7th workshop 23-25 March 2022

COMPUTATIONAL PROPERTIES OF PREFRONTAL CORTEX

CPPC 2022

Experimental Psychology
Medical Sciences Division

UNIVERSITY OF OXFORD

Contents

MESSAGE FROM THE COMMITTEE 2
PROGRAM 3
VENUE 6
SOCIAL EVENT 7
SESSIONS 8
POSTER 27

Message from the committee

CPPC (Computational Properties of Prefrontal Cortex) workshops began as a very small meeting in 2010 organized mostly by PFC electrophysiologists who felt they needed a relatively informal forum to discuss the currently most pressing questions revolving around PFC function and its underlying computations. Since then it ran every two years, attracting increasingly more attention as the committee has expanded and grown. It now includes a broader set of computational modelers, more cognitive elements and a larger cross section of species (from mouse to macaque and humans).

The spirit of the meeting has always been the exchange of ideas and knowledge. This is why we provide ample time for open discussions and only have short talks. For more junior researchers we hope the poster sessions will offer an opportunity to present their own work and contribute to the discussion.

We (the organizing committee) hope you will enjoy this meeting which has been 3 years in the making. Let's make the most out of this special opportunity to all meet and talk in person like three dimensional human beings!

We also want to give a special thanks to our amazing student/post-doc helpers, without whom the meeting wouldn't have been possible:

Kenza Kadri and Mathilde Lojkiewiez (Booklet and general planning)
Eleanor Holton (Posters and general planning)
Lisa Spiering (Hybrid setup, Lecture setup and general planning)
Sankalp Garud (Social)
Carla Cremer (printing and general help)
Michal Wójcik and Jan Grohn (general help)

Nils, Jacqueline, Jerome, Elsa and Miriam

Program

Day 1 – Wednesday 23rd of March

8:30am	**Registration**		
9:00am	**Welcome**		
9:15am	**Session 1**	**Neural networks maintaining, processing and integrating information**	
9:20am	Speaker 1	Chris Summerfield	Learning to partition knowledge
9:40am	Speaker 2	Guangyu Robert Yang	High throughput evaluation of recurrent neural networks on cognitive neuroscience datasets
10:00am	Speaker 3	Jake Stroud	Optimal information loading into working memory in the prefrontal cortex
10:20am	Coffee break (Posters)		
10:50am	Speaker 4	Abhishek Banerjee	Prefrontal reprogramming of sensory cortex: Insights from rodents and humans
11:10am	Discussion	Laurence Hunt	
12:15pm	Lunch		
1:20pm	**Session 2**	**What prefrontal computations support social cognition?**	
1:25pm	Speaker 1	Luke Chang	Triangulating multimodal representations of affective experiences during naturalistic movie viewing
1:45pm	Speaker 2	Xiaosi Gu	Humans use vmPFC-dependent forward thinking to exploit social controllability
2:05pm	Speaker 3	Marco Wittmann	Interlinked estimates of self and other performance in medial prefrontal cortex
2:25pm	Speaker 4	Olga Dal Monte	Widespread and interactive social gaze monitoring in the primate prefrontal areas
2:45pm	Discussion	Patricia Lockwood	
3:25pm	Coffee break (Posters)		
3:55pm	**Session 3**	**Role of PFC for emotions and clinical research**	
4:00pm	Speaker 1	Emma Robinson	Investigating prefrontal regulation of affective biases in a translational rodent model.
4:20pm	Speaker 2	Angela Roberts	Insights into the organisational principles underlying the regulation of negative emotion in the prefrontal cortex of the common marmoset.
4:40pm	Speaker 3	Micah Allen	Interoception and emotion: a role for the prefrontal cortex?
5:00pm	Speaker 4	Eran Eldar	The computational varieties of emotion
5:20pm	Discussion	Jacqueline Scholl	
6:00pm	**Finish**		
6:30pm	**Social Drinks and Snacks**		

Day 2 – Thursday 24th of March

9:15am	**Session 4**	**Self-organized behaviours, control and ecological problems**	
9:20am	Speaker 1	Jeremy Seamans	Non-cognitive signals in ACC ensembles during a cognitive task
9:40am	Speaker 2	Nils Kolling	Planning, motivation and reward learning in sequential environments
10:00am	Speaker 3	Alla Karpova	Strategy Contextualization is an Organizing Principle of the ACC ensemble dynamics
10:20am		Coffee break (Posters)	
10:50am	Speaker 4	Nathaniel Daw	Metalearning, partial observability, PFC, and flexible behavior
11:10am	Discussion	Matthew Rushworth	
12:15pm		Lunch	
1:20pm	**Session 5**	**Pharmacology, computation and PFC**	
1:25pm	Speaker 1	Paul Anastasiades	Fronto-thalamic circuitry and its potential for modulation
1:45pm	Speaker 2	Vikaas Sohal	The role of prefrontal gamma synchrony in cognitive flexibility
2:05pm	Speaker 3	Catharine Winstanley	The many moods of cues: how do win-paired cues bias decision making under uncertainty?
2:25pm	Speaker 4	Hanneke den Ouden	Frontal dopaminergic control of motivational-action coupling
2:45pm	Discussion	Mark Walton	
3:25pm		Coffee break (Posters)	
3:55pm	**Session 6**	**Representation, structure and memory**	
4:00pm	Speaker 1	Caswell Barry	Plus ca Change - homeostasis and visually drive transitions in place cells
4:20pm	Speaker 2	Helen Barron	Building and distorting cognitive maps in humans and mice
4:40pm	Speaker 3	Nicolas Schuck	Factorized Hidden State Representations in Orbitofrontal Cortex Facilitate Generalisation
5:00pm	Speaker 4	Kim Stachenfeld	Probabilistic predictive representations for flexible learning and generalization
5:20pm	Discussion	Jill O'Reilly	
6:00pm		**Finish**	

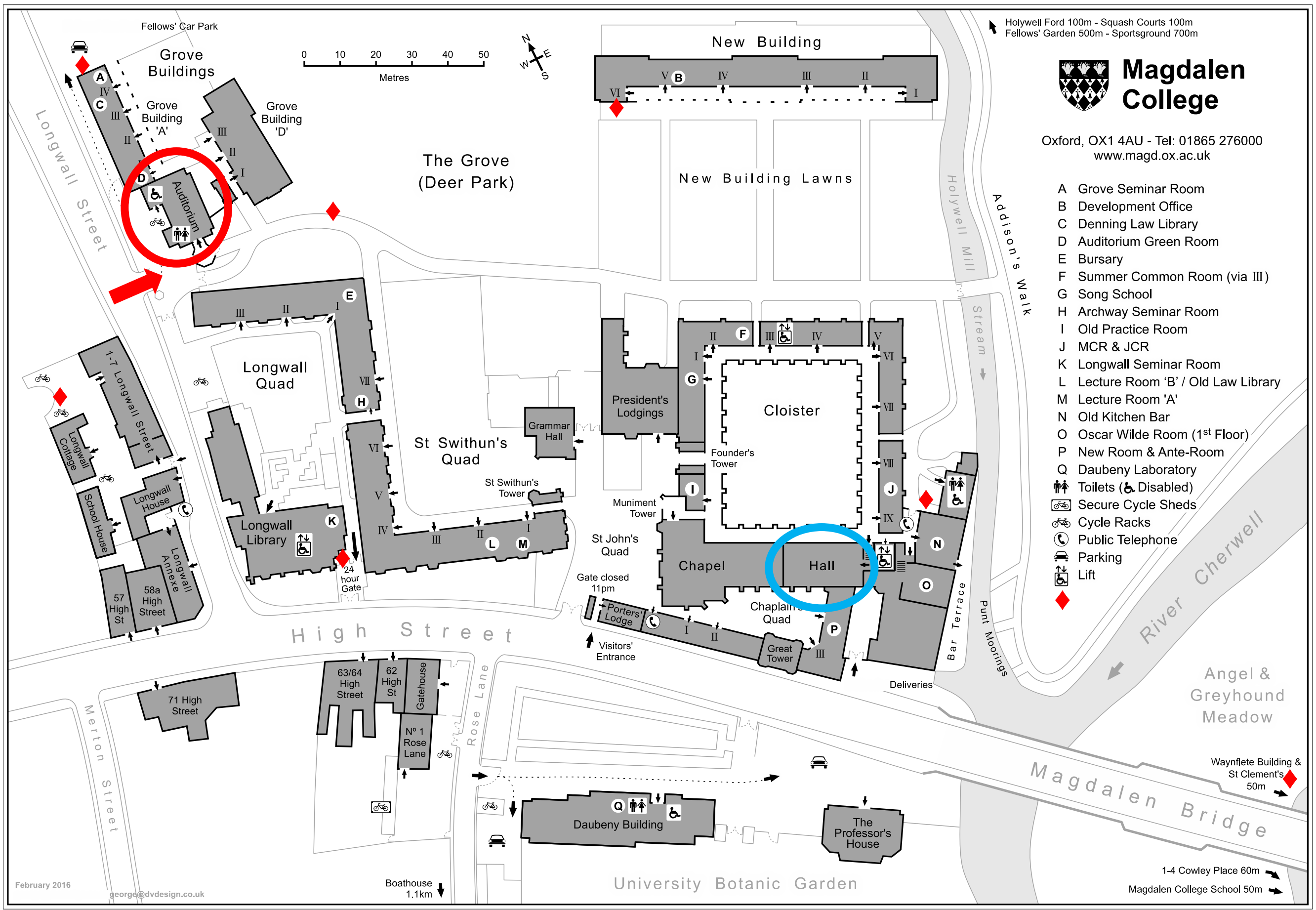
6:45pm **Dinner Drinks Reception at Magdalen College Hall**
7:15pm **Dinner at Magdalen College Hall**
Until 11:30pm **Old Kitchen Bar**

Day 3 – Friday 25th of March

8:25am	**Session 7**	**Neural oscillations and temporal dynamics of PFC computations**	
8:30am	Speaker 1	Suliann Ben Hamed	Neuronal oscillations modulate prefrontal cortical attentional and perceptual functions at multiple time scales
8:50am	Speaker 2	Charlie Wilson	What is a burst? Transient beta band phenomena in frontal oscillatory dynamics reflect cognitive and network phenomena on a trial-by-trial basis.
9:10am	Speaker 3	Erin Rich	Cognitive strategies dynamically shift mnemonic codes in prefrontal cortex
9:30am	Speaker 4	Thomas Akam	Reconciling parallel 'reinforcement learning' systems in cortex and basal ganglia
9:50am	Discussion	Elsa Fouragnan	
10:30am		Coffee break	
11:00am	**Session 8**	**Anatomy and comparative work**	
11:05am	Speaker 1	Rogier Mars	Analyzing different prefrontal cortices in a common space
11:25am	Speaker 2	Stefan Everling	Frontoparietal network connectivity as a product of convergent evolution in rodents and primates: functional connectivity topologies in grey squirrels, rats, and marmosets
11:45am	Speaker 3	Suzanne Haber	TBA
12:05pm		Lunch	
1:00pm	Discussion	Jerome Sallet	
1:40pm		**General discussion**	

Finish

Venue



Auditorium (conference & posters sessions) — **Auditorium Access**

Dinner

Covid Protocol during the meeting

The hall, Auditorium and foyer have a high ceiling. We can leave the double doors open to the Foyer and potentially the doors from the foyer to the Auditorium but there are no windows in the Auditorium.

Some of our rooms have carbon dioxide meters in them. If the level gets too high we ask everyone to vacate and let the air circulate.

We will provide alcohol-based hand sanitizers and masks.

We will advise people to wear masks, except for the speakers for clarity of speech. We will also closely monitor the use of microphones, cleaning them in between speakers.

Social event

We are pleased to invite you to the first CPPC social event.

The event will be held at the Cherwell Boathouse from 6:30pm to 11:30pm. A first drink will be offered on arrival at the venue with an alcoholic and non-alcoholic option. Vegetarian snacks will also be available during the event. We will try to avoid allergens as much as possible to suit as many people as possible.

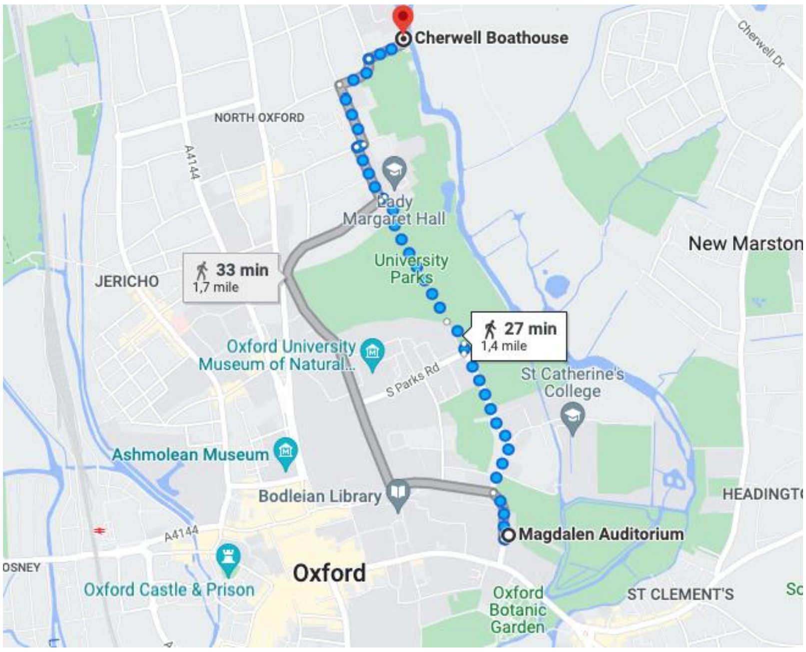
The venue is at a 30min walk from the Auditorium (the bus route shortens the walk by only 5min). The organizers will escort the participants to the venue at the end of the conferences. It is a nice walk and a good venue location. In addition, North Oxford is full of nice restaurants for dining after the event.

Thursday poster presenters can leave their poster at the Magdalen Auditorium. Please just detached them before leaving.

Info:

Time: Wednesday 23rd, 6:30pm to 9pm

Venue: Cherwell Boathouse,
Bardwell Rd,
Oxford OX2 6ST
https://cherwellboathouse.co.uk/



Sessions

Sessions and Chairs

Session 1: Neural networks maintaining, processing and integrating information

Laurence Hunt

One important characteristic of PFC is its functional flexibility. Depending on the task an agent is faced with, PFC can support many different kinds of working memory, evidence integration, decision making, task switching and monitoring. However, while the working memory and decision-making fields are seen as quite separate the maintenance and integration processes involved look remarkably similar, suggesting there might be a lot of potential to learn from each other. For example, recent suggestions of activity silent working memory representations make novel predictions about the potential circuit level implementation of flexible representations as well as integration and decision making.

In this theme we want to bring together different people working on circuit level explanation of flexible integration, representation and computation within the PFC to discuss possible PFC specific circuit rules and mechanisms supporting the retention and integration of many sources of information for the purpose of adaptive responding.

Confirmed speakers: Abhishek Banerjee, Guangyu Robert Yang, Jake Stroud, Chris Summerfield

Session 2: What prefrontal computations support social cognition?

Patricia Lockwood

Rather than trying to identify what brain mechanisms are uniquely 'social', increasingly, social neuroscience is asking what fundamental computational building blocks support social cognition and how are they implemented in the brain? Only by focusing on the mechanisms of high-level social cognition we can begin to implement a process account of our extensive capacity to engage in complex social reasoning. However, complex social processes will also heavily draw from a more general purpose computational machinery with many important mechanisms in the PFC. Thus, we need more extensive exchange between people working on the neural mechanisms of non-social cognitive processes and their social counterparts to identify and test the already established computational mechanisms that could support social cognition and what still needs to be addressed. Only then we can build theories about the differences in 'social' computation in terms of mechanisms and use of information sources.

In this theme we will have set of speakers that work on neural mechanisms underlying social behaviours on different levels of description in scale, complexity and species. We will hopefully link these descriptions to more general computational mechanism important for supporting social cognition. We will then discuss what we need going forward to define thus far unsolved questions about the implementation of different types of social cognition computationally.

Confirmed speakers: Luke Chang, Olga Dal Monte, Xiaosi Gu, Marco Wittmann

Session 3: Emotion and PFC
Jacqueline Scholl

PFC is relevant for many psychiatric disorders. A better understanding of PFC can therefore really benefit psychiatry. However, very little exchange between psychiatric and other PFC research exists. As a result, we know less than we should about how our theories might link to clinical profiles. Importantly, a better connection between the clinical, both psychiatry and neuropsychology, and other PFC research does not only increase its relevance to society but can also inform new ideas about core functions of PFC regions by observation of the behavioural consequences of their change.

The aim of this session is therefore to highlight the links between individual differences in psychiatric symptoms and lesion induced changes in PFC with other general theories of PFC functions. Hopefully this will lead into discussions of how these theories could be adapted to either account for clinical findings or what new experiments need to be designed to measure core concepts linking to both clinical profiles and PFC function.

Confirmed speakers: Micah Allen, Eran Eldar, Angela Roberts, Emma Robinson

Session 4: Self-organized behaviours, control and ecological problems
Nils Kolling and Matthew Rushworth

PFC is particularly important for complex and novel behaviours that require behavioural flexibility and control. In fact, PFC often becomes increasingly irrelevant with repetition even when the decision problem is initially complex. We have learned a lot about how PFC enables animals and humans to be flexible when choosing between specific options e.g. reversing preferences during learning or complementing model-free with more model-based value estimates based on planning. We know however, comparatively little on how the PFC enables us to solve more unstrained decision problems or make decisions about how to organize our behaviour efficiently across space and time in more ecological contexts. However, by taking an ecological perspective it is possible to make specific predictions about what kind of competing circuits might exists to optimize more self-organized behaviour within the context of a set of evolutionarily relevant types of decision.

In this theme we will have a set of speakers tackling the problem of self-organized behaviours and the navigation of complex environments from different perspectives. This will hopefully lead to a larger discussion about what an ecological perspective can contribute to understanding the role of PFC in generating more self-organized behaviours which require the concurrent evaluation of the when, what, where, how hard and for how long for.

Confirmed speakers: Nathaniel Daw, Alla Karpova, Nils Kolling, Jeremy Seamans

Session 5: Pharmacology, computation and PFC
Mark Walton

This session will look at the computational role of different neurotransmitters in PFC. It will bring together work in humans, rodents and macaques. We will be particularly focused on serotonin, dopamine and noradrenaline and try to understand how they could act as more global signals in PFC and in computational models (i.e. have a meta-role).

Confirmed speakers: Paul Anastasiades, Hanneke den Ouden, Vikaas Sohal, Catherine Winstanley

Session 6: Representation, structure and Memory

Jill O'Reilly

For a long time, humans have asked themselves the question of how knowledge is organized. With the addition of new computational theories and ways to probe brain mechanisms we now have a new perspective to this age old question. Specifically, we want to bring together ideas on statistical inference, world structure learning and the representation of knowledge and reward from the perspective of artificial intelligence, systems neuroscience and cognitive modelling to understand how the PFC supports learning, inference and planning. We also want to discuss the broader implication of our increasing understanding of how cognitive content is represented to other disciplines such as decision making.

Confirmed speakers: Helen Barron, Caswell Barry, Nicolas Schuck, Kim Stachenfeld

Session 7: Neural oscillations and temporal dynamics of PFC computations

Elsa Fouragnan

PFC circuit properties can be detected macroscopically by measuring its aggregate activity, oscillations and long range interactions and microscopically via direct recordings. These dynamics in general and oscillations in particular are constrained by the physiological and anatomical properties of the PFC. However, while we know a lot about oscillations in primary motor and sensory cortices and some subcortical brain regions such as the hippocampus, our knowledge of larger oscillatory patterns and other temporal dynamics in PFC is still very much lacking.

In this session we want to bring together some of the few people who have worked on temporal rhythms and patterns in PFC. We hope it will help us further integrate this feature of neural activity into our models of PFC computation.

Confirmed speakers: Thomas Akam, Suliann Ben Hamed, Erin Rich, Charlie Wilson

Session 8: Anatomy and comparative work

Jerome Sallet

PFC is principally investigated in 5 different species (mouse, rat, marmoset, macaque and human). Yet, our ability to integrate across each one of those models at will is still lacking. However, as pointed out by Passingham and colleagues (Passingham et al. 2002), understanding anatomical features should guide our interpretation of functional data. Thus, a better understanding of the neuroanatomical similarities but also specificities (associated for instance with ecological/physical constraints: whiskers to explore the world vs hands) will also lead to a better integration. This is particularly true for PFC, because it has many interspecies differences. Beyond interspecies mapping a more functionally oriented comparative neuroscience can also tell us about the link between different ecological niches and behaviours and brain function, informing future theories of the function of different subdivisions of PFC. Of course, good neuroanatomy is equally important to inform us about the neurobiological substrates of PFC circuits, as knowing about circuit organization constraints its computational and functional roles. It can also help us understand changes associated with learning.

Confirmed speakers: Stefan Everling, Susan Haber, Rogier Mars

Session 1

"Neural networks maintaining, processing and integrating information"
Session chair: Laurence Hunt

Speaker 1 – Chris Summerfield, University of Oxford
christopher.summerfield@psy.ox.ac.uk

Learning to partition knowledge
When we learn one task after another, there is a risk of catastrophic interference. Unlike neural networks, humans seem to actively benefit from learning tasks in discrete, non-overlapping temporal episodes. I will describe work which suggests that the brain avoids catastrophic interference between categorisation tasks by representing information in orthogonal subspaces in PFC and parietal cortex. I will show how the theory explains single-cell responses recorded in macaque PFC. I will discuss a model which learns to partition knowledge in this way from a mixture of supervised and unsupervised training, and which captures both the behavioural and neural data. (Joint work with Timo Flesch).

Speaker 2 – Guangyu Robert Yang, MIT
yanggr@mit.edu

High throughput evaluation of recurrent neural networks on cognitive neuroscience datasets
Natural intelligence entails the interactions between many systems: perception, cognition, action, memory, etc. and so ultimately many of the open questions in systems neuroscience will require models that bridge these systems. To make progress towards these multi-system models we are creating a high-throughput pipeline for training different recurrent neural network (RNN) models on a wide range of tasks and comparing them to experimental datasets. We have been inspired by community-wide efforts using mostly feedforward networks (e.g. ImageNet and Brain-Score) centered around benchmarks to both improve model architectures and evaluate model fits to data. The time is ripe for similar efforts with recurrent models that encompass a larger diversity of tasks and brain regions. Our framework provides the flexibility to add models, datasets and analysis methods, serving as a basis for further refinement and testing of RNN models by evaluating them against multiple datasets.

Speaker 3 – Jake Stroud, University of Cambridge
jps99@cam.ac.uk

Optimal information loading into working memory in the prefrontal cortex
Working memory involves the short-term maintenance of information and is critical in many tasks. The neural circuit dynamics underlying working memory remain poorly understood, with different aspects of prefrontal cortical (PFC) responses explained by different putative mechanisms. By mathematical analysis, numerical simulations, and using recordings from monkey PFC, we investigate a critical but hitherto ignored aspect of working memory dynamics: information loading. We find that, contrary to common assumptions, optimal information loading involves inputs that are largely orthogonal, rather than similar, to the persistent activities observed during memory maintenance. Using a novel, theoretically principled metric, we show that PFC exhibits the hallmarks of optimal information loading and we find that such dynamics emerge naturally as a dynamical strategy in task-optimized recurrent neural networks. Our theory unifies previous, seemingly conflicting theories of memory maintenance based on attractor or purely sequential dynamics, and reveals a normative principle underlying the widely observed phenomenon of dynamic coding in PFC.

Speaker 4 - Abhishek Banerjee, Newcastle University
abhi.banerjee@newcastle.ac.uk

Prefrontal reprogramming of sensory cortex: Insights from rodents and humans

Animals adapt their behaviour in response to variable changes in reward reinforcement. The prefrontal areas of the mammalian neocortex, especially the orbitofrontal cortex (OFC), play an important role in invoking rule-based strategies to enable flexible learning. However, the neural circuit mechanisms in OFC and its interactions with different hierarchical cortical areas underlying such processes remain elusive. In my talk, I will discuss neural interactions between orbitofrontal and sensory cortices that implement flexible decision-making in mice. I will also briefly highlight similar circuit mechanisms in operation in humans during probabilistic tactile learning tasks.

Session 2

"What prefrontal computations support social cognition?"
Session chair: Patricia Lockwood

Speaker 1 – Luke Chang, University of Dartmouth
Luke.J.Chang@Dartmouth.edu

Triangulating multimodal representations of affective experiences during naturalistic movie viewing
Emotions reflect coordinated, multi-system responses to events and situations relevant to survival and well-being. These responses emerge from appraisals of personal meaning that reference one's goals, memories, internal body states, and beliefs about the world. Consequently, ventromedial prefrontal cortex (vmPFC) activity involved in processing these subjective appraisals appears to be highly idiosyncratic across individuals. To elucidate the role of the vmPFC in processing our ongoing experiences, we developed a computational framework to characterize the spatiotemporal dynamics of individual vmPFC responses as participants viewed a 45-minute television drama. Through a combination of functional magnetic resonance imaging (n=13, n=35), intracranial recordings (n=14), facial expression tracking (n=30), and self-reported emotional experiences (n=183) across five studies, our data suggest that the vmPFC slowly transitions through a series of discretized states that broadly map onto affective experiences. Although these transitions typically occur at idiosyncratic times across people, participants exhibited a marked increase in state alignment during high affectively valenced events in the show. Our work suggests that the vmPFC ascribes affective meaning to our ongoing experiences.

Speaker 2 – Xiaosi Gu, Icahn School of Medicine at Mount Sinai New York
xiaosi.gu@mssm.edu

Humans use vmPFC-dependent forward thinking to exploit social controllability
The controllability of our social environment has a profound impact on our behavior and mental health. Nevertheless, neurocomputational mechanisms underlying social controllability remain elusive. In this talk, I will discuss recent findings supporting a role of the ventromedial prefrontal cortex (vmPFC) in implementing social forward thinking and exploiting the controllability of social environments. These findings expand the role of vmPFC beyond value encoding and spatial and cognitive mapping in non-social contexts. The breakdown of this vmPFC-supported mechanism could lead to social deficits observed in psychiatric disorders.

Speaker 3 – Marco Wittmann, University of Oxford
marco.wittmann@psy.ox.ac.uk

Interlinked estimates of self and other performance in medial prefrontal cortex
Humans have to track the success of their actions for survival. However, in a social world, we not only have to monitor our own performance, but also the performance of other people. This raises the question how the neural circuits that allow us to have insights in the success of our own actions are interlinked our ability to learn about other people. Here we show using functional magnetic resonance imaging, that dorsomedial prefrontal area 9, an area typically involved in mentalizing, tracks the performance of other people. In addition, it encodes information about the relationship between oneself and others (cooperation or competition), and also one's own performance success. Importantly, the presence of self-related signals in area 9 was crucial for how area 9 monitored other's performance. Knowledge about one's own performance spread to how well participants judged others. This resulted in estimating other people as more similar to oneself in cooperative relationships: if oneself performed well, people tended to overestimate the performance of the partner and if

oneself performed poorly, people tended to underestimate the performance of the partner. However, inversely, in competitive social context, the competitor's performance was underestimated if oneself performed well, and overestimated if oneself performed poorly. In a second study we show that transcranial magnetic stimulation to area 9 enhances this bias, causing judgements of other's performance to me even more merged with knowledge about one's own. These findings highlight a key role for area 9 in monitoring other's performance and suggest it operates in an implicit self-centred frame of reference.

Speaker 4 – Olga Dal Monte, Yale University/University of Turin
olga.dalmonte@unito.it

Widespread and interactive social gaze monitoring in the primate prefrontal areas

During spontaneous, face-to-face, social gaze interactions between pairs of macaques, we investigated spiking activity in over 1,200 neurons spanning four distinct primate brain regions implicated in social behaviors – the orbitofrontal cortex, anterior cingulate cortex, dorsomedial prefrontal cortex, and basolateral amygdala. A substantial proportion of neurons in each area showed distinct responses for looking at social stimuli (i.e., a conspecific's face or eyes) and non-social objects, with notable temporal heterogeneities across cells, suggesting continuous processing of upcoming as well as just happened social gaze events over time.

Furthermore, many neurons in each region parametrically tracked one's own gaze relative to another social agent, other's gaze relative to oneself, or the distance between the gaze positions of self and other. Critically, a subset of neurons in these brain regions showed distinct neural signals for the interactive context of social gaze, such as mutual eye contact, modulated by which agent initiated the gaze interaction.

These results therefore demonstrate widespread neuronal representations of essential variables underlying dynamic and contingent social gaze interaction – social discriminability, social gaze monitoring from the perspective of self and other, as well as signalling agent-specific interactive social gaze. Our findings emphasize the contributions of the prefrontal and amygdala circuits within the broad social interaction networks in the primate brain in regulating complex social interactions.

Session 3

"Role of PFC for emotions and clinical research"
Session chair: Jacqueline Scholl

Speaker 1 – Emma Robinson, University of Bristol
Emma.S.J.Robinson@bristol.ac.uk

Investigating prefrontal regulation of affective biases in a translational rodent model.
Affective biases influence cognition and behaviour in normal and pathological emotional states and lead to a relative positive or negative shift in the way information is processed and recalled. Both depression and anxiety have been found to be associated with negative affective biases impacting on a number of cognitive domains including learning and memory, decision-making and attention. We have developed a rodent model of affective biases associated with reward learning and memory and found that conventional and rapid-acting antidepressants have different but relevant effects on the modulation of affective biases. Whilst conventional antidepressant modify new learning via actions involving the amygdala, rapid-acting antidepressants attenuate, and even reverse, negative affective biases associated with previously learnt reward memories involving actions in the prefrontal cortex. In this talk, I will share our new data investigating the possible neuropsychological and underlying molecular mechanisms which we think may underlie these effects and could explain both the rapid and sustained antidepressant effects observed with treatments such as ketamine.

Speaker 2 – Angela Roberts, University of Cambridge
acr4@cam.ac.uk

Insights into the organisational principles underlying the regulation of negative emotion in the prefrontal cortex of the common marmoset.
Studies of the prefrontal and anterior cingulate cortex in marmosets, a new world monkey, are revealing its functional organisation in relation to the regulation of negative emotion. Subcallosal cingulate area 25 appears unique in its regulation of basal cardiovascular activity, its activation tipping the sympatho-vagal balance towards fight and flight. In the presence of threat, area 25 is recruited alongside additional prefrontal regions. When threat is proximal, as in typical Pavlovian threat conditioning, activity in area 25 and post-genu dorsal area 24, heightens and overgeneralises conditioned threat responses, in the apparent absence of contributions from neighbouring prefrontal regions. In contrast, in uncertain threat conditions, much of the prefrontal cortex is engaged, with a balance of control being played out between the medial areas 25, 24 and 14 - the activation of which heighten threat reactivity, and the more lateral orbitofrontal and ventrolateral areas, 11, 13 and 47 - the inhibition of which also heighten threat reactivity. These findings provide causal evidence for the recent proposal by Mobbs and colleagues that only when threat is more distal in time, space or probability, are higher-order executive mechanisms recruited in the decision-making process. These higher-order prefrontal mechanisms include attentional flexibility and evaluative processes and demonstrate the distinct underlying psychological causes that can lead to clinical anxiety.

Speaker 3 – Micah Allen, Aarhus University
micah@cfin.au.dk

Interoception and emotion: a role for the prefrontal cortex?
Interoception denotes the physiological sensation, perception, and metacognition of ones own visceral body. Interest in interoceptive ability as a putative biomarker for psychiatric research has recently enjoyed a resurgence. This renewed interest is in part due to an intellectual tradition, which following William James, assumes a key role for interoceptive awareness in emotional and affective processes. But is there any evidence for this linkage? In this talk I will briefly review extant approaches to the measurement of interoception, and ask what, if anything might be learned with respect to emotion regulation and the prefrontal cortex.

Speaker 4 – Eran Eldar, Hebrew University of Jerusalem
eran.eldar@mail.huji.ac.il

The computational varieties of emotion

Emotions ubiquitously impact action, learning, and perception, yet their essence and role remain widely debated. The recent emergence of computational cognitive accounts of emotion promises to answer these questions with greater conceptual precision informed by normative principles and neurobiological data. However, these nascent efforts have so far been mutually inconsistent and limited in scope. In this talk, I will offer an integrative computational account of the human emotional landscape as composed of different emotions, each promoting adaptive behaviour by mediating a distinct type of inference concerning the environment and oneself. This account builds on three parsimonious assumptions. First, that the inference each emotion mediates can be deduced from the circumstances that evoke it and the behaviour it promotes. Second, emotions that primarily differ in valence reflect similar inferences about positive versus negative experiences. Third, emotional states that primarily differ in scope (timespan and object-specificity) reflect similar inferences about the immediate context versus the general environment. We apply these principles to integrate a large body of empirical research on the causes and consequences of different emotions with the computational and cognitive neuroscience of learning and decision making. The results bring to light an emotional ecosystem composed of multiple interacting elements which together serve to evaluate outcomes (pleasure & pain), learn expected values (happiness & sadness), adjust behaviour (content & anger), and plan how to realize (desire & hope) or avoid (fear & anxiety) uncertain future prospects.

Session 4

"Self-organized behaviours, control and ecological problems"
Session chair: Nils Kolling & Matthew Rushworth

Speaker 1 – Jeremy Seamans, University of British Columbia
jeremy.seamans@ubc.ca

Non-cognitive signals in ACC ensembles during a cognitive task
The anterior cingulate cortex (ACC) plays a role in both cognitive and emotional processes, which poses some unique challenges for electrophysiologists. Neural correlates observed on cognitive tasks are often assumed to be directly related to the cognitive process of interest. Yet because most cognitive tasks are motivated by reward or punishment, the autonomic/affective state of the animal is in a constant state of flux. If a change in internal state coincides with a cognitive event of interest, how do we know whether the neural response to the event reflects an underlying cognitive process, a change in internal state or some mixture of the two? Complicating matter further, changes in internal state can far outlast the initiating event, meaning that event-related task correlates likely contain a complex mixture of signals related to past and present internal states. Our recent analysis of a delayed discounting task might help illuminate some of these issues. On this task, one lever pays out 6 pellets at a fixed delay (delayed trials) while the other pays out 0-6 pellets immediately (immediate trials) but in a variable manner depending on the rat's choice history. In order to perform optimally, the rat must dynamically adjust its choices so as to maximize the payouts on immediate trials. We found that ACC ensembles tracked the outcomes of immediate trials in a remarkably robust manner. In fact, the ensembles continued to track the outcomes of immediate trials throughout delayed trials, even in cases where there were large mismatches in payouts between the two trial types. The signal was present during decision epochs, but the lack of trial type differentiation meant that it could not be used to accurately predict choice. Furthermore, the signal was as robust when the animal was choosing disadvantageously as advantageously. Therefore, while the tracking of past outcomes was required to solve the task, the large outcome tracking signal generated by ACC ensembles simply provided an ongoing tally of how things were going in a general sense.

Speaker 2 – Nils Kolling, Inserm, Stem Cell & Brain Research Institute, Lyon & University of Oxford
nils.kolling@inserm.fr nils.kolling@psych.ox.ac.uk

Planning, motivation and reward learning in sequential environments
Deciding between apples and oranges has been an age-old question not just for hungry shoppers but within the field of decision-making research. However, very rarely have researchers considered the possibility to reject either and move on to the next shelf or even leave the shop altogether. I have previously argued that such a sequential decision making framework is not just essential for understanding foraging in the wild, but also ecological, real life, behaviour. In general, while some simplifications of decision making in real-life environments are necessary for laboratory settings, past studies have often removed essential complexity. A common reductionist approach making focuses exclusively on a framing in neuro-economic terms of one-shot decisions. However, this approach often neglects fundamental temporal aspects of decision-making in the real world: behaviour is often a sequence of choices, requiring planning and complex learning. Only by examining cognition, emotions and behaviour embedded in these extended sequences can we gain a full understanding of brain function.
Neurally, I will highlight novel insights that can be gleaned from such an approach about the potential functions of several prefrontal brain regions, particularly focused on dorsal and perigenual anterior cingulate cortex, but also ventromedial and frontal polar cortex. s

Speaker 3 – Alla Karpova, HHMI
karpovaa@janelia.hhmi.org

Strategy Contextualization is an Organizing Principle of the ACC ensemble dynamics

Medial frontal cortical areas are thought to play a critical role in the brain's ability to flexibly discern strategies effective in complex settings, but the specific circuit computations that underpin this foundational aspect of intelligence remain unclear. By examining neural ensemble activity in rats that evaluate different strategies in a self-guided search for latent task structure, we found a robust encoding of individual strategy contextualization in the anterior cingulate cortex (ACC) at a global and local approximated by strategy prevalence– scale. The encoding of local contextualization, approximated by a simple heuristic that computes the local strategy prevalence -- is wide-scale in the ACC, robust even in the absence of reward delivery, and persists through, a substantial degree of functional reorganization of the ACC ensemble that tags these representations with global contextual content. Our findings argue that strategy contextualization – a parametrization of one's choices that omits value and represents a summary statistic – is an organizing principle of ACC ensemble dynamics, raising the intriguing possibility that ACC may play a key role in the establishment of one's agency.

Speaker 4 – Nathaniel Daw, Princeton University
ndaw@princeton.edu

Metalearning, partial observability, PFC, and flexible behavior

In understanding flexible behavior (and PFC's role in it), there has recently been increased interest in learning-to-learn, metalearning, or generally the organism's ability to specialize its learning strategy to better suit a particular learning task. I discuss a new perspective for considering these issues in light of the formal relationship between meta-reinforcement learning (as it has been defined in a recent DNN model) and the problem of reinforcement learning in partially observable settings. In particular, a learning algorithm for a particular class of task can be obtained by solving a corresponding partially observable task. This perspective connects the metalearning problem to the latent state inference view of OFC, and also (via the notion of representing POMDPs by a finite state machine or "policy graph") to a different set of ideas about attractor networks.

Session 5

"Pharmacology, computation and PFC"
Session chair: Mark Walton

Speaker 1 – Paul Anastasiades, University of Bristol
paul.anastasiades@bristol.ac.uk

Fronto-thalamic circuitry and its potential for modulation
The mouse prelimbic cortex is a central hub for orchestrating a diverse array of cognitive capabilities. Although many factors contribute to this process, the thalamo-cortical system, particularly connections with the mediodorsal nucleus, and dopamine signalling have both been shown to play important roles. To better understand the circuitry behind these behaviours, we recently applied an array of optogenetic circuit mapping techniques to uncover the network architecture of fronto-thalamic connectivity. Focusing on this underlying circuitry, I will outline how it maps onto possible sites of neuromodulation, particularly dopaminergic modulation via D1-receptors, and discuss how these findings highlight important circuit-level mechanisms behind prefrontal computations.

Speaker 2 – Vikaas Sohal, University of California San Francisco
vikaas.sohal@ucsf.edu

The role of prefrontal gamma synchrony in cognitive flexibility
Many cognitive tasks elicit gamma oscillations in frontal regions, but the functional significance of these oscillations for normal cognition has been unclear. We have used genetically encoded voltage indicators to measure changes in gamma synchrony within specific cell types, and optogenetics to perturb these patterns of synchrony. Here we will present both recently published and unpublished work from our lab describing specific gamma generating circuits and showing how gamma synchrony causally influences behavior in an extradimensional rule shifting task.

Speaker 3 – Catharine Winstanley, University of British Columbia
cwinstanley@psych.ubc.ca

The many moods of cues: how do win-paired cues bias decision making under uncertainty?
The addition of reward-concurrent cues to laboratory-based gambling tasks can increase risky decision making in both rats and humans, yet the cognitive process and neurobiological mechanism through which this occurs remain opaque. Psychopharmacology studies in rats suggest that the neurochemical regulation of decision making on the rat gambling task is substantially altered by the addition of these win-paired cues, particularly within the orbitofrontal cortex. Specifically, both the noradrenaline reuptake inhibitor atomoxetine and antagonists at the serotonin 2C receptor can decrease risky choice on the cued version of the task when administered both systemically and into the OFC, yet these drugs have no effect on the uncued task. Both compounds can also improve reversal learning in tests of cognitive flexibility. Extrapolating across experiments, we hypothesise that the cues may be altering learning about the reinforcement contingencies, resulting in less model-based control of behaviour somehow. Reinforcement learning models suggest, perhaps counterintuitively, that cuing wins does not enhance learning from rewards but instead reduces value updating following losses. Just cuing loss trials, however, results in superior decision making as compared to the uncued task. Cuing both winning and losing outcomes lead to the riskiest decision-making profile of all, while playing cues on 50% of trials, regardless of whether they resulted in wins or losses, had minimal effect on decision making compared to the uncued task. Cues that were both predictable, frequent, and reward-associated, yet which carried minimal information, therefore appeared particularly effective at distorting choice biases.

Speaker 4 – Hanneke den Ouden, Radboud University
hanneke.denouden@donders.ru.nl

Frontal dopaminergic control of motivational-action coupling.

Motivations shape our behaviour: the promise of reward invigorates, while in the face of punishment, we hold back. Abnormalities of motivational processing are implicated in clinical disorders characterised by excessive habits and loss of top-down control, notably substance and behavioural addictions. Striatal and frontal dopamine have been hypothesised to play complementary roles in the respective generation and control of these motivational or 'Pavlovian' biases. However, while dopaminergic interventions have indeed been found to modulate motivational biases, these previous pharmacological studies used regionally non-selective pharmacological agents. Here, I will present two recent studies, testing the following hypotheses: i) We can overcome maladaptive motivational biases through frontal cognitive control. To test this hypothesis, we use a combination of EEG and computational modelling. ii) Frontal dopamine controls the balance between Pavlovian, bias-driven automated responding and instrumentally learned action values. Specifically, we examined whether selective enhancement of cortical dopamine enables adaptive suppression of Pavlovian control when biases are maladaptive, where we modulate frontal dopamine with COMT inhibitor tolcapone.

Session 6

"Representation, structure and Memory"
Session chair: Jill O'Reilly

Speaker 1 – Caswell Barry, University College of London
caswell.barry@ucl.ac.uk

Plus ca Change - homeostasis and visually drive transitions in place cells
The hippocampus occupies a central role in mammalian navigation and memory. Yet an understanding of the rules that govern the statistics and granularity of the spatial code, as well as its interactions with perceptual stimuli, are lacking. We analysed CA1 place cell activity recorded while rats foraged in different large-scale environments. We found that place cell activity was subject to an unexpected but precise homeostasis - the summary statistics of population-level firing being constant at all locations within and between environments. Using a virtual reconstruction of the largest environment, we showed that the rate of transition through this statistically-stable population matches the rate of change in the animals' visual scene. Thus place fields near boundaries were small but numerous, while in the environment interior they were larger but more dispersed. These results indicate that hippocampal spatial activity is governed by a small number of simple laws and in particular suggest the presence of an information-theoretic bound imposed by perception on the fidelity of the spatial memory system.

Speaker 2 – Helen Barron, University of Oxford
helen.barron@bndu.ox.ac.uk

Building and distorting cognitive maps in humans and mice
Every day we make decisions critical for adaptation and survival. We repeat actions with known consequences. But we can also infer associations between loosely related events to infer and imagine the outcome of entirely novel choices. In the first part of the talk I will show that during successful inference, the mammalian brain uses a hippocampal prospective code to forecast temporally structured learned associations. Moreover, during resting behavior, coactivation of hippocampal cells in sharp-wave/ripples represent inferred relationships that include reward, thereby "joining-the-dots" between events that have not been observed together but lead to profitable outcomes. Computing mnemonic links in this manner may provide an important mechanism to build a cognitive map that stretches beyond direct experience. However, mnemonic links that reflect deviations from actual experience may also create distortions in a cognitive map. In the second half of the talk I will show that when learning is performed under elevated levels of noradrenaline, systematic distortions in a participant's cognitive map can be measured using behaviour. These systematic distortions reflect maladaptive inferences which may be explained by unwanted coactivation or 'runaway excitation' between indirectly related memories.

Speaker 3 – Nicolas Schuck, Max Planck Institute
schuck@mpib-berlin.mpg.de

Factorized Hidden State Representations in Orbitofrontal Cortex Facilitate Generalisation
Agents can only act and learn efficiently if their internal representations characterise the environment beyond mere sensory observations. Ideally, 'state' representations will allow the agent to distinguish between identical observations based on hidden context and reflect task structure through state similarities. Little is known about how humans form such sophisticated internal representations.
We scanned human participants solving a partially observable markov decision process (POMDP) task. Participants were asked to escape a maze in which levers, doors and boxes could be operated. The causal

structure of the task was such that the same room had to be visited repeatedly while required actions depended on the preceding events. We modelled participants' behaviour using a function approximation temporal difference learning algorithm that was either supplied with basic observations, an unstructured MDP or a set of factorized features that facilitated generalization.

Participants showed fast learning and model comparisons indicated a better fit of the model using factorized features that supported optimal generalisation. Investigating the similarity structure of activation patterns in OFC during the task revealed a neural representation of the factorized MDP as well as unstructured MPD states. The relative balance of the two representations in OFC correlated with differences in model fit of the models using factorized or unstructured MDP representations, respectively. No comparable results were found in the hippocampus. The results support a unique role of the OFC during learning and generalisation in POMDPs by supplying sophisticated hidden state representations.

Speaker 4 – Kim Stachenfeld, Deepmind London
stachenfeld@google.com

Probabilistic predictive representations for flexible learning and generalization

Humans and other animals are able to solve a wide variety of decision-making problems with remarkable flexibility. This flexibility is thought to derive from an internal model of the world used to predict the future and plan actions accordingly. One hypothesis for the structure of this world model is that animal's represent statistics about upcoming events such as a "successor representation," in which the expected number of visits to future states is computed. Such statistics permit rapid inferences about future outcomes, such as expected reward under different goals. However, this proposal does not take into account how predictions should adapt under uncertainty and switches of context. To do this, we introduce a "probabilistic" successor representation that learns a distribution over expected outcomes, rather than a single statistic. This model allows different types of uncertainty -- uncertainty about upcoming predictions, as well as over context -- to inform the predictions that are learned and their downstream usage. We show that this probabilistic successor representation accounts for a number of additional findings in neuroscience and psychology that the successor representation alone does not cover. The work in this talk is joint work led by Jesse Geerts in collaboration with Sam Gershman, and Neil Burgess.

Session 7

"Neural oscillations and temporal dynamics of PFC computations"
Session chair: Elsa Fouragnan

Speaker 1 – Suliann Ben Hamed, CNRS, Institut des Sciences Cognitives Marc Jeannerod, Lyon
benhamed@isc.cnrs.fr

Neuronal oscillations modulate prefrontal cortical attentional and perceptual functions at multiple time scales

Recent accumulating evidence challenges the traditional view of attention as a continuously active spotlight over which we have direct voluntary control, suggesting instead a rhythmic operation. Some lines of evidence point towards inter-areal synchronization mechanisms in the theta range. Other lines of evidence point towards an attentional exploration of space in the alpha range. I will present monkey frontal eye field electrophysiological data reconciling these two views. I will then show that these processes are further impacted by a much slower rhythm, at the scale of several minutes. I will first apply machine learning methods to reconstruct, at high spatial and temporal resolution, the spatial attentional spotlight from monkey prefrontal neuronal population activity. I will provide evidence for a rhythmic spatial attention exploration by this prefrontal attentional spotlight in the alpha (7-12Hz) frequency range, directly impacting both behavioral overt report and neuronal responses to incoming sensory information. I will then show that the higher the phase locking between this neuronal population alpha rhythm and theta LFP content the higher overall behavioral performance and the more task driven the spatial exploration pattern of the prefrontal attentional spotlight. Changes in alpha-theta coupling organize over several minutes. Based on this data, I will propose a functional dissociation between prefrontal alpha and theta processes. Last, I will show that attentional and prefrontal perceptual processes consistently fluctuate at a much slower rhythm of cira 5 cycles per hour, thus uncovering a yet unexplored temporal coding scale in the prefrontal cortex.

Speaker 2 – Charlie Wilson, Inserm, Stem Cell & Brain Research Institute, Lyon
charles.wilson@inserm.fr

What is a burst? Transient beta band phenomena in frontal oscillatory dynamics reflect cognitive and network phenomena on a trial-by-trial basis.

Cognitive processes are reliably accompanied by trial-averaged differences in the beta band (12-35 Hz) in prefrontal cortex. But the act of averaging does a disservice to the true underlying dynamic - non-sustained transient 'burst-like' rhythms are the predominant feature in the frontal beta band, and analysis of these bursts is an increasing feature of the field. I will discuss and present data from monkey neurophysiology in support of two implications of this. First, the specific properties of these individual bursts are independently modulated by different cognitive factors, meaning that single-trial analysis provides insights about cognition-neurophysiology interactions that are hidden by analyses involving higher-level averaging. Second, because of variations in the methods used to detect and identify the bursts, the phenomena considered to be "beta bursts" can have strikingly different oscillatory and temporal properties between studies and methods. I will demonstrate that different forms of burst have different functional implications, arguing that they reflect different network phenomena. The results have methodological implications for the field and reveal the significant potential in digging down into the detailed nature of individual oscillatory phenomena.

Speaker 3 – Erin Rich, Icahn School of Medicine at Mount Sinai
erin.rich@mssm.edu

Cognitive strategies dynamically shift mnemonic codes in prefrontal cortex
Advanced cognitive abilities like planning and problem-solving involve dynamically organizing information held in working memory. This process likely depends on intact prefrontal cortical function, but to date it has been challenging to capture this flexible, self-generated aspect of cognition with traditional working memory paradigms. In this study, we capitalized on monkeys' advanced problem-solving abilities, and presented them with a difficult working memory task where they could spontaneously generate different strategies to improve their performance. Contrasting neural coding on problems where they did or did not adopt a common sequencing strategy revealed online shifts in prefrontal coding. We found that, when monkeys organized information into a regular sequence, task information was carried less by highly-tuned prefrontal neurons and became more distributed among a population. The distributed codes appeared more robust, since they improved behavioral performance and we could recover task-relevant information as well or better than when codes were dominated by a smaller number of highly-tuned neurons. Together, this study provides evidence for rapid shifts in the nature of prefrontal codes when information is organized by a cognitive strategy.

Speaker 4 – Thomas Akam, University of Oxford
thomas.akam@psy.ox.ac.uk

Reconciling parallel 'reinforcement learning' systems in cortex and basal ganglia
The reward prediction error (RPE) hypothesis of dopamine function is one of the great success stories of theoretical neuroscience, explaining a diverse set of experimental data from normative principles. Reinforcement learning (RL) models of cortico-striatal function typically assume that cortex represents the current state of the world, and dopaminergic RPE's update value estimates at cortico-striatal synapses. A wrinkle in this picture is the abundant evidence for what are apparently value signals in frontal cortex. What are they doing up there if value learning happens in basal ganglia? I will present a computational model of learning in cortico-basal ganglia circuits which speaks to this question.
A recurrent network representing frontal cortex is trained to predict the next observation, i.e. to minimize sensory prediction errors, and in doing so learns to infer latent states of the environment. Striatum, represented by a feedforward network, receives the observable task states and PFC activity as input, and implements actor critic reinforcement learning to predict reward and select actions. Trained to solve a multi-step decision task, the model explains a set of otherwise paradoxical observations from dopamine recording and manipulation experiments. Insomuch as the model is correct, it suggests that: i) Signals interpreted as action values in cortex may in fact represent beliefs about latent states of the environment. ii) The influence of rewards on future choices in decision tasks may be mediated by recurrent activity dynamics in cortex not dopamine-driven synaptic weight changes in striatum.

Session 8

"Anatomy and comparative work"
Session chair: Jérôme Sallet

Speaker 1 – Rogier Mars, University of Oxford
rogier.mars@ndcn.ox.ac.uk

Analyzing different prefrontal cortices in a common space
Differences in prefrontal organization across species are both a rich source of knowledge and a nuisance to neuroscience. Surprisingly, despite fierce debate about human PFC specializations, there are as yet few quantitative comparisons of PFC organization that go beyond coarse measures of size. Now, with the widespread availability of MRI data from different species, including major model species much as the macaque, marmoset, and mouse, quantitative between-species brain atlases are becoming a more realistic goal. Here, we present a framework for building such between-species atlases, even in cases where the brains differ vastly in size and morphology."

Speaker 2 – Stefan Everling, University of Western Ontario
severlin@uwo.ca

Frontoparietal network connectivity as a product of convergent evolution in rodents and primates: functional connectivity topologies in grey squirrels, rats, and marmosets
Robust frontoparietal network connectivity is a defining feature of primate cortical organization. Whether mammals outside the primate order, such as rodents, possess similar frontoparietal functional network organization is a controversial topic. Previous work has primarily focused on comparing mice and rats to primates. However, as these rodents are nocturnal and terrestrial, they rely much less on visual input than primates. Here, we sought to determine if the species-specific lifestyles could explain the previously reported differences in frontoparietal network connectivity between rodents and primates. We investigated the functional cortical organization of grey squirrels (Sciurus carolinensis) which are diurnal and have an arboreal lifestyle, thereby better resembling primate ecology. We used ultra-high field resting-state fMRI data to compute and compare the functional connectivity (FC) patterns of frontal regions in grey squirrels, rats, and marmosets. We also mapped the functional connectivity "fingerprints" of these regions in each species to common cortical and subcortical brain areas across the three species. The results show that grey squirrels, but not rats, possess a prominent frontoparietal network organization that resembles the connectivity pattern of marmoset lateral prefrontal cortical areas. Since grey squirrels and marmosets have acquired arboreal lifestyles but show no common arboreal ancestor, the expansion of the visual system and the formation of a frontoparietal network architecture might reflect convergent evolution driven by similar ecological niches in primates and tree squirrels.

Speaker 3 – Suzanne Haber, University of Rochester Medical Center
suzanne_haber@urmc.rochester.edu

TBA

Poster

Poster Abstracts

Dynamic interactions between action and attention during goal-directed recruitment of Pavlovian biases 32
The differential effect of prediction error and information on timing in a drumming task 33
Environmental reward rate modulates cognitive effort investment 34
Acquired distinctiveness in cognitive control of attention 35
Emergence of novel value representations and novelty-coding in the prefrontal cortex 36
Effects of expectation and response conflict on prefrontal cognitive control network activity 37
Contextual modulation of reward signals across object and spatial reversal learning in the macaque brain 38
Are the dynamics of feedback-based learning in a volatile environment modulated by working memory capacity? 39
Neural population dynamics and abstract rule encoding in macaque prefrontal areas 40
Elucidating the neural correlates of value-guided decisions in a rat prefrontal cortical basal ganglia network 41
Anticholinergic agent diminishes feedback learning in healthy participants 42
Neural activity tracking identity and confidence in social information 43
Selective biases in reinforcement learning signals in depression and schizophrenia 44
An ecological framework for prosocial behaviour: Foraging for others' rewards 45
Internally Organized Abstract Task Maps in the Mouse Medial Frontal Cortex 46
Neurochemical influences on prefrontal control over human emotional actions 47
Ventromedial prefrontal cortex lesions disrupt learning to gain prosocial rewards 48
Damage to ventromedial prefrontal cortex decreases effortful prosocial behaviours 49
How incidental emotions bias economic decisions 50
Transcranial direct current stimulation effects on emotion regulation in social contexts in patients with borderline personality disorder 51
The effect of bifrontal tDCS on reward learning in low mood 52
Trait anxiety is associated with hidden state inference during aversive learning 53
Voluntary action and problem solving 54
Temporal EEG dynamics of foraging decisions in humans 55
Behavioural and neural mechanisms of commitment and abandonment in sequential goal pursuit 56
Bayesian mechanisms underlying the neural trade-off between cooperation and competition in the Space dilemma 57
Freedom from what? A componential analysis of volitional behaviour 58
Decision-making in dynamic, continuously evolving environments: quantifying the flexibility of choice and exploration computations 59
How do MPFC regions relate to decision variables of varying complexity during sequential decision-making? 60
Neural correlates of action observation in dogs (Canis familiaris) and humans 61
Reward under risk: Observing the effects of predatory threat on foraging behaviour with 7T fMRI 62
Come for the Sugar, Stay for the Show: impacts of audiovisual cues on rodent impulsivity and gambling behaviour 63
Approach-avoidance decisions under threat: Effects of psychophysiological state on neural computations 64
Consistency within change: Evaluating the psychometric properties of a widely-used predictive-inference task 65
A cognitive map for value-guided choice in ventromedial prefrontal cortex 66
Linked brain networks of adaptive memory formation and error recognition processes 67
Orbitofrontal feedback-dependent and independent remapping of outcome-selective neurons in sensory cortex 68
Electrophysiological evidence for alternative value encoding in macaque frontopolar cortex 69
Emergence of abstract rules: A computational sketch 70
A hierarchy of distributed representations in the anterior cingulate cortex for cognitive control 71
Toward a new dimensional approach to addiction: Linking addiction markers to the connectivity profiles of striatum subdivisions 72
Identifying content-independent neural correlates of awareness 73
Learning-induced dimensionality transformations in the non-human primate prefrontal cortex 74

Poster Sessions Timetable

Posters are displayed in the foyer in front of the main hall. The poster sessions will be held across two days (Wednesday and Thursday), with each poster displayed for one full day. To maximise capacity for discussions, live poster presentations are divided between a morning session (10:20–10:50) and an afternoon session (3:25–3:55).

Presenter	Title	Session Day	Poster Location	Presentation Timings
Johannes Algermissen	Dynamic interactions between action and attention during goal-directed recruitment of Pavlovian biases	Weds 23/03	2	Morning
Yan Yan	The differential effect of prediction error and information on timing in a drumming task	Weds 23/03	4	Morning
Floortje S. Spronkers	Environmental reward rate modulates cognitive effort investment	Weds 23/03	6	Morning
William H Alexander	Acquired distinctiveness in cognitive control of attention	Weds 23/03	8	Morning
Elena Gutierrez	Emergence of novel value representations and novelty-coding in the prefrontal cortex	Weds 23/03	10	Morning
Jana Tegelbeckers	Effects of expectation and response conflict on prefrontal cognitive control network activity	Weds 23/03	12	Morning
Mathilde Lojkiewiez	Contextual modulation of reward signals across object and spatial reversal learning in the macaque brain	Weds 23/03	14	Morning
Lieneke K. Janssen	Are the dynamics of feedback-based learning in a volatile environment modulated by working memory capacity?	Weds 23/03	16	Morning
Juan M. Galeazzi	Neural population dynamics and abstract rule encoding in macaque prefrontal areas	Weds 23/03	18	Morning
Oliver Härmson	Elucidating the neural correlates of value-guided decisions in a rat prefrontal cortical basal ganglia network	Weds 23/03	20	Morning
Jonathan Hils	Anticholinergic agent diminishes feedback learning in healthy participants	Weds 23/03	22	Morning
Nadescha Trudel	Neural activity tracking identity and confidence in social information	Weds 23/03	1	Afternoon
Hans Kirschner	Selective biases in reinforcement learning signals in depression and schizophrenia	Weds 23/03	3	Afternoon
Luis Sebastian Contreras-Huerta	An ecological framework for prosocial behaviour: Foraging for others' rewards	Weds 23/03	5	Afternoon
Mohamady El Gaby	Internally Organized Abstract Task Maps in the Mouse Medial Frontal Cortex	Weds 23/03	7	Afternoon
Bob Bramson	Neurochemical influences on prefrontal control over human emotional actions	Weds 23/03	9	Afternoon
Margot Gueguen	Ventromedial prefrontal cortex lesions disrupt learning to gain prosocial rewards	Weds 23/03	11	Afternoon

Presenter	Title	Session Day	Poster Location	Presentation Timings
Jo Cutler	Damage to ventromedial prefrontal cortex decreases effortful prosocial behaviours	Weds 23/03	13	Afternoon
Roeland Heerema	How incidental emotions bias economic decisions	Weds 23/03	15	Afternoon
Lisco A.	Transcranial direct current stimulation effects on emotion regulation in social contexts in patients with borderline personality disorder	Weds 23/03	17	Afternoon
Verena Sarrazin	The effect of bifrontal tDCS on reward learning in low mood	Weds 23/03	19	Afternoon
Ondrej Zika	Trait anxiety is associated with hidden state inference during aversive learning	Weds 23/03	21	Afternoon
Silvia Seghezzi	Voluntary action and problem solving	Thurs 24/03	1	Morning
Franziska Kirsch	Temporal EEG dynamics of foraging decisions in humans	Thurs 24/03	3	Morning
Eleanor Holton	Behavioural and neural mechanisms of commitment and abandonment in sequential goal pursuit	Thurs 24/03	5	Morning
Pisauro M.A	Bayesian mechanisms underlying the neural trade-off between cooperation and competition in the Space dilemma	Thurs 24/03	7	Morning
Keiji Ota	Freedom from what? A componential analysis of volitional behaviour	Thurs 24/03	9	Morning
L. A. Weber	Decision-making in dynamic, continuously evolving environments: quantifying the flexibility of choice and exploration computations	Thurs 24/03	11	Morning
Lisa Doppelhofer	How do MPFC regions relate to decision variables of varying complexity during sequential decision-making?	Thurs 24/03	13	Morning
Magdalena Boch	Neural correlates of action observation in dogs (Canis familiaris) and humans	Thurs 24/03	15	Morning
Hailey Trier	Reward under risk: Observing the effects of predatory threat on foraging behaviour with 7T fMRI	Thurs 24/03	17	Morning
Melanie Lysenko-Martin	Come for the Sugar, Stay for the Show: impacts of audiovisual cues on rodent impulsivity and gambling behaviour	Thurs 24/03	19	Morning
Felix Klaassen	Approach-avoidance decisions under threat: Effects of psychophysiological state on neural computations	Thurs 24/03	21	Morning
Alisa M. Loosen	Consistency within change: Evaluating the psychometric properties of a widely-used predictive-inference task	Thurs 24/03	2	Afternoon
Sebastijan Veselic	A cognitive map for value-guided choice in ventromedial prefrontal cortex	Thurs 24/03	4	Afternoon

Presenter	Title	Session Day	Poster Location	Presentation Timings
Alexander Weuthen	Linked brain networks of adaptive memory formation and error recognition processes	Thurs 24/03	6	Afternoon
Jasper Teutsch	Orbitofrontal feedback-dependent and independent remapping of outcome-selective neurons in sensory cortex	Thurs 24/03	8	Afternoon
Matthew Ainsworth	Electrophysiological evidence for alternative value encoding in macaque frontopolar cortex	Thurs 24/03	10	Afternoon
Snigdha Dagar	Emergence of abstract rules: A computational sketch	Thurs 24/03	12	Afternoon
Iris Ikink	A hierarchy of distributed representations in the anterior cingulate cortex for cognitive control	Thurs 24/03	14	Afternoon
Kenza Kadri	Toward a new dimensional approach to addiction: Linking addiction markers to the connectivity profiles of striatum subdivisions	Thurs 24/03	16	Afternoon
Benjy O. Barnett	Identifying content-independent neural correlates of awareness	Thurs 24/03	18	Afternoon
Michał J. Wójcik	Learning-induced dimensionality transformations in the non-human primate prefrontal cortex	Thurs 24/03	20	Afternoon

Dynamic interactions between action and attention during goal-directed recruitment of Pavlovian biases

Johannes Algermissen[1] & Hanneke E. M. den Ouden[1]

Affiliation:
[1]Donders Institute for Brain, Cognition, and Behaviour, Radboud University, Nijmegen, The Netherlands

Prospective outcomes affect action selection, a phenomenon called Pavlovian biases: Reward prospect triggers action invigoration, while punishment prospect suppresses action. Such Pavlovian control might be helpful as a global "prior" on appropriate actions in novel and uncertain environments, but should be downregulated in well-known environments. However, past research suggested that Pavlovian control continues to interfere with instrumental action selection, frequently leading to maladaptive action slips. We reasoned that Pavlovian control over behavior might remain so strong because it is regularly recruited by the instrumental system itself in service of its action goals. The latter could do so by shaping the visual input to the Pavlovian system via selective attention to reward or punishment information. In two eye-tracking studies (the second a pre-registered direct replication), we used a novel Go/ NoGo learning task in which participants could preview potential outcomes in a gaze- contingent design. We found that Go/ NoGo action plans biased attention towards reward/ punishment information, which in turn strongly invigorated/ suppressed responses. These results suggest that humans can adaptively recruit motivational biases to facilitate the translation of their intentions into actions—even over extended time periods and under distraction. In a follow-up MEG study, we investigated how ongoing action preparation (indexed via sensorimotor beta power) and spatial attention (indexed via posterior alpha power lateralization) influenced each other over time. In particular, we tested whether such interactions arose via a) altered processing of bottom-up signals, reflecting changes in parietal saliency maps, or via b) anticipatory top-down influences of prefrontal value representations on attention allocation.

Presentation: Wednesday Morning Board 2

The differential effect of prediction error and information on timing in a drumming task

Yan Yan[1], Cameron Hassall[1*], Laurence Hunt[1*]

Affiliation:
[1]Department of Psychiatry, University of Oxford
* co-senior authors

Reward processing and timing both deploy the dopaminergic system in the brain, allowing reward to interfere with timing (Matell and Meck, 2000; Rao et al., 2001). Preliminary results showed that reward prediction error can bias interval timing, but the direction of impact remains inconclusive (Soares et al., 2016; Toren et al., 2020). We recorded electroencephalogram (EEG) from 16 participants while they engaged in a drumming task with varying tempo (fast: 150 BPM, medium: 100 BPM, slow: 60 BPM), to test how performance feedback, as a special case of reward, biases subsequent timing. We used regression-based EEG analysis and focused the feedback-related negativity (FRN).

Participants showed a systematic bias in time production, producing longer intervals than required during fast tempo, and shorter intervals during medium and slow tempo. This bias could not be explained solely by regression to the mean, as evidenced by permutation tests. Participants adjusted their response time (RT) after feedback. Notably, the size of adjustment is influenced by the interaction between feedback type and tempo (two-way ANOVA, significant interaction effect, $F = 23.34$ $p < .001$): participants made a larger adjustment upon receiving early versus late feedback during the fast tempo condition ($t = 6.99$, $p < .001$), but a larger adjustment when late during medium ($t = -3.393$, $p = .002$) and slow tempo ($t = -5.458$, $p < .001$).

Comparison between conventional ERP and regression-based ERP demonstrate that in rapid and overlapping cognitive tasks, between-trial interference may lead to spurious ERP difference. The FRN was only observed in the medium and slow tempo, and its amplitude did not differ between early and late feedback. This may imply that both early and late feedback elicits a similar negative neural prediction error. To evaluate the impact of this neural prediction error on timing, we derived residual EEG as a trial-by-trial proxy to the FRN (tbt-FRN), and used it to predict the RT adjustment during the next trial. Larger (i.e. more negative) tbt-FRN marginally predicted the decrease in response time across tempos and feedback (beta = .027, $p = .062$), suggesting that negative prediction error shortens the subsequently produced interval. Curiously, the opposite association was observed for the late feedback in slow tempo (slow × late × tbt-FRN, beta = -.17, $p < .001$), implying the involvement of other cognitive factors. A conceptual model suggests that the observed pattern of RT adjustment may be explained by the multitude of influences that feedback has on timing, which includes neural prediction error, information value, and possibly post-error slowing.

Keywords: Timing, interval production, reward processing, event-related potential, feedback- related negativity

Reference:
1. Matell MS, Meck WH (2000) Neuropsychological mechanisms of interval timing behavior. Bioessays 22:94–103.
2. Miltner WHR, Braun CH, Coles MGH (1997) Event-Related Brain Potentials Following Incorrect Feedback in a Time-Estimation Task: Evidence for a "Generic" Neural System for Error Detection. Journal of Cognitive Neuroscience 9:788–798.
3. Rao SM, Mayer AR, Harrington DL (2001) The evolution of brain activation during temporal processing. Nature neuroscience 4:317–323.
4. Soares S, Atallah BV, Paton JJ (2016) Midbrain dopamine neurons control judgment of time. Science 354:1273–1277.
5. Toren I, Aberg KC, Paz R (2020) Prediction errors bidirectionally bias time perception. Nature Neuroscience 23:1198–1202.

Presentation: Wednesday Morning Board 4

Environmental reward rate modulates cognitive effort investment

Floortje S. Spronkers[1], Ross Otto[2], Hanneke E.M. den Ouden[1]

Affiliations:
[1]Donders Centre for Cognition, Radboud University Nijmegen, the Netherlands;
[2]Department of Psychology, McGill University, Montreal

When we make decisions, not only what choice we make is important, but also how we make it. These ‘meta-decisions’ are thought to involve a cost-benefit trade-off, comparing the potential benefit of making the right choice, to the resource cost of engaging in the decision process. The opportunity cost of time has been proposed to reflect such a resource cost: Time spent making this decision cannot be spend on something else. This opportunity cost is suggested to be approximated by the average reward rate (ARR) in the environment: When ARR is high, time is 'expensive' (Niv et al., 2007). Consistent with this, high ARR increases physical vigor on a speeded response task (Guitart-Masip et al., 2011). In this study, we replicate a controversial finding testing the effect of ARR on cognitive effort investment. Replicating Otto & Daw (2019), we show that people respond faster and less accurately on a classic cognitive control (Simon) task. Moreover, higher ARR counterintuitively lowered cognitive effort investment, evidenced by a ‘breaking’ of the speed- accuracy trade-off, where the same RT in a high versus low ARR environment is accompanied by lower accuracy for the former. In conclusion, our results confirm that the ARR influences cognitive effort investment.

References:
1. Guitart-Masip, M., Fuentemilla, L., Bach, D. R., Huys, Q. J., Dayan, P., Dolan, R. J., & Duzel, E. (2011). Action dominates valence in anticipatory representations in the human striatum and dopaminergic midbrain. Journal of Neuroscience, 31(21), 7867-7875.
2. Niv, Y., Daw, N. D., Joel, D., & Dayan, P. (2007). Tonic dopamine: opportunity costs and the control of response vigor. Psychopharmacology, 191(3), 507-520.
3. Otto, A. R., & Daw, N. D. (2019). The opportunity cost of time modulates cognitive effort. Neuropsychologia, 123, 92-105.

Presentation: Wednesday Morning Board 6

Acquired distinctiveness in cognitive control of attention

Alexander, William H

Affiliation:
Department of Psychology, Center for Complex Systems & Brain Sciences, Brain Institute, Florida Atlantic University

Several accounts of cognitive control and the neural structures supporting it invoke reinforcement learning formulations to explain behavior and brain function. At its heart, reinforcement learning depends on the concept of surprise: learning is driven by the discrepancy between observations and predictions, and can be used to update associative weights as well as the distribution of attention. In contrast to reinforcement learning's emphasis on surprise, the principle of acquired distinctiveness suggests that attention should be allocated to features that are good predictors of subsequent outcomes. Here I propose a new model of cognitive control of attention that learns to distribute attention to features based on this idea, and show how it captures congruency effects frequently reported in the literature, as well as reverse congruency effects that have not previously been explained. The model recasts attentional strategies in control as attempting to optimize information use, consistent with early studies of congruency sequence effects.

References:
1. Gratton, G., Coles, M. G. & Donchin, E. Optimizing the use of information: strategic control of activation of responses. *J Exp Psychol Gen* **121**, 480–506 (1992).
2. Pearce, J. M. & Hall, G. A model for Pavlovian learning: Variations in the effectiveness of conditioned but not of unconditioned stimuli. *Psychological Review* **87**, 532–552 (1980).
3. Mackintosh, N. J. A theory of attention: Variations in the associability of stimuli with reinforcement. *Psychological Review* **82**, 276–298 (1975).

Presentation: Wednesday Morning Board 8

Emergence of novel value representations and novelty-coding in the prefrontal cortex

Elena Gutierrez[1], Sebastijan Veselic[1], James L. Butler[1], Timothy H. Muller[1], W. M. Nishantha Malalasekera[1], Laurence T. Hunt[2,3], Timothy E.J. Behrens[3,4,5], Steven W. Kennerley[1]

Affiliations:
[1]Department of Clinical and Movement Neurosciences, University College London, London, WC1N 3BG, United Kingdom
[2]Department of Psychiatry, University of Oxford, Oxford OX3 7JX, United Kingdom
[3]Wellcome Centre for Integrative Neuroimaging, University of Oxford, John Radcliffe Hospital, Oxford OX3 9DU, UK
[4]Wellcome Centre for Human Neuroimaging, University College London, London, WC1N 3AR, UK
[5]Sainsbury Wellcome Centre for Neural Circuits and Behaviour, University College London, London W1T 4JG, UK

Every day we are faced with choices between novel options whose value we must learn. While neurons encoding value of decision variables have been widely reported in the prefrontal cortex (PFC) of non-human primates1-3, most evidence stems from tasks performed for thousands of trials4,5. How encoding of novel values arises in prefrontal neurons thus remains largely unexplored. Here we show that individual neurons in the anterior cingulate cortex (ACC) and orbitofrontal cortex (OFC) rapidly acquire novel value representations, but with divergent strategies. While both regions represented the value of novel cues after cue presentation, ACC neurons learnt the value of items the fastest, with some just needing five cue presentations to encode its value. The two regions further differed in the way in which the value codes merged: OFC created a unique value code orthogonal to that of previously learned cue values, whereas ACC employed the same value code that it used for previously learnt stimuli. In line with this, OFC strongly dissociated between whether cues were recently learned or heavily overtrained. Our findings suggest distinct learning dynamics across prefrontal areas in response to novel options: ACC promptly generates value representations using a common value code2,6, whereas OFC precisely tracks the identity3,7 and novelty of each cue while learning its value.

References:
1. Padoa-Schioppa C. Neurobiology of Economic Choice: A Good-Based Model. Annu Rev Neurosci. 2011;34:333-59.
2. Kennerley SW, Behrens TEJ, Wallis JD. Double dissociation of value computations in orbitofrontal and anterior cingulate neurons. Nature Neuroscience. 2011;14(12):1581-89.
3. Murray EA, Rudebeck PH. Specializations for reward-guided decision-making in the primate ventral prefrontal cortex. Nat Rev Neurosci. 2018;19(7):404-17.
4. Bongioanni A, Folloni D, Verhagen L, Sallet J, Klein-Flugge MC, Rushworth MFS. Activation and disruption of a neural mechanism for novel choice in monkeys. Nature. 2021;591:270-4.
5. Cavanagh SE, Malalasekera WMN, Miranda B, Hunt LT, Kennerley SW. Visual fixation patterns during economic choice reflect covert valuation processes that emerge with learning. PNAS. 2019;116(45):22795-801.
6. Hunt LT, Malalasekera WMN, de Berker AO, Miranda B, Farmer SF, Behrens TEJ, et al. Triple dissociation of attention and decision computations across prefrontal cortex. Nature Neuroscience. 2018;21(10):1471-81.
7. Klein-Flugge MC, Barron HC, Brodersen KH, Dolan RJ, Behrens TEJ. Segregated Encoding of Reward-Identity and Stimulus-Reward Associations in Human Orbitofrontal Cortex. Journal of Neuroscience. 2013;33(7):3202-11.

Presentation: Wednesday Morning Board 10

Effects of expectation and response conflict on prefrontal cognitive control network activity

Jana Tegelbeckers[1], Theresa Schaaf[1], Markus Ullsperger[1,2]

Affiliations:
[1]Dept. of Neuropsychology, Otto von Guericke University, Magdeburg, Germany
[2]Center for Behavioral Brain Sciences, Magdeburg, Germany

Cognitive control refers to the ability to overcome task conflicts or prepotent responses in order to achieve a goal. This process requires effort and should thus be regulated by the amount of control that is required. However, typical paradigms probing cognitive control focus either on (in)congruency (e.g., Stroop, Flanker) or task switching effects. We developed the Color-Orientation-Interference task (COIN) to modulate both aspects simultaneously and compare response conflict and expectation effects. In this task, targets are composed of a circle filled with one of four colors and a needle pointing in one of four directions. Participants have to either respond to the color or orientation based on a cue that appears 1.5s after the stimulus onset. The correct response can either map on the same (congruent, task independent) or different buttons (incongruent, task dependent). Furthermore, expectation effects are induced by a 25-75 probability ratio of either color or orientation trials per run. Preliminary results with eleven healthy adult subjects undergoing functional magnetic resonance imaging (fMRI) revealed distinct network activations for task switch demands and response incongruency. Interactions between expectation and response conflict were found in the rightsuperior and middle frontal gyrus as well as posterior medial frontal cortex (pMFC). Activity in the prefrontal cognitive control network therefore seems to be adjusted to task demands. We'll further explore whether these effects translate into differential adaptations after errors.

Presentation: Wednesday Morning Board 12

Contextual modulation of reward signals across object and spatial reversal learning in the macaque brain

Mathilde Lojkiewiez[1,2*], Elsa Fouragnan[1*], Bolton Chau[3,4], Claire Pouillas[5], Urs Schüffelgen[3], Matthew FS Rushworth[3], Jérôme Sallet[2,3]

Affiliations
[1]School of Psychology, University of Plymouth, Plymouth, UK.
[2]Université Lyon 1, Inserm, Stem Cell and Brain Research Institute U1208, Bron, France.
[3]Wellcome Integrative Neuroimaging (WIN), Department of Experimental Psychology, University of Oxford, Oxford, UK.
[4]Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong.
[5]Department of Physiology, Anatomy and Genetics, University of Oxford, Oxford, UK.
*These authors contributed equally to this work.

Decision-making situations could differ along many dimensions. For example, we may have to choose between options characterised by their spatial position (e.g., choosing to turn left or right at a crossroad), or by their identity (e.g., choosing the red or the blue pill). To make such decisions in a changing environment, the brain needs to assign a value to each option, compare these associated values to make a choice and update them based on the obtained outcome. In our study, we investigated in two groups of non-human primates how learning about spatial position or object identity are represented in specific cortical and subcortical areas and to what extent these two learning strategies rely on similar computational principles. We used functional magnetic resonance imaging (fMRI) data from rhesus macaque performing deterministic reversal discrimination tasks in which monkeys had to choose between stimuli with either different identities or target locations. In previous studies, we linked an area located on the lateral part of the orbital surface (area 47/12o) to win-stay-lose-shift (WSLS) behaviours in object learning[1]. In a spatial context, this region seems to be important during the learning stage[2], but did not show the same functional role in trained animals. We further investigated the fundamental difference between the two task contexts and found that a different pattern of activation in the ventromedial Prefrontal Cortex (vmPFC) in processing reward information seems to originate an adaptive coding across contexts. While this region was functionally connected with the putamen in the two tasks, its activity was only correlated with activity in area 47/12o in the object reversal learning task. Our findings reveal different recruitments of areas of the prefrontal cortex in object and spatial learning contexts and suggest that reward encoding is a main driver of these different network activities.

References:
1. B. K. H. Chau et al., 'Contrasting Roles for Orbitofrontal Cortex and Amygdala in Credit Assignment and Learning in Macaques', Neuron, vol. 87, no. 5, pp. 1106–1118, Sep. 2015, doi: 10.1016/j.neuron.2015.08.018.
2. J. Sallet et al., 'Behavioral flexibility is associated with changes in structure and function distributed across a frontal cortical network in macaques', PLOS Biol., vol. 18, no. 5, p. e3000605, May 2020, doi: 10.1371/journal.pbio.3000605

Presentation: Wednesday Morning Board 14

Are the dynamics of feedback-based learning in a volatile environment modulated by working memory capacity?

Lieneke K. Janssen[1,2], Hans Kirschner[1], Lara Kramer[1], Ruslan Klymentiev[1], Jil Humann[5], Adrian G. Fischer[1,4,5], Markus Ullsperger[1,3,4]

Affiliations:
[1]Institute of Psychology, Otto-von-Guericke-Universität, Magdeburg, Germany
[2]Department of Neurology, Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany
[3]Donders Institute for Brain, Cognition and Behaviour, Radboud University Nijmegen, Netherlands
[4]Center for Behavioral Brain Sciences, Magdeburg, Germany
[5]Freie Universität Berlin, Berlin, Germany

Research suggests that working memory has an important role in instrumental learning when reinforcement histories of multiple options must be tracked. Working memory capacity not only reflects the ability to maintain items, but also to update and shield items against interference in a context-dependent manner; functions conceivably also essential to instrumental learning in an ever-changing environment. To address the relationship of WMC and the dynamics of instrumental learning in a volatile environment, we studied choice behavior and EEG of healthy young participants performing a probabilistic reinforcement learning task with sudden changes in reward probability (20, 50, 80%). Working memory capacity, as assessed with the automated Operation Span (OSPAN) task, positively correlated with learning performance. A hybrid Rescorla-Wagner/Pearce-Hall model was implemented to capture dynamic changes in people's learning rate around changes in reward probability. Low-capacity participants modulated learning rates less dynamically around such changes. Their choices were more stochastic and less guided by learnt values, resulting in less stable performance and higher susceptibility to misleading probabilistic feedback. Single-trial model-based EEG analysis furthermore revealed that prediction errors and learning rates were less strongly represented in cortical activity of low-capacity participants, while the centroparietal positivity, a general correlate of behavioural adaptation, was independent of working memory capacity. In conclusion, cognitive functions tackled by complex span tasks, such as the OSPAN task, seem also beneficial in feedback-based learning in a volatile environment. Whether working memory capacity contributes to optimal learning performance in this task, or performance on both tasks relies on a common underlying mechanism, is an open question that we will address in a planned follow-up with working memory manipulation.

Presentation: Wednesday Morning Board 16

Neural population dynamics and abstract rule encoding in macaque prefrontal areas

Juan M. Galeazzi[1], Ilenia Salaris[1], Matthew Ainsworth[1] and Mark J. Buckley[1]

Affiliation:
[1]Department of Experimental Psychology, University of Oxford (UK)

Previous studies identified different prefrontal areas contributing in different ways to rule-guided behavior in the context of a Wisconsin Card Sorting Test (WCST) analog for macaque monkey; dorsolateral prefrontal cortex (dlPFC) is necessary to maintain a specific abstract rule in working memory, ventrolateral prefrontal cortex (vlPFC) supports rule maintenance in general, and orbitofrontal frontal cortex (OFC) is needed to rapidly update representations of rule value based on reward. (Buckley et al., 2009; Mansouri et al., 2009). Furthermore, recent studies on role of the frontopolar cortex (FPC) suggest it contributes to representing the relative value of unchosen alternatives, including but not limited to rules (Mansouri et al., 2017). As neuronal activity from these different areas was not previously recorded simultaneously we do not yet understand the underlying computations and functional interactions operating within and between these regions. Multi-electrode micro-arrays ('Utah arrays') were chronically implanted in dlPFC, vlPFC, OFC and FPC of two rhesus macaques, allowing us to simultaneously record single and multiunit activity and local field potential (LFP) from all four regions together while the animals performed a WCST analog. Here we present preliminary results from these recordings showing the neural activities underlying task performance. We obtained a typical daily yield of 100-200 separable units/clusters from all arrays combined, with single and multiunit activity responsive to different task-relevant components. For example, we found a variety of pre-reward and post-reward unit responses in dlPFC, vlPFC, OFC, and FPC with different onsets and durations. We present here the extent to which different aspects of the task can be accurately decoded from the neural activity recorded on each of the arrays employing a variety of commonly used machine learning classification algorithms. Lastly, we also show the differences of time evolving neural trajectories of population activity in a low dimensional state space.

References:

1. Buckley MJ, Mansouri FA, Hoda H, Mahboubi M, Browning PGF, Kwok SC, Phillips A, Tanaka K (2009) Dissociable Components of Rule-Guided Behavior Depend on Distinct Medial and Prefrontal Regions. Science (80-) 325:52–58.
2. Mansouri FA, Koechlin E, Rosa MGP, Buckley MJ (2017) Managing competing goals — a key role for the frontopolar cortex. Nat Rev Neurosci 18:645–657.
3. Mansouri FA, Tanaka K, Buckley MJ (2009) Conflict-induced behavioural adjustment: A clue to the executive functions of the prefrontal cortex. Nat Rev Neurosci 10:141–152.

Presentation: Wednesday Morning Board 18

Elucidating the neural correlates of value-guided decisions in a rat prefrontal cortical basal ganglia network

Oliver Härmson[1,2,] Isaac Grennan[2], Brook Perry[2], Robert Toth[2], Sanjay Manohar[1,2,] Mark E. Walton[1], Andrew Sharott[2]

Affiliations:
[1]Department of Experimental Psychology, University of Oxford
[2]Nuffield Department of Clinical Neurosciences, University of Oxford

Adaptive value-guided decision-making often requires the weighing-up of costs and benefits[1]. The brain must thus be able to represent these quantities and the eventual decision to act upon them. Little is currently known regarding how offer evaluation and decision-related coding evolves on the single cell and population levels across the medial prefrontal cortex and the associated basal ganglia circuitry within the confines of a single behavioural paradigm. To address this, we developed a novel rat cost-benefit task, which requires a comparison between effort cost (3 different quantities of barriers to overcome to gain reward, cost varied over blocks of trials) and prospective amount of reward (0, 1, 3 or 6 sucrose pellets, varied trial-by-trial) to determine whether to invest physical effort to earn rewards or opt out of the offer (termed run and omit trials, respectively). We further developed a driveable micro-electrode device capable of recording from 5 brain areas that are known to be important for value-guided decision-making - the medial orbitofrontal cortex (MO), anterior cingulate cortex (ACC), dorsal medial striatum (DMS), ventral pallidum (VP) and subthalamic nucleus (STN) - while rats are performing the above-mentioned task. Data collected from 13 rats to date suggests a positive effect of reward and a negative influence of effort on willingness work, without an interaction between the two. Preliminary electrophysiology data suggests distributed reward and effort coding on both run and omit trials. Further work is aimed toward 1) clarifying the amount of per-structure variance in the single cell spiking data accounted for by reward magnitude, effort cost and the consecutive decision, 2) detailing the current trial's reward, effort and decision categorisation accuracies of decoders trained on each region's population neural data, 3) elucidating the fingerprints of network connectivity by examining the correlations between each structure's population spiking patterns2.

References:
1. P. W. Glimcher, C. F. Camerer, E. Fehr, and R. A. Poldrack, eds., Neuroeconomics: Decision Making and the Brain. Elsevier, 1st ed., 2009.
2. M. N. Coutanche and S. L. Thompson-Schill, "Using informational connectivity to mea- sure the synchronous emergence of fMRI multi-voxel information across time," Journal of Visualized Experiments, no. 89, pp. 1–7, 2014.

Presentation: Wednesday Morning Board 20

Anticholinergic agent diminishes feedback learning in healthy participants

Jonathan Hils[1], Alexander Weuthen[1], Steve Schulz[1], Markus Ullsperger[1,2]

Affiliations:
[1]Department of Neuropsychology, Institute of Psychology, Otto-von-Guericke Universität Magdeburg, Germany
[2]Center for Behavioral Brain Sciences, Magdeburg, Germany

Cholinergic dysfunction has been related to deficits in memory function, although it is still debated which cognitive processes required for memory formation are affected. Based on previous results on diminished post-error adaptations, we suspect that intact cholinergic function is crucial for successful interactions between feedback processing in the posterior medial frontal cortex (pMFC) and subsequent allocation of attention to relevant stimulus features. To test this assumption, a placebocontrolled double-blind electroencephalography (EEG) study with young male participants (age range 18 to 30 years) was initiated. During two separate sessions, participants received 4mg of the selective muscarinic acetylcholine receptor 1 (M1) antagonist biperiden or placebo. At expected peak time of biperiden blood levels, participants performed a feedback associative learning task (FALT) and a 1- back localizer task during simultaneous EEG recording. Participants were instructed to memorize associations between faces or houses with a set of twelve gabor patch orientations. After indicating their level of confidence, they received feedback on respective retrieval correctness. Preliminary results of the first 20 participants showed that biperiden diminished memory performance by 15.3 % during biperiden session (mean accuracy = 48.6 %) compared to placebo (mean accuracy = 63.9 %). Analyses of event-related potentials showed modulation of the feedback-related negativity (FRN) and subsequent P300 amplitude by biperiden administration. In time-frequency power analyses, alpha power modulation during encoding explained performance differences between biperiden and placebo sessions. Further analyses will investigate how biperiden influences attentional allocation during encoding by using stimulus-specific decoding models derived from the localizer task.

Presentation: Wednesday Morning Board 22

Neural activity tracking identity and confidence in social information

Nadescha Trudel[1,3,4], Patricia Lockwood[1,6], Matthew Rushworth*[1,2], Marco Wittmann*[1,4,5]

Affiliation
[1]Wellcome Centre of Integrative Neuroimaging (WIN), Department of Experimental Psychology, University of Oxford, Oxford, UK
[2]Wellcome Centre of Integrative Neuroimaging (WIN), Centre for Functional MRI of the Brain (MRI), Nuffield Department of Clinical Neuroscience, John Radcliffe Hospital, University of Oxford, Oxford, UK
[3]Wellcome Centre for Human Neuroimaging, University College London, UK
[4]Max Planck UCL Centre for Computational Psychiatry and Ageing Research, University College London, UK
[5]Department of Experimental Psychology, University College London, UK
[6]Centre for Human Brain Health, University of Birmingham, Birmingham, UK

Humans learn about the environment either directly by interacting with it or indirectly by seeking information about it from social sources such as conspecifics. The degree of confidence in the information obtained through either route should determine the impact that it has on adapting and changing behaviour. We examined whether and how behavioural and neural computations differ during non-social learning as opposed to learning from social sources. Trial-wise confidence judgments about non- social and social information sources offered a window into this learning process. Despite matching exactly the statistical features of social and non-social conditions, confidence judgments were more accurate and less changeable when they were made about social as opposed to non-social information sources. In addition to subjective reports of confidence, differences were also apparent in the Bayesian estimates of participants' subjective beliefs. Univariate activity in dorsomedial prefrontal cortex (dmPFC) and posterior temporo-parietal junction (pTPJ) more closely tracked confidence about social as opposed to non-social information sources. In addition, the multivariate patterns of activity in the same areas encoded identities of social information sources compared to non-social information sources.

Reference
1. Neural activity tracking identity and confidence in social information Nadescha Trudel, Matthew FS Rushworth, Marco K Wittmann bioRxiv 2021.07.06.449597; doi: https://doi.org/10.1101/2021.07.06.449597

Presentation: Wednesday Afternoon Board 1

Selective biases in reinforcement learning signals in depression and schizophrenia

Hans Kirschner[1]*, Adrian G. Fischer[2], Thomas Frodl[3,4] , Tilmann A. Klein[1,5] and Markus Ullsperger[1,5]

Affiliations:
[1]Institute of Psychology, Otto-von-Guericke University, D-39106 Magdeburg, Germany.
[2]Department of Education and Psychology, Freie Universität Berlin, D-14195 Berlin, Germany.
[3]Department of Psychiatry, Otto-von-Guericke University, D-39106 Magdeburg, Germany.
[4]Department of Psychiatry, Psychotherapy and Psychosomatics, RWTH Aachen University, Aachen, 52074 Germany.
[5]Center for Behavioral Brain Sciences, D-39106 Magdeburg, Germany.

Objective: Emerging evidence indicates reward processing abnormalities in patients diagnosed with major depressive disorder (MDD) and schizophrenia (SZ). Specifically, findings are consistent in associating both conditions with disrupted phasic striatal dopaminergic signaling, which is critical for reinforcement learning. Here, we aimed to characterise possible abnormalities in probabilistic learning and its temporal neural correlates in MDD and SZ.
Methods: Participants performed a variant of an established probabilistic learning task providing factual and counterfactual feedback. The sample consisted of 31 MDD, 24 SZ, and 33 matched healthy controls. We combined computational modelling, single-trial regression approaches and electroencephalography (EEG) to study distinct learning effects within each group.
Results: Both patient groups showed decreased task performance. Patients with MDD demonstrated stronger negative learning and increased choice stochasticity. Patients with SZ attributed higher initial values to stimuli leading to biased choice behavior and were less able to utilized simple decision heuristics. On the neural level, there was no tracking of expected values in patients with SZ and MDD for factual feedback. Moreover, outcome and prediction error (PE) encoding was less pronounced in the P3b in patients with SZ during both, factual and counterfactual feedback processing. Specific to counterfactual feedback, we observed enhanced allocation of attention in MDD that was quantified in larger P3a and exclusive coding of PE and outcome in the FRN in SZ.
Conclusion: We demonstrate shared and distinct abnormalities in reinforcement learning signals across two patient groups, that may inform future treatments and research.

Keywords: reinforcement learning, EEG, Depression, Schizophrenia

Presentation: Wednesday Afternoon Board 3

An ecological framework for prosocial behaviour: Foraging for others' rewards

Luis Sebastian Contreras-Huerta[1,2,3], and Matthew Apps[1,2,3,4]

Affiliation:
[1]Department of Experimental Psychology, University of Oxford, Oxford, UK;
[2]Wellcome Centre for Integrative Neuroimaging, University of Oxford, Oxford, UK;
[3]Centre for Human Brain Health, School of Psychology, University of Birmingham, Birmingham, UK;
[4]Institute for Mental Health, School of Psychology, University of Birmingham, Birmingham, UK

The survival of many species, including some modern-day human societies, depends on hunter-gatherers. One conspecific foraging prosocially for rewarding resources for others. Research has suggested that people are generally selfish, and value their own rewards more than others. However, this work has largely failed to consider theories from behavioural ecology that provide rich frameworks to understand how animals make foraging decisions which are shaped by the environment. As a result, we have a poor understanding of how people process rewards for others when faced with crucial hunter-gatherer foraging problems. Here, we leverage ecological theories of how to solve one of most significant foraging problems: patch-leaving. When in a location (patch) as you collect rewards, the resource is depleted, meaning that the rate of (foreground) reward accumulation declines over time. When should you leave and spend some time travelling to find another patch? Theoretically, it is optimal to leave when the foreground rate declines to the average rate rewards that can be obtained in the environment (background). We developed a social patch-leaving task where participants decided when to leave patches where rewards were accrued at different foreground rates, in two different environments (background). Crucially, in some blocks participants foraged for themselves but in others rewards would be given to anonymous other. We found that peoples' patch-leaving decisions conformed to foraging theory principles in both self and other conditions. But people were less sensitive to changes in foreground reward rates for others' compared to self, staying longer when the foreground rate was high when foraging for self. However, people did not show differences in background rate sensitivity for self-compared to other. These results highlight that people are not always selfish when it comes to rewards, with the antecedents of prosociality lying in our ability to consider the environment when foraging prosocially.

Presentation: Wednesday Afternoon Board 5

Internally Organized Abstract Task Maps in the Mouse Medial Frontal Cortex

Mohamady El-Gaby[1]

Affiliation:
[1]*MRC Brain Network Dynamics Unit, University of Oxford, UK*

Abstract: New tasks are often similar in structure to old ones. Animals that take advantage of such conserved or "abstract" task structures can master new tasks with minimal training. To understand the neural basis of this abstraction, we developed a novel behavioural paradigm for mice and recorded from their medial frontal neurons as they learned. Freely moving mice learned multiple tasks where they had to visit 4 rewarded locations in sequence (ABCD) on a 3x3 spatial maze. Tasks shared the same circular transition structure (… ABCDABCD …) but differed in the locations and geometric arrangement of rewards. As well as improving across tasks, mice inferred that A followed D (i.e. completed the loop) on the very first trial of a new task. This "zero-shot inference" is only possible if animals had learned the abstract structure of the task. Medial frontal cortex (mFC) neurons showed several signatures of internally organized tuning to abstract task-space. Firstly, the majority of state-tuned neurons in the mFC responded to the mouse's "location" in abstract task space, conserving their state tuning across distinct tasks. Secondly, we found robust, task-stage modulated offline replay of activity in task-space during sleep. Thirdly, a minority of state-tuned neurons remapped across tasks. Preliminary evidence suggests that such remapping is quasi-coherent across neurons, consistent with the existence of task-space modules analogous to modules of grid-cells that coherently remap in physical space. These findings point to separable neuronal substrates for internally organised representations of task structure that may guide abstraction in the mammalian brain.

Presentation: Wednesday Afternoon Board 7

Neurochemical influences on prefrontal control over human emotional actions

Bob Bramson[1,2], Sjoerd Meijer[1], Annelies van Nuland[1], Ivan Toni[1,*] and Karin Roelofs[1,2,*]

Affiliation:
[1]Donders Institute for Brain, Cognition and Behaviour, Centre for Cognitive Neuroimaging, Radboud University Nijmegen, 6525 EN Nijmegen, The Netherlands
[2]Behavioural Science Institute (BSI), Radboud University Nijmegen, 6525 HR Nijmegen, The Netherlands
*These authors contributed equally

The ability to control emotional action tendencies is important for successful participation in society. This cognitive function can fail during socially challenging situations, and is chronically attenuated in social psychopathologies such as anxiety and aggression. Previous studies have shown that control over emotional action tendencies depends on anterior prefrontal cortex (aPFC) modulating activity in downstream regions such as the amygdala and the sensorimotor cortex (SMC). We know that to avoid runaway activity or stagnation, neural information processing requires a delicate balance between excitation and inhibition (E/I ratio). Glutamate and GABA, the two major excitatory and inhibitory neurotransmitters, can be measured non-invasively with Magnetic Resonance Spectroscopy (MRS) and index E/I ratios in specific cortical areas. Here, we use MRS to test whether E/I ratio in aPFC and SMC accounts for inter-participant variability in social-emotional control. We found that a total of 20% of inter-individual variation in social-emotional control is accounted for by E/I ratio in aPFC. People with more excitable aPFC are better in controlling their emotional action tendencies, and their aPFC modulates SMC activity more effectively during social- emotional control. Together, these findings suggest that the neural implementation of social-emotional control depends on a distributed circuit regulated by a PFC excitability.

Presentation: Wednesday Afternoon Board 9

Ventromedial prefrontal cortex lesions disrupt learning to gain prosocial rewards

Margot Gueguen[1*], Jo Cutler[1,2*], Daniel Drew[2], Matthew A. J. Apps[1,2], Deva S. Jeyaretna[2], Masud Husain[2], Sanjay Manohar[2] & Patricia L. Lockwood[1,2]

Affiliations
[1]Centre for Human Brain Health | Institute for Mental Health, University of Birmingham
[2]Department of Experimental Psychology | Nuffield Department of Clinical Neurosciences, University of Oxford
*equal contribution

Keywords: vmPFC, lesion, social learning, reinforcement learning, computational modelling

The ventromedial prefrontal cortex (vmPFC) has long been associated with learning and decision- making as well as social cognition. Human neuroimaging studies have repeatedly shown that the vmPFC encodes computational parameters relevant for self-benefittin learning, including value, prediction errors, and learning rates1. A separate line of research suggests that the vmPFC is linked to social processing2, with damage to this area associated with abnormal social behaviours3 including greater utilitarianism4, and meta-analyses of imaging studies demonstrating coding of prosocial decisions5. However, neuroimaging studies cannot show a causal role of this region in learning and decision-making, and studies of vmPFC damage have so far often relied on small samples or patients with diffuse damage. Here, we studied the effects of focal vmPFC damage on learning to help oneself (self-benefitting learning), another person (prosocial), or neither individual in a large cohort of adults with localised vmPFC damage (n=26) and a carefully age-, gender-, and education-matched control group. All participants completed a probabilistic reinforcement-learning task in which they learned to deliver rewards in these three conditions. This paradigm allowed us to separately assess the influence of vmPFC lesions on learning for self, prosocial learning or learning where no one will benefit. Initial analyses show that subjects with vmPFC lesions perform significantly worse than healthy controls for prosocial and self-benefitting learning, but not when learning for neither. Computational modelling will reveal the parameters affected by vmPFC damage. Our results could have important implications for understanding the causal role of vmPFC in learning, decision-making, and social cognition.

References

1. Lockwood, P. L., Wittmann, M. K., Apps, M. A., Klein-Flügge, M. C., Crockett, M. J., Humphreys, G. W., & Rushworth, M. F. Neural mechanisms for learning self and other ownership. Nature Communications 9, 1-11 (2018).
2. Lockwood, P. L., Apps, M. A., Valton, V., Viding, E., & Roiser, J. P. Neurocomputational mechanisms of prosocial learning and links to empathy. Proceedings of the National Academy of Sciences 113, 9763-9768 (2016).
3. Schneider, B., & Koenigs, M. Human lesion studies of ventromedial prefrontal cortex. Neuropsychologia 107, 84-93 (2017).
4. Koenigs, M., Young, L., Adolphs, R., Tranel, D., Cushman, F., Hauser, M., & Damasio, A. Damage to the prefrontal cortex increases utilitarian moral judgements. Nature 446, 908-911 2007).
5. Cutler, J., & Campbell-Meiklejohn, D. A comparative fMRI meta-analysis of altruistic and strategic decisions to give. NeuroImage 184, 227-241 (2019).

Presentation: Wednesday Afternoon Board 11

Damage to ventromedial prefrontal cortex decreases effortful prosocial behaviours

Jo Cutler[1,2], Matthew A. J. Apps[1,2], Daniel Drew[2], Deva S. Jeyaretna[2], Masud Husain[2], Sanjay Manohar[2,*], & Patricia L. Lockwood[1,2,*]

Affiliations:
[1]University of Birmingham,
[2]University of Oxford
* Equal contributions

Prosocial behaviours – actions that help others – have vital interpersonal and societal benefits[1]. Most prosocial acts are effortful and require weighting of costs and benefits. Previous work has identified the ventromedial prefrontal cortex (vmPFC) as a key neural correlate of effort valuation[2] and of prosocial decisions[3]. However, studies have often used imaging methods that cannot show a causal role of vmPFC in prosocial behaviour or tested small samples of lesion patients. We assessed the impact of focal vmPFC damage on prosociality and dissociated it from general effort and reward sensitivity with an effort-based decision-making task[4] where these factors are manipulated independently. Participants chose to rest (no effort) or 'work' (30-70% of their maximum grip strength) to earn reward either for themselves, or prosocially for another person. We compared a large group of patients with focal vmPFC lesions (n= 25, aged=37-76, 14 females), carefully matched to patients with lesions elsewhere (n=16, aged=28-74, 11 females), and healthy controls (n=40, aged=36-67, 23 females) on age, gender, and education. Taking a computational neurology approach, we used modelling to quantify how the required effort cost was integrated with rewards for self or other to determine the decision to work.

Strikingly, patients with vmPFC damage showed decreased willingness to put in effort to help other people, compared to those with lesions elsewhere and healthy controls. This was shown by higher discounting of reward by effort (K) when decisions could benefit another person compared to decisions that could benefit them (Fig. 1a). Model-free analysis of choices also showed vmPFC damage decreased prosociality, whilst willingness to put in effort for self-benefitting choices was preserved (Fig. 1b). Our findings suggest a specific and causal role of vmPFC in computing the effort costs of prosocial behaviour, with damage to this region decreasing willingness to exert effort to gain rewards for others. This computational neurology approach could be key for understanding the causal role of specific brain areas in prosociality and decision making.

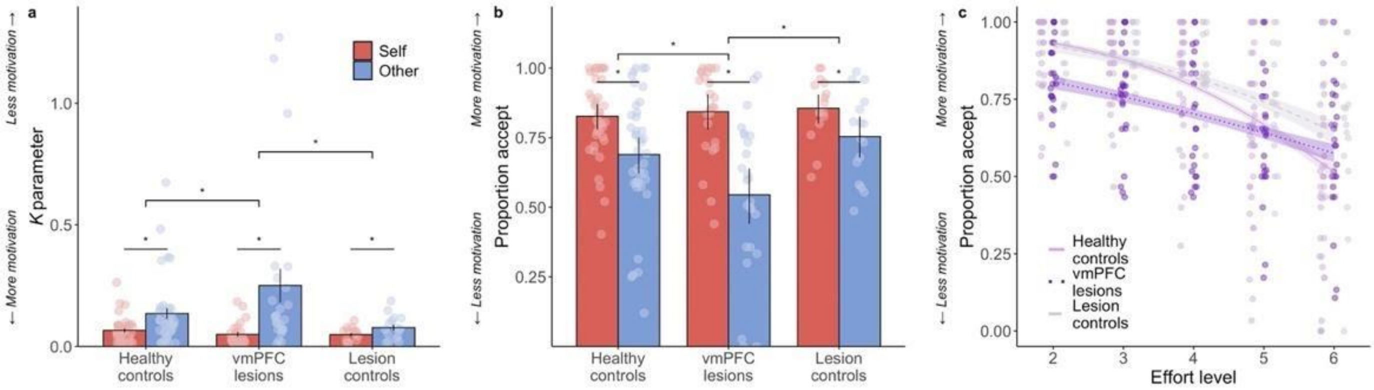


Fig 1. Patients with vmPFC lesions show decreased prosociality compared to both healthy controls and lesion control patients. Decreased prosociality was demonstrated in **(a)** higher discounting of rewards by effort (*K*) for other relative to self and **(b)** lower willingness to accept "work" offers for other relative to self.

References:
1. Fehr, E. & Fischbacher, U. The nature of human altruism. Nature 425, 785–791 (2003).
2. Lopez-Gamundi, P. et al. The neural basis of effort valuation: A meta-analysis of functional magnetic resonance imaging studies. Neuroscience & Biobehavioral Reviews 131, 1275–1287 (2021).
3. Cutler, J. & Campbell-Meiklejohn, D. A comparative fMRI meta-analysis of altruistic and strategic decisions to give. NeuroImage 184, 227–241 (2019).
4. Lockwood, P. L. et al. Prosocial apathy for helping others when effort is required. Nature Human Behaviour 1, 1–10 (2017).

Presentation: Wednesday Afternoon Board 13

How incidental emotions bias economic decisions

Roeland Heerema[1] and Mathias Pessiglione[1]

Affiliation:
[1]"Motivation, Brain, Behavior" team, Paris Brain Institute, Pitié-Salpêtrière Hospital, Paris, France

The idea that emotions can influence our decisions is quite intuitive. An emotional state has a certain duration, allowing it to spill over to proximate decisions, even if they are unrelated to the emotional trigger. For example, momentary incidental happiness may enhance risk taking (Otto, Fleming, & Glimcher, 2016; Vinckier, Rigoux, Oudiette, & Pessiglione, 2018). However, the incidental impact of emotional states on economic decision-making has not been extensively documented.
Our aim was to establish a mapping between incidental emotional states (happiness and sadness) and sensitivity to costs (delay, risk, effort) involved in economic choices. Emotional states were induced using text vignettes paired with music extracts and validated by both subjective reports and physiological measures. Computational modelling of economic decisions showed that the valence of emotional states biased choices by increasing the willingness to accept additional costs in order to obtain higher rewards. This bias was reflective of gaze fixation patterns during decision-making: attention was drawn towards more rewarding but costly options in happy states, and towards uncostly but less rewarding options in sad states. These results suggest a generalization of previous findings: momentary incidental happiness enables overcoming costs, including not just risk but also delay and effort.

References
1. Otto, A. R., Fleming, S. M., & Glimcher, P. W. (2016). Unexpected but Incidental Positive Outcomes Predict Real-World Gambling. Psychological Science, 27(3), 299–311. https://doi.org/10.1177/0956797615618366
2. Vinckier, F., Rigoux, L., Oudiette, D., & Pessiglione, M. (2018). Neuro-computational account of how mood fluctuations arise and affect decision making. Nature Communications, 9(1).https://doi.org/10.1038/s41467-018-03774-z

Presentation: Wednesday Afternoon Board 15

Transcranial direct current stimulation effects on emotion regulation in social contexts in patients with borderline personality disorder

Lisco A.[1], Fabietti C.[2], Gallucci A.[3], Preti E.[3], Riva P.[3], De Panfilis C.[1, 2]

Affiliations:
[1]Department of Medicine and Surgery, Unit of Neuroscience, University of Parma, Italy.
[2]Department of Mental Health, Local Health Agency, Parma, Italy.
[3]Department of Psychology, Unit of Clinical Psychology, University of Milan-Bicocca, Italy

Background and goals: Right Ventrolateral Prefrontal Cortex (rVLPFC) is involved in the successful regulation of negative emotions -such as anxiety, social pain, affective instability- following social exclusion[1]. The application of transcranial Direct Current Stimulation (tDCS) upon this area, in healthy subjects, was effective in reducing risk taking behavior, decision-making difficulties, aggressive and pain reactions following social exclusion[2,3]. Patients with Borderline Personality Disorder (BPD) are known to be particularly affected by social exclusion, showing a tendency to readily perceive and over-react to interpersonal rejection[4], and tends to feel rejected even in normally-including social environments[5]. However, to date, little is still known about tDCS effects on the perception of social interactions in BPD samples. This study investigates whether, in BPD, stimulating rVLPFC with tDCS is effective in reducing negative emotions arising from social interactions, as shown on healthy subjects.

Methods: 26 BPD patients were recruited and randomly assigned to two groups: one receiving active tDCS (real group), the other receiving a simulated tDCS (sham group). During the stimulation the two groups performed a modified Cyberball experiment reproducing three different social conditions: inclusion, ostracism, and overinclusion (a proxy for extreme social inclusion). After each experimental condition, participants were asked, using self-administered questionnaires, to rate their level of negative emotions (Rejected Emotion Scale – RES), social pain (Pain Face Scale – PFS) and feelings of threats toward their fundamental needs (Need-Threat Scale - NTS). The resulting data were then analyzed using a mixed model repeated measure ANOVA, inserting the Group as a "between" factor and the experimental condition of Cyberball as a "within" factor.

Results: The real group reported lesser anxiety and threat feeling toward their fundamental needs than the sham group in any experimental condition (Group Effect, respectively: $F=4,33$, $p=.048$; $F=4,221$, $p=.05$). Furthermore, the real group reported less social pain and sadness than the sham group following ostracism: while the sham group reported greater social pain and sadness following ostracism than after inclusion and overinclusion, in the real group social pain and sadness did not differ across conditions (Group X Condition Interaction, respectively: $F=4.9$; $p=.011$; $F=3.1$, $p=.05$). Finally, the sham group felt more rejected than the real group after social inclusion. While the real group reported similar feelings of rejection after inclusion and overinclusion, the sham group felt more rejected after inclusion than after overinclusion (Group X Condition Interaction: $F=3.89$; $p=.027$).

Conclusions: In patients with BPD, tDCS on rVLPFC reduces anxiety and feelings of threat, regardless of the type of social interaction. In addition, tDCS specifically reduces the levels of social pain and sadness arising from objectively-excluding social contexts, and the feelings of rejection perceived by BPD patients even in "normally includent" social scenarios. Thus, tDCS may potentially improve affective regulation in social contexts for BPD patients.

Disclosure: No conflicts of interest to declare.

References:

1. Eisenberger NI, Lieberman MD, Williams KD. Does rejection hurt? An FMRI study of social exclusion. Science. 2003 Oct 10;302(5643):290-2. doi: 10.1126/science.1089134. PMID: 14551436.
2. Riva, P., Romero Lauro, L. J. R., DeWall, C. N., & Bushman, B. J. (2012). Buffer the pain away stimulating the right ventrolateral prefrontal cortex reduces pain following social exclusion. Psychological Science, 23, 1473–1475.
3. Riva P, Lauro LJR, Vergallito A, Dewall NC, Bushman BJ (2014) Electrified emotions: modulatory effects of transcrania direct stimulation on negative emotional reactions to social exclusion. Social Neuroscience.
4. Gunderson, JG, Lyons Ruth K. (2008). BPD's interpersonal hypersensivity phenotype: a gene-environment-developmental model. Journal of personality disorders, 22, 22-41
5. De Panfilis, C., Riva, P., Preti, E., Cabrino, C., & Marchesi, C. (2015). When social inclusion is not enough: Implicit expectations of extreme inclusion in borderline personality disorder. Personality Disorders: Theory, Research, and Treatment, 6(4), 301.

Presentation: Wednesday Afternoon Board 17

The effect of bifrontal tDCS on reward learning in low mood

Verena Sarrazin[1,2,3,] Margot Overman[4], Michael Browning[2,5] & Jacinta O'Shea[1,2,3]

Affiliations:
[1]Wellcome Centre for Integrative Neuroimaging, FMRIB, Nuffield Department of Clinical Neurosciences, University of Oxford, Oxford OX3 9DU, England
[2]Department of Psychiatry, University of Oxford, Warneford Hospital, Oxford OX3 7JX, England
[3]Oxford Centre for Human Brain Activity (OHBA), Wellcome Centre for Integrative Neuroimaging, Department of Psychiatry, University of Oxford, Oxford OX3 7JX, England
[4]MRC Cognition and Brain Sciences Unit, University of Cambridge, 15 Chaucer Road, CB2 7EF, England
[5]Oxford Health NHS Trust, Warneford Hospital, Warneford Lane, Oxford OX3 7JX, England

Learning and decision-making processes are perturbed in several mental health conditions. Individuals with depression, for example, tend to show an affective bias, prioritizing the processing of negative over positive outcomes[1]. This bias is thought to causally maintain low mood[2]. During learning, outcomes which are informative (e.g. that occur in a volatile rather than stable context) exert a greater influence on beliefs[3]. Patients' estimates of the information content of positive and negative outcomes may therefore underlie negative biases and may present a novel intervention target to remediate symptoms of depression[4,5]. Transcranial direct current stimulation (tDCS) applied to the dorsolateral prefrontal cortex (DLPFC) has been shown to have small to moderate antidepressant effects[6]. In clinical trials tDCS is typically applied at rest. However, tDCS has been shown to boost learning effects[7] and might therefore be more effective if applied during a learning task. In our previous study, we found that tDCS applied to the DLPFC during a reinforcement learning task selectively increases learning from positive outcomes in healthy individuals[8]. This effect might be beneficial in depression treatment to counteract negative biases. The aim of the present study was to test whether bifrontal tDCS applied during reinforcement learning can increase learning from positive outcomes in participants suffering from low mood. We hypothesised that tDCS applied during, but not before the learning task would increase measures of positive learning biases. 85 participants with a BDI score of 10 or above received tDCS during (n = 41) or before (n = 44) performing a learning task. Each participant attended two sessions in which real or sham tDCS was applied in counter- balanced order. The paradigm was the Information Bias Learning Task in which the volatility of win and loss outcomes was manipulated independently so that learning rates could be estimated separately for wins and losses. Our results indicate that bifrontal tDCS did not increase win learning rates in participants with low mood, independent of the time point of stimulation. Exploratory analyses revealed that tDCS applied during task performance increased the adjustment of loss learning rates between stable and volatile conditions. This finding is of potential clinical relevance since prior research suggests that anxiety and depression are associated with a deficit of adjusting learning rates to volatility[4,9]. Further research should replicate this effect and test whether it can be increased through multiple sessions of combined tDCS and reinforcement learning.

References:
1. Kube T, Schwarting R, Rozenkrantz L, Glombiewski JA, Rief W. Distorted Cognitive Processes in Major Depression: A Predictive Processing Perspective. Biol Psychiatry. 2020;87(5):388-98. doi:10.1016/j.biopsych.2019.07.017.
2. Disner SG, Beevers CG, Haigh EA, Beck AT. Neural mechanisms of the cognitive model of depression. Nat Rev Neurosci. 2011;12(8):467-77. doi:10.1038/nrn3027.
3. Behrens TE, Woolrich MW, Walton ME, Rushworth MF. Learning the value of information in an uncertain world. Nat Neurosci. 2007;10(9):1214-21. doi:10.1038/nn1954.
4. Browning M, Behrens TE, Jocham G, O'Reilly JX, Bishop SJ. Anxious individuals have difficulty learning the causal statistics of aversive environments. Nat Neurosci. 2015;18(4):590-6. doi:10.1038/nn.3961.
5. Pulcu E, Browning M. Affective bias as a rational response to the statistics of rewards and punishments. Elife. 2017;6. doi:10.7554/eLife.27879.
6. Razza LB, Palumbo P, Moffa AH, Carvalho AF, Solmi M, Loo CK et al. A systematic review and meta- analysis on the effects of transcranial direct current stimulation in depressive episodes. Depress Anxiety. 2020;37(7):594-608. doi:10.1002/da.23004.
7. Fritsch B, Reis J, Martinowich K, Schambra HM, Ji Y, Cohen LG et al. Direct current stimulation promotes BDNF-dependent synaptic plasticity: potential implications for motor learning. Neuron. 2010;66(2):198-204. doi:10.1016/j.neuron.2010.03.035.
8. Overman MJ, Sarrazin V, Browning M, O'Shea J. Stimulating human prefrontal cortex increases reward learning. bioRxiv. 2021.
9. Gagne C, Zika O, Dayan P, Bishop SJ. Impaired adaptation of learning to contingency volatility in internalizing psychopathology. Elife. 2020;9. doi:10.7554/eLife.61387.

Presentation: Wednesday Afternoon Board 19

Trait anxiety is associated with hidden state inference during aversive learning

Zika, O[1,2,3], Wiech, K. A[3], Reinecke, A[4], Browning, M[4] and Schuck, N. W[1,2]

Affiliations
[1]Max Planck Research Group NeuroCode, Max Planck Institute for Human Development, Berlin, Germany
[2]Max Planck UCL Center for Computational Psychiatry and Aging Research, Berlin, Germany, and London, UK
[3]Wellcome Center for Integrative Neuroimaging (WIN), University of Oxford, Oxford, UK
[4]Department of Psychiatry, University of Oxford, Oxford, UK

Aversive experiences o53en stay in memory longer than we want them to, and helping anxiety patients to update their beliefs and expectations represents a major obstacle in clinical practice. Updating beliefs in changing environments can be achieved by either adapting expectations gradually, or by identifying a hidden structure composed of separate states and inferring which state best fits one's observations. Previous studies have found that relapse phenomena, such as return of fear, are associated with high trait anxiety (TA; Rodriguez et al. 1999; Staples-Bradley et al. 2018). We tested whether high trait anxiety in healthy individuals is associated with a tendency towards inferring a hidden structure of an aversive environment, as opposed to learning gradually from observations. In a Pavlovian probabilistic aversive learning paradigm, participants had to follow changes in shock contingencies by providing expectancy ratings on each trial. In three sessions, the contingencies switched between two levels of shock probability (60/40%, 75/25% and 90/10%) in semi-regular intervals. High trait anxiety was associated with closer tracking of true shock contingencies and steeper behavioral switches a53er contingency reversals. To elucidate the computational mechanisms behind these behavioral patterns we used a gradual updating "1-state" model (Wise & Dolan, 2020) and a novel state inference model ("n-state"). In the session characterized by most abrupt changes (90/10) high trait anxiety was strongly associated with better relative fit of the state inference model (n-state) compared to the gradual model (1-state). This finding provides evidence that high TA is associated with learning the hidden structure of the environment, particularly in environments with low outcome uncertainty. This association may represent the underlying cause for relapse phenomena observed among high trait anxious individuals.

Presentation: Wednesday Afternoon Board 21

Voluntary action and problem solving

Silvia Seghezzi[1] & Patrick Haggard[1]

Affiliation:
[1]Institute of Cognitive Neuroscience, University College of London, UK

Introduction: Volition refers to the mental capacity to initiate actions through one's autonomous decisions. Scholars disagree over definitions of volition (1). Further, existing experimental paradigms for studying volitional action focus on arbitrary, meaningless actions and on their neural precursors. In contrast, this project develops a new view of volition as means-ends problem solving. We study how volition contributes to the organisation and execution of complex goal-directed action sequences, thus linking volition to classical neuropsychology of executive functions and problem-solving. The project considers volition as a 'smart' cognitive function, providing an alternative to current views of volition as either randomness, or subjective preference in evaluative decision- making. Here, a structured series of three experiments used "Tower of London" tasks (2) to identify distinct cognitive processes related to volition, such as planning, choice, and inhibitory control.

Methods: Participants (N=31) performed ToL problems on a computer. They moved coloured balls between pegs, transforming a start configuration into a goal configuration. Each trial thus involves planning and then executing a path through a problem-space, by a series of voluntary actions. Each action is assumed to follow from a prior plan, barring planning or execution errors, to approach the goal. We selected problem configurations, so that contrasts between specific configurations provided an operational definition of a cognitive process previously identified as fundamental to voluntary action. These were processes of pre-planning, of choice between alternatives, and of inhibition of a prepotent but suboptimal action. The timing (RT: reaction time) of each action was recorded.

Results: We distinguished three main parameters of the problem that modulated the timing of voluntary actions.

1. Plan capacity: longer action sequences were associated with increased RTs for the FIRST keypress of the sequence.

2. Counterintuitive moves involve displacing a ball AWAY from its goal position to get another ball in place first. These were associated with increased RTs compared to the other moves within the sequence.

3. Turning point moves commit a participant to one of two alternative paths that have equal value. These were associated with increased RTs compared to the other moves within the sequence.

Discussion: Our results showed that three key cognitive processes that underpin many voluntary actions can be identified within the ToL task, from their effects on movement timing. These are the capacity of an internal action plan, the inhibition of a suboptimal move, and picking between alternative action possibilities. Thus, ToL fulfils many of the criteria that cognitive neuroscience expects of a definition of volition1, namely: internally-generation, goal-directedness, and spontaneity. This pilot study shows that the cognitive psychology of means-ends problem-solving and executive functions can provide insightful and valuable tools for investigating the neuropsychological processes of voluntary action, paving the way for the use of ToL type problems for the investigation of the neural precursors of voluntary action.

References:
1 Haggard, P. Annu Rev Psychol 70, 9-28, (2019).
2 Shallice, T. Philos Trans R Soc Lond B Biol Sci 298, 199-209, (1982).

Presentation: Thursday Morning Board 1

Temporal EEG dynamics of foraging decisions in humans

Franziska Kirsch[1], Hans Kirschner[1], Adrian G. Fischer[1,2,3], Tilmann A. Klein[1,2,4], Markus, Ullsperger[1,2]

Affiliations:
[1]Otto-von-Guericke University, Magdeburg, Germany
[2]Center for Behavioral Brain Sciences, Magdeburg, Germany
[3]Freie Universität Berlin, Berlin, Germany
[4]Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany

In dynamic environments, humans need to sequentially choose between exploitation and exploration to maximize reward. According to the marginal value theorem (MVT), current reward rates need to be continuously compared to potential future rewards to forage optimally. We created a Gold-treasure-task in which participants are instructed to gain as much gold as possible within a given time while EEG was recorded. Participants first decide between two harvesting options varying in objective value. As the instantaneous reward rate (iRR) declines while harvesting, participants need to decide when to leave the chosen option to obtain greater rewards elsewhere. The foraging environment varied between blocks and could be more or less advantageous. We used robust regressions to examine factors influencing iRR at leave time. In a time-frequency regression approach, we investigated temporal EEG dynamics prior to the decision to leave. Consistent with MVT, in advantageous harvest environments participants leave the chosen option at a higher iRR. The objective value of the option predicts the instantaneous reward rate at leave time in both environments. Additionally, in the disadvantageous block, the time left for foraging appears to be crucial for deciding to leave. A preliminary exploratory time-frequency analysis shows that differences between environments are reflected in frontocentral delta activity starting one second before the leave decision. By creating two different environments, we investigate adaptive foraging behavior of humans and its influencing factors. Analysis of behavioral data confirms the MVT and shows differences in behavior between environments. Analysis of concurrently recorded EEG revealed neuronal representations of variables underlying foraging decisions.

References:
1. Constantino, S. M., & Daw, N. D. (2015). Learning the opportunity cost of time in a patch-foraging task. Cognitive, Affective & Behavioral Neuroscience, 15(4), 837–853.
2. Kaiser, L. F., Gruendler, T. O. J., Speck, O., Luettgau, L., & Jocham, G. (2021). Dissociable roles of cortical excitation-inhibition balance during patch-leaving versus value-guided decisions. Nature Communications, 12(1), 904.
3. Abram, S. V., Hanke, M., Redish, A. D., & MacDonald, A. W. (2019). Neural signatures underlying deliberation in human foraging decisions. Cognitive, Affective & Behavioral Neuroscience, 19(6), 1492–1508.
4. Kolling, N., & Akam, T. (2017). (Reinforcement?) Learning to forage optimally. Current Opinion in Neurobiology, 46, 162–169.
5. Charnov, E. L. (1976). Optimal foraging, the marginal value theorem. Theoretical Population Biology, 9(2), 129–136.
6. Le Heron, C., Kolling, N., Plant, O., Kienast, A., Janska, R., Ang, Y.-S., Fallon, S., Husain, M., & Apps, M. A. J. (2020). Dopamine Modulates Dynamic Decision-Making during Foraging. The Journal of Neuroscience : The Official Journal of the Society for Neuroscience, 40(27), 5273–5282.

Presentation: Thursday Morning Board 3

Behavioural and neural mechanisms of commitment and abandonment in sequential goal pursuit

Eleanor Holton[1], Jill O'Reilly[1], Nils Kolling[1]

Affiliation:
[1]University of Oxford

Agents often need to pursue a goal for an extended period of time before any rewards are obtained. In dynamic environments, the relative value of the chosen goal compared to alternatives may change mid-pursuit, meaning agents must evaluate the optimal level of goal commitment. Being too committed to a poorly chosen goal could mean losing out on better options, while being too ready to abandon risks the agent never completing any goals. We used a sequential goal pursuit task with fMRI to investigate how people move between states of goal selection and goal commitment, how they weigh up the different kinds of pressure to abandon a goal they are committed to (such as frustration with the current goal versus temptation from an alternative), and how this evaluation process varies with sunk costs. Participants' choices in the task were best explained by a sequence sampling model which sampled possible future trajectories of the different goal options. However, beyond capturing choices with this prospective model, participants consistently showed a bias to persevere with the current goal rather than switch to a better option, which worsened with the number of trials invested. The bias to persist was associated with reduced attention allocated to stimuli associated with non-selected goals during an independent spatial working memory task. It was also linked to a decreased representation of alternative goals in the dACC as people progressed through the current goal, suggesting goal commitment is manifested as progressive inhibition of alternative courses of action during goal pursuit.

Presentation: Thursday Morning Board 5

Bayesian mechanisms underlying the neural trade-off between cooperation and competition in the Space dilemma

Pisauro M.A[1], Fouragnan E[2], Arabadzhiyska D.H[3], Apps M[1], Philiastides M.G[4]

Affiliations:
[1]Department of Experimental Psychology, University of Oxford, Walton St, Oxford OX2 6GG
[2]School of Psychology, University of Plymouth, Drake Circus, Plymouth PL4 8AA
[3]Institute of Neuroscience and Psychology, University of Glasgow, 58 Hillhead Street, Glasgow, G12 8QB
[4]Institute of Neuroscience and Psychology, University of Glasgow, 58 Hillhead Street, Glasgow, G12 8QB

Social interactions evolve continuously. In some moments we are highly competitive, in others we are very cooperative, but sometimes we are somewhere in between and we constantly adjust our social orientation over time to account for the ever-changing social context and the variable behaviour of the people we are interacting with. However research on social interactions often focuses on a binary dichotomy between competition and cooperation, ignoring people's evolving shifts along a continuum of social orientations. Here, we use a novel economic game – the Space Dilemma – in which 25 couples of unfamiliar players (one inside a fMRI scanner and the other outside) make a choice of a spatial location to indicate their degree of cooperativeness on each trial. The game was designed to provide a continuous, dynamical and probabilistic generalisation of the Prisoner's Dilemma. Participants played the game across different social environments allowing us to compare their behaviour and neural responses in cooperative and competitive contexts. Using computational modelling and fMRI we show that social environments, social biases and inferences about others' intentions shape people's decisions about their degree of cooperativeness, in a manner consistent with a Bayesian learning model. We show that sub-regions of the brain previously linked to social cognition, including the Temporo-Parietal Junction (TPJ), dorso-medial prefrontal cortex (dmPFC) and the anterior cingulate gyrus (ACCg), signalled features of the Bayesian model. This included context independent surprise signals in the TPJ, context dependent signals in ACCg and dmPFC when monitoring others' changes in competitiveness, as well as signals guiding shifts along the cooperation-competition continuum in posterior dMPFC. These results provide the first account of the computational and neural mechanisms underlying the continuous trade-off between cooperation and competition.

Presentation: Thursday Morning Board 7

Freedom from what? A componential analysis of volitional behaviour

Keiji Ota[1] & Patrick Haggard[1]

Affiliation:
[1]Institute of Cognitive Neuroscience, University College London

Introduction. Volition is the cognitive process by which agents endogenously initiate actions without being triggered by external stimulus. One of the key features of volition is spontaneity which refers to a capacity for generating innovative actions. Such voluntary control induces variability in behavioural choices while preventing habitual responses. This capacity becomes critical when agents explore a reward landscape in the environment, and when they need to avoid predators. However, investigating this aspect of volition is challenging because human subjects show poor performance in responding randomly even if they are explicitly asked to do so. One possibility is to expose subjects to different situations where they must randomise behavioural choices in order to get reward. **Methods.** Here we sought to develop a new experimental paradigm by confronting subjects with a virtual competitor that attempts to predict their future choice, and then rewarding them only when they avoid predictability. In a laboratory experiment, twenty participants viewed birds resting on a tree. In each trial, the participants were asked to decide the time they threw food. If the time participants threw matched the time the birds flew out of the tree, the food was eaten, and the participants lost. If the participant's action time did not match the birds' flight time, the participants avoid getting their food eaten by the birds, and thereby win. Importantly, the competitor (birds) could learn when the participants would act based on past behaviour. Thus, the participants had to produce the variability in the timing of their actions to avoid the competitor's prediction. **Results.** Three separate virtual competitors were programmed so that they had increasingly sophisticated predictive power of reading four habitual responses. 1. Choice bias: the competitor could predict the tendency to respond early or late. 2. Transition bias: any choice patterns in the relation between one action to the next were predicted. 3. Reinforcement bias: any choice patterns in the relation between one outcome to the next action were predicted. For participants to perform successfully again each class of competitor, they need to act in a way that is even more unconstrained than required by the preceding class of competitor. Thus, participants require different elements of 'free' action in a structured series. We measured the statistical distance between the probability distribution of the participant's choice pattern and the probability distribution of the ideal observer's pattern. We found that the statistical distance after loss trials increased compared to the distance after win trials. **Discussion.** The results showed that the negative reinforcement was the primarily component which limits the freedom of choices. People were more successful in avoiding any regular transitions following the positive outcome. However, they failed to become less dependent on the negative outcome. These results suggest that our paradigm can effectively examine the spontaneous aspect of volition in a self-paced movement, and that a cognitive hierarchy of different forms of freedom underlies the innovation aspect of voluntariness. This paradigm allows systematic investigation of the different cognitive components of endogenous action initiation.

Presentation: Thursday Morning Board 9

Decision-making in dynamic, continuously evolving environments: quantifying the flexibility of choice and exploration computations

L. A. Weber[1], M. Ruesseler[1], L. Stahr[1], J. Grohn[1], L. Mezossy-Dona[1], T. Marshall[1], C. Hassall[1], J. O'Reilly[1], L. Hunt[1]

Affiliation:
[1]University of Oxford, Oxford, United Kingdom

How do we evaluate multiple available options and choose the best course of action in a dynamic environment? How far back in time do we look for evidence to guide our current choice? And how do we decide when to explore other options? To study the sub-components of decision-making, previous research has mostly employed trial-based choice paradigms, where participants choose between two options, the value of which remains fixed within (and often across) trials. However, in everyday life we do not make decisions in confined trials and between two options. Instead, we have to continuously accumulate information about multiple decision options whose value might be changing over time. Here, we present data from novel continuous decision tasks designed to study decision-making in dynamic and temporally extended choice settings (Hunt et al., 2021). Instead of emitting one choice per trial, in our tasks, participants are presented with a continuous stream of evidence for several minutes and need to continuously integrate evidence over time to decide when to commit to a choice and/or explore another option.

In two EEG studies (N=28 and N=20) we used such a continuous task design in the perceptual domain, where participants had to detect transient changes in the dominant motion direction of a random dot motion display. We found that participants adapt their evidence integration kernels – the amount to which they downweighed past information during decision formation – to the dynamics of their environment: when signal changes were rare (stable environment), they integrated evidence over longer timescales compared to an environment with frequent changes (study 1). This is compatible with normative accounts of evidence accumulation in changing environments (Glaze et al., 2015; Veliz-Cuba et al., 2016). Similarly, when the noise in the evidence stream was higher, participants also adopted longer integration time windows as compared to low noise conditions (study 2). These behavioural differences were accompanied by changes in the neural response to changes in the evidence (an EEG signal resembling the centro-parietal positivity known to track sensory evidence accumulation).

Moreover, in the reward domain, a novel continuous reward-based choice paradigm with multiple options allows us to examine the interaction of dynamic changes in reward rate, endogenous shifts in attention, and decision formation. Participants are presented with three patches (fishing locations) from which they can decide to harvest. The rate of gains (fish) and losses (algae) dynamically changes within the patches. Participants can separately indicate choices to harvest from a patch and decisions to sample from a patch. Pilot behavioural data from this paradigm shows a similar flexibility of integration time scales as observed in the perceptual task. Moreover, this task allows us to separately examine decision formation computations, and the underlying neural signals, for harvest choices and sampling choices. In the future, we will use this paradigm to study the interaction of endogenously generated shifts in attention, reward processing, and decision formation.

References

1. Hunt LT, Daw ND, Kaanders P, MacIver MA, Mugan U, Procyk E, Redish AD, Russo E, Scholl J, Stachenfeld K, Wilson CRE, Kolling N. 2021. Formalizing planning and information search in naturalistic decision-making. Nat Neurosci 24:1051–1064. doi:10.1038/s41593-021-00866-w
2. Glaze CM, Kable JW, Gold JI 2015. Normative evidence accumulation in unpredictable environments. Elife 4:1–27
3. Veliz-Cuba A, Kilpatrick ZP, Josić K 2016. Stochastic models of evidence accumulation in changing environments. SIAM Rev 58:264–289.

Presentation: Thursday Morning Board 11

How do MPFC regions relate to decision variables of varying complexity during sequential decision-making?

Christoph W. Korn[1,2,3], Lisa M. Doppelhofer[1,2], Dominik R. Bach[3,4,5]

Affiliations:
[1]Department of General Adult Psychiatry, Heidelberg University, 69115, Heidelberg, Germany
[2]Institute for Systems Neuroscience, University Medical Center Hamburg-Eppendorf, 20246, Hamburg, Germany
[3]Department of Psychiatry, Psychotherapy, and Psychosomatics, University of Zurich, Zurich, Switzerland
[4]Wellcome Centre for Human Neuroimaging, Institute of Neurology, University College London, London, WC1N 3BG, United Kingdom
[5]Max Planck UCL Centre for Computational Psychiatry and Ageing Research, University College London, London, WC1B 5EH, United Kingdom

Optimal decision-making often requires calculating the probabilities and values of possible outcomes over extended time horizons. That is, to compute future rewards and losses decision-makers need to search over probabilistic future states (Kolling et al, 2012; 2018). They need to balance immediate and delayed rewards and losses and take multiple future outcomes into account (Korn & Bach, 2015). We have previously shown that humans take advantage of simplifying heuristic policies when computing the optimal policy is too complex (Korn & Bach, 2018; 2019). Nevertheless, choices in addition relied on the optimal policy, which takes all relevant variables into account. This optimal policy as well as its uncertainty correlated with activity in parts of the dorsomedial prefrontal cortex.
However, it is unclear how humans balance the optimal policy and simple heuristics. Here, we adapted our previous paradigms to investigate (1) a wider range of heuristic policies with intermediate complexity, (2) shorter time horizons, and (3) different magnitudes of monetary incentives. Thereby, we aim to provide a delineation of how subparts of the medial prefrontal cortex (MPFC) relate to the relevant decision variables. Participants completed a sequential decision-making task framed as a virtual foraging game. Participants (fMRI sample final N = 27, behavioural sample final N = 28) made binary decisions in various foraging environments with different expected values (EV).
Model comparison of logistic regressions using heuristics and the optimal policy revealed that participants in both samples rely on the optimal policy and the adjusted EV, which does not take future time steps into account. Preliminary results indicate that heuristic policies of intermediate complexity might fit participants' decisions better. First fMRI results suggest that decision policies link to activation in anterior and ventral parts of the MPFC and choice uncertainties correlate with activation in posterior and dorsal parts of the MPFC. Importantly, the discrepancy between heuristics and optimal policies is related to activation in the pregenual anterior cingulate cortex. Overall, we characterize gradients within the MPFC that relate to calculations of decision variables that vary in complexity across probabilistic future states.

Presentation: Thursday Morning Board 13

Neural correlates of action observation in dogs (Canis familiaris) and humans

Magdalena Boch[1,2], Sabrina Karl[3], Isabella C. Wagner[1], Ludwig Huber[3*], Claus Lamm[1*]

Affiliations:
[1]Social, Cognitive and Affective Neuroscience (SCAN) Unit, Department of Cognition, Emotion, and Methods in Psychology, Faculty of Psychology, University of Vienna, Vienna, Austria
[2]Department of Cognitive Biology, Faculty of Life Sciences, University of Vienna, Vienna, Austria
[3]Comparative Cognition, Messerli Research Institute, University of Veterinary Medicine Vienna, Medical University of Vienna and University of Vienna, Vienna, Austria
[4]Vienna Cognitive Science Hub, University of Vienna, Austria
*These authors share senior authorship

The ability to perceive and understand actions performed by another individual is fundamental for social interactions and an important source for social learning. In humans and non-human primates, similar brain regions, such as the premotor cortex, are active both when they perform and observe the same action[1,2]. However, not much is known about how their complex social environment might have shaped the neural bases of action perception[3]. As they have shared a special bond and the same environment with humans for thousands of years[4], dogs (Canis familiaris) constitute an excellent model to study the convergent evolution of socio-cognitive skills[5]. Our main aim in this study was to investigate whether dogs possess an action observation network similar to the one identified in primates[1,2]. Moreover, we were interested in uncovering the neural substrates of how humans and dogs perceive actions performed by a conspecific vs. heterospecific. While undergoing functional MRI, 16 unrestrained and awake[6] pet dogs and 40 human participants were presented with videos of an agent grasping a visible (transient action) or invisible ball (intransient action), an invisible agent grasping a ball (ghost) or a scrambled version of the transient action (visual control, non-biological motion). The agents were either humans grasping with their right hand or dogs grasping with their snout. Considering the link between the ability to imitate actions and "mirroring" activation during action observation[7,8], as well as dogs' exceptional capacity to imitate dog and human actions[9–11], we expected increased activation during action observation (transient and intransient) compared to the ghost and visual control in temporal, parietal and sensorimotor brain regions in dogs, like humans[1]. Based on the Associative Learning Model [12] and the Predictive Coding Model[13], we would not expect differences in activation for dog compared to human actions, since pet dogs have consistent experiences with conspecifics as well as heterospecifics actions. However, dogs cannot grasp with their paws. Thus, considering the Direct Matching Model[8], we would therefore anticipate that only the dog action elicited a mirroring activation in premotor and parietal cortices of dogs. In humans, we expect the activation to be modulated by their experience with dogs, measured as years spent living in the same household. In line with the Associative Learning Model[12], we would expect to observe a positive correlation between activation levels and experience with dogs. However, considering the Predictive Coding Model[13], we would anticipate the opposite effect, with the lack of prior experience requiring stronger engagement of the action observation network. Data analysis is still in progress and final results will be reported at the meeting. By using a comparative neuroimaging approach with a non-standard model species, we may provide novel insights into the neural and evolutionary foundations of social cognition and behaviour.

References
1. Fabbri-Destro, M. & Rizzolatti, G. Mirror Neurons and Mirror systems in Monkeys and Humans. Physiology 23, 171–179 (2008).
2. Ferrari, P. F. & Rizzolatti, G. Mirror neuron research: the past and the future. Philos. Trans. R. Soc. B Biol. Sci. 369, 20130169–20130169 (2014).
3. Dunbar, R. I. M. & Shultz, S. Evolution in the Social Brain. Science (80-.). 317, 1344–1347 (2007).
4. Freedman, A. H. & Wayne, R. K. Deciphering the Origin of Dogs: From Fossils to Genomes. http://dx.doi.org/10.1146/annurev-animal-022114-110937 5, 281–307 (2017).
5. Bunford, N., Andics, A., Kis, A., Miklósi, Á. & Gácsi, M. Canis familiaris As a Model for Non- Invasive Comparative Neuroscience. Trends Neurosci. 40, 438–452 (2017).
6. Karl, S., Boch, M., Virányi, Z., Lamm, C. & Huber, L. Training pet dogs for eye-tracking and awake fMRI. Behav. Res. Methods 52, (2020).
7. Cook, R., Bird, G., Catmur, C., Press, C. & Heyes, C. Mirror neurons: From origin to function. Behav. Brain Sci. 37, 177–192 (2014).
8. Rizzolatti, G. & Sinigaglia, C. The functional role of the parieto-frontal mirror circuit: interpretations and misinterpretations. Nat. Rev. Neurosci. 2010 114 11, 264–274 (2010).
9. Huber, L., Salobir, K., Mundry, R. & Cimarelli, G. Selective overimitation in dogs. Learn. Behav. 2020 481 48, 113–123 (2020).
10. Huber, L., Popovová, N., Riener, S., Salobir, K. & Cimarelli, G. Would dogs copy irrelevant actions from their human caregiver? Learn. Behav. 2018 464 46, 387–397 (2018).
11. Range, F., Huber, L. & Heyes, C. Automatic imitation in dogs. Proc. R. Soc. B Biol. Sci. 278, 211– 217 (2011).
12. Heyes, C. Where do mirror neurons come from? Neurosci. Biobehav. Rev. 34, 575–583 (2010).
13. Kilner, J. M., Friston, K. J. & Frith, C. D. Predictive coding: an account of the mirror neuron system. Cogn. Process. 8, 159–166 (2007).

Presentation: Thursday Morning Board 15

Reward under risk: Observing the effects of predatory threat on foraging behaviour with 7T fMRI

Hailey Trier[1], Nima Khalighinejad[1], Luke Priestley[1], Sorcha Hamilton[1], Caroline Harbison[1], Matthew Rushworth[1]*, Jacqueline Scholl[2]*

Affiliations:
[1]Wellcome Centre for Neuroimaging, Department of Experimental Psychology, University of Oxford
[2]Wellcome Centre for Neuroimaging, Department of Psychiatry, University of Oxford
*Shared senior authorship

When animals forage for food under threat of predation, they must be vigilant and switch between behavioural strategies. Understanding how animals decide between attending to rewards versus risks may have clinical relevance to understanding disordered responses to threatening stimuli in psychopathology. To investigate this, we designed a task and a cognitive model to explore what information humans consider when choosing freely and continuously among foraging, vigilance, and hiding. Further, we used 7T fMRI to investigate brain activity associated with this task in healthy adults. We hypothesised that the ACC will be linked with encoding of action timing and task switching, and that the amygdala and periaqueductal gray will show activity relevant to transitioning from foraging to vigilance.

Presentation: Thursday Morning Board 17

Come for the Sugar, Stay for the Show: impacts of audiovisual cues on rodent impulsivity and gambling behaviour

Melanie Lysenko-Martin[1,3], Craig Hutton[2], Catharine Winstanley[1,3]

Affiliations:
[1]Djavad Mowafaghian Centre for Brain Health, University of British Columbia.
[2]Research Branch, Government of British Columbia.
[3]Department of Psychology, University of British Columbia

INTRODUCTION: Gambling Disorder is a psychiatric condition associated with poor impulse control. Impulsivity can be measured by delay-discounting, motor response inhibition, and risky/optimal decision-making[1]. The rodent Gambling Task (rGT), a rodent analogue of the Iowa Gambling Task, is used to assess decision-making under uncertainty[2]. Recent evidence suggests that win-paired audiovisual cues, which are used liberally in electronic gambling products, can encourage risky decision-making in humans[2] and on the rGT[3]. However, the nuanced ways in which audiovisual cues impact facets of impulsivity such as choice behaviour and motor disinhibition are still poorly understood. By modelling rodent gambling decisions as a function of experience in the rGT, we can further parse which choice outcomes lead to impulsive behaviour and risky decision-making. We aimed to understand how choice, reward magnitude, and the experience of winning or losing, were associated with motor impulsivity as measured by premature responding. We also sought to uncover how drugs which disrupt prefrontal cortex activity (e.g., cannabinoids) and perturb response inhibition[4] impacted rodents on these measures. We hypothesized that impulsive responding would be more common in the presence of win-paired audiovisual cues. We also hypothesized that chronic cannabinoid exposure would lead to riskier and more impulsive choice behaviour.
METHODS: Data were analysed from Long Evans adult male rats (N=280) that had learned the cued or uncued versions of the rGT, compiled across 11 different experiments. We evaluated the occurrence of a premature response from three perspectives: whether a win or loss preceded it, which intended choice was impulsively selected, and which choice was selected next. Winning or losing, audiovisual cue presence, and an animal's risk preference, were examined using a series of logistic mixed effects models applied to data from 117,898 total responses in the rGT. Individual experience (trials/sessions completed) and option response rates were statistically controlled for as covariates. Another sample of Long Evans adult males (N=32) was orally given cannabis oil (or sunflower oil) daily, and their decision-making and impulsivity were similarly evaluated on the rGT.
RESULTS: Among untreated rats, premature (impulsive) responses were found to be slightly, but consistently, more likely to occur after experiencing a win than a loss (OR [95% CI] = 1.045 [1.002 – 1.092]). Unexpectedly, this positive urgency was predominantly observed among optimal decision-makers (1.124 [1.076 – 1.175]) and not risk-preferring rats (0.972 [0.907 – 1.047]). Risk-preferring rats were found to be more impulsive on the uncued rGT (1.260 [1.117 – 1.403]), and less impulsive on the cued rGT (0.807 [0.733 – 0.881]), compared to optimal decision-makers. When prematurely responding, and immediately afterwards, rats were more likely to choose a lower-risk option (during, OR [95% CI] = 2.104 [1.273 – 3.477]; after, OR [95% CI] = 4.048 [2.172 – 7.544]) on the uncued rGT and a higher risk option (during, OR [95% CI] = 2.618 [1.508 – 4.546]; after, OR [95% CI] = 3.002 [1.688 –5.335]) on the cued rGT. Cannabis-exposed rodents made significantly more premature responses, and those treated with C. Sativa initially made more risky decisions. C. Indica-exposed rodents exhibited greater levels of negative urgency than controls (3.286 [1.243 – 8.683]), who exhibited positive urgency (1.399 [1.057 – 1.852]). Sativa-treated rats were also significantly more likely to prematurely respond in holes associated with risky options.
CONCLUSION: In this study we dissociated impulsivity from risky decision-making on the rGT. Contrary to our predictions, in the uncued rGT, winning precipitates impulsivity in risk-averse rats. Audiovisual cues in the cued rGT reduce impulsivity yet exacerbate risky decision-making, enticing rats to choose a high-risk option. Furthermore, levels of negative urgency are amplified when cannabinoids are chronically administered, supporting the role of cannabinoid signaling in CB1 receptor-dense brain regions such as the prefrontal cortex in controlling response inhibition.

References:
1. Ioannidis, K., Hook, R., Wickham, K., Grant, J. E., & Chamberlain, S. R. (2019). Impulsivity in gambling disorder and problem gambling: a meta-analysis. Neuropsychopharmacology, 44(8), 1354-1361.
2. Zeeb, F. D., Robbins, T. W., & Winstanley, C. A. (2009). Serotonergic and dopaminergic modulation of gambling behavior as assessed using a novel rat gambling task. Neuropsychopharmacology, 34(10), 2329-2343.
3. Cherkasova, M. V., Clark, L., Barton, J. J., Schulzer, M., Shafiee, M., Kingstone, A., ... & Winstanley, C. A. (2018). Win-concurrent sensory cues can promote riskier choice. Journal of Neuroscience, 38(48), 10362-10370.
4. Kucewicz, M. T., Tricklebank, M. D., Bogacz, R., & Jones, M. W. (2011). Dysfunctional prefrontal cortical network activity and interactions following cannabinoid receptor activation. Journal of Neuroscience, 31(43), 15560-15568.

Presentation: Thursday Morning Board 19

Approach-avoidance decisions under threat: Effects of psychophysiological state on neural computations

Felix Klaassen[1], Linda de Voogd[1], Anneloes Hulsman[1,2], Floris Klumpers[1,2], Bernd Figner[1,2], Karin Roelofs[1,2]

Affiliation:
[1]Radboud University, Donders Institute for Brain, Cognition and Behaviour, Nijmegen 2Radboud University, Behavioural Science Institute, Nijmegen

When deciding whether to approach or avoid an acute threat, it is crucial to optimally weigh the potential positive and negative choice outcomes. We previously showed that threat-anticipatory bradycardia may affect the integration of the potential outcomes, depending on whether an action has to be performed or not (Klaassen et al., 2021). However, it remains unclear how bradycardia modulates neural pathways underlying fronto-striatal value-based computations.
In this fMRI study, 66 participants made passive and active approach-avoidance decisions in prospect of receiving varying money (1-5 euros) and shock (1-5 stimulations) amounts. Simultaneously, we measured heart rate and BOLD-fMRI. We hypothesized that bradycardia modulates activity in brain regions involved in threat (PAG, amygdala), value integration (dACC), and/or switching to action (pgACC).
Replicating Klaassen et al. (2021) we observed increased approach vs avoid choices for higher money vs shock amounts, respectively. Additionally, anticipation of approach-avoidance actions induced freezing-like bradycardia. Preliminary fMRI analyses (N=50) indicate activation of reward and punishment related regions (e.g., vmPFC, anterior insula) in response to receiving money and shocks. Moreover, anticipation of approach-avoidance choices showed activation in networks involved in appetitive-vs-aversive processing and action preparation. We will present analyses of the main hypotheses on the full sample.

References
1. Klaassen F.H., Held, L., Figner, B., O'Reilly, J.X., Klumpers, F., de Voogd, L.D., & Roelofs, K. (2021). Defensive freezing and its relation to approach-avoidance decision-making under threat. Scientific Reports, 11:12030. doi: 10.1038/s41598-021-90968-z

Presentation: Thursday Morning Board 21

Consistency within change: Evaluating the psychometric properties of a widely-used predictive-inference task

Alisa M. Loosen[1,2], Tricia X. F. Seow[1,2] & Tobias U. Hauser[1,2]

Affiliations:
[1]Max Planck UCL Centre for Computational Psychiatry and Ageing Research
[2]Wellcome Centre for Human Neuroimaging, University College London

Background: Rapid recognition and adaptation to sudden change is a hallmark of human behaviour. Many computational, neuroimaging and even clinical investigations capturing this ability have relied on the same behavioural paradigm in which participants are asked to adapt to changes in the task environment (change-points; Nassar et al., 2010). However, the psychometric quality of this predictive-inference task has not sufficiently been examined, leaving unanswered whether this task is indeed suited to capture behavioural differences on a within- and between-subject level.
Methods: We conducted a large-scale (N=330), re-test online study in which participants played this predictive-inference task on two occasions (~3 months apart). We assessed the internal (internal consistency) and temporal (test-retest reliability) stability of the task's relevant raw measures (i.e., confidence and learning rate) and their associations with a Bayesian learner. We estimated the internal consistency of these measures using their Spearman-Brown corrected Pearson correlation (rSB) and their test-retest reliability with their intraclass correlation (ICC). All psychometric scores were computed relative to the change-points in the task to ascertain whether measures robustly captured responses to environmental changes.
Results: We show that the main measures capturing flexible action and belief adaptation yield good internal consistency (rSB≥0.72) and mostly moderate to good test-retest reliability (ICC≥0.65). However, links between these measures as well their association with the Bayesian learner lack convincing psychometric quality.
Conclusions: We found that the main measures of this predictive-inference task consistently and reliably capture belief and behavioural adaptations before and after environmental changes, making them suitable for studies investigating individual differences. We also note that the complex links between these task measures and Bayesian predictions are of mostly low psychometric quality and should only be used with caution. Our findings have implications for the large corpus of previous studies using this task and provide clear guidance as to which measures should and should not be used in future studies.

Keywords: Decision-making, Learning, Predictive-inference, Test-retest reliability, Internal consistency, Psychometric qualities

References

1. Nassar, M. R., Wilson, R. C., Heasly, B., & Gold, J. I. (2010). An Approximately Bayesian Delta-Rule Model Explains the Dynamics of Belief Updating in a Changing Environment. Journal of Neuroscience, 30(37), 12366–12378. https://doi.org/10.1523/JNEUROSCI.0822-10.2010

Presentation: Thursday Afternoon Board 2

A cognitive map for value-guided choice in ventromedial prefrontal cortex

Sebastijan Veselic[1,2]*, Timothy Muller[1]*, Timothy Behrens[2,3], Laurence Hunt[2,3,4], James Butler[1]¬, Steve Kennerley[1]¬

Affiliations:
1Clinical and Movement Neurosciences, Department of Motor Neuroscience, University College London, London, UK
2Wellcome Centre for Human Neuroimaging, University College London, London, UK
3Wellcome Centre for Integrative Neuroimaging, University of Oxford, FMRIB, John Radcliffe Hospital, Oxford OX3 9DU, UK
4Max Planck-UCL Centre for Computational Psychiatry and Aging, University College London, London, United Kingdom
*¬ Equal contribution

The prefrontal cortex (PFC) is crucial for economic decision making. Neural representations for both the value of options subjects choose between, as well as their difference, have been repeatedly found across different subregions of the PFC (Kennerley et al. 2011; Hunt et al. 2018). Here we reframe economic decision-making in PFC guided by findings of how structure is represented within the medial temporal lobe (MTL): we framed choice between different options as a navigation process in value space (Behrens et al. 2018; Bongioanni et al. 2021). We looked for evidence of a value space in PFC in a task where rhesus macaques choose between two options parametrized by magnitude and probability of reward. We found that the angle between options subjects had to decide between was represented with a grid-like code in LFP theta frequency within ventromedial PFC (vmPFC) right before subjects made their choice. Crucially, this grid code was also present in single neurons recorded from nearby locations, confirming for the first time that population level measures of grid coding can be found in firing rates of neurons. In addition to a map-like representation of value at choice, we also found sharp-wave ripples, another computation important for flexible behaviour and planning. The observed ripple events were dynamically modulated by both reward and success of each trial. In sum, we have shown vmPFC represents the structure of a value space using a grid-like which is utilized right before subjects make choices, together with exhibiting sharp wave ripples throughout the choice process. This means PFC employs two fundamental map-like computations during value guided choice, similarly to MTL during spatial navigation.

References:
1. Behrens, T. E. J. et al. What Is a Cognitive Map? Organizing Knowledge for Flexible Behavior. Neuron 100, 490–509 (2018).
2. Bongioanni, A. et al. Activation and disruption of a neural mechanism for novel choice in monkeys. Nature (2021).
3. Hunt, L. T. et al. Triple dissociation of Attention and decision computations across prefrontal cortex. Nat. Neurosci. 21, 1471–1481 (2018).
4. Kennerley, S. W., Behrens, T. E. J. & Wallis, J. D. Double dissociation of value computations in orbitofrontal and anterior cingulate neurons. Nat. Neurosci. 14, 1581–1589 (2011).

Presentation: Thursday Afternoon Board 4

Linked brain networks of adaptive memory formation and error recognition processes

Alexander Weuthen[1]; Markus Ullsperger[1,2]

Affiliations:
[1]Department of Neuropsychology, Institute of Psychology, Otto-von-Guericke Universität Magdeburg, Germany
[2]Center for Behavioral Brain Sciences, Magdeburg, Germany

The formation of new associative memories does not always succeed within a single attempt. In order to address the question how recognition of inaccurate memories can improve encoding performance, 30 adults (15 female, mean age = 24.7 years) performed a feedback associative learning task and a 1-back localizer task during simultaneous acquisition of functional magnetic resonance imaging data. Conventional general linear model analyses revealed increased hemodynamic signals in posterior medial frontal cortex related to errors – unsuccessful retrieval, low confidence and processing of negative feedback. Retrieval success on subsequent trials was related to increased hemodynamic signals in regions among dorsolateral, inferior frontal and posterior medial frontal cortex during encoding. Based on the localizer task, a linear support vector machine was trained to predict processing of face information from voxels in right fusiform gyrus. This model was then used to predict face representativity during encoding of associative memories between face cues and a set of eight tilted gabor patches as targets. Stronger face representativity during encoding – indicated by the algorithm's decision function – was related to increased hemodynamic signals in the posterior medial frontal cortex overlapping with the conventional performance-based contrasts. These results suggest a link between regions for error recognition, upregulation of stimulus representativity and encoding success.

Keywords: performance monitoring, cognitive control, long-term memory

Presentation: Thursday Afternoon Board 6

Orbitofrontal feedback-dependent and independent remapping of outcome-selective neurons in sensory cortex

Jasper Teutsch[1]*, Rohan Rao[1], Anastasia Dimitriou[1], Abhishek Banerjee[1]†

Affiliation:
[1]Adaptive Decisions Lab, Biosciences Institute, Newcastle University, Newcastle upon Tyne, United Kingdom
*Presenting Author: Jasper Teutsch
†Corresponding Author: Abhishek Banerjee

Animals learn to adapt their behaviour rapidly to new environmental challenges. Flexible behavioural adaptation relies on the ability to learn and adjust 'rules' that link sensory experience to potential action-outcomes. Does rule learning, re-learning and generalization involve similar circuits in the brain? While mechanisms of learning and generalising complex rules have been identified in the prefrontal cortex[1], their interactions with primary sensory areas remain unknown. To study rule learning and generalisation, we trained head-fixed mice on a 'Go/No-go' based tactile serial reversal-learning task where the animal experienced two successive rule switches (first rule switch, R1 and second rule switch, R2, back to original context). We studied task-dependent longitudinal functional responses using two-photon Ca^{2+} imaging in mice expressing GCaMP6f in cortical excitatory layer 2/3 neurons. We focused on the primary somatosensory cortex (S1) and lateral orbitofrontal cortex (lOFC), as their respective involvement in learning and rule-switch have previously been reported[2]. We used a receiver operating characteristic analysis to assess the selectivity of single-neuron activity for specific trial types to define distinct functional subclasses and employed tensor decomposition to analyse inter-trial population dynamics across all task stages.

Upon R1, S1 neurons lose outcome-selectivity acquired during initial learning, whereas lOFC neurons showed increased activity, signalling a feedback prediction error. Lateral OFC top-down feedback instructs S1 response-remapping, slowly reinstating their outcome-selectivity. Silencing OFC→S1 projections following R1 impaired behavioural performance (d') and S1 remapping, however, did not affect R2, indicating the involvement of lOFC when task demands are relatively high. Despite a comparable drop in d', lOFC and S1 showed distinct engagements across R1 and R2. While lOFC showed no significant activity upon R2, a substantial fraction of S1 neurons crucially retained outcome-selective and reward-history-dependent responses during early R2. This engagement of lOFC and S1 differed when task rules altered. Our findings propose feedback-independent assignment of outcome values in sensory areas that switch between conserved states depending on task demand. This further strengthens the emerging idea that local mechanisms in the primary sensory areas can crucially contribute to higher cognitive functions[3].

Reference:
1. Rushworth, MF. et al. Neuron 70, 1054-1069 (2011).
2. Banerjee, A. et al. Nature 585, 245-250 (2020).
3. Banerjee, A. et al. Curr. Opin. Behav. Sciences 38, 133-140 (2021).

Presentation: Thursday Afternoon Board 8

Electrophysiological evidence for alternative value encoding in macaque frontopolar cortex

Juan M. Galeazzi[1], Matthew Ainsworth[1], Carlos Pedreira[1], Mark J Buckley[1]

Affiliation:
[1]Department of Experimental Psychology, University of Oxford, Oxford, United Kingdom;

Although the importance of prefrontal cortical regions in decision making is well established, the exact contribution of frontopolar cortex (FPC) has remained elusive. A number of recent studies have suggested that FPC is essential for representing the value of unchosen, alternative stimuli and rules with the cortex (Mansouri 2017). However, this hypothesis relies primarily or the neuroimaging in humans and combined behavioural (Boorman 2009) and lesion studies in non-human primates (NHPs) and there remains little electrophysiological evidence supporting the encoding of alternative/unchosen stimuli within the neuronal circuits in FPC. Here we use a combination of reinforcement learning (RL) models, local field potential recordings, and electrical micro-stimulation in two NHPs implanted chronically with Utah microelectrode arrays to explore local circuit activity in FPC whilst they performed a WCST analogue. In this task animals were required to match one of three targets with a sample stimuli. The correct target was determined by either shape or colour, on a block-by-block basis. To determine how animals learnt the correct rule we fit RL models to the animals choices. This modelling suggested that both animals attempted to estimate the value of both the current and the alternative rule throughout the task. Examination of LFP activity recorded from FPC revealed increased gamma frequency activity (60-120Hz) after animals made a choice, but not on presentation of sample stimuli or choice targets. This choice-aligned LFP activity corresponded both to whether animals received a reward, and to an RL derived value attached to the alternative rule. Electrical micro-stimulation of FPC did not impact the animals performance within a block. However it did decrease their ability to switch rules following a block change. These data directly link local circuit output from FPC, with the valuation of alternative choices and stimuli in decision making, and should motivate future research involving single unit recordings from FPC.

Presentation: Thursday Afternoon Board 10

Emergence of abstract rules: A computational sketch

Snigdha Dagar[1], Frederic Alexandre[1], Nicolas Rougier[1]

Affiliations:
[1]Inria Bordeaux Sud-Ouest, Univ. Bordeaux, CNRS Univ

Flexible behavior entails responding appropriately to an environment that could be dynamic and changing. In the simplest case, this means learning associations between an object's properties and a direct response. Such rules can be called concrete, while more complex rules may involve the learning of second order relations on top of the first-order rules. The PFC is believed to provide the ability to contextualize concrete rules that leads to the acquisition of abstract rules. However, one difficulty is that a concrete rule may have been implicitly acquired, without any explicit knowledge that marks it as a rule. The question is then, "How are such implicitly acquired rules made explicit?". Furthermore, how can the context influence the learning of abstract rules based on concrete ones?

There is sufficient evidence to suggest that the PFC is organized hierarchically[1] with caudal areas learning first-order associations and the more rostral areas putting them in context to facilitate learning of abstract rules. This can be done by top-down modulation in the PFC, which underlies the ability to focus attention on task-relevant stimuli and ignore irrelevant distractors, in two ways: either a result of weight changes in modulated pathways and predictions or through activation based biasing provided by the working memory system.

For example, in experimental paradigms, discrimination or categorization tasks can be considered as first-order rules which could be learned individually. However, when conflicting stimuli are presented simultaneously, a contextual cue is needed to identify which of the first order rules is to be applied. We considered one such task[2] for our simulations and explored the ability of the HER model[3] to learn such rules. The HER model takes a hierarchical view of the PFC and learns the rule by top-down modulation of weight changes in predictions in the hierarchical layers. We show that in certain cases, the use of a biasing selective attention mechanism is more effective than modulated weights in the learning of an abstract rule, by selecting or biasing the appropriate concrete rule, an ability missing in the HER model.

Another drawback of the model is the assumption of explicit knowledge of the concrete rules, which are acquired implicitly. To address this issue, we think the emergence of meta-representations[4] is a more biologically plausible approach, ie, using a higher-order network which observes and classifies the internal states of the first-order networks that have learned simple associative rules. Both computational models have their merits and drawbacks which we highlight through our analysis, and suggest a theoretical model which can combine them.

References
1. Badre D. Cognitive control, hierarchy, and the rostro–caudal organization of the frontal lobes. Trends in cognitive sciences. 2008 May 1;12(5):193-200.
2. Koechlin E, Ody C, Kouneiher F. The architecture of cognitive control in the human prefrontal cortex. Science. 2003 Nov 14;302(5648):1181-5.
3. Alexander WH, Brown JW. Hierarchical error representation: a computational model of anterior cingulate and dorsolateral prefrontal cortex. Neural Computation. 2015 Nov 1;27(11):2354-410.
4. Cleeremans A, Timmermans B, Pasquali A. Consciousness and metarepresentation: A computational sketch. Neural Networks. 2007 Nov 1;20(9):1032-9.

Presentation: Thursday Afternoon Board 12

A hierarchy of distributed representations in the anterior cingulate cortex for cognitive control

I. Ikink[1], T. R. Colin[1], C. B. Holroyd[1]

Affiliation:
1 Department of Experimental Psychology, Ghent University, Ghent, Belgium

The function of the anterior cingulate cortex (ACC) remains a mystery. Uni-variate functional magnetic resonance imaging (fMRI) analyses fail to discriminate between dominant theories, which predict similar univariate responses: the ACC is sensitive to errors, conflict, difficulty, rewards and punishments, and shows activation during many sequential decision-making tasks. We used multivariate fMRI and computational modeling to investigate the hypothesis that ACC implements distributed representations of hierarchically-organized sequential tasks. First, we developed a family of artificial recurrent neural network (RNN) models of the ACC and trained those models on a hierarchical sequence task (i.e., making coffee or tea according to a pre-specified set of rules). Second, we conducted a representational similarity analysis using a searchlight procedure to compare the activity patterns of these RNN models to multivoxel patterns of fMRI activity of participants performing the same task. Comparisons were obtained using three successively more complex models: (1) an Elman RNN (2) an Elman RNN with goal units and (3) a goal model that incorporated an abstraction gradient in the hidden layer of the network. We find that all three models produce representations that match caudal areas of the ACC, but models (2) and (3) also match more rostral areas, confirming our hypothesis of a topographically hierarchical organization of ACC. Finally, we evaluate the goal model behaviourally by scaling up the task and using the goal units for top-down control. We find that applying control from the goal units can improve the robustness of the network against distractions coming from other cognitive processes (modeled as noise to the hidden layer) or from the environment (modeled as noise to the input layer); suggesting that this architecture supports cognitive control.

Presentation: Thursday Afternoon Board 14

Toward a new dimensional approach to addiction: Linking addiction markers to the connectivity profiles of striatum subdivisions

Kenza Kadri[1,2], Jacqueline School[3], Billy Hosking[1], Miriam Klein-Flugge[3*], Elsa Fouragnan[1,2*]

Affiliations:
[1]Department of Psychology, University of Plymouth, Plymouth, PL48AA, UK (United Kingdom)
[2]The Brain Research Imaging Centre (BRIC) Faculty of Health, Plymouth, PL6 8BU, UK
[3]Wellcome Centre for Integrative Neuroimaging (WIN), Department of Experimental Psychology, University of Oxford, Oxford, OX1 3UD, UK
* Authors contributed equally to this work

Examining a dimensional approach to addiction - and mental pathology in general – is essential for refining possible treatments and prevention strategies, particularly because there is significant heterogeneity of the disease across addiction to different substances. One promising avenue to inform this approach is to advance our understanding of large-scale variation in neurobiological circuits mediating addiction to different substances. In this new study, we aim at capitalizing on the natural variation in 1) latent behaviours related to different substances as well as 2) connectivity profiles of several subdivisions of the striatum- the main subcortical hug for reward processing - in a large population extracted from the Human Connectome Project (HCP). In this study, we used factor analyses on the HCP questionnaires' answers from 564 individuals to extract latent behaviours relevant for addiction and impulsivity. We found four addiction-related factors underlying general behavioural variation in (i) use of tobacco, (ii) alcohol, (iii) marijuana, and (iv) illicit drugs as well as one transdiagnostic factor defining (v) impulsivity. We then explored variations in functional brain connectivity related to these behavioural factors. We first segmented the striatum according to anatomically and functionally defined landmarks. We also used 23 cortical and 13 subcortical regions that are anatomically or functionally known to be strongly linked to the striatum to infer the Resting-State-Functional Connectivity (RSFC) of the striatum subdivisions. We postulate that distinct RSFC of the striatum are related to distinct substances abuse disorders. We hope that by building on the effectiveness of large- scale imaging and online data collected on a general population (n=662), we will provide a reliable link between precise anatomical relationships and markers of addiction.

Presentation: Thursday Afternoon Board 16

Identifying content-independent neural correlates of awareness

Benjy O. Barnett[1], Lau M. Andersen[2,3,4], Stephen M. Fleming[1,5,6], Nadine Dijkstra[1]

Affilitations:
[1]Wellcome Centre for Human Neuroimaging, University College London, London WC1N 3BG, UK.
[2]Center of Functionally Integrative Neuroscience, Universitetsbyen 3, Building 1710, Aarhus University, Aarhus, Denmark
[3]Aarhus Institute of Advanced Studies (AIAS), Aarhus University, Høegh-Guldbergs Gade 6B, 8000 Aarhus C, Denmark.
[4]Department of Linguistics, Cognitive Science and Semiotics, Jens Chr. Skous Vej 2, Aarhus University, 8000 Aarhus C, Denmark.
[5]Max Planck University College London Centre for Computational Psychiatry and Ageing Research, London WC1B 5EH, UK.
[6]Department of Experimental Psychology, University College London, London WC1H 0AP, UK.

Various theoretical frameworks have attempted to describe how conscious awareness arises in the brain. A divisive question relating to these theories is whether or not they predict the neural correlates of awareness should generalise over perceptual content. Some, such as Global Workspace Theory, assume that awareness ensues when neural representations of perceptual content are globally broadcast. In contrast, other theories explicitly predict a dissociation between neural correlates of perceptual content and awareness of that content. In a reanalysis of existing MEG and fMRI data from two distinct studies, we test these conflicting predictions by investigating to what extent neural correlates of awareness generalise over perceptual content.

We find content-independent representations of awareness localised to visual and frontal brain regions that change slowly over time – in line with a propagation of neural correlates of awareness from posterior to anterior areas. Importantly, decoding of abstract awareness representations was just as successful as the decoding of stimulus-specific representations.

Furthermore, we show that abstract awareness states display a graded representational structure, such that each awareness rating is represented as more similar to its neighbouring rating than any other. These results advance our understanding of the neural and computational underpinnings of conscious awareness and support theories that assume a distinction between perceptual content and awareness states.

Presentation: Thursday Afternoon Board 18

Learning-induced dimensionality transformations in the non-human primate prefrontal cortex

Michał J. Wójcik[1], Dante Wasmuht[1], Makoto Kusunoki[2], Mikiko Kadohisa[2], Jake P. Stroud[3], Nicholas E. Myers[1,4], Laurence T. Hunt[5], John Duncan[1,2] & Mark G. Stokes[1]

Affiliation:
1Department of Experimental Psychology, University of Oxford, Oxford, UK
2 MRC Cognition and Brain Sciences Unit, University of Cambridge, Cambridge, UK
3 Department of Engineering, University of Cambridge, Cambridge, UK
4 School of Psychology, University of Nottingham, Nottingham, UK
5 Department of Psychiatry, University of Oxford, Oxford, UK

Primates navigate through complex and information-rich environments with remarkable ease. This is based on the ability to flexibly adapt the dimensionality of neuronal representations to the task demands. More specifically, the mammalian prefrontal cortex (PFC) has both the capacity to expand the dimensionality of neuronal codes in tasks that require flexible input-output mappings[1,2] and to reduce it when multiple instances of a task share the same underlying structure[3,4]. Although several advances have been made in elucidating the neuronal geometry resulting from these dimensionality transformations[5,6], their learning dynamics are still poorly understood. Here, we explored how neuronal dimensionality changes as a function of learning using a novel learning paradigm with multiple XOR contingencies. We tracked how cells in the macaque PFC represented task features that varied in terms of their relevancy for the current computation of the outcome and how these features were integrated to generate a task representation. We found that prefrontal cells represented every task feature at the beginning of the learning, irrespective of their relevancy for outcome computations. As learning continued, neurons started to supress the features that were not predictive of reward. Ultimately, we found two key changes in PFC dynamics: (1) nonlinear dimensions emerged that are necessary to solve the task, and (2) an abstract dimension emerged along which multiple instances of the task were aligned.

References:
1. Mante, V., Sussillo, D., Shenoy, K. v. & Newsome, W. T. Context-dependent computation by recurrent dynamics in prefrontal cortex. Nature 503, 78–84 (2013).
2. Rigotti, M. et al. The importance of mixed selectivity in complex cognitive tasks. Nature 497, 585–590 (2013).
3. Mack, M. L., Preston, A. R. & Love, B. C. Ventromedial prefrontal cortex compression during concept learning. Nature Communications 11, (2020).
4. Wallis, J. D., Anderson, K. C. & Miller, E. K. Single neurons in prefrontal cortex encode abstract rules. Nature 2001 411:6840 411, 953–956 (2001).
5. Bernardi, S. et al. The Geometry of Abstraction in the Hippocampus and Prefrontal Cortex. Cell 183, 954-967.e21 (2020).
6. Fusi, S., Miller, E. K., Rigotti, M., Karpova, A. & Kiani, R. Why neurons mix: high dimensionality for higher cognition This review comes from a themed issue on Neurobiology of behavior. Current Opinion in Neurobiology 37, 66–74 (2016).

Presentation: Thursday Afternoon Board 20