UNIVERSITY OF BIRMINGHAM

The Mechanistic Basis of Foraging Conference

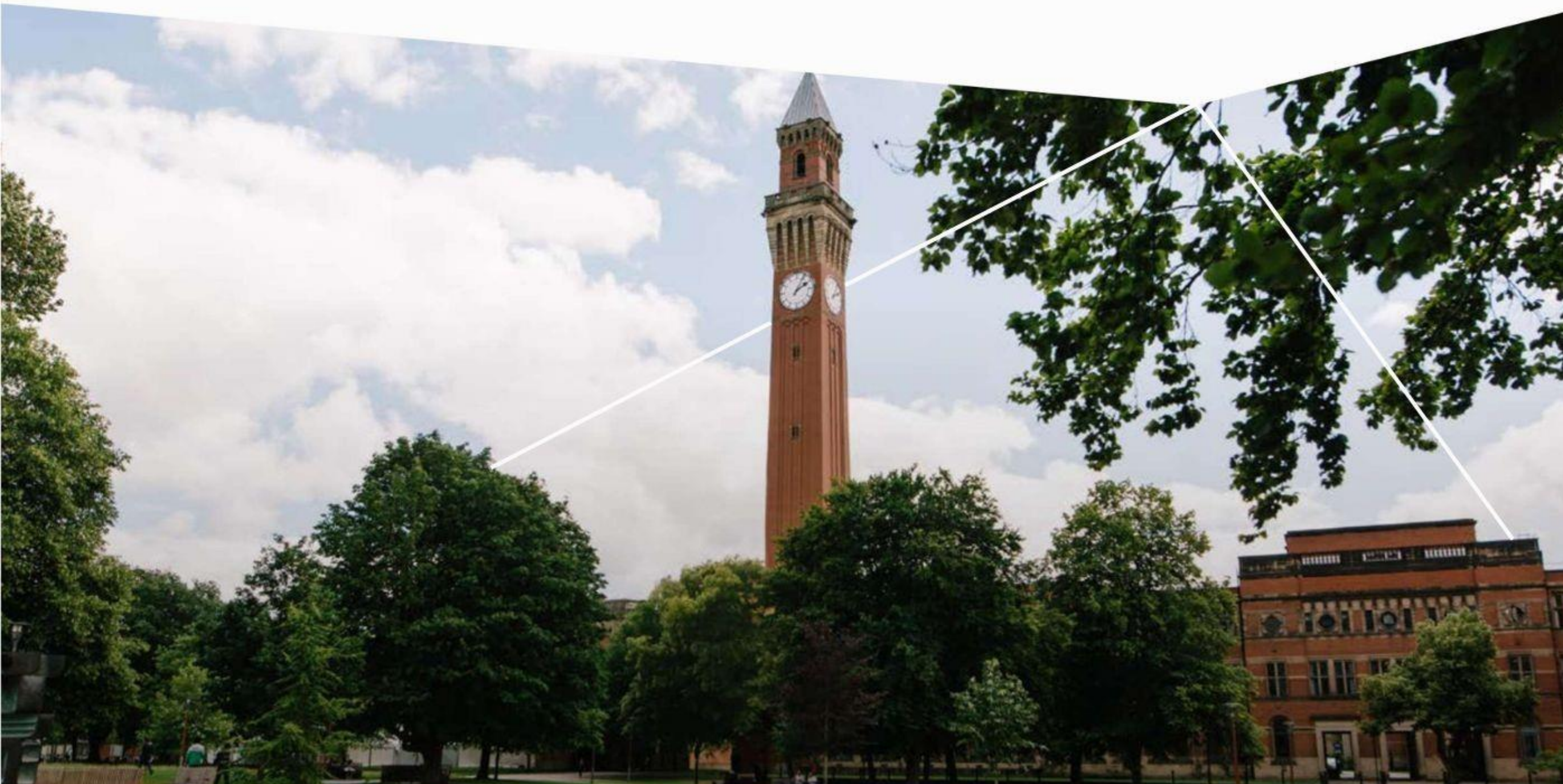
Abstract Book

3rd - 5th November 2025

Edgbaston Park Hotel, University of Birmingham

CHBH
CENTRE FOR HUMAN BRAIN HEALTH

UKRI Biotechnology and Biological Sciences Research Council



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Welcome

Dear Colleagues,

We are delighted to welcome you to the Mechanistic Basis of Foraging 2025.

This conference builds on the exciting momentum of last year's first gathering at Janelia, where researchers from across disciplines came together to explore how foraging can serve as a unifying paradigm for understanding decision-making in biological systems.

This year, we're pleased to continue and expand that conversation—bringing together experts in neuroscience, psychology, psychiatry, and behavioural ecology—and on this occasion placing a special emphasis on the role of computational neuroscience in this dialogue. This new focus is catalysed by a recent BBSRC-funded initiative led by the conference co-chairs, aimed at elucidating the computational mechanisms that underpin foraging decisions. Foraging is a deeply fundamental process, providing a powerful lens through which to study perception, valuation, learning, and action. Our goal is to foster cross-disciplinary exchange, stimulate new collaborations, and move closer to a mechanistic understanding of how a brain makes foraging choices.

For those unfamiliar, Birmingham is the UK's "second city", and has a vibrant and diverse population, with a dynamic culture and food scene. It has a rich history and was once known as the heart of the Industrial Revolution. Birmingham also has more canals than Venice, is the birthplace of heavy metal (and the late Ozzy Osbourne's Black Sabbath!) and the Balti curry. The University of Birmingham is one of the city's five universities and is one of the oldest in the UK founded in 1900, recently rising to 76^{th} in the QS world ranking, and part of the "Russell Group" of prestigious research-intensive UK universities. The city also has a sense of humour, adopting the bull as its symbol – encapsulated by "Ozzy" the 10-metre-high mechanical beast in New Street station. Welcome to Birmingham!

Around the meeting there are planned social events including the opening reception with poster presentations, and a dinner at Asha's restaurant, offering the Indian cuisine that Birmingham is so famous for. Beyond this, you can sample the city centre's blend of modern and historical architecture, walk around the lovely campus -- including seeing Old Joe, the world's largest free standing clock tower – or take a stroll through the beautiful Winterbourne House and gardens next to the campus.

We would like to express our huge gratitude to all participants for joining us, to the speakers and poster presenters, and to the wonderful members of the organising committee and events team (Laura, Emma, Adithya, Tiago, Kubra, and Mark (Walton), as well as Rebecca and Louise). We also warmly thank the BBSRC, Centre for Human Brain Health and University of Birmingham for sponsoring the meeting. Once again, welcome to the university, to Birmingham, and to the UK. We look forward to meeting you all at the opening reception and we hope you enjoy the conference and your visit.

Warmest wishes,

Matt & Mark

Co-Chairs organising committee
Professor Matthew Apps & Professor Mark Humphries

Organising Committee

Prof. Matthew Apps

Professor of Cognitive Computational Neuroscience, University of Birmingham

Prof. Mark Humphries

Chair in Computational Neuroscience, University of Nottingham

Prof. Mark Walton

Professor of Behavioural Neuroscience, University of Oxford

Dr. Adithya Rajagopalan,

Leon Levy Scholar in Neuroscience, NYU

Dr. Laura Grima

Research Scientist, HHMI's Janelia Research Campus

Dr. Tiago Monteiro

Postdoctoral Researcher, University of Aveiro

Emma Scholey

PhD Candidate, University of Birmingham

Kubra Karatas

Research Associate, University of Birmingham

Key Information

Conference Venue:

Edgbaston Park Hotel
53 Edgbaston Park Road
Birmingham
B15 2RS, United Kingdom

The conference will take place in the Lloyd Suite at the Edgbaston Park Hotel, which is a short walk from our University Train Station.

The hotel is marked as G23 in the green zone on the campus map, which is available to view/download here.



Conference Registration and Query Desk:

Day	Opening Times	Venue
Tuesday 4 November	8:30 – 17:30	Hornton Grange Lounge
Wednesday 5 November	9:00 – 17:00	Hornton Grange Lounge

Conference Social Events:

Event	Date/ Time	Venue
Welcome Reception	Monday 3 November 18:00 – 19:30	Lloyd Suite, Edgbaston Park Hotel 53 Edgbaston Park Road Birmingham B15 2RS
Conference Dinner	Tuesday 4 November 18:00 - Late	Asha's Restaurant 12-22 Newhall Street Birmingham West Midlands B3 3AS

Lunch and refreshment breaks:

Refreshments will be served in the Lloyd Suite, and Lunch in the hotel restaurant at the times specified in the programme.

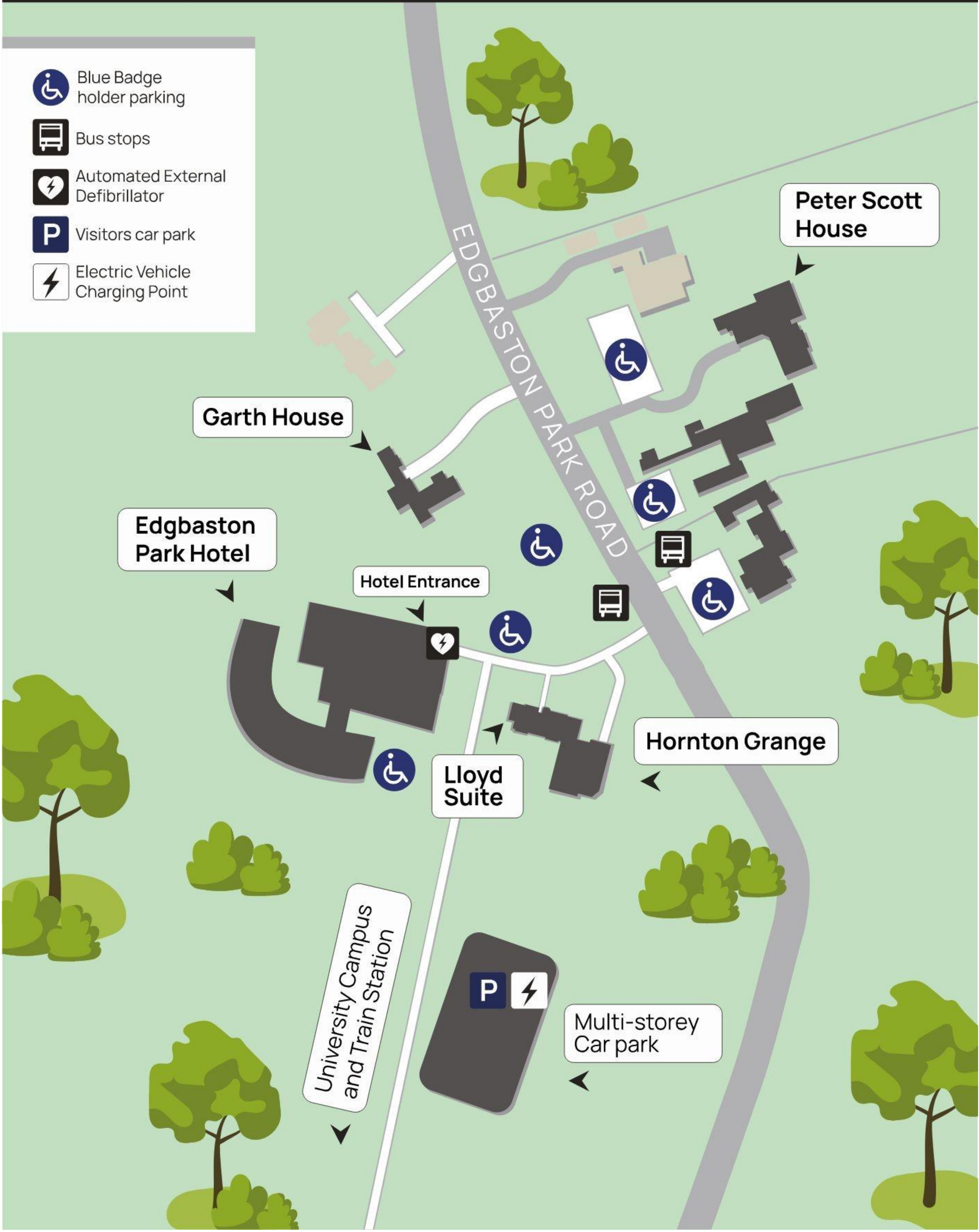
Wi-Fi:

Free Wi-Fi will be available throughout the venue, via the Edgbaston Park hotel - Ask4 network.

If you have any problems connecting, please ask for support at the Registration Desk.

Campus Map

Edgbaston Park Hotel and Conference Centre



Keynote Speakers

Prof. Benjamin Hayden

Professor of Neurosurgery, Baylor College of Medicine, Rice University

Title: Neural basis of prey-pursuit behavior

Abstract: Foraging is economic choice in the naturalistic domain. However, unlike in most laboratory economic choice tasks, naturalistic goal-directed foraging behavior typically requires continuous actions directed at dynamically changing goals. In that context, the closest analogue of choice is a strategic reweighting of multiple goal-specific control policies in response to shifting environmental pressures. Moreover, the trivially simple process of identifying options and associating them with their expectations becomes a difficult tracking problem. Understanding how these processes work is crucial for extending neuroeconomics to the real. We examined behavior and brain activity in humans performing a continuous prey-pursuit task. Using a newly developed control-theoretic decomposition of behavior, we find pursuit strategies are well described by a meta-controller dictating a mixture of lower-level controllers, each linked to specific pursuit goals. Examining hippocampus and anterior cingulate cortex (ACC) population dynamics during goal switches revealed distinct roles for the two regions in parameterizing continuous controller mixing and meta-control. Hippocampal ensemble dynamics encoded the controller blending dynamics, suggesting it implements a mixing of goal-specific control policies. In contrast, ACC ensemble activity exhibited value-dependent ramping activity before goal switches, linking it to a meta-control process that accumulates evidence for switching goals. Our results suggest that hippocampus and ACC play complementary roles corresponding to a generalizable mixture controller and meta-controller that dictates value dependent changes in controller mixing. Moreover, we find that people use separate, semi-orthogonal hippocampal maps for tracking distinct prey. The semi-orthogonality of these maps is crucial because it provides a representational scheme that allows for both functional differentiating different items but allows for simultaneous cross-item generalization. Ultimately, these results provide a core neurocomputational foundation for dynamic interactive choice in a simple context, one that can in the future be extended to ever more complex contexts.

Biography: Benjamin Hayden is a Professor of Neurosurgery at Baylor College of Medicine. He got his Ph.D. at Uc Berkeley where he studied the neural basis of working memory and choice with Jack Gallant. He did a post-doctoral fellowship at Duke University with Michael Platt where he began to focus on reward, choice, and executive control. His has consistently been interested in naturalistic behavior, especially foraging behavior. This interest has included studies of neural mechanisms underlying patch-leaving and diet selection, on freely moving behavior, and the psychology of foraging decision-making. In all of his work, he has focused on prefrontal structures, especially the anterior cingulate cortex, and on understanding the kinds of cognitive processes that are dysregulated in depression, anxiety, and addiction.

Prof. Susan Healy

Professor & Director of Centre for Biological Diversity, School of Biology, University of St. Andrews

Title: What we might learn from mistakes: using foraging decisions in wild hummingbirds as a 'model' system

Abstract: In the 1970's and 1980's bees and hummingbirds were useful organisms for testing predictions from Optimal Foraging Theory (OFT) in the field. Those tests were focussed on the role played by energy, both intake and expenditure. When it became clear that learning and memory were integral to foraging decisions for many animals, it became relevant to determine the roles these abilities played. Subsequent tests of learning and memory in wild, free-living hummingbirds have demonstrated that these birds, even under conditions without the control of the laboratory, learn multiple features of the flowers on which they feed. For example, a flower's location, its colour, and how long ago it was emptied. Furthermore, in an episodic-like manner, these birds can combine all three of these components in a single memory. The multi-component nature of these memories enable dissection of the errors that the birds make when they forage on experimental arrays of flowers. I will briefly review this background work before describing some of our most recent experiments in which we examine not only the birds' correct decisions but also the nature of their errors. This recent work returns us, in a sense, to the early days of OFT, as we are now comparing decision making between honeybees and hummingbirds.

Biography: I began my career at the University of Otago, New Zealand with a joint degree in Zoology and Physiology. A DPhil at Oxford, with John Krebs, on brain and behaviour in food storing birds was followed by a Junior Research Fellowship, at St John's College, Oxford. I then began to move north. First to a lectureship in the Department of Psychology at the University of Newcastle, then to a readership in the Institute for Cell, Animal and Population Biology, University of Edinburgh, before reaching St Andrews in 2009, a joint position in Biology and Psychology. I became a Professor in Biology in 2017 and in 2021 was elected a Fellow of the Royal Society of Edinburgh. Since my DPhil I have combined behaviour, cognition, and neurobiology together in a Tinbergian framework to address questions in animal cognition in the laboratory and (minus the neurobiology) in the field. My primary questions have concerned in spatial learning, memory and the hippocampus in various bird and mammal species, and the adaptive evolution of the brain, with my interests now (not entirely) focussed on understanding how birds know what nest to build. I also address questions of cognition in wild hummingbirds in the Rockies with collaborators Andy Hurly (University of Lethbridge, Canada) and Maria Tello

Dr. Miriam Klein-Flugge

Associate Professor of Neuroscience, Department of Experimental Psychology, University of Oxford

Title: Background reward rate and effort shape behavioural and neural signatures of learning and decision-making in human foraging

Abstract: In everyday life, agents typically encounter choice options sequentially. To make appropriate choices, they need to compare new options against the average value of alternative options (background reward rate) and consider costs, such as the effort associated with foraging. We designed a novel patch-leaving task in which human participants steered an agent over multiple patches of unknown depleting value, receiving probabilistic binary outcomes. The value of the foreground was not explicitly signalled and had to be inferred. We manipulated the overall environmental richness via the distribution of patch values (rich/poor). In addition, we systematically varied the effort associated with foraging, requiring participants to invest variable numbers of button presses to forage and obtain an outcome. This design allowed us to study the influence of background reward rate and effort on learning and foraging choices.First, considering the effects of background reward rate, we observed that participants adjusted their behaviour to the environmental richness and became more selective in rich environments, but more frugal in poor environments. Computational modelling revealed that environmental richness affected the threshold at which participant left a patch, but also the learning rate with which they updated their belief about the current patch. In line with optimal filtering considerations, participants show stronger updates after negative feedback in rich environments and after positive feedback in poor environments. In a 7T fMRI study, this asymmetry in learning rates was also reflected in BOLD responses to outcomes in a network comprising dorsal anterior cingulate cortex, lateral orbitofrontal cortex, dorsal anterior insula, thalamus, and several brainstem nuclei.Second, looking at effort preferences, we found that effort investment tracked past outcomes and thus overall patch quality. Furthermore, greater anticipated effort encouraged participants to leave patches sooner, while greater committed past effort encouraged prolonged stay behaviour (sunken cost). This was despite effort being irrelevant for optimal reward performance in our task. These influences of effort on choice behaviour correlated with levels of depression and anhedonia. In sum, our study shows that background value fluctuations at slow time scales modulate behavioural and neural signatures related to the learning of single foreground choice options, and that effort influences during foraging choices reflect basic features of the environment and relate to markers of depression.

Biography: Miriam Klein-Flügge is an Associate Professor, Wellcome Trust Sir Henry Dale and UKRI-ERC fellow at the Departments of Experimental Psychology and Psychiatry and the Oxford Centre for Integrative Neuroimaging at the University of Oxford. Her research group studies human cognitive processes, with a particular focus on motivation and decision making. She has extensive experience with neuroimaging and neuromodulation approaches. Her long-term vision is to conduct fundamental research that provides a platform for translation to psychiatric disease.

Conference Programme

Monday 3rd November

Time	Session
18:00 – 19:30	**Welcome Reception and Posters**

Tuesday 4th November

Time	Session
8:30 - 9:15	**Registration and Refreshments**
9:15 - 9:30	**Opening Remarks**
9:30 - 10:15	**Keynote Speaker:** **Background reward rate and effort shape behavioural and neural signatures of learning and decision-making in human foraging** *Miriam Klein-Flugge, University of Oxford*
10:15 - 11:00	**Blitz Talks:** **A progressive ratio task with costly resets reveals adaptive effort-delay tradeoffs** *Zeena Rivera, University of California, Los Angeles* **The Effort Based Forage Task: An Ethological Behavioural Test for Assessing Motivation and Apathy-related Behaviour in Mice** *Megan Jackson, University of Bristol* **Computational mechanisms underlying how humans adapt their foraging choices to the average effort of the environment** *Emma Scholey, University of Birmingham*
11:00 - 11:30	**Refreshment Break**
11:30 - 12:00	**Navigational strategies for foraging: insights from ants and flies** *Hannah Haberkern, University of Würzburg*
12:00 - 12:30	**Stochastic choice drives variability in patch foraging decisions across species** *Mark Humphries, University of Nottingham*
12:30 - 13:00	**The behavioral mechanisms underlying human social foraging dynamics in the wild** *Alexander Schakowski, Max Planck Institute for Human Development*
13:00 - 14:00	**Lunch**
14:00 - 14:30	**Brain-wide dynamics of time-limited foraging strategies in changing environments** *Jennifer Li, Max Planck Institute for Biological Cybernetics*
14:30 - 15:00	**Aeon: an open-source platform to study the neural basis of ethological behaviours over naturalistic timescales** *Dario Campagner, University College London*
15:00 - 15:30	**Foraging in Naturalistic Environments: The Role of Threat and Social Context** *Toby Wise, King's College London*
15:30 - 16:00	**Refreshment Break**

16:00 - 16:45	**Keynote Speaker:** **Neural basis of prey-pursuit behavior** *Benjamin Hayden, Rice University*
16:45 - 17:20	**Discussion Session**
17:20	**Close**
18:00 - Late	**Conference Dinner**

Wednesday 5th November

Time	Session
9:00 - 9:30	**Registration and Refreshments**
9:30 - 10:15	**Keynote Speaker:** **What we might learn from mistakes: using foraging decisions in wild hummingbirds as a 'model' system** *Susan Healy, University of St. Andrews*
10:15 - 11:00	**Blitz Talks:** **Optimal foraging under structured replenishment** *Roxana Zerati, Max Planck Institute For Biological Cybernetics* **Foragax: Large-Scale Agent-Based Modeling of Adaptive Multi-Agent Foraging** *Siddharth Chaturvedi, Radboud University* **Continuous dynamics of cooperation and competition in social decision-making** *Darius Lewen, MPI for Dynamics and Self-organization*
11:00 - 11:30	**Refreshment Break**
11:30 - 12:00	**Foraging: From Food to Inquiry** *David Barack, University of Pennsylvania & Lingnan University*
12:00 - 12:30	**Ecology dictates the benefits of memory: an empirical case study in foraging bees** *Elli Leadbeater, University College London*
12:30 - 13:00	**Naturalistic foraging tasks in freely moving rodents for mechanistic and neuronal insights into learning, decision-making, and movement** *David Robbe, Mediterranean Institute of Neurobiology*
13:00 - 14:00	**Lunch**
14:00 - 14:30	**Neural Circuit Basis for Foraging Under Conflict** *Carolina Rezaval, University of Birmingham*
14:30 - 15:00	**Exploration Under Uncertainty: Computational Insights from Childhood Adversity and Adolescence** *Nicholas Furl, Royal Holloway University of London*
15:00 - 15:30	**Emotions and individual differences in naturalistic tasks** *Jacquie Scholl, Lyon Neuroscience Research Centre*
15:30 - 16:00	**Refreshment Break**
16:00 - 16:30	**Overharvesting as a window into optimal learning and planning in humans** *Aaron M. Bornstein, University of California*
16:30 - 17:00	**Humans forage in reinforcement learning tasks** *Becket Ebitz, University of Montreal*
17:00	**Closing remarks**

Invited Speakers Abstracts

In order of appearance in the programme

I1. Navigational strategies for foraging: insights from ants and flies

Hannah Haberkern[1]
[1]*University of Würzburg*

Effective foraging in inhomogeneous, patchy environments requires dynamic shifts in navigational strategies, alternating between long-range movement, and local exploration. Dissecting the neural control underlying these strategies and transitions between them has been challenging. In insects, both long-range movement and local search have been associated with conserved central brain circuits, specifically the compass-like head direction system. This apparent convergence raises an intriguing possibility for higher-level control of navigational strategies through the head direction system and downstream circuits. We analyzed the contribution of different navigational strategies to local search in Drosophila and found that the head direction system is dispensable for structured, local exploration. At the same time, search is flexible and depends on both internal state variables and recent feeding experience. We relate these findings to different types of searches observed in foraging desert ants (Cataglyphis spp) in the field and discuss possible roles of the head direction system in insect foraging behavior.

I2. Stochastic choice drives variability in patch foraging decisions across species

Mark Humphries[1]
[1]*University of Nottingham*

Staying to exploit remaining resources or leaving to seek better options elsewhere is a fundamental decision across species. Optimal patch foraging theories propose deterministic rules for when to leave a depleting resource but real foragers show considerable variability in when they leave. Here we show that foragers making deliberately stochastic choices of when to leave a patch is sufficient to explain their variability. We show that, under a wide range of conditions, stochastic choice predicts foragers' leaving variability will be independent of the rewards available in the environment. These predictions matched observed patterns of leaving variability in humans and rats and its dependence on how resources decay in the patch. We further show that foragers' variability is consistent with them setting the stochasticity of their choice in proportion to their environment's average reward. Our findings suggest stochastic choice is an underappreciated but powerful contributor to foraging decisions.

I3. The behavioral mechanisms underlying human social foraging dynamics in the wild

Alexander Schakowski[1]
[1]*Max Planck Institute for Human Development*

Humans have mastered diverse foraging styles in extreme habitats from the tropics to the Arctic across a range of social settings. The unique complexity of the human foraging niche is considered a main driver of the evolution of cognition and social learning skills. Yet, the mechanisms underlying social foraging decisions (such as where to go and when to leave) in the real world remain unknown as existing field studies typically focus on individual-level behavior. Integrating high-precision GPS tracking and video footage from large-scale ice-fishing competitions in Finland with cognitive-computational modeling and agent-based simulations, we show how foragers integrate personal information (e.g., foraging success) with social information (e.g., the location of other foragers) to guide spatial search and patch-leaving decisions. We find, that foragers adaptively rely on social information to locate resources when unsuccessful and extend giving-up-times in the presence of others, resulting in increased area-restricted search at high social densities. These findings demonstrate the importance of sociality for human foraging decisions, and provide a template for harnessing high-resolution tracking data to study real-world cognition.

I4. Brain-wide dynamics of time-limited foraging strategies in changing environments

Jennifer Li[1]
[1]*Max Planck Institute for Biological Cybernetics*

Effective foraging requires animals to continually assess environmental conditions and adjust behavior to balance food intake against energy expenditure. While many theoretical models of optimal foraging have been proposed, identifying their neural implementation across the brain has remained challenging. My lab develops technology to record cellular-resolution neural activity across the brain of freely moving larval zebrafish, providing a unique window into how innate foraging strategies are implemented at brain-wide scale.

Using this approach, we previously showed that zebrafish spontaneously alternate between exploration and exploitation states even in constant environments with abundant prey, each associated with distinct global brain activity patterns (Marques et al., 2020). I will present new findings that external changes in prey density trigger exploration and exploitation states of precisely timed duration. Computational modeling indicates that such time-limited responses optimize the balance between food intake and energy costs. Finally, although larval zebrafish prey capture is typically viewed as vision-driven, we find that olfactory detection of prey density change is the primary driver of global state transitions. Together, these results demonstrate how the vertebrate brain can organize adaptive exploration–exploitation strategies through dynamic, time-limited brain states.

I5. Aeon: an open-source platform to study the neural basis of ethological behaviours over naturalistic timescales

Dario Campagner[1]
[1]*Sainsbury Wellcome Centre*

Ethological behaviours are a powerful tool for neuroscience since they leverage the robust neural computations shaped by the species' evolution to study the neural basis of cognitive functions. However, such behaviours are often transitory and dependent on factors that vary over space, time and number of individuals, making them difficult to capture with standard laboratory tasks. Here we present Aeon, an open-source platform designed for continuous, long-term study of self-guided behaviours in multiple mice and simultaneous recording of brain activity within large, customizable habitats. By integrating specialized modules for navigation, nesting and sleeping, escaping, foraging, and social interaction, Aeon enables the expression of key ethological behaviours while achieving experimental control and multi-dimensional quantifications from sub-millisecond to month-long durations. Its software architecture ensures robust data acquisition via many synchronized data streams and delivers a new standardised, unified data format that yields seamless, integrated analysis pipelines. Using assays such as digging-to-threshold and social foraging, Aeon reveals how mice adapt strategies in a changing environment and in response to conspecifics. Aeon bridges ecological relevance with rigorous experimental control to advance our understanding of how neural circuit activity gives rise to a range of highly conserved and adaptive behaviours.

I6. Foraging in Naturalistic Environments: The Role of Threat and Social Context

<u>Toby Wise</u>[1]
[1]*Kings College London*

Real world environments are complex, and our decision-making must account for a multitude of potential rewards and dangers, alongside potential collaborators or competitors who may help or hinder progress towards our goals. I will present work demonstrating how humans forage when accounting for the presence of both threat and social competitors, whose presents can dilute the potential for danger but also increase competition for reward. Combining computational modelling with neuroimaging, I will detail how the brain computes expected patch values by integrating information about social context. I will also discuss how the use of more naturalistic paradigms might enhance our understanding of foraging, and decision-making more broadly, but capturing how humans respond to the complexities inherent in real world decision problems.

I7. Foraging: From Food to Inquiry

David Barack[1]
[1]*Lingnan University*

The capacity to forage is central to all mobile organisms. Foraging is the search for resources of a general type, including food, minerals, social and sexual opportunities, and more, where the forager is ignorant of the specific location of their goal and is not searching for a specific item. Foragers make exclusive decisions between accepting and rejecting an item, where accepting or rejecting one item does not imply the acceptance or rejection of another. These items are persistent: when the item is rejected, it typically does not disappear but can be returned to. Further, foragers make these decisions repeatedly, coming across options in their environment and accepting or rejecting them. Foraging is the serial search for general resources in accept-or-reject, exclusive, persistent decision contexts.

This analysis of foraging offers two promising payoffs. First, foraging presents special cognitive demands on organisms and, hence, on the evolution of decision mechanisms. I will assess the evidence for a specialized foraging circuit, arguing that much decision making results from foraging selective pressures placed on the brain. The consideration of these foraging choice mechanisms can explain suboptimal aspects of some decisions, such as violations of transitivity due to comparisons of offers to expectations instead of other items. Second, considering the selective demands from foraging yields novel explanation of types of cognition. Besides searching for resources in the environment, foragers can cognitively search for memories, ideas, reasons, and more. Specifically, inquiry is a type of foraging, requiring repeated accept or reject decisions in foraging-like internal environments. This offers a startling novel hypothesis for the origins of reasoning, inference, and other cognitive processes enlisted during inquiry: reasoning and inference evolved to keep track of progress during the goals of inquiry, using pre-existing cognitive machinery deployed in these new cognitive domains.

I9. Naturalistic foraging tasks in freely moving rodents for mechanistic and neuronal insights into learning, decision-making, and movement

David Robbe[1]
[1]*Institute of Mediterranean Neurobiology*

Understanding how animals integrate reward and effort to guide decisions and adapt movement kinematics requires tasks that are both ethologically relevant and experimentally tractable. I will present results from our recent development of two naturalistic foraging paradigms in rodents. I will first introduce the Towers Foraging Park (Schaffhauser et al., 2025), a new task for mice developed in our team that captures the exploration–exploitation trade-off central to patch foraging. In this self-paced task, mice harvest rewards along the walls of square towers (patches) by making repetitive quarter-turns around them (exploit) and alternating between towers (explore) under experimenter-controlled contingencies: patches deplete after a random number of rewards and must be harvested in one direction. I will present results from two groups of mice illustrating the potential of this task to simultaneously investigate decision-making and motor control and their modulations by the history of reward outcome. Then I will present recent and ongoing results from an effort-based foraging paradigm in rats (Morvan et al., 2024), which provides a framework to study how decision-making and movement speed are modulated by action utility including time and movement costs. I will also share preliminary data from lesion experiments showing complementary contributions of the ventral and dorsal striatum to utility-based modulation of foraging behavior.

I10. Neural Circuit Basis for Foraging Under Conflict

Carolina Rezaval[1]
[1]*University Of Birmingham*

Animals must constantly arbitrate between competing drives, such as avoiding danger and pursuing reward. Foraging often presents such conflicts: approaching food can carry the risk of predation or injury. Yet how the brain integrates internal state with external cues to resolve these competing demands remains poorly understood.

We tackle this challenge harnessing the neural circuit tractability of Drosophila and a novel behavioural assay where flies must decide whether to cross an aversive barrier to access food. We find that starvation biases flies towards risk-taking, but only when food is perceptible. In the absence of sensory cues, even hungry flies avoid danger, revealing that internal drive alone is insufficient to trigger action.

Using behaviour, neurogenetics, and in vivo imaging, we identify a neural circuit mechanism that integrates motivational state and environmental cues to guide adaptive decision-making. This work reveals how the brain resolves fundamental survival conflicts and provides a tractable platform to uncover conserved principles of foraging under conflict.

I11. Exploration Under Uncertainty: Computational Insights from Childhood Adversity and Adolescence

Nicholas Furl[1]
[1]*Royal Holloway University Of London*

Computational accounts connect developmental experience to decision-making strategies. Our recent work applied patch-foraging paradigms with reinforcement learning models to test how exploration and reward learning are shaped across the lifespan. In adults, adverse childhood experiences predicted reduced exploration. Modelling revealed these individuals learned less from recent outcomes when estimating environmental reward rates, dampening their ability to exploit novel opportunities and leading to suboptimal reward accumulation. In complementary work, we examined how adolescents and adults adapt to changing reward rates. Adolescence, in particular, is an especially dynamic life stage that demands adaptation to volatility. Contrary to canonical assumptions, adaptation was not supported by higher learning rates. Instead, participants increased their decision stochasticity (more random exploration), which facilitated adjustment. Crucially, anxiety disrupted this stochastic exploration, highlighting a computational route through which psychopathology biases adaptive learning. Together, these findings feed into a theoretical framework in which heightened exploration in youth is not simply “risk-taking” but a developmental feature: it provides the experiential foundation for mature exploitative strategies. When this trajectory is perturbed—by early adversity or anxiety—individuals may miss critical learning opportunities, with consequences that persist into adulthood.

I12. Emotions and individual differences in naturalistic tasks

Jacqueline Scholl[1]
[1]*Lyon Neuroscience Research Centre*

Our emotions fluctuate as we go through our day in response to what we encounter – for example, seeing someone cough might make us feel worried or stressed about getting ill. These emotions in turn can help us to act appropriately in the situation – for example we might try to avoid the person or wash our hands. Here, we examined the role of emotions in shaping people's behaviour across three naturalistic task: foraging under threat, continuous goal pursuit and intrinsic motivation during patch leaving. We capture emotions through self-reports, as well as using a novel method of facial emotion recognition. Emotional traits were captured through standard questionnaires (apathy, anhedonia, anxiety etc.) in large online samples and linked to task behaviour and emotions.

I13. Overharvesting as a window into optimal learning and planning in humans

Aaron Bornstein[1]
[1]University of California

We developed a computational model that explains apparent overharvesting as a by-product of two mechanisms: 1) statistically rational learning about the distribution of alternatives and 2) optimally adapting planning horizon to subjective uncertainty -- looking ahead farther when more sure about the options available. We tested this model using a variant of a serial stay-leave patch foraging task and find that human foragers' behavior is consistent with both mechanisms. Our findings suggest that overharvesting, rather than reflecting a deviation from optimal decision-making, is instead a consequence of optimal learning and adaptation. Ongoing work follows up on these findings to understand how individuals adapt to their environments and experiences, across the lifespan.

I14. Humans forage for reward in classic reinforcement learning tasks

Becket Ebitz[1]
[1]University of Montreal

Because the world is dynamic and imperfectly observable, many of the decisions we make are uncertain. How do we navigate this uncertainty? In cognitive neuroscience, the classic answer is that we evaluate the benefits of each alternative and choose the one promising the greatest reward, modulo exploratory noise. Conversely, an ethologist would argue that we exploit previously rewarding choices until the payout drops below a certain threshold, at which point we explore alternatives. Both hypotheses wield considerable influence within their respective fields, but it remains uncertain which account best describes human decision-making. Here, we asked whether human decisions in a classic cognitive neuroscience testbed are better described as a compare-to-threshold process or as a value-comparison process. We found that decisions were better described as a compare-to-threshold process. This insight is difficult to reconcile with traditional reinforcement learning (RL) models, which center value-comparison computations. Therefore, we next developed a novel class of compare-to-threshold RL models called RL-Foraging models. These models outperformed traditional compare-alternatives RL models on both the individual and group levels. These findings indicate that humans use foraging-like compare-to-threshold computations—even in tasks that were designed as testbeds for standard compare-alternatives algorithms. They also offer a novel cognitive account of decision-making under uncertainty with widespread implications for the cognitive and brain sciences.

Blitz Talks

In order of appearance in the programme

B1. A progressive ratio task with costly resets reveals adaptive effort-delay tradeoffs

Zeena Rivera[1], Megan Cervera[1], Alicia Izquierdo[1], Andrew Wikenheiser[1]
[1]*University of California*

The Progressive Ratio (PR) schedule is a widely used method for quantifying the motivational value of a reinforcer, where subjects are required to exert an increasing amount of work to earn each successive reward. A limitation of PR is that, as the ratio requirement balloons over the length of the session, so does the time it takes to reach the subsequent ratio. Time to reward and effort are inextricably linked in the standard PR. Instead, the Progressive Ratio with Reset (PRR) task transforms PR into a problem that can be modeled similarly to existing patch-leaving foraging scenarios where time and effort costs can be discretely manipulated. In this task, rats engage with a standard PR1 schedule on one lever but have the option to press a second lever to reset the current ratio requirement back to its initial level. This reset action comes at the cost of a delay period, during which both levers are retracted, introducing an opportunity cost. We tested 24 Long-Evans rats (PND ≥ 96; 12 females), and found that they used the reset lever adaptively, with decisions sensitive to the imposed reset delay. We developed a normative model to compute the optimal bout length—the number of rewards rats should obtain before resetting to maximize the long-term rate of reward. Rats adjusted their behavior in ways that closely tracked these optimal strategies, suggesting a high degree of cost-benefit sensitivity. The PRR task offers a novel and more nuanced tool for evaluating motivational decision-making than previously explored. It extends traditional reinforcement learning frameworks into the domain of sequential decision-making and connects behavioral performance in laboratory settings to ecologically relevant foraging principles.

B2. The Effort Based Forage Task: An Ethological Behavioural Test for Assessing Motivation and Apathy-related Behaviour in Mice

Foteini Xeni[1], Caterina Marangoni[1], Lynn Lin[1], Emma Robinson[1], **Megan Jackson**[1]
[1]*University of Bristol*

Motivational deficits such as apathy syndrome are prevalent across a wide range of neurological and neurodegenerative disorders. They have a significant impact on patient quality of life and severity of disease progression. Despite this clear clinical burden, there is currently no agreed treatment approach for this symptom domain. This may be driven by limitations associated with animal models. At the preclinical level, motivational state is traditionally assessed in operant tests and requires food restriction and prolonged training times to motivate the rodent to perform a conditioned response. Animals monitored in more naturalistic environments may display more ethologically-relevant behaviours of greater translational value. The newly developed Effort Based Forage (EBF) task draws on the intrinsic drive of the mouse to forage for nesting material. The apparatus is designed to encourage the mouse to exert effort to forage nesting material and shuttle it back to a safe and enclosed environment. Motivated behaviour is quantified by the amount of nesting material foraged. We aimed to validate the task as a sensitive measure of motivational state using acute dopaminergic manipulation and phenotypic models with pre-established motivational deficit. Treatment with D2 antagonist haloperidol decreased foraging without affecting general movement while the dopamine reuptake inhibitor methylphenidate increased foraging behaviour. Surprisingly the stimulant amphetamine reduced foraging behaviour, contrasting with operant paradigm findings and potentially reflecting the differing complexities of the task environments. The EBF task detected motivational deficit in both a chronic corticosterone model of depression-related behaviour, and a healthy ageing model. Post-validation, the EBF task was used to demonstrate that acute SSRI treatment impaired foraging behaviour aligning to the clinical scenario but contrasting operant-based paradigm findings. Thus, without requiring prolonged training times or food restriction, this task provides rapid insight into intrinsic motivational state with notable differences to operant-based paradigms necessary for informing translational drug development.

B3. Computational mechanisms underlying how humans adapt their foraging choices to the average effort of the environment

Emma Scholey[1], Nikita Mehta[1], Matthew Apps[1]
[1]*University Of Birmingham*

Would a hill in Birmingham seem as effortful to climb if you found the same slope in the Alps? Everyday, we decide whether effort is ‘worth it' for rewards. But how do we modulate our preferences to exert effort when an environment’s overall effort demands change, i.e. the average effort of other possible options? While previous research utilising foraging paradigms suggests that humans track the average reward rate in an environment via reinforcement learning mechanisms, a comparable framework for how average effort influences choice is absent. Here, we examine how effort-based decisions are modulated by the average effort of the environment, using a foraging prey selection paradigm, computational modelling, and fMRI. Participants (in three studies: n = 38, n = 40, n = 38) were presented offers of different amounts of effort (20%, 40% or 60% maximum grip strength) and chose whether to exert that effort to obtain unknown, random amounts of reward, or forego it to wait for an easier offer. Participants completed this task in both easy environments (more likely to observe low effort offers) and hard environments (more likely to observe high effort offers). We found that participants were more willing to exert moderate effort in harder environments with higher background effort requirements. A reinforcement learning-based model that tracks average effort over time successfully accounted for this choice behaviour. Preliminary fMRI results suggest fronto-basal ganglia circuits track and update the estimated value and average cost of effort in an environment. These findings provide a neuro-computational framework for how the average effort in an environment can shift preferences to exert effort. By integrating behaviour, foraging theory, computational modelling, and neuroimaging, these results offer insight into a previously unexplored but fundamental aspect of motivation.

B4. Optimal foraging under structured replenishment

Roxana Zeraati[1], Tiffany Oña Jodar[2], Shervin Safavi[1,3], Bruno Cruz[2], Cindy Poo[2], Peter Dayan[1,4]
[1]*Max Planck Institute for Biological Cybernetics,* [2]*Allen Institute for Neural Dynamics ,* [3]*Technical University of Dresden,* [4]*University of Tübingen*

Patch foraging---deciding when to leave a depleting resource to search for alternatives---is a fundamental aspect of animal behavior and offers a window into ethologically grounded decision processes. Several theories, most notably the Marginal Value Theorem (MVT), have proposed strategies for optimal foraging. However, they typically simplify the details of the spatiotemporal structure of the environment, and particularly the dynamics of patch replenishments.

We investigate how richer replenishment dynamics affect optimal foraging decisions. We employ the average-reward reinforcement learning (RL) framework to find the optimal policy given various environmental statistics, and compare its behavior with MVT and other, more complex, heuristic policies. We show that under slow replenishment timescales, optimal policies leverage the statistics of the environment to generate higher reward rates, which depend on patterns of behavior distinct from both MVT and other fixed-threshold policies. In particular, the optimal policy applies flexible leave thresholds to each patch depending on the replenishment state of other patches, allowing it to maximize its acquisition of resources. These results suggest that in the presence of replenishment with realistic timescales, acting on the basis of a complete model of the environment is required to make optimal foraging decisions. Since slow replenishment is a realistic property of natural environments, we hypothesize that animals learn a world model and leverage it to inform their foraging decisions (perhaps, but not necessarily, using model-based RL). We are testing this hypothesis in mice using a naturalistic patch-foraging paradigm designed based on our theoretical predictions.

B5. Foragax: Large-Scale Agent-Based Modeling of Adaptive Multi-Agent Foraging.

<u>Siddharth Chaturvedi</u>[1], Ahmed El-Gazzar[1], Marcel van Gerven[1]
[1]*Radboud University, Nijmegen*

Analyzing the task of foraging when performed by neuroscience-inspired artificial adaptive agents can elucidate links between the observed foraging behaviors and the neural mechanisms responsible for them. To broaden the scope and ecological validity, such agents should be simulated in more naturalistic settings. We present Foragax, a large-scale agent-based model for multi-agent patch foraging in common-pool resources. Foragax extends single-agent models to populations that adapt concurrently, framing foraging as a large-scale non-cooperative game. The resulting equilibria depend on environmental resource distributions and agents' adaptive capacity, making Foragax a useful test-bed for benchmarking adaptive foraging behaviours. Agent brains are modelled using recurrent neural networks based on brain-inspired rate-based models. More importantly, when the agents are homogeneous in their brain structure and parameters and are evaluated in the same rollout, the model captures the important properties of auto-curricula and self-play. Brain models that exhibit more diverse, stable, niche-specialized behaviors while sustaining higher resource intake rank higher in adaptability. We benchmark combinations of brain-inspired learning algorithms and neuron models on such a multi-agent adaptive patch foraging task using Foragax. Built on Abmax, a JAX-based agent-based modeling framework, Foragax enables massively vectorized simulations that scale to thousands of agents on hardware accelerators.

B6. Continuous dynamics of cooperation and competition in social decision-making

Vladyslav Ivanov[3], **Darius Lewen**[1,2], Johannes Ruß[2], Anna Fischer[2], Lars Penke[2], Anne Schacht[2], Alexander Gail[2,3], Viola Priesemann[1,2], Igor Kagan[3]
[1]*MPI for Dynamics and Self-organization,* [2]*University of Göttingen,* [3]*German Primate Center*

Real-life social interactions often unfold continuously and involve dynamic cooperation and competition, yet most studies rely on discrete games that do not capture the adaptive and graded nature of continuous sensorimotor decisions. To address this gap, the Cooperation–Competition Foraging game was developed — a novel, ecologically grounded paradigm in which pairs of participants (dyads) navigate a continuous shared space under face-to-face visibility, deciding in real time to collect rewarded targets either individually or jointly. Dyads spontaneously converged on distinct stable strategies along the cooperation–competition spectrum, forming three similarly sized groups: cooperative, intermediate, and competitive. Despite the behavioral complexity, a computational model incorporating travel path minimization, sensorimotor communication, and recent choice history predicted dyadic decisions with 87% accuracy, and linked prediction certainty with ensuing dynamics of spatiotemporal coordination. Further modeling revealed how sensorimotor factors, such as movement speed and skill, shape distinct strategies and payoffs. Crucially, the cost of cooperation was quantified, demonstrating that in many dyads, prosocial tendencies outweighed the individual benefits of exploiting skill advantages. This versatile framework provides a predictive, mechanistic account of how social and embodied drivers promote the emergence of dynamic cooperation and competition, and offers rigorous metrics for investigating the neural basis of naturalistic social interactions and for linking personality traits to distinct strategies.

Poster Abstracts

In alphabetical order

P1. Expectancy violation shapes foraging behaviour in a food-caching bird

Victor Ajuwon[1], Alexandra Schnell[1], Nicola Clayton[1]
[1]*University of Cambridge*

While foraging individuals represent the expected value of reward opportunities and use this information to guide their decisions. Such value judgements are crucial for food-caching birds like the Eurasian jay (Garrulus glandarius) that regularly decide between a multitude of their own caches to retrieve, but also steal the caches of other birds. While studies have shown that jays are sensitive to the content and perishability of their own caches, less is known about the representations they form of caches hidden by other individuals, and how they integrate these factors to optimise foraging. In this study, we used a violation-of-expectation paradigm to investigate whether jays are sensitive to the quantity of rewards they observed being hidden by an experimenter. We hypothesised that when jays' expectations were negatively violated, their behavioural responses would reflect the absolute magnitude of the discrepancy between their expectation and the outcome. Subjects were presented with two conditions in which hidden reward was consistent with their expectations (expect 5, get 5; expect 1, get 1) and three conditions in which food was manipulated to negatively violate their expectations (expect 5, get 0; expect 1, get 0; expect 5, get 1). Overall, Jays spent more time inspecting the baited cup and were more likely to inspect an alternative cup in violation compared to control conditions. Consistent with our hypothesis, responses were stronger in expect 5, get 0 than in expect 1, get 0, but did not differ from controls in expect 5, get 1, though subjects experienced a large absolute discrepancy in reward quantity in this condition. Overall, our results show that jays are sensitive to quantities of items that others have hidden, and suggest that behavioural responses to expectancy violation may be mediated by both the magnitude of discrepancies and the utility of observed outcomes.

P2. A Modular, Multi-Sensory Maze to Investigate Foraging, Exploration and Sensory-Driven Decisions in Mice.

Alejandra Carriero[1], **Shahd Al Balushi**[1]
[1]*University Of Sussex*

Animals in nature sense their surroundings by actively engaging with them and processing the resulting signals according to their utility. Head-fixed experiments have provided an essential platform for determining the neuronal circuitry of sensory signalling and behaviour. However, head fixation induces long-term stress [1], limits natural movements [2], and disrupts sensory perception and exploration strategies [3]. It has been proposed that learning under those conditions occurs more slowly than when animals are free to spontaneously explore contingencies [4].

To interrogate natural mouse capacities for flexible exploration, learning, and decision-making that underlie foraging, we have developed a modular maze for freely moving mice. The maze includes automated stimulus presentation and reward delivery triggered by mouse tracking. This setup enables the study of foraging behaviour without restricting movement or nutrition, while providing high levels of experimental control. Its low-cost, modular design supports simple, flexible, and scalable modification of behavioural tasks, and broad reproducibility.

Mice habituate to the maze within minutes and are intrinsically motivated to explore it with no need for fluid or food restriction. We provide examples of object-in-place recognition and of shifts between exploratory/itinerant/engaged and settled/nestbuilding behavioural states. We also present tasks in which mice interact with tactile and auditory stimuli as they move through the maze. Preliminary data suggest that individual mice with a tendency for exploration over risk aversion were also more motivated to experience sensory stimuli of varying levels of predictive complexity and structure, even when those stimuli were not explicitly rewarded, supporting a link between curiosity, neophilia, and exploratory preference.

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P3. Modelling Dissociable Effects of Methylphenidate and Amphetamine on Learning Rate and Reward-Prediction Error

Madeleine Bartlett, Michael Furlong, Terrence Stewart, Jeff Orchard
[1]*University Of Waterloo*

Foraging behaviour naturally maps well to reinforcement learning (RL) paradigms – animals explore their environment using trial-and-error to locate rewards, and update their strategy in the face of changing costs or reward availability. Foraging behaviours also offer a naturalistic approach to investigating how changes to motivation, perceived effort or reward value impact goal-driven behaviours. As such, both foraging paradigms and computational models of foraging are indispensable tools in elucidating learning and decision-making mechanisms, and the pathologies that impair them such as depression, apathy, and addiction. Recently, an investigation into the effects of dopamine agonists on motivation in a foraging task revealed that methylphenidate and amphetamine, known to increase effortful behaviours in Pavlovian tasks (Marangoni et al., 2023), had opposing effects on foraging (Xeni et al., 2024). Whilst methylphenidate led to an increase in foraging, amphetamine reduced foraging compared when no drugs were administered. Both drugs are often modelled as increasing reward sensitivity by increasing the learning rate in RL algorithms. However, over time, models of these drugs have incorporated more biological detail to capture how the two differ. In particular, whilst methylphenidate is purely a dopamine reuptake inhibitor, amphetamine is known to both inhibit dopamine reuptake and stimulate dopamine release. We extend these efforts by attempting to model the two drugs and capture their effects in an Effort-for-Reward and an Effort-Based Foraging task using RL. We model the drugs as both causing an increase in the learning rate, while only amphetamine introduces noise into the reward-prediction error signal. These models are sufficient to replicate the concordant increase in effortful behaviours for high-value rewards, and the simultaneous opposing effects observed on foraging behaviours. Improving our understanding of the effects of dopaminergic drugs has implications for our understanding of how individuals respond to amphetamine-based therapies, thereby elucidating potential side-effects and therapeutic mechanisms.

P4. Threat or Reward? Brain Dynamics of Behavioral Shifting

<u>Camille Fakche</u>[1], Jacqueline Scholl[1]
[1]*Lyon Neuroscience Research Center*

In natural environment, humans and other animals constantly face the challenge of balancing their time between two fundamental goals: pursuing rewards and monitoring potential threats. To uncover how the brain supports these shifts, we used magnetoencephalography (MEG) to track neural dynamics while participants (n=42) engaged in a naturalistic task that required them to alternate between reward-seeking and threat-monitoring. From a behavioral perspective, a reinforcement learning model suggested that participants increased their threat-monitoring as perceived threat increased, while higher reward values encouraged them to forage more actively. At the neural level, multivariate pattern analysis of MEG data showed that the brain reliably distinguished between reward- and threat-oriented outcomes. These patterns then allowed us to track, throughout the experiment, whether participants were focused on potential threats or engaged in pursuing rewards. Next, we will explore how these shifts are shaped not only by levels of threat and reward but also by participants' emotional states, such as stress, excitement, and boredom. Together, these findings will shed light on how environmental and emotional contexts guide decision-making.

P5. Using the Effort-Based Forage task to examine strain differences in intrinsic motivation

Eleanor Grayson[1], Emma Robinson[1], Megan Jackson[1]
[1]*University Of Bristol*

Apathy syndrome, seen in neurodegenerative and psychiatric disorders as well as healthy aging, is a multidimensional syndrome defined by reduced motivation and emotional blunting. Apathy-like behaviour is measured preclinically using effort-based decision-making tasks. Motivation, reward sensitivity, and stress sensitivity vary across mouse strains due to genetic and neurological differences. Hence, mouse strains could be a useful tool for detection of patterns in apathy-like behaviour and providing a link to underlying mechanisms of motivation. The Effort-Based Forage (EBF) task measures apathy-like behaviour through naturalistic foraging behaviour. Mice forage nesting material from a nesting box and shuttle the material to a home box. The amount of nesting material foraged and shuttled is used as a measure of motivation. To explore behavioural domains influencing EBF performance, we tested three strains with different behavioural profiles: C57Bl/6J, 129sv, and BALB/c (N = 12 males per strain; Janvier, France). Mice completed the EBF task for effort modulation and affective reactivity measures, the Effort-for-Reward (EfR) task to measure any differences between intrinsic and conditioned motivation, and three anxiety tests to determine anxious state in each strain.

129sv mice foraged more than BALB/c mice in the EBF task, whereas in the EfR task BALB/c mice showed greater selection of high effort trials, suggesting different underlying mechanisms in the tasks. 129sv mice displayed higher anxiety behaviour than BALB/c mice in the elevated plus maze, suggesting that strain differences in EBF are unlikely to be driven by anxiety response. However, BALB/c mice foraged very little compared to the other strains, and due to the floor effect interpretation is limited. The contrasting results between EBF and EfR tasks indicate they measure different motivational processes. These findings support the use of mouse strains to interpret behavioural and neurological components of natural variation in motivated behaviour.

P6. Mechanisms of Coordination during Foraging in Cooperative and Competitive Interactions

Sepideh Khoneiveh[1], Giorgio Manenti[1], Jan Gläscher[1]
[1]*University Medical Center Hamburg-Eppendorf (UKE)*

Human interaction often requires flexible coordination as contexts shift between cooperation and competition. To study these dynamics, we designed a two-player Social Foraging Task (SFT) in which participants repeatedly chose between cooperative, competitive, or independent resource patches without communication. Behavioral analysis of choice patterns revealed four distinct clusters of participants, reflecting economic, sticky, mixed, and avoiding tendencies, each linked to different coordination behaviors.

To uncover the cognitive mechanisms behind these behaviors, we implemented a hierarchical Hidden Markov Model (HMM) of Theory of Mind (ToM) reasoning. At its base, the model assumes that players rely on a set of candidate strategies, including imitation, repetition, leader–follower, win–stay/lose–shift, resource tracking, or preference-based choices. These strategies constitute the latent state space at Level 0, for both the agent and their opponent. At higher levels, the model incorporates recursive reasoning, with an L1 agent best-responding to a Level 0 opponent and an L2 agent best-responding to an opponent reasoning at L1. Crucially, the HMM implements Markovian transitions in two locations: between strategies within Level 0 and between different ToM depths. This framework captures both the dynamics of strategy use and potential shifts in recursive reasoning within each trial.

To test whether coordination is linked to value similarity, we analyzed the relationship between coordination frequency and the absolute difference in self-value functions derived from the best-fitting model. Across all pairs, coordination negatively correlated with value difference ($r = -0.23$, $p = 0.048$), indicating that alignment of internal valuations promotes more stable interaction.

These findings suggest that value alignment provides a key mechanism for coordination in dynamic social contexts. Finally, analyses of reaction times will further test whether differences in ToM sophistication levels produce systematic behavioral signatures.

P7. Environmental Context Modulates Effort-Based Foraging Decisions

Meijia Li[1], **Emma Scholey**[1], **Matthew Apps**[1]
[1]*Centre for Human Brain Health, University of Birmingham*

Would reaching for medium-height fruit feel equally effortful on an island where most resources are easy to gather, versus on an island where resources require significant effort to obtain? Inspired by foraging paradigms, we investigated whether decision-makers dynamically adjust their willingness to exert effort for reward based on environmental effort distributions.
We collected choice data from 493 participants (age range: 18–45 years; M = 31.9, SD = 7) playing an online prey selection game. Participants chose whether to spend time exerting effort by button pressing at low, medium or high effort levels (30, 50, or 70% of maximum pressing rate) for fixed rewards, or to forego the offer. Each time-limited block was a different environment, either a high-effort environment, containing predominantly difficult options (3:2:1 ratio of high:medium:low effort trials), or low-effort environment with predominantly easy options (1:2:3 ratio).
Using generalised linear mixed-effects models (GLMMs), we replicated key findings from lab-based experiments (Scholey et al, in prep). Environmental effort distributions shifted willingness to exert effort: medium-effort offers were accepted more often in high-effort environments than in low-effort environments, indicating that identical demands are valued differently depending on environmental context. This effect remained significant ($\beta = 0.072$, $p = .028$) after controlling for reward history.
Our findings suggest that foragers do not simply weigh absolute effort costs but recalibrate choices to match the environmental opportunity structure. This adaptive mechanism may represent a general foraging principle, with implications for understanding how environmental context shapes motivation and decision-making. Ongoing modelling analyses will test whether psychiatric symptom dimensions predict foraging parameters, linking environmental effort tracking to clinical and subclinical changes in motivation.

P8. Reward As Signal: Minimal neural networks replicate a range of cross-species two-choice foraging behaviors with no explicit training

Chenguang Li[1], Jeffrey Erlich[1]
[1]*University College London*

Foraging emerges from local neural mechanisms that respond rapidly and appropriately to changing environments. Recent work has sought to identify these mechanisms, but it has been challenging to build online, mechanistic models that capture the flexibility and variability of animal choices. Even in two-alternative forced choice (2AFC) tasks, mechanistic models using covariance-based plasticity [1], Hebbian learning [2] and/or biophysical circuits [3] replicate some behavioral patterns but do not explain other phenomena: for instance, autonomous switching between discrete behavioral states, and observations of exponential action length distributions in 2AFC but heavy-tailed distributions in naturalistic environments.

Here we present a novel framework that aims to unify these observations. Self-Supervised Behavior (SSB) uses local predictive learning, slow neural dynamics, and noise in autonomous, closed-loop operation. Crucially, SSB treats neural activity itself as "rewarding": reward signals are not optimization targets, but observations to be predicted, leading to emergent reward-seeking behavior. We show that 2-3 neuron SSB models are sufficient to replicate key behavioral signatures in 2AFC tasks: (1) probability matching in baited and unbaited bandits, (2) autonomous switching between discrete behavioral states, (3) high intra-trial variability, and (4) environment-dependent action length distributions.

In summary, SSB is a simple, biologically plausible mechanistic model for foraging behavior. By reframing reward as a signal to predict rather than optimize, it offers a possible means to unify complex foraging behaviors observed across species.

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P9. Exploration-exploitation of rewards and losses using function learning.

Ingrid Martin[1], Toby Wise[1]
[1]*Kings College London*

Human decisions often rely on recognizing structure in the environment and using this knowledge to guide exploration. One powerful approach to modeling this behavior is function learning, which assumes that people generalize observed outcomes across space or time based on prior assumptions about smoothness and correlation. Gaussian Processes (GPs) provide a flexible and interpretable framework for formalizing these inductive biases and for modelling how people explore to maximize outcomes. However, most existing work focuses on reward-driven exploration. In this study, we extend GP-based models to environments that include both positive and negative outcomes. Participants complete a spatially correlated bandit task involving either rewards, losses or both, where values are sampled from a hidden spatial function. We examine whether GP function learning can account for behaviour in both settings, and whether the nature of the outcomes (positive vs. negative) affects generalization and exploration strategies. By fitting different decision policies to participant behaviour, this work aims to clarify how search and learning processes vary with outcome valence, and to test the flexibility of function learning models across motivational contexts.

P10. Balancing Survival Needs: Neural Mechanism Underlying the Choice between Feeding and Fleeing

Milan K. Narzary[1], **Saloni Rose**[1], **Amber Kewin**[1], Marta Moita[2], **Carolina Rezaval**[1]
[1]*University Of Birmingham*, [2]*Champalimaud Foundation*

The ability to prioritise one goal over others is a fundamental aspect of life. Successful action selection involves weighing internal needs and environmental cues to choose the most appropriate behaviour for each situation. Our work aims to shed light on the neural processes controlling this universally relevant brain computation.

To gain a mechanistic understanding of action-selection during conflict, we devised a novel assay where Drosophila flies must decide whether to prioritise feeding or escaping from a visual threat, two crucial but mutually exclusive behaviours. Our findings reveal that flies cease feeding when exposed to the visual threat. However, when experiencing severe hunger, they ignore the threat and carry-on feeding. Thus, the choice between feeding and escaping from threats is flexible and modulated by hunger state. Moreover, we uncover a sexual dimorphism in this behavioural choice, with females requiring longer periods of starvation to shift their behaviour from escape to feeding. By employing our innovative assay, along with neurogenetic approaches, behavioural techniques, and insights from the connectome, we identify the key neural circuitry that establishes priority during this sensory conflict, connecting sensory inputs with motor output. Our research provides insights into the neural circuit mechanisms that balance risks and rewards to prioritise actions during conflicting situations.

P11. Neural, physiological and behavioural markers of vigilant attention track hidden environment states during foraging

Angela Renton[1], Nan Ye[2], Jonathan Wilton[2], Jayce Rushton[3], Jason Mattingley[3,4,5]
[1]*Neuro-X Institute, École Polytechnique Fédérale de Lausanne*, [2]*School of Mathematics and Physics, University of Queensland*, [3]*Queensland Brain Institute*, [4]*School of Psychology, University of Queensland*, [5]*Canadian Institute for Advanced Research (CIFAR)*

The evolutionary survival of many animal species depends upon the ability to forage. Our human ancestors continuously monitored their environments for resources which waxed and waned in availability depending on hidden variables unknown by the forager. Today, humans are still required to remain vigilant during monotonous monitoring tasks with rare targets. From driving to supermarket shopping, modern vigilant foraging tasks are ubiquitous. Laboratory research shows that humans struggle to sustain attention to such tasks over long durations. Here, we sought to investigate whether hidden task states which govern target frequency, characteristic of real-world foraging tasks, also influence sustained attention. To this end, we recorded EEG and eye-tracking data while participants (N=32) performed a novel frequency-tagged foraging task. In four, 20 minute blocks participants monitored coloured figure-8's which drifted down a screen, reminiscent of rain drops on a window. Participants were asked to identify brief periods when individual characters of a target colour transformed into target shapes (e.g figure-3's). Critically, a Markov model was used to generate a sequence of hidden states, such that the relative probability of target vs. distractor events lulled and surged over time. Behavioural response measures, steady-state visual evoked potentials, event-related potentials, alpha-band oscillations, pupilometry, and saccade analyses all demonstrated that this task elicited established markers of the vigilance decrement. A Hidden Markov Model (HMM) trained on participants' response sequences revealed that participants spent more time in "off-task" states over time-in-block. Interestingly, the slope of the decline in sustained attention differed by hidden task state. Further, as sustained attention waned, HMM probability sequences for "on-task" states more closely tracked the true state probabilities. Thus, participants tracked hidden task states and these states did influence attentional allocation. Further, as sustained attention to exogenous visual information waned, behaviour depended more upon endogenous state-dependent predictions.

P12. Foraging with the mind's eye: perceptual multistability as internal foraging

Mohammdreza Bigham[1], Adel Movahedian[2], **Shervin Safavi**[3,4]
[1]*Institute for Cognitive and Brain Sciences*, [2]*Department of Electrical Engineering, Sharif University of Technology*, [3]*Faculty of Medicine, TU Dresden*, [4]*Department of Computational Neuroscience, Max Planck Institute for Biological Cybernetics*

Foraging is critical to survival and has played a central role in shaping cognitive functions. We argue that perceptual multistability—a centuries-old phenomenon in which a single stimulus produces alternating interpretations (e.g., the Necker cube)—is best understood as a form of internal foraging. Perceptual multistability has been observed across many species, from Drosophila and fish to primates and humans. Inspired by reinforcement learning (RL) models of ecological patch foraging, we developed an RL framework showing that seemingly random perceptual switches reflect structured internal foraging for information.

We formalize multistability as a dynamic, value-based choice using a Partially Observable Markov Decision Process (POMDP). Each percept, treated as a "perceptual patch," is assigned a dynamic value determined by the properties of the sensory input. This value reflects an optimization principle: the sensory system seeks to maximize processing of both present and future stimuli. Estimating the parameters based on behavioral data revealed striking dynamics: values of currently perceived images gradually decay, while those of suppressed images rise. This pattern resembles depletion of informational resources in one patch and replenishment in the alternative. A perceptual switch occurs when the expected reward of the suppressed percept exceeds that of the current one (factoring in a switching cost). As in ecological foraging, switching is not rigid: it is modulated by competing task demands and attentional priorities, consistent with empirical evidence on multistability.

Finally, we provide neural evidence for our foraging account. In macaques performing binocular rivalry (a well-established form of multistability), feature-selective neurons in ventro-lateral prefrontal cortex (vlPFC) exhibited spiking activity that closely tracked predicted value dynamics of perceptual patches. These findings suggest that vlPFC encodes informational value during perceptual choice. Taken together, our results position perceptual multistability as a form of internal foraging, governed by value-based computations that bridge ecological, cognitive, and neural domains.

P13. Time it takes to reach consensus in group foraging depends on the expected value of the environment

Zhilin Su[1], Elizabeth Berry[1], Todd Vogel[1], Matthew Apps[1], Patricia Lockwood[1]
[1]*Centre for Human Brain Health, University of Birmingham*

Both animals and humans typically forage in groups rather than alone, as group foraging offers significant evolutionary benefits in the wild. As humans, we make collective reward-based decisions all the time, both in the workplace and in our social lives. To fully benefit from group living, individuals have to coordinate their behaviours and reach consensus. However, to our knowledge, no existing studies have examined how human social groups reach consensus when foraging for rewards in different environments based on the average reward rate. Here, we investigated whether group foraging improves or impairs decision optimality compared to foraging alone, and how these decisions are shaped by the environment and patch yield. We also examined how these factors affect when a group reaches consensus. In our study, participants (N=39; 13 groups) in groups of three completed a computerised, gamified patch-leaving task in which they decided when to leave the current patch. The task was framed as a job where participants were 'hired' to make juice (forage) and decide when to clean the blender (leave/travel), either individually or in a group of three. They made decisions in two seasonal environments: in autumn (poor environment), thick juice (low-yield patches) was more common; in spring (rich environment), smooth juice (high-yield patches) was more common. We found that people's decisions to leave a patch in both individual and group foraging were influenced by patch yield quality ($ps < 0.001$) but not by the environment ($ps > 0.05$). Exploratory analyses revealed that groups took longer to reach consensus in poor environments than in rich ones, particularly when deciding to leave high-yield patches ($p = 0.039$). Together, these results provide initial evidence for environmental effects on consensus time in group foraging, with further work underway to test their robustness and uncover the mechanisms driving them.

P14. Reinforcement learning and foraging strategies for animals under starvation

Jonathan Undelikwo[1], Jiamu Jiang[1], **Mark Van Rossum**[1]
[1]*University Of Nottingham*

Traditionally, foraging strategies have been formulated using reinforcement learning. This naturally leads to exploration/exploitation trade-offs and optimal algoriths. Typically in reinforcement learning the only objective is to maximize the reward. Bandit algorithms such as UCB and Thomson sampling are known to under general conditions maximize the reward that the agents collect over time (i.e. minimize the regret).

In this work we examine a situation where the organism has a limited energy reserve. Using a hazard framework, we model that, when the energy reserve becomes low, the animal has an increased probability of dying of starvation. Rather than maximizing reward, the objective of the foraging strategy is now to maximize the lifetime of the animal.
We present numerical simulation of this framework and show how traditional bandit algorithms lead to high reward but sub-optimal lifetimes. However, these reinforcement learning can be modified and made dependent on the internal energy reserve of the animal so that they lead to longer lifetimes. We compare our findings to existing data and applications to other Reinforcement learning algorithms.

P15. Environmental influence on human decision-making to help others

Todd Vogel[1], Luke Priestley, Jo Cutler, Tabith Hogg, Nima Khalighinejad, Neil Garrett, Matthew Apps, Matthew Rushworth, Patricia Lockwood
[1]*University Of Birmingham*

Everyday behaviours are often interrupted with alternative options, such as deciding to stop watching TV to make dinner for your family. However, most studies on these kinds of prosocial behaviours—actions that help others—focus on selecting which action to take, rather than deciding whether to act at all. Ecological theories of prey selection suggest that animals' choices to act are influenced by the reward distribution of the environment, being more likely pursue rewarding opportunities in poorer environments. Here, we extend these ideas to examine how the environment influences choices to interrupt behaviour to pursue reward for other people.

We measured people's willingness to interrupt their ongoing behaviours to help others or themselves in a sequential accept-reject task inspired by foraging paradigms. Participants watched a movie whilst encountering opportunities to interrupt their behaviour to benefit another person, or on separate trials, themselves. In poor environments, opportunities were on average lower in value and probability compared to those in rich environments. We found a stronger environmental influence (more likely to act in poor environment than rich one) on decisions that affected other people compared to self-benefitting decisions. Computational modelling of choice behaviour revealed that the opportunity costs of different environments were encoded distinctly for others and self.

Collection of MRI and MEG data is currently ongoing; we will examine neural representations of value when deciding for others vs oneself (focusing on areas of the anterior cingulate cortex (sub-region in the gyrus vs. subgenual region; Lockwood et al., 2022) and the temporal parietal junction), and tracking of environmental features (Khalighinejad, et al., 2021). Overall, these findings demonstrate that the quality of one's immediate environment can have strong, robust effects on decisions to act, and that these effects differ when the decisions affect other humans.

P16. Tonic dopamine in patch foraging decision

Tsz Fung Woo[1], Laura Grima[2], Dario Sarra[3], Thomas Akam[1,4], Mark Walton[1,4]
[1]*Department of Experimental Psychology, University of Oxford*, [2]*Janelia Research Campus*, [3]*Champalimaud Research*,[4]*Wellcome Centre for Integrative Neuroimaging, Oxford University*

Patch foraging decisions represent a fundamental form of decision-making in which animals must determine when to abandon a depleting resource patch in favor of exploring alternatives. According to the Marginal Value Theorem (MVT), an optimal foraging agent should compare the local patch value with the average environmental value to decide when to leave. In this study, we developed an operant patch foraging task in which both the local reward rate (patch value) and global reward rate (environment value) were modulated. Mice exhibited hallmarks of optimal foraging behavior. To model these decisions, we implemented a reinforcement learning model grounded in MVT principles to capture animals' subjective estimates of patch and environment value.
In parallel with behavior, we recorded dopamine signals from the dorsomedial striatum, nucleus accumbens, and ventral tegmental area. While transient dopamine responses are well known for their role in reinforcement learning, recent findings suggest that dopamine dynamics on slower timescales reflect reward rate. In this study, we demonstrated that these slow dopamine signals exhibit region-specific dynamics in encoding local and global reward rates, suggesting that distinct brain areas may differentially represent patch and environmental value.

P17. Investigating circadian modulation of motivation using an effort-based foraging task in mice

Foteini Xeni[1]
[1]*University Of Bristol*

Motivation is defined as a measurable approach, avoidance or action in response to a specific sensory stimulus aimed at fulfilling a biological need. The circadian system plays a critical role in the temporal organization of motivated behaviours, by regulating the daily activity in motivation-related neural networks. This relationship is bidirectional, as natural rewards, such as food, can act as time cues and resynchronize the circadian system. However, the specific mechanism(s) underlying these interactions remain unclear, limiting our ability to develop targeted interventions to restore circadian function and motivation when both systems decline, such as in healthy ageing. Behavioural research on this topic has mostly relied on food reward to assess circadian modulation of motivation. However, food-intake is regulated by homeostatic and hedonic (motivation) mechanisms which are both under circadian control. Thus, when using food as reward, these factors, make it difficult to isolate circadian influences on motivation. To overcome this, studies must explore decision-making and motivation using non-food-based, ethologically relevant tasks. Rodents are foraging animals, and the search for nesting material represents an intrinsically motivated form of decision-making. This study investigates daily rhythms in motivation using an effort-based foraging (EBF) task. In initial experiments under standard light-dark conditions we observed a rhythmic pattern of foraging motivation in male mice, with a peak occurring 4-6h after lights-off. We are now assessing whether this rhythm persists under constant darkness, indicating endogenous circadian regulation. Finally, we will test whether non-food-motivated foraging can act as a reward-entrainable oscillator. By utilizing an innate, evolutionary conserved behaviour the EBF task enables investigation of the bidirectional interaction between the circadian system and motivation in a translationally relevant framework. This approach overcomes key limitations of previous behavioural models and open-up new ways for understanding how intrinsic motivation is modulated by circadian processes, an area that remains largely unexplored.

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