting objective performance. Despite the evident connection between confidence judgments and decision-making, the functional importance of confidence judgments and how they affect decisions remains largely unknown. Here, we study how people use confidence when choosing between different types of information before making a decision. We hypothesize that confidence guides information sampling flexibly, depending on people's immediate goal.

In a series of three experiments, participants performed a perceptual decision making task, in which they reported which of two boxes presented briefly on the screen contained more dots, and how confident they are in their decision. After giving an initial response, participants chose between viewing the stimulus again for a longer period and receiving advice from a virtual adviser. Following reception of this additional information, they gave their final response and confidence on which box contained more dots. Adviser accuracy varied between blocks, and the availability of external information about adviser quality was manipulated, with participants receiving no information, direct information (e.g. this advisor's accuracy is 70%) or indirect information (through feedback on perceptual task performance).

We find that, when external information about adviser quality was not available, participants chose to view advice more frequently when confidence was high, allowing them to learn about the adviser's quality. When external information about adviser quality was available, either directly or indirectly through feedback, participants showed a trend towards selecting advice more when confidence was low. We suggest these results reflect the flexible use of confidence, depending on one's immediate goal.

SESSION 3: WEDNESDAY 29 MAY, 12:15 – 14:15 (POSTERS 87-127)

[POSTER 87]

Tired of working: Neurocomputational mechanisms of moment-to-moment fatigue and its effect on effort-based decisions

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Prominent theories suggest that fatigue - a feeling of exhaustion arising from effortful exertion - has a significant impact on motivation, reducing the willingness to exert effort over time [1-3]. A considerable body of research has identified the role of sensorimotor brain systems in effortful behaviour and implicated fronto-striatal systems in ascribing value to - and motivating - the exertion of effort [e.g. 4-5]. However, the majority of studies assume that motivation is static. Yet, motivation fluctuates moment-to-moment, and fatigues over-time. Here, using an effort-based decision-making paradigm in combination with computational modelling and fMRI, we were able to identify the neural mechanisms underlying moment-to-moment fluctuations in fatigue and their effects on effort-based decisions. Young healthy participants (N = 36) made a series of choices between two alternatives: a rest option for a low reward (1 credit) or a work option, requiring the exertion of one of three levels of grip force (30-48% of their maximal grip strength), for one of three higher amounts of reward (6-10 credits). Computational modelling revealed that the willingness to exert effort, in particular high effort, fatigues over trials as a function of the effort previously accumulated over the course of the whole task but is partly recovered by rest trials. Preliminary fMRI results suggest that dorsal anterior cingulate cortex and dorsolateral prefrontal cortex track moment-to-moment, model-estimated levels of fatigue, whereas ventral striatum and frontal pole signal subjective value weighted by the current, momentary level of fatigue.

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Motivational Control during Multi-Option Decision Making

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Why do we think carefully about some decisions but not others? We propose that effort is strategically deployed–the amount of executive resources that a decision-maker allocates to a task optimizes a cost-benefit trade-off. We developed a computational model to demonstrate the mechanics of this process. According to our model, a decision starts with a default assessment of option values, which is progressively refined through mental effort. Such effort investment increases the probability of making the right choice but carries a cost. The optimal effort allocation will be the level at which the marginal cost equals the marginal benefit. A core driver of the benefit is decision difficulty (option value similarity). Difficult decisions start with a low probability of choosing correctly, and thus induce a demand for resources. Our model predicts a non-trivial relationship between difficulty and effort, depending on individual cost and efficacy parameters.

To validate our model predictions, we conducted a behavioral experiment. Participants rated items, then chose between pairs of the items, then re-rated the items (motivated from the prediction that effortful decisions would induce changes in items' values). Choice confidence, rating confidence, decision time and pupil dilation were also measured. In accordance with the model, our results show larger rating revisions, higher subjective effort, and longer response times for more difficult decisions. The data also support the counter-intuitive model predictions that, controlling for difficulty, rating change correlated negatively with RT and positively with confidence.

We also included different conditions to demonstrate the effects of reward and cost manipulations. In the reward condition, choices were made consequential to incentivize effort. In the penalty condition, decision time was financially penalized to disincentivize effort. The results show higher RT and subjective effort in the reward condition, and lower RT and effort in the penalty condition. In sum, our findings validate our model predictions with respect to mental effort allocation in general, as well as to reward and cost in particular.

For the final phase of this project, we expanded our model to include more than two options (demonstrated with three options, but valid for any number of options). We conducted a behavioral experiment (similar to the one described above) in which participants chose from triples of items. The items in these triples were selected so as to parametrically vary the proximity of the values of the best and second best items ("ease") as well as the proximity of the values of the second and third best items ("distance"). Our model predicts that both ease and distance will correlate negatively with mental effort and positively with choice confidence. It also makes the non-intuitive prediction that an "irrelevant" option (that is, when the value of an option in a triple is clearly lower than the other two) will cause more interference in the choice (greater effort, lower confidence) when the decision-maker is less certain about its value. The data validate our model predictions.

[POSTER 89]

The influence of confidence on post-decision evidence processing

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Confidence has been suggested to act as a top-down control mechanism for guiding future information processing and behaviour[1], but experimental evidence for this hypothesis is sparse. Here we investigated how confidence in an initial decision influences post-decision evidence processing and subsequent changes of mind. In a random dot motion task, participants were presented with pre-decision evidence and made an initial decision, before seeing the moving dots again (post-decision evidence) and making a final decision. Behavioural results and drift-diffusion modelling indicated that high confidence in the initial decision reduced later changes of mind through a selective increase of choice consistent information processing. By applying decoding analyses to MEG data we could obtain a neural measure of evidence accumulation, enabling us to investigate how this accumulation process is altered in response to post-decision evidence. Temporal generalization of these decoding scores revealed neuronal markers of a confidence-induced bias in post-decisional processing. Together these results reveal a candidate neuronal mechanism underlying the phenomenon of confirmation bias.

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[POSTER 90]

Disruption of Affect Integration on Aesthetic Evaluation Following Sleep Deprivation

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Classical behavioral studies assumed a psychological misattribution process, in which consumers misperceive their affective states, elicited by incidental events, as the reaction towards evaluative targets at hand (Schwarz, 2010). Taking a neurophysiological perspective, a recent study proposed a novel two-stage process to explain how incidental affect is misattributed (Ling, George, Shiv, & Plassmann, 2018): 1) arousal of affect, which acts as the catalyzer, transports the valence of affect, representing positivity or negativity of

affective value, to brain's valuation system (BVS); 2) the valence is integrated as the subjective value of evaluative targets when these targets are being appraised by the BVS.

Motivated by this new conceptualization, the current research tests whether the integration of affect valence is attenuated when the function of BVS is interrupted. Based on the findings in sleep research that value signals in the vmPFC, a key region in the BVS, are diminished following sleep loss (Greer, Goldstein, & Walker, 2013; Killgore et al., 2013; Menz, Buchel, & Peters, 2012), we hypothesize that 1) the impact of incidental affect on subsequent evaluation is greater when participants are in a rested state than in a sleep deprived state; 2) the impact of incidental affect reduces along the times of a day.

We adopted an incidental reward paradigm to elicit incidental affect and to test participants' aesthetic evaluations of images on a 9-point scale as a seemingly unrelated task (Ling et al., 2018). Two groups of participants were recruited for this experiment. In the sleep deprivation (SD) group (N=57), participants performed the task in the evening and stayed overnight in the lab under supervision before performing the task again in the morning. Every two hours (6-run in total overnight), SD participants performed a Psychomotor Vigilance Task (PVT) to access their reaction times towards visual stimuli. In the sleep control (SC) group (N=18), participants performed the task in the evening and slept in the lab before the morning session of the task. Two runs of PVT were administered before and after sleep.

We found a significant interaction of reward and session time (β = -.727, p = .018) and a main effect of reward (β = .586, p = .007) in the SC group. Replicating affect-as-information effects, participants in the SC group provided a higher rating of images after receipt of reward (M_{reward} = 6.555) vs. no-reward ($M_{no-reward}$ = 5.968) after sleep (p = .007). There were a significant interact of reward and session time (β = .605, p = .002) and a main effect of reward (β = -.433, p = .002) in the SD group. These results suggested that affective influences on image evaluation diminished after a night of sleep deprivation (M_{reward} = 5.848 vs. $M_{no-reward}$ = 5.414, p = 0.001). We further tested how the times of a day (morning vs. evening vs. sleep deprived) influenced image evaluations across two groups. We found a significant main effect of this variable (β = -.287, p < .001), showing an attenuated net impact of incidental affect on image evaluations ($M_{morning}$ = .586 vs. $M_{evening}$ = .096 vs. $M_{sleep\ deprived}$ = -.433).

Taken together, we found that the impact of incidental affect on image evaluation was disrupted following sleep deprivation, and the extent of disruption varied as a function of times of a day as participants were getting sleepier.

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[POSTER 91]

Neural correlates of deliberation across rating, choice and learning tasks

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Some decisions are made impulsively, without properly weighing costs and benefits, whereas others are made thoroughly, after careful consideration of every potential outcome. Response time (RT) is a good proxy for the duration of deliberation and hence, for the effort invested in a choice. In the decision-making literature, RT is known to vary with the (subjective) value of choice options and the (subjective) difficulty of the choice task. Subjective difficulty can be conceived as the opposite of confidence in the response, which relates to the distance between choice options. Here, we investigate the residual variance in RT, once value and confidence factors have been regressed out.

We have defined value, confidence and RT regressors across standard rating, choice and learning tasks. In the rating task, subjects had to judge how much they would like to receive various rewards (e.g. a chocolate cake) and how much they would dislike exerting various efforts (e.g. filling a tax form). In the choice task, they had to decide between accepting and declining to exert an effort (e.g. a 1km run) in order to obtain a reward (e.g. a movie ticket). In the learning task, they had to figure out, by trial and error, which of two symbolic cues was providing more frequent financial gains, or less frequent financial losses.

Both fMRI data in healthy participants and intra-cranial EEG in epileptic patients showed that RT correlated with activity in the dorsal medial prefrontal cortex (dmPFC). This functional cluster was dissociated from the cluster reflecting value (summed over choice options) in the vmPFC and the cluster reflecting confidence (quadratic function of decision value) in the mPFC. We interpret dmPFC activation with RT as reflecting the effort invested in the deliberation process, because it was positively correlated with pupil size. Furthermore, the time course of dmPFC activity suggested that deliberation was not only prolonged but also more intense.

Thus, we conclude that dmPFC activity provides a signature of the effort invested in the duration process that is common to all value-based judgement or decision tasks. The sources of variation in the level of effort expenditure remain to be explored, as they were not related to known factors such as option value and task difficulty.

[POSTER 92]

Distraction-induced rIFG decreases relate to reduced goal-directed effort for food reward after satiation

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Distracted eating is associated with increased food intake [1]. However, little is known about the underlying neural mechanisms. We hypothesized that distraction attenuates outcome-sensitive, i.e. goal-directed, responses towards food rewards. We expected this attenuation to be associated with decreased responses in the ventromedial prefrontal cortex (vmPFC) or other fronto-striatal regions associated with goal-directedness. For the preregistration of this study, see: https://osf.io/k998e/?view_only=ae19c2bb78ac4b59a69669a5b129cab8.

Thirty-eight healthy, normal-weight participants performed a visual detection task varying in attentional load (high or low distraction) during fMRI. Simultaneously, participants exerted effort for food reward by repeated button presses for two types of snacks (sweet or savoury). Goal-directedness was assessed by comparing effort before versus after outcome devaluation by satiation on one of the two snacks (i.e. sensory-specific satiation).

Behaviourally, there was no effect of distraction on effort for food reward as a function of outcome devaluation. Neurally, the vmPFC was sensitive to the devaluation, but these effects did not interact with distraction. Instead, distraction tended to affect goal-directed responses in the right inferior frontal gyrus (rIFG, $p<.001$, uncorrected). Importantly, these distraction-sensitive rIFG responses for devalued versus valued food rewards significantly correlated with the same effect in the number of button presses ($r=-.40$, $p=.014$). Specifically, distraction-related rIFG decreases were associated with continued button presses for food reward after satiation, in line with rIFG's established role in response inhibition. Furthermore, psychophysiological interactions showed that distraction decreased functional connectivity between the rIFG (seed) and bilateral putamen for valued versus devalued food rewards (left putamen: $p<.001$, right putamen: $p=.007$, FWE-corrected at the cluster-level).

Taken together, our results suggest that distraction attenuates the ability to inhibit responses for food reward after outcome devaluation by acting on the rIFG. Furthermore, distraction seems to disrupt communication between two regions involved in response inhibition - rIFG and putamen [2][3] - after outcome devaluation. The reduction in goal-directed control towards food rewards, and the disruption of communication within the response inhibition network, might explain why distraction can lead to overeating.

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[POSTER 93]

Brain dynamics for adaptive learning

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Learning in a world that is both changing and uncertain is a difficult problem. An efficient solution is to pool past observations, which averages noise out, and to assign larger weights to more recent observations, which enables to cope with changes in the statistics of our environment. This algorithm is popular in artificial intelligence and among neuroscientists as a model of learning in the brain [1,2]. The balance between past and current observations is key to the performance of this algorithm since it sets the tradeoff between flexibility and stability of learned estimates.

Adaptive learning is the capability to balance dynamically past and current data so as to promote stability when the environment is stable, and flexibility when the environment changes [3,4]. Adaptive learning is achieved by hierarchical Bayesian learning models. Those models entertain several levels of representations: (i) the observations, (ii) the statistics generating those observations, (iii) the occurrence of changes in those statistics, and potentially higher-order properties. Bayesian models also estimate, for each level, the associated uncertainty, or conversely, confidence. A discrepancy between new observations and the current estimate of statistics leads to update those statistics, but this update is all the smaller that the confidence associated with this statistics is higher. Those confidence-weighted updates are a key feature of adaptive learning in Bayesian models [5,6].

Here, human participants performed a probability learning task, in which the hidden statistics generating a sequence of auditory stimuli changed unpredicably and discontinuously. I used the optimal Bayesian model of the task as reference to quantify the optimal confidence about an estimate as its posterior precision. Subjects occasionally reported the probability of the next item in the sequence, and their confidence in this estimate. Both reports were well accounted for by the optimal Bayesian model, replicating previous studies [7,8].

Brain waves evoked by each stimulus were recorded with magneto-encephalography. They were greatly enhanced when the stimulus appeared unlikely to the optimal model, akin to surprise and prediction error signals reported in the literature [9]. Some of those surprise signals (peaking at 200 ms) were modulated by optimal confidence: for a given surprise level, their amplitude was reduced when confidence was higher while later waves (400-700ms) reflected surprise unmodulated by confidence. Beta-range (15-40 Hz) oscillations were stronger when confidence was higher, and trials with higher beta-range power were associated with reduced evoked surprise responses. In addition, beta range power immediately before questions predicted subjective confidence. Together, those results support the following mechanism for adaptive learning. Confidence about current estimates would increase beta-range oscillations, which are often associated with top-down control [10-

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[POSTER 94]

Neural encoding of subjective values for cultural goods depends on cardiac monitoring in vmPFC

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Do you prefer Forrest Gump or Matrix? A slice of cake or an apple? You may feel that the answer to these questions “depends” on the context. Indeed, preferences are variable and fluctuate according to internal states. Food choices are tightly related to the state of the organism [1,2], which can induce a modulation of subjective values and account for fluctuations in preferences [3]. Here, we show that preference-based choices on cultural goods entailing no direct physiological consequences have nonetheless inherited a tight link with the neural circuitry monitoring internal states.

To this aim, we relate the quality of the neural monitoring of a vital internal physiological variable - i.e., cardiac activity - to the stability of subjective value representation in ventromedial Prefrontal Cortex (vmPFC). Recent studies showed that heartbeat-evoked responses (HERs), an electrophysiological index of the neural monitoring of cardiac activity, take place in vmPFC [4-6]. Furthermore, vmPFC also plays a pivotal role in the encoding and comparison of subjective values [7-9]. Despite their anatomical overlap, to date, the neural monitoring of cardiac activity and the value encoding have been considered as separate functions.

In this study, healthy participants (N=21) were asked to perform either a preference-based or a perceptual choice between two movie titles presented on the screen, while their brain and cardiac activities were measured with magnetoencephalograhy (MEG) and electrocardiography (ECG), respectively. We found that weaker HERs in vmPFC before options presentation predicted a reduced neural encoding of subjective value. Furthermore, the magnitude of this reduction was predictive of subjects' preference consistency with respect to movie ratings given the day before. Control analyses revealed that the influence of HERs was specific to subjective value encoded in vmPFC. Importantly, we ascertained that no changes in cardiac parameters, in arousal-related measures (alpha power, pupil diameter) and in vmPFC baseline activity could explain the results.

We show how spontaneous fluctuations in the neural monitoring of physiological variables impact the stability of subjective value encoding of cultural goods and affects relative preferences, in the absence of changes in physiological parameters. More specifically, we reveal that a portion of the variability in neural circuitry subserving decision-making - considered to be a source of preference fluctuations - specifically arises from the neural monitoring of cardiac activity. The results cast new light on the functional coupling between the neural circuitry subserving homeostatic regulation and stability of subjective preferences for abstract goods.

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A decision model for information retrieval from visual working-memory

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Background

It has been proposed that recall from working memory can be envisaged as a decision process in which evidence is accumulated about different retrieval options [1]. Here we test how changes in retrieval cues influence this decision-making process. Greater similarity (high competition) between cues presented at retrieval might lead to poorer recall due to greater competition between accumulators in the decision process. By contrast, increasing the amount of information in the cue might help recall by increasing the rate of accumulation for the correct option.

Methods

In two experiments on healthy human subjects, participants were asked to remember both the identity and location of circles composed of two semicircles of different colours. After a brief maintenance interval, they were presented a test display containing an item they had previously seen (a target) and a 'non-target' distractor. They were asked to select the object that they saw in the initial array and to drag it to its remembered location.

In Study 1, we first varied the amount of information in the retrieval cue by displaying either 'complete' items composed of two semi-circles, or 'incomplete' items composed of just a single semi-circle. Second, we manipulated the level of similarity between cues: the distractor either contained novel colours or had the same colours as the target, but flipped in position.

In Study 2, we manipulated cue similarity by varying how many colours from the original memory display were contained in the distracter cue. In addition, we also varied whether those colours were presented in their original, or the incorrect position.

Results

Across both experiments, we found that increasing similarity between the cues reduced identification performance and that increasing the information available in the cue generally benefited identification.

We modelled this data as a decision process using linear ballistic accumulator models. The model assumes that evidence for each response option accumulates linearly over time, with a rate that varies stochastically across trials. The response choice is determined by which accumulator first reaches the threshold. The response time is determined by the time taken for the accumulator to reach the threshold in addition to some uniform non-decision time. We tested models in which the decision was made on the basis of object features or objects as whole. Additionally, we tested models in which participants accumulate evidence for a match (whereby the winning accumulator is accepted as having been present) as well as for a mismatch (in which case the winning accumulator is rejected as having not been present).

Conclusion

The results show that these data can be modelled well as a decision process. Models in which information was accumulated separately for individual features showed better fits than object-based accumulators. Additionally, models with distractor rejection were better able to explain the data. These findings suggest that the nature of retrieval cues can significantly affect the decision process involved in identification and that this relies on both accepting valid information and rejecting invalid information, rather than accepting valid cues alone.

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[POSTER 96]

Do people punish you less when you belong to a group? The role of intention and outcome in third-party punishment for collective harm

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Animals seek “safety in numbers” by forming groups to avoid being eaten by predators. A similar benefit may exist for humans too. Here we asked if being in a group could lower the punishment issued by an observer (third party punishment). We tested if a third-party observer would punish a person less when she belonged to a group perpetrating harm on others.

Psychological and brain imaging studies have shown that third party punishment is composed of two distinct neuro-cognitive components: intention (did the agent mean to harm?) and outcome (what was the consequence of the harm?). [1] We predicted that less punishment would be given to collective (vs individual) that perpetrated a harm and that this punishment would be modulated by intention and outcome.

To test this hypothesis, using short vignette case descriptions modified from [2], we asked participants to assign punishment to “X” in two different conditions: X took part in a collective action, as a member of a group ; X did the very same action individually. We manipulated the intention and outcome in a 2x2 design varying intention (Neutral, Malign) and outcome (Neutral, Harmful).

1100 participants were recruited using Amazon’s Mechanical Turk and divided into two groups of “group action” and “individual action” condition. Each participant read and responded to 4 different vignettes.As predicted, the main effect of the group was significant: independent observers punished a hypothetical protagonist significantly less when they belonged to a collective. We also observed that punishment decreased in all the accidental (neutral intention / harmful outcome), intentional (malign intention, harmful outcome) and even failed attempts of collective harm in comparison to individual harm. In addition, an item-based analysis showed that in all but one of the scenarios, participants punished the protagonist less if he/she belonged to a group of three. Participants punished an individual less if he/she belonged to a group in cases of 1- malign intention, regardless of the outcome and 2- harmful outcome, regardless of the intention. The results suggest that by participating in collective harm, individuals would benefit from more lenient future punishment from a third-party observer.

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[POSTER 97]

A mechanistic account of transferring structural knowledge across cognitive maps

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Animals can learn abstract generalizable knowledge from different environments and transfer this knowledge to similar circumstances. This ability has been characterised several decades ago, yet its underlying neuronal and computational mechanisms are unknown. It has been suggested that upon entering a new environment, or encountering a new task, a cognitive map that represents the relationships between elements in this environment or task is being learned. We suggest that generalization across environments occurs by representing sets of prior knowledge about the probable relationships between elements in different environments and tasks that have been encountered previously. Frequently the relationship between elements in the environment will follow some pattern, or structure. For example, in some environments elements can be clustered while in others they can be organised along a tree. An important question concerns how animals transfer such structural knowledge between different cognitive maps and use it to efficiently construct a new cognitive map to guide their decisions. We present a computational architecture that supports the flexible construction of a cognitive map within a novel environment, based on an explicit representation of a basis set for structural knowledge. These basis sets represent structural knowledge in a compressed manner and are disentangled from sensory stimuli. We show that this type of representation allows inference of important states and drawing inferences about routes that have not been yet taken). In line with our model, we show that participants who have a correct structural prior are able to make better inferences about unobserved routes compared to participants with the wrong prior and are able to infer better important task states. Therefore supporting the idea that this abstract relational code can be acquired and generalised across different cognitive maps.

[POSTER 98]

Novel choices in macaques: activation and disruption of a neural mechanism for value integration

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Bridging the neuroscientific literatures in human and non-human primate (NHP) decision-making is made challenging by, among other factors, the long training required by NHPs in preparation for a cognitive task. Repeatedly making a choice, or a type of choice, leads to automated responses that will differ cognitively and, possibly, neurally from those of human subjects in a comparable task. However, monkeys can and do adapt quickly to novel contexts and complex decisions if the conditions are appropriate.

Here we designed an economic two-dimensional decision task, where four Rhesus macaques, the most used NHP model in neuroscience, perform choices to obtain juice in different amounts and with different probabilities. Crucially, they were extensively trained in a limited subset of the full space of possibilities, but this was sufficient to let them learn the associations between stimuli features and amounts and probabilities of reward. We then acquired functional Magnetic Resonance Imaging (fMRI) of their brains while they performed for the first time novel choices between new pairs of stimuli. The fMRI analysis revealed, for a comparable level of performance, different activity in the medial prefrontal cortex (MFC) for novel versus familiar stimuli pairs.

In a complementary set of sessions, monkeys observed a fast series of novel stimuli. Blood-oxygen-level dependent (BOLD) signal is expected to decline when a stimulus is identical to the preceding one (repetition suppression effect). We observed such an effect in the frontopolar region, not only for identical stimuli, but also for stimuli with different magnitude, different probability but similar expected value, indicating that the region can encode the expected value of complex novel stimuli.

In a separate analysis of the same data, we looked for a BOLD effect consistent with a grid-like coding of the position and movement across the abstract 2-dimensional reward space, in analogy to grid cells' hexagonal symmetry in physical space encoding. We found such an effect in the medial prefrontal cortex and this became stronger across sessions, as monkeys became more familiar with the 2-dimensional reward space.

We subsequently ran a causal experiment, disrupting the neural activity in the medial prefrontal region identified with fMRI, using Focused Ultrasound Neurostimulation and we observed an alteration in the performance for novel choices. Stimulating a control brain region did not produce such an effect.

In conclusion, we showed that macaques can make inferential decisions when facing novel stimuli, analogously to humans, and MFC is involved specifically by novel but not overlearned decisions.

[POSTER 99]

The neural dynamics of decisions in changing conditions in humans: A MEG study

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Imagine you are driving to a new destination, deciding on the best route. As you drive, your decision is informed by road signs, advice from your passengers, your GPS, etc. Crucially, as you approach a potential turn, you are urged to make your decision even if you are not yet fully confident. In ecological settings, the available information for making a choice can change without warning, and the urgency to choose one way or another is among many factors influencing the decision process. Recently, neurophysiological studies in monkeys performing dynamic perceptual decision-making tasks, combined with computational models, have paved the way for theories about how the brain makes decisions in a constantly changing environment. However, the underlying mechanisms and whole-brain dynamics involved in processing sensory information and making a variety of trade-offs between the speed of a decision and its accuracy in humans are still poorly understood. For the first time, this study sheds light on the role of whole-brain rhythmic synchronization during deliberation, commitment and evaluation of a choice during dynamic decision-making in human (n = 30) using magnetoencephalography. Here, we show that source-reconstructed local field potentials in the beta band [15-30 Hz]) build up in an evidence-related manner in sensorimotor regions, reflecting the competition between response options biased by sensory information during deliberation. In the same regions, low frequency oscillations ([2-8 Hz])] are not influenced by sensory evidence but are implicated in executing motor commands after having committed to a choice. Finally, we found a feedback-related increase in high gamma oscillations ([60-90 Hz]) in the insula when participants made an error. This may indicate that high frequency field potentials play a crucial role in our ability to evaluate choices by monitoring errors.

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Differences in reward variability induce value-depended biases in a learning task

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Decision making under uncertainty has been extensively studied using tasks in which decisions are based on explicitly stated (as opposed to learned) information. This has resulted in the widely-accepted prospect theory. It is unclear whether the laws of prospect theory (e.g. risk aversion for gains, concave utility [1]) are specific features of explicit tasks or general features of human cognition. We show that the laws of prospect theory break down in a task where risks are not stated but implicitly realised as feedback variability. Hence, uncertainty-related biases and their explanations are strikingly different when the uncertainty is implicit.

Decision making under uncertainty has been extensively studied; several phenomena (such as risk-averseness for gains) and their respective theoretical underpinnings (such as concave utility functions) are now widely considered to be basic features of human decision making [1].

These phenomena have been established through studies that used gambles as paradigms of decision-making. Those gambles feature explicit statements of outcome probabilities, thus providing subjects with all information required to make an informed decision (explicit tasks).

However, the impact of uncertainty on decisions remains poorly understood for situations in which relevant information must be learned from experience (implicit tasks). Some pioneering studies indicate that the phenomena discovered in explicit tasks might not generalise to implicit settings [2].

We developed a choice task in which reward values were sampled from probability distributions that differed in mean as well as in variance to examine how these parameters affect choices. Our data (N=30), which exhibits the hallmarks of reinforcement learning in choices, reaction times, and pupil sizes [3], shows clear biases induced by differences in reward variability: For low valued options, participants tend to prefer the less variable option. For high valued choice options, they tend to prefer the more variable option. Prospect theory predicts the opposite tendencies in both cases.

To explain these findings, we tested a variety of Rescorla-Wagner-style cognitive learning models. Specifically, we compare models emulating confirmation bias (formalised as different learning rates for affective versus aversive outcomes), non-linear utility over outcomes, context-specific learning (where the context is defined by the options currently available), and habitual learning (which assumes that mere encounters of an option suffice to make it more attractive in the future).

Using those models to simulate data, we demonstrate how different effects (confirmation bias, nonlinear utility, context and habituation) introduce variability-related choice biases. We further use principled Bayesian model selection to compare their relative fit to our data and investigate which features of the data are captured by the different models. Our findings indicate a clear difference between decision making under uncertainty in implicit and explicit tasks, in behaviour patterns as well as their explanations.

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[POSTER 101]

The relationship between freezing and passive vs. active approach/avoid decisions under acute threat

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Decision-making under threat is crucial for survival. Over the years, the field of value-based decision-making has made great progress in the development of models that explain these decisions as a function of Subjective Value (SV) computations. However, these models typically do not take into account the psychophysiological state of the decider. One such psychophysiological state which has been identified in both rodents and humans is the parasympathetic freezing response. Freezing is typically characterised by movement cessation, heart rate deceleration, and increased muscle tone, and is thought to be a defensive state serving to prepare the body for subsequent action (e.g., approach vs. avoid) [1]. While it has been proposed that freezing might facilitate risk assessment [2] and enhances visual perception [3] to aid decision-making, it remains unclear to what extent freezing directly affects people's decisions, for example by influencing SV computations or biasing individual passive vs. active avoidance tendencies.

In the current study, we set out to investigate how threat-related freezing, indexed by reductions in heart rate and motion, is related to approach/avoid decisions under threat. In a novel experimental task, participants were asked to make decisions whether to approach or avoid a moving target under acute approach-avoidance conflict, while we recorded psychophysiological and posturographic measures. Each target was associated with a specified reward (money) and punishment (shock), which were systematically varied across trials according to a factorial design with 5 reward levels and 5 punishment levels. In each trial, the participant could either approach or avoid the target, and across trials we systematically varied whether it was active or passive approach or avoidance as the target was either moving towards them (passive approach, active avoidance) or to another location (passive avoidance, active approach). Participants responded by pressing a button to move towards or away from the target while standing on a force platform (to assess changes in motion indicative of anticipatory freezing). To fit the data, we use computational models that incorporated SV computations, psychophysiological and motion-based indicators of freezing, and active versus passive response tendencies to predict approach/avoid choices. First, we hypothesised that freezing interacts with SV computations and is associated with a higher probability to avoid. Second, we predicted that stronger freezing (being a passive defensive state) is associated with a higher probability to respond passively.

Fitted model parameters estimated from pilot data indeed indicate an interaction of freezing (i.e., heart rate deceleration) with the punishment component of the SV computation, as well as a trend towards a higher tendency for passive responses with stronger freezing. Results of the full data set (N=45) will be included in the presentation.

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[POSTER 102]

Towards single-subject neural markers of decision formation at clinically relevant timescales

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A characteristic of mental disorders is abnormal decision behaviour. However, existing methods and task paradigms are often time consuming, expensive and often they are not informative of decision formation in a single subject. We developed a new task paradigm that allows us to measure neural signals of decision formation on the single-subject level from just 10 minutes of data recording with Electroencephalography (EEG). Our task paradigm is similar to the random dot motion paradigms which have been extensively used in the past to study evidence integration across species, including humans [1]. However, these paradigms consist of discrete trials in which the subject hast to judge the overall motion direction of a cloud of moving dots that stays constant across a trial. In contrast, our paradigm is continuous meaning that the participant has to observe a stream of moving dots which constantly change directions lasting several minutes. The participant has to identify periods in which the average motion direction is either leaning to the left or the right. Therefore, the participant is required to constantly integrate information of the movement direction of the moving dot cloud to judge whether they are currently in a period that requires a response. This means that the data acquired over the entire time while the participant is doing the task contains information about their decision formation reducing the amount of dead time such as intertrial periods that are required in discrete task paradigms. By using a convolutional GLM we can make use of the continuous EEG recording and can show that we find neural signals of decision formation within 10 minutes of data recordings in single subjects. We think that our new task paradigm would allow to investigate decision formation in patient populations without requiring hour long experiment sessions but still allowing for meaningful results on the single subject level.

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[POSTER 103]

A Neurally-Informed Modelling Approach for Investigating Cross-Modal Associations in Perceptual Decision-Making

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Our brains process multisensory information by formulating cross-modal associations between stimulus features from different modalities [1]. A common cross-modal association is the phenomenon whereby humans associate high-pitch auditory tones with small visual objects, and low-pitch auditory tones with large visual objects [2]. Preferred pairings of these cross-modal stimuli are defined as "congruent" and non-preferred pairings as "incongruent" [3]. The congruency of cross-modal associations has been found to have a modulatory effect on behavioural performance in perceptual decision-making tasks, i.e., participants produce shorter reaction times (RTs) and higher choice accuracy on congruent trials [4]. However, which decision-related processes are dynamically modulated by cross-modal associations, what brain networks are involved in their representations, and how congruency conveys such behavioural advantages remain open questions [5].

To address these questions, we employed a modified version of the auditory pitch-visual size Implicit Association Task [4]. Twenty participants were presented with a single sensory stimulus (i.e. either a high/low pitch tone - auditory or a small/large size circle - visual) on each trial and had to report as quickly and accurately as possible which stimulus was presented. Auditory congruency was manipulated through stimulus-response key mappings. On congruent trials preferred pairings (high tone, small circle) were assigned to the same response key, whereas on incongruent trials non-preferred pairings were (low tone, small circle). Hence, overall three variables were controlled on a trial-by-trial basis: stimulus, sensory modality and congruency. We measured the participants' behavioural performance, i.e. choice accuracy and response times (RTs), and their brain activity using electroencephalography (EEG) [6]. Behavioural results indicated that congruency had a modulatory effect, with faster RTs for congruent compared to incongruent auditory stimulus presentations.

We then probed the neural encoding of the three variables that define this task. To this end, we used a supervised dimensionality reduction technique, termed demixed Principal Components Analysis (dPCA; [7]), to identify EEG components that encode the three task variables. We did find stimulus-encoding, modality-encoding and congruency-encoding EEG components consistently across participants.

To further understand the functional role of these EEG components in decision-making performance, we employed neurally-informed behavioural modelling using the Hierarchical Drift Diffusion Model (HDDM; [8]); an implementation of the Drift Diffusion Model that uses hierarchical Bayesian parameter estimation. HDDM estimates latent parameters representing internal processing components; i.e. the rate of evidence accumulation ("drift rate"), the amount of evidence required to initiate a choice ("boundary separation"), and the duration of sensory/motor-specific processes ("non-decision time") [9]. Here we used the single-trial values of the EEG components as regressors of the three core HDDM parameters to examine what aspects of the decision-making process these neural representations are involved in and how they could lead to the observed differences in behaviour.

Our preliminary results indicate that the congruency-encoding neural component is predictive of non-decision time variations. This finding suggests that the neural representation of congruency modulates early sensory processing, not decision-related, mechanisms. Ultimately, our neurally-informed modelling approach offers a unique window into the neural correlates of latent perceptual and cognitive processes underlying perceptual decision-making.

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[POSTER 104]

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

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Throughout their lives, humans display the ability to compare the value of different behavioural options, even when such options are incommensurable [1]. The neural circuits underpinning these value-based decisions have been object of intense investigation over the past two decades, which led to a consensus about the central role of the ventromedial prefrontal cortex (vmPFC) [2]. In most previous studies, however, the value of options or actions was not explicitly manipulated, as options were usually evaluated in terms of monetary value [1] or subjective pleasantness [3]. In real-life situations, however, the value of a behavioural option is tied to the agent’s goal, implying the existence of a flexible option-value map.

In this study, we sought to investigate how preferences between behavioural options and the underlying neural activity are affected by changing goals. To this end, we acquired behavioural and imaging data while volunteers made decisions under two different goals. In short, participants were asked to imagine having to escape a deserted island following two strategies, which involved distinct goals: starting a fire or anchoring a boat. On a first Day 1 (pre-scanning phase), participants were presented a fixed set of everyday-life items to evaluate in the context of the two different goals. On Day 2 (scanning phase), participants were required (in most of the trials) to imagine using each item to achieve one of the two goals, while in some of the trials were asked to choose (amongst two item) the most useful one.

We found that behaviour, as well as vmPFC activity, was driven by the value that the item acquired under the current goal but were insensitive to the value for the alternative goal or to the item’s monetary value. This implies a goal-dependent neural mapping between the sensorial input and the behavioural output; therefore, perceptually identical stimuli elicited distinct brain activity patterns under different goals. We then used representational similarity analysis (RSA) to test how new goal-dependent geometries were created, in which similarity between items was decoupled from the items’ sensorial appearance and was instead determined by the usefulness to achieve a specific goal. Our results revealed evidence of value representations (even in absence of evaluation or choice) in brain network including the vmPFC and the orbitofrontal cortex (OFC). Interestingly, the OFC appeared to support an integrative code of value and confidence. Since the idiosyncratic estimation of how useful an item was to achieve a goal depended on participants’ individual experience [4], we sought to assess the role of the hippocampus in this remapping. We found that the hippocampus represents value and enhances representational separation across goals. Moreover, during binary choice, the hippocampus appeared to preferentially reinstate the representation of the item that was later chosen.

In summary, with this study we broad the role of the vmPFC in value-based decision making, providing evidence of a flexible reorganization of the neural representation that is shaped by different behavioural goals.

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[POSTER 105]

A neural circuit for graph-search in internal world models

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The behavior of an animal interacting with the world can to a large extent be explained by a pursuit of reward and avoidance of penalty. Learning a behavior in presence of positive and negative rewards is often referred to as *reinforcement learning* [1]. Algorithms for reinforcement learning can broadly be divided into two classes: *model-free* and *model-based* [2]. In model-free algorithms, the policy for action selection is learned directly so that the (discounted) expected future value of each state or action is implicitly or explicitly cached. Once learned, this allows computationally cheap and therefore rapid decision making. A model-based algorithm, on the other hand, learns a forward model of the world. To make a decision, such a forward model may then be used to *plan* a sequence of actions leading to any desired outcome. While planning using a forward model comes at a considerable computational cost, it greatly improves generalization and allows the agent to flexibly reuse the same world model to solve disparate goals.

Theoretically, the computational problem of planning can be posed as having a world-model consisting of a graph where the nodes correspond to states and edges correspond to actions. Planning entails finding a path from the currently occupied state in this graph to some rewarded or otherwise desired end-state. We propose a biologically plausible model of a neural circuit capable of first learning a world graph and second perform a stochastic search in the learnt graph. Our model exhibits several computationally desireable properties : it is capable to dynamically enable and disable nodes (states), it has internal dynamics that prevents it from backstepping and the depth of the graph search can be controlled by variying a driving input.

It is well-established that neural correlates of essential components of model-free reinforcement learning can be found in the basal ganglia of mammals [3]. Interestingly however, there is also evidence suggesting that mammals are capable of explicit planning, i.e. model-based reasoning [2, 4]. Although what precise brain area or network is responsible for planning remains obscure, one would expect *some* circuit in the brain possessing the ability to perform the essential computational steps required for model-based planning. With minor modifications, our model is compatible with both excitatory (e.g. neocortex or hippocampus) and inhibitory (e.g. striatum) circuits and we therefore remain agnostic to the specific brain area in which it may be implemented. Rather, we have proposed a general circuit-level mechanism that might be employed somewhere in the brain to provide one of the essential computational requirements of model-based planning and decision making.

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[POSTER 106]

Causal role of the lateral orbitofrontal cortex in credit assignment

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Adaptation to a volatile environment requires being able to flexibly learn contingent associations between choice options and outcomes and using the associations formed to guide subsequent behaviour. This type of learning is often referred to as “credit assignment”. Orbitofrontal cortex (OFC) and adjacent ventral prefrontal cortex have been shown to play a key role in encoding stimulus-outcome associations based on the history of outcomes in past choices (Murray and Rudebeck, 2018; Walton et al., 2010).

Functional Magnetic Resonance Imaging (fMRI) experiments and computational modelling are powerful in showing temporal correlations between certain behaviours, i.e. different parameters associated with a choice, and concomitant activity in specific brain areas or networks. An fMRI investigation (Chau et al., 2015) suggested the key region might lie in the lateral OFC/area 12o. However, to determine whether such activation is truly necessary for credit assignment, the impact of disrupting it must be assessed.

To address this issue, here we used offline focused Transcranial Ultrasound Stimulation (TUS) in 4 rhesus macaque monkeys while they performed a probabilistic three-arm reversal learning bandit task in which the values of the three options were uncorrelated with one another. Focal effects of ultrasound manipulation on neural activity (Folloni et al., 2019;

Verhagen et al., 2019) and behaviour (Deffieux et al., 2013; Fouragnan et al., 2018) have recently been shown. Control (sham) and stimulation (TUS) sessions were interspersed within each animal and their order was counterbalanced across animals. The ultrasound wave frequency was set to the 250 kHz resonance frequency and 30 milliseconds bursts of ultrasound were generated every 100 milliseconds. Overall, the stimulation lasted for 40 seconds and was applied to the lateral OFC in both hemispheres immediately before the animals performed the task.

After TUS, the animals showed a deficit in the encoding of credit assignment and in using these associations to guide future behaviour. After stimulation, animals were indeed able to independently encode either choices or outcomes (reward) alone but were impaired in learning the contingent relationships between them and so they were unable to flexibly adapt their subsequent behaviour in response to environmental changes. The diminished influence of experience was most apparent when the impact of learning from recent trial outcomes was considered but the impact of disruption decreased as trials further in the past were considered. More specifically, TUS disrupted the animals' ability to update their estimate of a choice option's value after trials in which a reward was received ("win trials") for choosing it but not in trials in which reward was not obtained ("lose trials"). This credit assignment deficit led the animals to be more sensitive to the volatile environment and to exhibit a higher rate of switching between choice options.

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Task-switching increases beta and theta oscillations in the human subthalamic nucleus

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Task switching is the ability to shift adaptively between sets of rules, or task set. Previous studies identified neurons in a dorso-medio-prefrontal-subthalamic network, which increased their activity when monkeys switch between task sets in response to visual cues [1]. In humans, the precise cortico-subcortical neural dynamics associated with task switching remains poorly known [2,3]. Here, we recorded local field potentials in the subthalamic nucleus (STN) of four patients with severe and treatment-resistant obsessive-compulsive disorder while they performed a task-switching paradigm [1]. As expected, switch trials had significantly higher reaction times and error rates compared to non-switch trials. At the neural level, theta (5-10Hz) and beta (15-35Hz) bands activity in the STN increased shortly after rule onset, and was significantly higher during switch trials compared to non-switch trials. To investigate the computational mechanisms underlying task-switching, we next used a drift diffusion model (DDM). DDM assumes that decisions reflect the accumulation of information over time until evidence in favor of one course of action exceeds a decision threshold [4]. We found that switch cost (i.e., the increased reaction times and error rates observed when contrasting switch and non-switch trials) was resulted from a lower starting point during switch trials, which could reflect the active inhibition of the pre-selected response. Moreover, including trial-by-trial relative theta activity as a modulator of the starting point better accounted for observed behavior in this task. Taken together, these results suggest that human STN is involved during task-switching at a latency consistent with an active inhibition of the preselected response during rule-updating process. This suggest that human STN possibly implements a versatile mechanism through which to rapidly overcome persisting responses.

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Static and dynamic brain functional connectivity changes associated with effort-based decision-making in clinical apathy

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Apathy, a disorder of goal-directed behaviour, is a common feature of cerebrovascular small vessel disease (SVD), which frequently occurs in older people in the context of raised blood pressure, diabetes, smoking, raised cholesterol and other vascular risks. SVD also occurs in a rare monogenetic form in younger adults, known as cerebral autosomal dominant arteriopathy with subcortical infarcts (CADASIL) [1]. Apathetic CADASIL patients have reduced reward sensitivity and reduced white matter integrity of key tracts associated with decision-making and reward-processing compared to non-apathetic patients and healthy controls [2]. However, the relationship between structural changes and such disrupted behaviour is still illusive.

Here we investigated the higher-order processes of the brain, in an attempt to understand whether apathetic behaviour in CADASIL is also reflected in changes of the static and dynamic functional connectome. We analysed resting-state fMRI data from 18 CADASIL patients (mean age = 54.3 ± 10.3, 6 males), scanned with a 3T MRI and that underwent neuropsychological and cognitive testing. Apathy was assessed with the Apathy Evaluation Score (AES) [3] and the Lille Apathy Rating Scale (LARS) [4]. Computational modelling of responses on an effort-based decision-making task for reward were used to derive measures of effort and reward sensitivity in apathetic compared to non-apathetic patients. In this behavioral task, participants were offered, on a trial-by-trial basis, a single combination of monetary reward and effort (different levels of squeeze force using a hand-held dynamometer). They chose either to perform the effort for the reward offered, or decline it. Behavior on this task provides a simple index of reward and effort sensitivity.

Static functional connectivity (FC) was estimated using dual regression independent component analysis (ICA) [5] averaging across the entire scan time course. Dynamic functional connectivity states were estimated by clustering the different leading eigenvectors of the phase coherence matrices (distinct FC patterns) [6].

Apathetic patients showed reduced static functional connectivity between nodes of decision-making and reward processing networks compared to their non-apathetic counterparts. Dynamic functional connectivity demonstrated that apathetic patients also visited distinct functional states less often and for a shorter duration than non-apathetic individuals.

These findings provide evidence of reduced static functional connectivity and an altered repertoire of dynamic functional connectivity brain states in clinical apathy that is associated with impaired effort-based decision-making.

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[POSTER 109]

A simulation meta-analysis of the role of reinforcement-learning in mood and anxiety disorders

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Introduction

Reinforcement learning models of behaviour have been used in recent years, in particular during the advent of the field of computational psychiatry, to allow better characterisation of altered learning and decision-making processes in mood and anxiety disorders. Some of the symptoms of mood and anxiety disorders, such as affective biases[1] or avoidance[2], [3] could plausibly be generated by differences in learning about the rewarding and punishing properties of environmental stimuli. These potential differences can be empirically tested using reinforcement learning models, but, as yet, papers taking this approach have not always found the same pattern of results. Thus, we develop a new meta-analytic simulation modelling approach to synthesise this evidence base whilst exploiting the properties of reinforcement learning models to generate synthetic data.

Methods

Parameters were extracted from papers which a) used reinforcement learning models in b) mood and anxiety disorders with c) a case-control design and d) reported either sufficient statistics of each parameter in the model or individual-level parameter estimates.

Performance on a two-armed bandit task was simulated for each individual using the model specified in the respective paper. In this synthetic task, both win and loss outcomes were possible on each trial, and the association between these and each option varied according to a random walk with Gaussian noise.

Model comparison was performed (8 models, fit using a Markov-Chain Monte-Carlo approach) over this simulated choice data and group comparisons using ANOVAs (with two between-subject factors: study and patient/control status) were performed on the individual level parameters from the best-fitting model.

Results

Parameters from four papers (n=226, of which 126 were cases) were used [2], [4]-[6].

The best-fitting model comprised two learning rate terms (one for reward, one for loss), a lapse term, and a sensitivity term.

Group-level comparisons found no main effect of group on learning rate for rewards ($F_{1,218}=0.001, p=0.975$), learning rate for losses, ($F_{1,218}=2.67, p=0.104$), lapse ($F_{1,218}=1.11, p=0.294$), or sensitivity ($F_{1,218}=0.001, p=0.970$). There was a main effect of study (all $p<0.001$).

Conclusions

This novel meta-analytic simulation approach to reinforcement learning allows us to use data from a variety of studies (increasing power) to attempt to reconcile the different results obtained by different researchers. Our initial results indicate that there is no difference in either reward or punishment learning in those with mood and anxiety disorders compared to control participants, but we hope to include estimated parameters from more studies and a greater range of models in the future. Notably, however, significant effects of study were found, indicating that individual effects reported in studies may depend on task design, participant group and other idiosyncratic features.

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Generalisation of structural knowledge in hippocampal – prefrontal circuits

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A hallmark of intelligence is the ability to generalise previously learned knowledge to solve novel analogous problems [1]. For instance, someone who knows how to drive a car in Europe can quickly adapt to driving in the U.K without having to relearn driving from scratch simply because some rules and motor actions are different. Such transfer of knowledge relies on formation of representations that are abstracted from sensory states [2]. Little is known about how the brain generalises abstract representations while maintaining the content of individual experiences.

Here we present a novel behavioural paradigm for investigating generalisation of structural knowledge in mice, and report preliminary electrophysiological findings from single neurons in hippocampus and prefrontal cortex. Mice serially performed a set of reversal learning tasks, which shared the same structure (e.g., one choice port is good at a time), but had different physical configurations and hence different sensory and motor corelates. Subjects' performance on novel configurations improved with the number of configurations they had already learned, demonstrating generalisation of knowledge.

Single unit recordings showed that many hippocampal neurons 'remapped' across tasks, for example acquiring a firing field at a given nose-poke port in one task that was not present when the same port was visited in another. In contrast, prefrontal representations generalised more across tasks, with neurons tuned to particular trial events irrespective of the current physical configuration. Using singular value decomposition, we asked whether population activity in each region shared the same low dimensional space across tasks. Singular vectors corresponding to patterns of activation across neurons generalised better (i.e. explained more variance in a new task) in prefrontal cortex than hippocampus, confirming hippocampus remapped more than PFC between tasks. Strikingly this was true even when analysis was restricted to trials which shared the same physical ports, i.e. when the spatial correlates of the trial were the same in both tasks. Singular vectors corresponding to temporal patterns across time and trial type generalised near perfectly across tasks, i.e. temporal patterns that described activity in one task described activity in all tasks. This confirms that the structure of each task is represented strongly in both regions, even though different neuronal assemblies participate in each task's representation in hippocampus.

These results are analogous to remapping of grid and place cells across different physical environments, where grid cells maintain their relative firing positions (i.e. their correlation structure) across environments, while place cells remap apparently at random [3]. Our results provide preliminary evidence for common neuronal mechanisms underlying generalisation of structure knowledge in spatial and non-spatial domains.

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[POSTER 111]

An Architectural Theory of Efficient Planning

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An architectural theory of biological control and decision-making must address a number of *representational* and *computational* challenges in order arrive at a satisfactory hypothesis of how flexible control can be tractable for time-dependent and logically-contingent tasks. Current theory used in computational neuroscience has been imported from reinforcement learning and control theory and is based on objective functions that maximize expected reward. The difficulties with this assumption lie in the details, and there are severe limitations as to what kinds of tasks can be represented and efficiently solved with reward-maximization, even for hierarchical RL theory. A major class of such tasks are those with rewards that are conditioned on an acceptable history of sub-goals. In order to encode such a task for reward maximization, the state-space must be augmented with a partial and complete history of the agent's progress in completing the sub-goals of the task. This can lead to a factorial increase in the state-space size depending on reasonable assumptions of how the task is specified. As an alternative, we demonstrate a framework called Constraint Satisfaction Propagation (CSP), which maximizes the probability of solving a temporal-logic model of a task using a finite set of precomputed stationary policies. CSP does not require an intractable state-space expansion, and it can solve problems where individual sub-goals have uncertain deadlines and the world has dynamic obstacles. CSP achieves this result by using a new kind of value function, we term a "feasibility function," which can be *explicitly* interpreted in terms of what states an agent can reach before a deadline. The explicit nature of these functions allows us to reuse them in a combinatoric satisfiability optimization in order to find task-satisfying policies while avoiding the use of history-augmented state-spaces. We put forth a new theory of what information a nervous system should represent, and a computational process for using such representations, in order to solve ethologically realistic tasks. Our work also opens up new avenues for theories of compositionality, task-transfer, and state-abstraction.

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[POSTER 112]

The effect of risk and ambiguity on curiosity.

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Curiosity is a basic biological drive that has a profound influence on our behaviour, choices and learning. Despite the vital role it plays in our daily lives, its functions and mechanisms remain poorly understood. It has been proposed that the intensity of curiosity for certain information is tightly linked to the ability of that information to reduce uncertainty, thereby closing the gap between what is currently known and what is yet to be discovered [1]. A recent study found evidence in support of this account, showing that curiosity for finding out the outcome on a lottery task increases as a function of the level of outcome uncertainty [2]. Here, we extend this work to investigate two different forms of uncertainty: risk, which is present when there are multiple possible outcomes that have known probabilities, and ambiguity, which is present when there are multiple possible outcomes whose probabilities are unknown. These two generators of uncertainty have been shown to have different effects on decision-making, and involve distinct neural mechanisms [3]. In order to investigate whether they also have a dissociable impact on curiosity, we manipulated the levels of these two sources of uncertainty on each trial in a lottery task, and asked subjects to report their level of curiosity for the trial outcomes. Importantly, we did this in a reward-free context, which allowed us to investigate how these two sources of uncertainty may differentially impact intrinsic curiosity in the absence of reward. We found that subjects were more curious to find out the outcome of the lottery when the risk level was higher, and this relationship was stronger under low levels of ambiguity. When the level of ambiguity was higher, curiosity was invoked across all levels of risk. Together, our findings show that intrinsic curiosity is differentially influenced by the levels of risk and ambiguity.

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One-shot generalisation of learned hierarchical reward structure

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Theories of efficient planning suggest that humans may organise their knowledge of the world into hierarchical state spaces, which enable actions to be structured and policies reused at multiple levels of abstraction[1]. Computational models of hierarchy often focus on the environment's topological structure or contain implicit assumptions of task homogeneity[2,3]. However in practice, the same physical environment may support skilled behaviour under multiple distinct contexts that have different structure in their associated rewards. For example, a school sports hall requires people to switch between multiple different internal representations of space (helpfully supported by coloured floor markers), depending on whether the current context is a game of basketball, netball or badminton. Here we asked how such hierarchical representations of the world are learned in order to support planning across multiple contexts, which have conflicting or shared reward structures.

Participants virtually searched four connected rooms for items that were one of two reward types, and whose locations covaried across the rooms. Pairs of rewards were structured within the environment across pairs of rooms either vertically (cheese) or horizontally (wine), resulting in distinct reward x space covariance structures for each reward type. Under contextually-blocked training, participants learned to structure their search for each reward type according to the reward x space covariance structure. That is, after discovering the first reward on each trial, participants preferentially searched for the corresponding second reward in a room which was within the same reward-type spatial chunk, rather than across chunks. Furthermore, upon subsequent exposure to two new tasks which shared the originally learned reward structures, but which required search in differently coloured rooms for different reward types (now peanuts and martinis), participants demonstrated complete transfer of latent reward structure knowledge after a single exposure. This demonstrates that under conditions of blocked contextual training, humans can learn to plan across multiple distinct hierarchical representations of a single environment, and rapidly generalise these representations to new tasks containing different reward instances and sensory cues.

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Computational mechanisms of structure learning: how humans update relational knowledge

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Introduction: How do humans and animals learn about and represent environments that are structurally similar? Doing so efficiently holds the key to evaluating actions and states appropriately and generalising knowledge gained in one environment to others with the same structure. Whilst a wealth of evidence has suggested that people use a combination of model-based [1], model-free [1], and successor representation [2] strategies to solve value-based decision-making tasks, generally the paradigms used place an emphasis on tracking variability in rewards that accrue in each state. Here we design a task that removes the need to track rewards and instead coerces participants to learn the transition dynamics within and between different environments allowing us to investigate the computational mechanisms involved.

Methods: Human participants (n=31) completed a novel economic decision task in which they made one of two actions starting in one of four different environments. Each action probabilistically transitioned them (with probability p) to a "reward/loss state" where they would either win or lose money, or to a "neutral state" (with probability 1-p) where they would receive nothing. On each trial, participants were presented with one of the four environments and explicitly told whether the trial was a reward trial (in which they would win money if their action transitioned them to the reward/loss state) or a loss trial (in which they would lose money if they transitioned to the reward/loss state). Importantly, whilst the trial type and environment was explicitly signalled to participants, the probability of each action/transition pair had to be learned and was subject to random reversals. Unbeknownst to participants, two of the environments had identical probability schedules. This design allowed us to: (1) Decompose relational learning within an environment into model-based and model-free components and investigate their separable contributions; (2) Evaluate whether valence of the outcome on each trial influenced updating of transition structures; (3) Examine whether similarity of transitions between environments enabled participants to generalise belief updating following new information about state transitions beyond their current environment.

Results: We found evidence for both model-free and model-based learning in this task. Whilst model-free learning was insensitive to the specific environment participants were in, model-based learning was sensitive to the environment and this sensitivity was modulated by how related the different environments were to one other. Specifically, participants were able to generalise learning between environments when it was appropriate to do so. Interestingly, we also found that valence (whether an outcome was good or bad) strongly modulated the strength with which participants updated the transition structure, indicating an interaction of model-free and model-based effects.

Conclusion: While participants are able to learn and track transitions within a task, our results indicate that both the transition dynamics information and the kind of feedback this information is contained in matter for how the information is used in updating estimates. This indicates that how we learn to represent environments around us may be dependent on the valence of the feedback we get within them, even if the environmental representation itself is not value-focussed.

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[POSTER 115]

From Meta-Plasticity to Meta-Learning

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A superiority of the brain function is its ability to speculate the world rather than to respond reflexively. Indeed, the brain can adjust its functional characteristics based on environment attributes, the ability that is called “meta-learning”. In this research we have proposed a model which addresses a basic mechanism in cellular level that enhances a neural circuit with the ability to adjust its learning rate to the optimal value. Firstly, we have investigated the effect of environment attributes on a basic reinforcement learning model in a two alternative forced choice task with probabilistic reversals which introduces volatility and affects the optimal learning rate of the model, such that more volatility demands higher learning rates. Secondly, in the previous studies a model of spiking neural networks has been used to model reward-based decision making along with a stochastic plasticity rule[1,2]. In this study, by adding BCM meta-plasticity rule [3] to the model, we have been able to equip it with the meta-learning ability. We have simulated a rate-based version of the neural network model with the specified version of BCM rule combined with dopamine modulation (three factor learning) [4] and measured the effective learning rate in a range of tasks with different volatility index. The effective learning rates of the enhanced model, in contrast to the basic model which has a fixed learning rate, closely follows the optimal learning rate in each task.

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The influence of varied gaze-cue validity on social perception

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When encountering new people, we quickly make judgements about their traits and intentions. It has been well documented that appearance based impressions happen quickly and are robust for perceived warmth, which includes trustworthiness. While these personality judgements offer insight into spontaneous impressions extracted from static images, they fail to capture how we form and update impressions over time based on dynamic social behaviours. One such behaviour is gaze. Not only can it replace speech during interactions, it can also permit an onlooker access to the contents the gazer's mind, allowing their intentions or desires to be inferred. It is likely, then, that when we observe another's gaze pattern, we will form an incidental impression of them.

Adopting a gaze-cueing paradigm, researchers used gaze-cue validity to drive impression formation processes. Faces selected for looking similarly trustworthy were subsequently judged as being more trustworthy when they provided wholly valid gaze-cues compared to those who provided only invalid gaze-cues [1]. A more recent study [2] employed the Trust Game to measure social decision-making in the form of trusting behaviour, finding that wholly valid gaze-cues elicited larger investments. These findings suggest that perceivers translate gaze-cue validity into a belief about the face's character; a face that always helps by looking towards a target can be trusted, whereas one that always deceives cannot.

We know that gaze-cue validity can influence social perception, but it is not known how such impressions are modulated when the gazer changes their behaviour. Using a 2*3 within-subject design, this study manipulated gaze-cue validity to produce six unique helping profiles. Faces averaged either overall helpful (75% valid) or unhelpful (25% valid) behaviour. Crucially, the order in which they offered their help varied, either decreasing, increasing or maintaining cue validity over time. Following the gaze-cueing task, participants (n=54) rated how nice they thought each face was and chose how much to invest in a one-shot trust game. The design aimed to capture the influence of changing behaviour, but it also allowed for the detection of primacy, recency or averaging effects. The study was pre-registered and an a priori power analysis was performed.

We found that overall helpful faces were trusted and liked more than unhelpful faces. Within a helping category, those who increased helping behaviour were trusted more than those who decreased. Importantly, a medium sized interaction revealed that order effects were not constant across helpful and unhelpful faces. A simple recency based linear model can explain perceptions of unhelpful faces, whereas the pattern for helpful faces was non-linear. Results suggest that people value consistency; the helpful face that displayed a constant level of cue validity (75%) was trusted more than the face that increased to 100% validity. Surprisingly, despite displaying overall different patterns of helping behaviour, the two faces ending at 50% validity were perceived similarly. We found no evidence for primacy or averaging effects.

When incidentally learning about a person over time, their most recent behaviour informs our decisions, but we are especially sensitive to stable, positive behaviour.

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[POSTER 117]

Curriculum learning for human categorisation of naturalistic stimuli

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In novel environments, humans are often faced with the problem of learning to categorize complex, naturalistic stimuli with minimal prior knowledge of the relevant decision criteria. Past studies of category learning have typically employed settings where the relevant dimensions are instructed or intuitively obvious, so little is known about category learning in the wild. Here, we asked humans to categorise naturalistic stimuli (trees) according to one of two uninstructed criteria. Our research questions concerned (i) the nature of the training regime that promotes learning about naturalistic stimuli, (ii) computationally informed theories of why a given curriculum should succeed or fail, and (iii) neural signatures of these curriculum effects. These questions were investigated in three experiments.

In the first experiment, participants learned to classify naturalistic trees according to either their leafiness or branchiness, from trial-and-error feedback alone. To address question (i), we varied the heterogeneity of the training examples along both relevant and irrelevant dimensions between subjects. To assess learning differences between curricula, we interspersed no-feedback trials which were drawn uniformly across the leafiness by branchiness space, providing a commensurable test metric. Our core behavioral finding is that humans perform best at test when trained on exemplars that lay far from the category boundary, compared both to boundary-proximal training and training on a representative distribution. Furthermore, this benefit extends to test exemplars that were close to the category boundary. We conclude that humans can interpolate effortlessly from exemplars distal to the category boundary, yet find it difficult to extrapolate from boundary-proximal exemplars.

While these and other[1,2,3] studies highlight that human learning depends on the nature and sequence of experiences that occur during training, we currently lack computationally informed theories of why a given curriculum should succeed or fail. In the second experiment, we used supervised deep networks as a computational theory to explain our findings. In a series of experiments in which we train convolutional neural networks to classify RGB images of the stimuli, we found curriculum benefits which observed the same hierarchy of learning speeds as in human learning. This is of interest especially because several theories of flexible hypothesis selection and learning about multidimensional stimuli posit that curriculum benefits are driven by human limitations in memory[1] and/or attention[4]. However, neither of these factors apply to the neural network. To gain more insight into the dynamics driving these results, we also conducted simulations in an intentionally simplified setting. More detailed analyses revealed that the proximal training is highly vulnerable to input noise, which forestalls learning.

Finally, we aimed to reconcile these findings with human brain function. To this end, we replicated the first experiment with minor adaptations while recording electroencephalography. The main analysis of interest was to investigate the functional significance of the centro-parietal positivity (CPP) signal in this semi-naturalistic learning context. The CPP is related to the classical P300/P3b and has been interpreted as an evidence integration or decision certainty signal[5,6]. This prompts the question to what extent this signal reflects relevant and irrelevant dimensions, and how this is influenced by learning curricula. A preliminary finding is that CPP amplitudes are driven primarily by the relevant dimension under the boundary-distal curriculum, but by the irrelevant dimension under the boundary-proximal curriculum. This suggests a critical role for dimension variance in how humans navigate complex hypothesis spaces.

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[POSTER 118]

Order matters: how the sequence of information disclosure affects multi-attribute choice

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When people make choices in everyday life, the different pieces of information about available options are not simultaneously revealed. Instead, they are disclosed in a sequential order that may affect the decision-making process and bias the eventual choice.

In the present study, we compared the simultaneous presentation traditionally used in behavioral economics to three sequential ways of presenting the information about two options with two attributes (reward and effort) of varying levels. The two options were always presented side by side, with their reward attribute above their effort attribute. In the ‘simultaneous’ condition, the four pieces of information appeared on screen simultaneously: small reward (top left), low effort (bottom left), big reward (top right) and high effort (bottom right). In the ‘sequential-by-option’ condition, one option was first presented, either the small reward for low effort on the left or the big reward for high effort on the right, 3-5 seconds before the other option appeared and completed the choice set. In the ‘sequential-by-attribute’ condition, the information first presented was either the two rewards on the top or the two efforts at the bottom, and the complementary information was then presented 3-5 seconds later. In the ‘sequential-control’ condition, the early and late information were the reward attribute for one option, and the effort attribute for the other option. Decision values were computed from individual ratings of every reward and effort item, and balanced across conditions to match choice difficulty.

Choice behavior was collected in two independent groups of healthy participants, one outside the fMRI scanner (N = 41) and one inside the scanner (N = 24). We observed that response time (RT) was significantly shorter in test sequential conditions compared to not only the simultaneous condition but also the control sequential condition. This suggests that participants could make use of the information when it was presented either by option or by attribute. The shortening of RT was best explained by a linear model including a default policy regressor that indicated which option was favored by the first piece of information. We also found an effect on choices, which was best captured by a model with differential weighting of the second information, depending on the first information. More specifically, the second information was down-weighted when the first information presented an option that was either very good or very bad (in the sequential-by-option condition), or when it presented a first attribute with either a large or a minimal difference between options (in the sequential-by-attribute condition). This means that the second information was partially ignored when the first information offered a strong prior about which option was better.

Thus, people make different decisions, among the same set of options, depending on the order with which the different pieces of information are revealed. These findings highlight the importance of integrating cognitive processes in the economic theory of choice.

[POSTER 119]

The dynamical interaction between attribution and belief: Evidence from a novel task

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Learning to predict one’s causal impact on the world by correctly assigning credit or blame for past outcomes to one’s previous actions is essential for decision-making. This is challenging, since the extent to which outcomes are due to one’s own actions, rather than other people’s, or environmental circumstances is often unknown, and must be inferred. Attribution, and its implications for the maintenance of beliefs about one’s abilities and effects, has been suggested as going awry in various psychiatric disorders. In particular, “negative attributional style” is correlated with vulnerability to depression, but of questionable reliability as predictor of depression onset [1]. Bentall [2] suggested that this is because attributional style is not fixed, but interacts with the dynamics of beliefs about the self. Detecting such interactions would require extended time series of both attribution and self-beliefs - something that is currently lacking. We therefore designed and administered a novel task to quantify the relationships between attributions and beliefs.

Subjects repeatedly played a game of skill or watched 'another subject' do so (actually their own previous trials), whilst making attributions about outcomes and estimating how skilled they/the 'other' are. We investigated the effect of attributions on skill estimates and the effect of reported skill on attributions - in both cases for beliefs about the self versus the ‘other’. We also measured reaction times.

We find that participants used outcomes to update their estimates of their own and ‘other’s skill, and they did so differently for losses attributed internally vs externally (KS test p self, ‘other’ = 0, Hedges corrected d self = 0.19, ‘other’ = 0.35), but not for wins. A comparison between different models of belief updating favors accounts with different learning rates for internal vs external attributions. Conversely, we find that for both self and ‘other’, subjects are more likely to attribute wins, and less likely to attribute losses, internally in the case of high estimated skill (bottom vs top quartile skill responses repeated measures t-test self p = 0.03, Hedges d = 0.36, ‘other’ p= 0, Hedges d= 1.05) and losses (self p = 0.003, d=0.47, ‘other’ p=0 , d=1.09).

We also find differences in the RTs for reporting skill: subjects do so significantly faster after wins vs losses (repeated measures t test p = 0.013, Hedges corrected d= 0.25) and after outcomes attributed internally vs externally (repeated measures t test p =0.0066 , Hedges corrected d=0.26). They are also significantly faster in reporting their own vs the ‘other’s skill(repeated measures t test p =0.0035, Hedges corrected d= 0.54).

Our task quantifies changes in, and interactions between, attribution propensities and beliefs about the self/’other’. We found differences in such interactions when processing wins vs losses, consistent with positive belief maintenance plus sensitivity to sources of learning about negative avoidable outcomes. We find similar mechanisms for self and other, but stronger effects for the latter, which might stem from greater complexity in the more emotionally salient self condition.

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[POSTER 120]

It’s new, but is it good? How generalization and uncertainty guide the exploration of novel options

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How do people decide whether to try out novel options as opposed to tried-and-tested ones? We argue that they infer a novel option's reward from contextual information learned from functional relations and integrate the experienced uncertainty in their final decision. We propose a Bayesian optimization model to describe their learning and decision making. This model relies on similarity-based learning of functional relationships between features and rewards, and a choice rule that balances exploration and exploitation by combining predicted rewards and the uncertainty of these predictions [1]. Our model makes two main predictions. First, decision makers who learn functional relationships will generalize based on the learned reward function, choosing novel options only if their predicted reward is high. Second, they will take uncertainty about the function into account, and are attracted by novel options that can reduce function uncertainty.

We preregistered two experiments in which we test our predictions. In the experiments participants completed a feature-based multi-armed bandit task in which rewards are a noisy function of observable features [2]. Participants choose across 70 trials between the same options with the goal of accumulating as much reward as possible. The rewards associated to each option depend on the observable features through an initially unknown function which can be learned through experience. Crucially, after 40 trials of choosing between the same nine options, we introduce a novel, tenth option. We manipulated the features of this novel option and whether the features are visible throughout the task (invisible features make it a standard multi-armed bandit task) in between-subject manner to test our predictions. In Experiment 1 participants (N=320) faced a novel option with features that indicated either low or high rewards, aiming to discern whether participants learned the reward function and generalized it to the novel options. We call this a functional generalization effect. In Experiment 2 participants (N=423) encountered either an ordinary novel option with feature values from within the experienced range, or an exotic novel option with feature values from outside the experienced range. If people’s choices are guided by uncertainty, on top of the functional generalization, they would be more attracted by the exotic-novel option. Our main measure for testing our predictions are participants' choices of novel options from trial 41 onwards.

Experiment 1 produced evidence for the functional generalization effect. Participants avoided the novel option in the low value condition and chose it more frequently in the high value condition. Participants' beliefs about expected rewards further corroborated this result --- they correctly believed that the value of the high novel option was higher than that of the low novel option. Experiment 2 revealed moderate evidence that participants preferred the exotic-novel over the ordinary-novel option in the period soon after the novel option was introduced. Examining participants' beliefs about average rewards and their confidence in these beliefs provided evidence for functional uncertainty guidance: people explored novel options to obtain functional knowledge. Overall, our experiments provide a powerful and expressive account of human behavior in the face of novelty.

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Sequential dependencies in value-based decisions

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Decisions are usually more accurate when there is more time to deliberate before committing to a choice. For some perceptual decisions, the link between accuracy and time is mediated by a process of sequential sampling: the noise in our senses and in the external world is averaged out by considering more samples of evidence before making a choice. Similar explanations have been given for decisions based on internal preferences (e.g., which food snack to buy) [1]. The extrapolation from perceptual to value-based decisions, however, implies that each alternative has a fixed desirability (a 'true' value), and that, at any moment in time, the decision maker can only access a noisy rendering of this value. Unlike perceptual decisions, for value-based decisions the noise has no clear psychological or neural basis. Further, it is unclear why these complex decisions would be mediated by the comparison of scalar quantities.

We consider an alternative mechanism to resolve decisions based on preferences by considering the role of memory-based deliberation [2]. The theory posits that (i) the alternatives are compared along different dimensions that can be recovered from memory, such as caloric contribution, price and taste; (ii) these comparisons help resolve a decision by providing information about how much closer to a desired state (eg, satiated) we would be if we selected that item; (iii) limited sampling (and not noise) explains why decisions are stochastic. A prediction of the theory is that the dimensions over which the items are compared may continue to be relevant over multiple decisions, as if the desirability of each item fluctuated slowly (i.e., over a time scale longer than that of a single decision).

We tested this prediction in an experiment in which people had to choose which of two food snacks they would rather consume. Decisions were faster and more consistent when comparing items whose values were more dissimilar, and these regularities were captured by a model of bounded evidence accumulation in which subjective reports of value were taken as the 'true' desirability of each item, consistent with previous studies [1]. However, choices and response times were better explained by a model in which the desirability of the items changed over the course of the experiment. Specifically, the desirability increased after choosing an item, and decreased after rejecting the item. Unlike previously reported choice-induced preference changes inferred from reports on a rating scale, the revaluation that an item underwent was more prominent for decisions that were made quickly or with high confidence. These results are expected under the theory because fast and high-confidence decisions imply that the items were compared along a dimension that strongly favors the chosen item–a dimension which is likely to be explored in subsequent decisions. Our results are consistent with the idea that choice-induced preference changes may, in some cases, be a consequence of using memory to resolve a decision, rather than solely due to resolution of cognitive dissonance after a decision.

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[POSTER 122]

How emotional states incidentally affect economic decisions

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How many times did you make a stupid choice because you were angry? The idea that our emotional reactions can bias our decisions is quite intuitive. Furthermore, because emotional states have a certain duration, they may spill over to subsequent decisions that are unrelated to the emotional triggers. For example, momentary happiness induced by incidental events may enhance risk-taking [1, 2]. However, the incidental impact of emotional states on economic decision-making have not been extensively documented. Here, we systematically tested how 4 emotion categories (happiness, sadness, fear, anger) might affect discounting of reward with 3 types of cost (delay, effort, risk).

In two studies, participants (n = 39) performed batteries of economic delay, effort and probability discounting tasks that featured binary choices between a costly high-reward option and an uncostly low-reward option. The actual payoff was based on a number of selected trials, for which the chosen delay (time until payment), probability (risk of no win), or effort (power level on a fitness bike) was actually implemented after the experiment. Emotional states were induced with short vignettes and music extracts unrelated to the choice tasks. A neutral condition, with encyclopedic texts and no music, was also interleaved with the 4 emotional conditions. In every block, participants first viewed and heard an emotion stimulus, then performed a series of choice trials, and finally rated the preceding emotion stimulus on analog scales. All the while, heart rate, skin conductance, pupil dilation, and facial EMG (corrugator and zygomaticus activity) were continuously recorded.

The efficacy and specificity of the emotional induction was apparent in both subjective ratings and physiological measures. Moreover, the perceived intensity of the emotion was correlated to the amplitude of pupil dilation, suggesting that participants actually felt the emotion that they reported. Regarding choices, we only found two significant effects: a reduced preference for zero-delay options following happiness inductions, and an increased preference for zero-effort options following sadness inductions. Thus, participants were more willing to wait in states of momentary happiness, and less willing to exert effort in states of momentary sadness.

These preliminary results are initial steps in a more global endeavor to establish a systematic mapping between basic emotional states and computational parameters of decision-making models. Depending on the natural statistics of the environment, these incidental effects of emotions on choices can be considered as biases or adaptations. In a more extreme form, they may turn into pathological behaviors, as seen in mania, depression and anxiety disorders.

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[POSTER 123]

Phasic norepinephrine is a neural interrupt signal for unexpected events in rapidly unfolding sensory sequences – evidence from pupillometry

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The ability to track the statistics of our surroundings is a key computational challenge. Dayan and Yu [1] proposed that the brain monitors for unexpected uncertainty – events which deviate substantially from model predictions, indicating model failure. Norepinephrine (NE) is thought to play a key role in this process by serving as an interrupt signal, initiating model-updating.

To determine whether NE routinely reports the statistical structure of our surroundings, we used rapid tone-pip sequences that contained perceptually salient pattern-changes associated with abrupt structural violations vs. emergence of regular structure (stimulus example: https://bit.ly/2KzVXLu).

Participants were instructed to detect short silent gaps within the sequences. This ensured broad attention to the auditory stimuli but without requiring active tracking of the transitions. We found that even though both transition directions (regular-to-random and random-to-regular) are clearly detectable behaviourally and both evoke strong MEG [2] and EEG [3] responses in naïve distracted listeners, only abrupt structural violations (regular-to-random) evoked pupil dilation. This pattern of results demonstrates that, when pattern transitions are not behaviourally relevant, NE tracks unexpected uncertainty on rapid time scales relevant to sensory signals.

In a following experiment, we sought to understand how pupil responses are affected by behavioural relevance. We asked participants to monitor for and report both types of transitions. Marked differences in pupil dynamics were observed. Most notably, active monitoring gave rise to a pupil dilation response to the emergence of regularity. Importantly, this response was not strongly linked to the execution of a motor command as response time accounted for relatively little variance in various pupil diameter metrics (e.g. change in pupil diameter, pupil diameter derivative, etc.) and this effect was preserved in a delayed response version. These behaviour-related changes in the pupil diameter suggest that behavioural relevance may alter the boundary between different types of uncertainty (e.g. expected/unexpected), resulting in a threshold change for model reset.

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[POSTER 124]

Multiple memory traces of choice and reward in macaque frontal cortex

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Prefrontal cortex signals relate to different aspects of the choices we are about to pursue [1]. Rewards increase the value of the choices with which they are associated, but the way rewards and choices influence decision making can be multifaceted. Choices are sometimes simply repeated regardless of whether they have been linked to reward receipt and rewards can reinforce choices to which they are not causally linked [2,3]. We investigate the brain networks underlying linked and unlinked choice and reward representations using reinforcement learning models and functional magnetic resonance imaging in macaque monkeys.

The history of reward paired with a choice guided decision making, but in addition unlinked effects of choice and reward drove behaviour. In particular, animals were more likely to repeat choices during phases of high average reward rates. We implemented memory traces of choice and reward in an RL model in addition to contingent learning. This improved model fit. Reward traces led to asymmetric and dynamic value updates consistent with the influence of the average reward rate on stay/switch choices.

Behavioural analyses and modelling suggest that choices are driven by an integration of different types of evidence. We found that, similarly, ventromedial prefrontal cortex (vmPFC) activity is better described by both value signals and choice memories and not value difference alone. Based on the modelling, we identified unlinked memories of choice and reward in frontal cortex. Medial orbitofrontal cortex (mOFC) represented whether animals stayed with their previous choice stimulus or switched, while dorsal anterior cingulate (dACC) and agranular insula (AI) tracked the reward trace. Time course analyses of AI demonstrate a gradual change in coding the reward trace to coding of the current outcome, suggesting that this brain region integrates new reward into the reward trace.

Behavioural and RL modelling analyses suggest that memory traces of choice and reward persist to some degree independently and influence decision making. MOFC as well as dACC and AI carried such unlinked memory traces of choice and reward, respectively. Ventromedial prefrontal cortex signals reflected the general integration of choice evidence.

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[POSTER 125]

Ventral motor thalamic input to prelimbic cortex is involved in cost-benefit decision-making

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Thalamocortical input is important in controlling the activity of cortical pyramidal neurons. For instance, tinput from the posterior medial thalamic complex can disinhibit these neurons and is crucial in long-term potentiation [1]. Cortex also receives an extensive input from ventral motor thalamic nuclei (ventrolateral, ventral anterior and ventromedial thalamus) that target and drive pyramidal neurons in layers 2/3 and 5 [2]. We focus on the involvement of input from these ventral motor thalamic nuclei to prelimbic cortex in choice behaviour [3, 4], specifically in cost-benefit decision-making. Prelimbic corticostriatal neurons project to striosomes and participate in cost-benefit decision-making, which provides animals with a choice between a high cost-high reward and low cost-low reward option. Optogenetic inhibition of prelimbic corticostriatal neurons increases the choice of rats for the high cost-high reward option, while optogenetic simulation increases the choice for the low cost-low reward option [5, 6].

We trained five-week-old Sprague-Dawley rats on a benefit-benefit, cost-cost and cost-benefit decision-making task. These tasks offer animals a choice between: i- a high reward and a low reward ii- a high cost and a low cost, and iii- a high cost-high reward and low cost-low reward option. Once animals acquired all three tasks and reached 9 weeks of age, we stereotaxically injected an adeno-associated virus expressing archaerhodopsin (AAV5-CAG-ArchT-GFP) or a control virus (AAV5-CAG-GFP) into ventromedial thalamus (interaural AP +7.0, ML -1.2; from dura DV +6.56) and implanted a LED fibre optic into prelimbic cortex (bregma AP +3.24, ML 0.0; from dura DV 3.1). After two weeks the virus was expressed in ventral motor thalamic axon terminals in prelimbic cortex. The performance of animals was compared between two conditions; with and without administering optogenetic inhibition to ventral motor thalamic axon terminals in prelimbic cortex. On the cost-benefit decision-making task optogenetic inhibition significantly increased the preference of animals for the high cost-high reward as compared to the low cost-low reward option. In the other two tasks changes were less pronounced. This result indicates that ventral motor thalamic input to prelimbic cortex is involved in evaluating cost against benefit, but not in processing cost or benefit as such.

Interestingly, optogenetic inhibition of prelimbic corticostriatal neurons in the cost-benefit decision-making task induces disinhibition of high-frequency neurons in striosomes that in turn inhibit striatal projection neurons [5, 6]. These striatal projection neurons may receive an excitatory input from ventromedial thalamus [7, 8] that may itself be involved in cost-benefit decision-making; an option that we currently explore further.

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Knowing whom to learn from: Individual differences in metacognition and weighting of social information

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Social learning enables us to acquire skills and knowledge more efficiently, provided that we learn from the right others. However, little is known about the cognitive factors that determine whom we decide to learn from and how much we benefit from such learning. Here we address this question using a perceptual task where participants had the opportunity to revise their responses (choice about a noisy stimulus and confidence in this choice being correct) in light of the responses made by two advisors of different reliability [1]. We found consistent individual differences in the weights assigned to the social sources, and in the benefit obtained from the social sources - factors which we collectively refer to as Social Weighting Sensitivity (SWS). We also found that an individual's metacognition predicted SWS, with participants who were overconfident about their performance listening less to and benefiting less from social information. Finally, at the trial level, we found that participants adjusted the reliance on social information in light of the response and feedback history, indicating that they formed metacognitive estimates about the social sources. In conclusion, we show that metacognition, the ability to evaluate and report on properties of one's own cognitive processes, is intimately linked to the ability to estimate how reliable others are (e.g., as models for social learning). Further, we provide evidence for individual differences in the ability to use social information in accordance with its estimated reliability across social contexts, suggesting that it is an individual trait. Our novel findings have direct implications for theoretical conceptions of social learning and are in line with recent suggestions that metacognition may play a central in human social learning strategies, group coordination and cultural development.

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Mechanisms underlying apathy in neurological disorders: A multimodal investigation

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Background: Clinical apathy is a common, debilitating syndrome that occurs across a multitude of conditions, including cerebrovascular small vessel disease (SVD) and Parkinson's disease (PD). In both conditions, apathy affects more than a third of patients but, despite its high prevalence, little is known about the mechanisms underlying apathy in neurological disorders.

Apathy can be conceptualised as the decision not to act. Typically, a decision is incentivised by reward, which increases its subjective value and deterred by effort, which increases its subjective cost. Previous investigations have demonstrated that apathy in PD is associated with subjective devaluation of reward rather than hypersensitivity to effort costs. Here we investigated whether apathy in SVD arises because of similar mechanisms, and examined whether there might be any white matter network changes associated with apathy in SVD.

Methods: We conducted a prospective study in 83 patients with SVD. Participants performed an effort-based decision making task for reward, previously used to assess PD patients with apathy [1]. In this task, on a trial-by-trial basis, participants are offered different levels of monetary reward which can be obtained for different levels of physical effort (force exertion). On any one trial they are offered a single combination of reward and effort. They can either choose to perform the effort for the reward offered, or decline that particular offer. Behavior on this task provides a simple index of reward and effort sensitivity. Patients also underwent multimodal MR imaging, including diffusion weighted acquisitions.

Results: The results demonstrated a decrease in reward sensitivity in SVD patients with clinical apathy. Compared to those without apathy, they were less inclined to invest effort for low rewards. Importantly, this effect was independent of depression, despite a significant correlation between apathy and depression in this group. These findings in SVD are consistent with findings from investigations of apathy in PD, lending support to common underlying brain mechanisms across clinical conditions with different underlying pathologies[1]. Importantly, behavioral changes associated with apathy were related to white matter tract changes in the cingulum bundle, which connects medial frontal brain regions, previously implicated in the genesis of apathy[2]

Discussion: Our findings support a common transdiagnostic mechanism associated with apathy, namely a decrease in reward sensitivity, which is observed in apathetic individuals with SVD as well as PD. Importantly, we were also able to demonstrate that these behavioral changes are related to white matter tract changes in the cingulum bundle which provides an important system of connections between medial prefrontal cortical regions, including anterior cingulate cortex, and medial premotor areas such as the supplementary motor area[3,4]

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[POSTER 128]

Interaction between mood and adaptive learning and choice under uncertainty

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Prediction errors are widely considered in terms of learning (1) . Subjective well-being is also known to be substantially affected by prediction errors in a non-learning context, resulting from the outcomes of risky choices (2). Manipulating dopamine tonic levels affect both risky choices and subjective well-being variations, showing a close link between those processes (3). However, little is known about the potential influence of mood on choice under uncertainty and learning.

Here, we manipulate the degree of learning required to accurately predict the environment, i.e., the weight placed on prediction error. In a stable environment where the probabilities of reward are stable, no learning is involved, the prediction errors reflect the probabilistic noise and should be ignored. In a volatile environment, the probabilities of rewards are reversed regularly, requiring to be learnt through prediction errors. We addressed three questions: (A) Is mood more susceptible to prediction errors in a more volatile environment? (B) Is mood more susceptible to recent trials in a more volatile environment? (C) Does mood influence choices differently in environments with different volatility?

Replicating previous studies (4), we showed that the learning rate is indeed higher in the volatile environment than in the stable environment. Unlike the behaviour, we showed that mood is equally susceptible to prediction errors and is integrating the same number of trials in both environments. Moreover, we found a significant correlation across participants between the temporal integration factors from both environments. These findings suggest that unlike the behaviour, mood is not flexibly adapting to the environment, and how mood response to events is more the reflection of a trait. Then, we show that mood does not affect risk attitude or choice noise but is affecting the propensity to choose the same option as in the previous trial (i.e., the propensity to perseverate) in the stable environment. Finally, we show that mood is impacting the learning rate differently in the stable and in the volatile environment.

Overall, we showed that mood is invariantly susceptible to task events in environment differing in their respective volatility and influences choice perseveration and probability learning. Our findings thus identify a specific novel influence of mood on learning.

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