SBDM 2016

Sixth Symposium on Biology of Decision-Making

May 25-27, 2016, ICM-ENS, Paris, France

Organizers

Thomas Boraud, Kenji Doya, Mehdi Khamassi

Etienne Koechlin & Mathias Pessiglione

Local organizers

Natacha Logerot, Marine Magne & Delphine Oudiette

Our partners & Funders

Presentation

The Sixth International Symposium on "**Biology of Decision Making**" (SBDM) will take place on **May 25-27, 2016** in Paris, France.

The first two days of conference will take place at the Institut du Cerveau et de la Moelle (ICM), 47 Boulevard de l'Hôpital, 75013 Paris.

The third day will take place at Ecole Normale Supérieure (ENS), 45 rue d'Ulm, 75005 Paris.

A Social Event will take place in the evening of **May 26** in Zamansky Tower on the campus of Université Pierre et Marie Curie, 4 place Jussieu, 75005 Paris.

The objective of this three-day symposium will be to gather people from different research fields with different approaches (economics, ethology, psychiatry, neural and computational approaches) to decision making.

The conference will include 6 sessions:

1) Dynamics of decision-making;
2) Emotion, stress and decision-making;
3) Cost of control, fatigue and decision-making;
4) Decision-making across primates;
5) Confidence, mood and decision-making;
6) Learning, memory and decision-making.

May 25 (ICM)

8:30 am Registration
8:50 am Welcome word

Dynamics of Decision Making

Chair: Mathias Pessiglione

9:00 – 10:45 am

Adèle Diederich,
"Multi-stage sequential sampling model for multiattribute choice alternatives with random attention time and processing order"

Anne Churchland,
"Neural circuits for multisensory decision making"

Jonathan Pillow,
"Exploring the single-trial dynamics of neural activity in parietal cortex during decision-making."

10:45 – 11:15 am Break

11:15 – 12:30 am

Birte Forstmann,
"Striatum codes for the dynamics of decision urgency in the human brain"

Tobias Donner,
"Phasic Arousal Reduces Bias by Shaping Parietal Decision Signals"

12:30 – 14:30 pm Poster sessions and Lunch

Emotions, Stress & Decision-making

Chair: Delphine Oudiette

14:30 – 16:15 pm

Carmen Sandi,
"The role of brain bioenergetics on the effects of stress and anxiety in social behaviors"

Daniela Schiller,
"Dynamic tracking of social relationships in the human brain."

Cendri Hutcherson,
"Neurocomputational insights into social decision making and self-control"

16:15 – 16:45 pm Break

16:45 – 18:00 pm

Julie Grèzes,
"The interpersonal impact of emotional displays on action decision-making"
Anastasia Christakou,
"Multi-modal neuroimaging of flexible decision-making at the experiential and developmental time-scales."

May 26 (ICM)

Cost of control, fatigue & decision-making

Chair: Mehdi Khamassi

9:00 – 10:45 am

Amitai Shenhav,
"The attraction and costs of choice"

Alexandre Zénon,
"Re-exploring the psychophysiology of mental effort"

Veronika Job,
"Is the capacity for self-control a limited resource?"

10:45 – 11:15 am Break

11:15 – 12:30 am

Mathias Pessiglione,
"Executive fatigue and decision-making in the long run".

Michael Chee,
"To Press On or Not: Mental Effort Exertion When Sleep Deprived"

12:30 – 14:30 pm Poster sessions and Lunch

Decision-making across primates

Chair: Thomas Boraud

14:30 – 16h15 pm

Mark Sheskin,
"Moral decision-making across primates"

Alexandra Rosati,
"Evolutionary economics: Decision-making under uncertainty in chimpanzees, bonobos, and humans"

Valérie Dufour,
"Decision making under risk in several primate species: can we differentiate loss aversion from risk aversion?"

16:15 – 16:45 pm Break

16:45 – 18:00 pm

Sebastien Bouret,
"What is the function of the ventromedial prefrontal cortex? Insight from a comparative perspective."

Jérôme Sallet,
"Neural circuits associated with behavioral flexibility in humans and macaques"

19:30 – 22:00 pm Social Event (Zamansky Tower, Jussieu)

May 27 (ENS)

Confidence, Mood & Decision-making

Chair: Kenji Doya

9:00 – 10:45 am

Stanislas Dehaene & Florent Meyniel,
"Confidence in a learning context"

Steve Fleming,
"Knowing that we know: the building blocks of self-knowledge in decision-making"

Robb Rutledge,
"A computational and neural model of momentary subjective well-being"

10:45 – 11:15 Break

11:15 – 12:30 am

Pascal Mamassian,
"Comparison of Signal Detection Theory and Accumulation of Evidence Models for Visual Confidence"

Tim Pleskac,
"Mapping the dynamic properties of confidence"

12:30 – 14:30 pm Lunch

Learning, memory & decision-making

Chair: Etienne Koechlin

14:30 -16:15 pm

Hiromu Tanimoto,
"Neural circuits that distinguish memory processes in the fly brain"

Shelly Flagel,
"Elucidating the neural circuitry underlying individual differences in response to reward-associated cues"

Angela Yu,
"Change-Point Detection without the Need to Detect Change-Points"

16:15 – 16:45 pm Break

16:45 – 18:00 pm

Mehdi Khamassi,
"A computational account of the role of dopamine in model-free learning and exploration modulation."

Randal O'Reilly,
"A computational Framework for Goal-Driven Learning in the Brain"

Meeting venues

May 25-26 Institut du Cerveau et de la Moelle Epinière (ICM),

Hôpital Pitié-Salpêtrière, 47 boulevard de l'hôpital – 75013 Paris

Institut du Cerveau et de la Moelle Epinière (ICM)

- **Chevaleret** (line 6), allowing access to the hospital from the 54 Bd Vincent Auriol
- **Austerlitz** (line 5 & 10, RER C), allowing access to the hospital from the 47 Bd de l'Hôpital
- **Saint Marcel** (line 5), allowing access to the hospital from the 47 Bd de l'Hôpital

May 27 Ecole Normale Supérieure (ENS)

29 rue d'Ulm, 75005 Paris

Ecole Normale Supérieure (ENS)

- **Censier-Daubenton**: line 7
- **Luxembourg**: RER B

Social event (May 26 evening): Zamansky Tower (24th fl.), UPMC campus

Univ. Pierre & Marie Curie, 4 place Jussieu – 75005 Paris

University Pierre & Marie Curie is served by metro station:

- **Jussieu**: line 7 and line 10

SBDM 2016 // Talks

Authors by alphabetical orders

Each talk will be 25-min long, followed by 10 min of questions

What is the function of the ventromedial prefrontal cortex? Insight from a comparative perspective.

Sebastien Bouret
Team Motivation Brain & Behavior (MBB)
Institut du Cerveau et de la Moelle Epiniere, Paris

To Press On or Not: Mental Effort Exertion When Sleep Deprived

Michael WL Chee; Stijn Massar
Centre for Cognitive Neuroscience
Duke-NUS Medical School, Singapore

Multi-modal neuroimaging of flexible decision-making at the experiential and developmental time-scales

Anastasia Christakou
School of Psychology and Clinical Language Sciences
Centre for Integrative Neuroscience and Neurodynamics
University of Reading UK

Neural circuits for visual decision-making

Anne Churchland
Cold Spring Harbor Laboratory, Cold Spring Harbor, New York, USA

Confidence in a learning context

Stanislas Dehaene; Florent Meyniel
Neurospin, CEA, Gif-sur-Yvette

Multi-stage sequential sampling model for multiattribute choice alternatives with random attention time and processing order

Adele Diederich
Jacobs University Bremen

Phasic Arousal Reduces Bias by Shaping Parietal Decision Signals

Tobias Donner, MD, PhD
University Medical Center Hamburg-Eppendorf

"Decision making under risk in several primate species: can we differentiate loss aversion from risk aversion?"

Dufour V. [1], [2], Romain A.[1].[2], Broihanne M.-H.[3],
[1] Centre National de la Recherche Scientifique, Institut Pluridisciplinaire Hubert Curien Département Ecologie, Physiologie et Ethologie, Strasbourg, France
[2] Université de Strasbourg, Strasbourg, France
[3] Laboratoire de Recherche en Gestion et Economie, EM Strasbourg Business School, Université de Strasbourg, Strasbourg, France

Elucidating the neural circuitry underlying individual differences in response to reward-associated cues

Shelly B. Flagel, Ph.D.
Department of Psychiatry, Molecular and Behavioral Neuroscience Institute, University of Michigan, Ann Arbor, USA

Knowing that we know: the building blocks of self-knowledge in decision-making

Stephen M. Fleming
Wellcome Trust Centre for Neuroimaging, University College London

Striatum codes for the dynamics of decision urgency in the human brain

Birte Forstmann
Amsterdam Brain & Cognition Center, University of Amsterdam, Amsterdam, the Netherlands

The interpersonal impact of emotional displays on decision-making

Julie Grèzes, Marwa El Zein and Emma Vilarem
Lab of Cognitive Neurosciences, INSERM U960, Ecole Normale Supérieure, Paris

Neurocomputational insights into social decision making and self-control

Cendri Hutcherson
University of Toronto, California Institute of Technology

Is the capacity for self-control a limited resource?

Veronika Job
University of Zurich

A computational account of the role of dopamine in model-free learning and exploration modulation.

Mehdi Khamassi[1], [2]
[1] CNRS, Institute of Intelligent Systems and Robotics (ISIR), UMR 7222, F-75005 Paris Cedex, France
[2] Sorbonne Universités, UPMC Univ Paris 06, ISIR, F-75005 Paris, France

Comparison of Signal Detection Theory and accumulation of evidence models for visual confidence

Pascal Mamassian
Laboratoire des Systèmes Perceptifs,
CNRS & Ecole Normale Supérieure, Paris, France

A Computational Framework for Goal-Driven Learning in the Brain

Randal O'Reilly
Department of Psychology and Neuroscience, University of Colorado Boulder, Boulder CO USA.

Executive fatigue and decision-making in the long run

Mathias Pessiglione
Motivation, Brain & behaviour (MBB) team
Institut du Cerveau et de la Moelle épinière, Hôpital de la Pitié-Salpêtrière, Paris

Exploring the single-trial dynamics of neural activity in parietal cortex during decision-making

Jonathan Pillow, Kenneth Latimer, Jacob Yates, Miriam Meister, & Alex Huk
Princeton University

Mapping the dynamic properties of confidence

Timothy J. Pleskac, Shuli Yu, and Peter D. Kvam
Max Planck Institute for Human Development & Michigan State University

Evolutionary economics: Decision-making under uncertainty in chimpanzees, bonobos, and humans

Alexandra G. Rosati
Department of Human Evolutionary Biology
Harvard University

A computational and neural model of momentary subjective well-being

Robb B Rutledge, Archy O de Berker, Svenja Espenhahn, Nikolina Skandali, Peter Dayan, Raymond J Dolan
University College London

Neural circuits associated with behavioral flexibility in humans and macaques

Jérôme Sallet
University of Oxford

The role of brain bioenergetics on the effects of stress and anxiety in coping behaviors

Carmen Sandi
Brain Mind Institute, Ecole Polytechnique Federale de Lausanne (EPFL), Switzerland

Dynamic tracking of social relationships in the human brain

Daniella Schiller
Icahn School of Medicine at Mt. Sinai

The Attraction and Costs of Choice

Amitai Shenhav[1], [2], Uma Karmarkar [3], Randy Buckner[4], [5]
[1] Princeton University
[2] Brown University
[3] Harvard Business School
[4] Harvard University
[5] Harvard Medical School

Moral decision-making across primates

Mark Sheskin
Yale University

Neural circuits that distinguish memory processes in the fly brain

Mai Kanno, Toshiharu Ichinose, Hiromu Tanimoto
Tohoku University, Graduate School of Life Sciences

Change-Point Detection without the Need to Detect Change-Points

Angela Yu, Chaitanya Ryali
University of California San Diego

Re-exploring the psychophysiology of mental effort

Alexandre Zénon
Université catholique de Louvain; Bruxelles, Belgium

SBDM 2016 // Abstracts of the talks

Authors by alphabetical orders

What is the function of the ventromedial prefrontal cortex? Insight from a comparative perspective.

Sebastien Bouret
Team Motivation Brain & Behavior (MBB)
Institut du Cerveau et de la Moelle Epiniere, Paris

The primate ventro-medial prefrontal cortex (VMPFC) is involved in value-based decision making, but two questions remain open: why and how?
I will address these questions using two approaches: 1) a comparaison of neuroanatomical and ecological features across several primate species 2) neurophysiological and behavioral studies in rhesus monkeys performing well controlled laboratory tasks. The VMPFC seems particularly involved when primates adjust their behavior based on internal representations, rather than individual events and sensory inputs. More generally, the primate VMPFC might be critical for building cognitive constructs that drive goal directed behavior irrespectively of immediate changes in the environment. This function would be critical for foraging in the complex and variable environments in which primates evolved.

To Press On or Not: Mental Effort Exertion When Sleep Deprived

Michael WL Chee; Stijn Massar
Centre for Cognitive Neuroscience
Duke-NUS Medical School, Singapore

An increasing number of persons work and interact with others when sleep deprived. Performing under conditions of decreased cognitive capability puts one at a disadvantage. Selective attention, rate of visual information processing and distractor inhibition are degraded with sleep deprivation and these are accompanied by accelerated time on task effects. Against this, some faculties like implicit estimation of temporal intervals and delay discounting are not affected. Given this backdrop, one can expect alterations in how mental effort is allocated when we are sleep deprived. Indeed, greater effort discounting has been observed but interestingly, at least in the short term, increasing reward in vigilance tasks may provide some respite.

Multi-modal neuroimaging of flexible decision-making at the experiential and developmental time-scales

Anastasia Christakou
School of Psychology and Clinical Language Sciences
Centre for Integrative Neuroscience and Neurodynamics
University of Reading UK

Human adaptive behaviour depends less on brute computational force and more on the ability to continually and flexibly re-evaluate the environment. This ability matures slowly and is deployed differently at different stages of life, and its perturbation is associated with disorders of affect, thought and behaviour.
In our work we use multimodal neuroimaging techniques and computational modelling to track the maturation of behavioural and neural mechanisms that contribute to this flexibility, and characterise the components that may explain its pathology in internalising and externalising disorders.
We focus on the maturational remodelling of corticosubcortical circuitry (basal ganglia and amygdala), and of afferent influences on the striatum, principally from the midbrain and the thalamus.
In recent work we integrate structural and functional connectivity with dynamical analysis methods to understand flexible decision-making at multiple time-scales.

Neural circuits for visual decision-making

Anne Churchland
Cold Spring Harbor Laboratory, Cold Spring Harbor, New York, USA.

Neurons in putative decision-making structures can reflect both sensory and choice signals, making their causal roles in decisions unclear. Here, we tested whether rat posterior parietal cortex (PPC) is causal for processing visual sensory signals or instead for accumulating evidence for choice alternatives. We optogenetically disrupted PPC activity during decision-making and compared effects on decisions guided by auditory vs. visual evidence. Deficits were largely restricted to visual decisions. To further test for visual dominance in PPC, we evaluated electrophysiological responses following individual sensory events and observed much larger responses following visual, compared to auditory stimuli. Finally, we measured spike count variability during stimulus presentation and decision formation. This sharply decreased, suggesting the network is stabilized by inputs, unlike what would be expected if sensory signals were locally accumulated. Our findings argue that PPC plays a causal role in discriminating visual signals that are accumulated elsewhere to guide choice.

Confidence in a learning context

Stanislas Dehaene and Florent Meyniel
Neurospin, CEA, Gif-sur-Yvette

Multi-stage sequential sampling model for multiattribute choice alternatives with random attention time and processing order

Adele Diederich
Jacobs University Bremen

A sequential sampling model for multiattribute binary choice options assumes a separate sampling process for each dimension/attribute. During the deliberation process attention switches from one attribute consideration to the next. The order in which attributes are considered as well for how long each attribute is considered - the attention time - influences the predicted choice probabilities and choice response times. Several probability distributions for the attention time including deterministic, geometric, and uniform with different variances are investigated. Depending on the time and order schedule the model predicts a rich choice probability/choice response time pattern including preference reversals and fast errors. Predictions of the model and applications to data (perceptual and preferential) are shown. Its relation to the dual process metaphor is provided.

Phasic Arousal Reduces Bias by Shaping Parietal Decision Signals

Tobias Donner, MD, PhD
University Medical Center Hamburg-Eppendorf

A hallmark of decision-making is its variability: People make different choices in the face of repeated presentations of the same information. Many decisions entail the gradual accumulation of decision-relevant evidence towards bounds, crossing of which determines the commitment to a choice. Posterior parietal association cortex is implicated in this evidence accumulation process. Parietal cortex also receives dense projections from modulatory brainstem systems, which activate phasically during decisions and control cortical arousal state. We hypothesize that phasic arousal signals during decisions shape the state of parietal decisions circuits and, thereby, the evidence accumulation process; consequently, trial-to-trial fluctuations in phasic arousal produce variability in choice behavior.

In this talk, I will present ongoing work from our lab that addresses this hypothesis in healthy human subjects, by combining pupillometric assessment of central arousal state, quantitative modeling of choice behavior, and fMRI/MEG measurements of brain activity. We find that trial-to-trial fluctuations in pupil-linked, phasic arousal during decisions are mirrored in the phasic activation of a set of brainstem centers, including the locus coeruleus, the source of noradrenergic projections to the cortex. In a yes-no decision, the amplitude of phasic arousal also accounts for a significant reduction in the (conservative) bias of the evidence accumulation process. This effect is mediated by a surprisingly selective modulation of decision signals in parietal cortex.

Our results indicate that phasic arousal signals can “edit” cortical evidence accumulation processes as decisions unfold. This accounts for a significant component of the variability in choice behavior over and above the objective evidence. These insights may have implications for the disturbances of choice behavior observed in the neuropsychiatric disorders associated with altered arousal systems.

Decision making under risk in several primate species: can we differentiate loss aversion from risk aversion?"

Dufour V. [1], [2], Romain A.[1].[2], Broihanne M.-H.[3,]
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[3] *Laboratoire de Recherche en Gestion et Economie, EM Strasbourg Business School, Université de Strasbourg, Strasbourg, France*

Decision making under risk, i.e. choices involving benefits and/or losses, is fundamental in humans and other animals. Biologists generally aim at highlighting particular attitudes towards risk (i.e. risk proneness or risk aversion for example) that would reflect naturally selected adaptations to past environmental conditions for a given species. By contrasts with human studies of choice, those studies often fail to consider the interplay between the mechanisms involved in the decision such as the respective role of loss aversion, risk attitudes and probability distortion, for example. Here we analyse and compare four ape and two monkey species decisions in a food gambling game under a stochastic dominance framework to uncover the determinants of their gambling decisions. We detect an asymmetry in gambling behaviour that depends both on probability levels and on the “domain” (gain versus loss). As subjects exhibit risk aversion under gains and risk proneness under losses (reflection effect), their decision process is not primarily driven by loss aversion but by different attitudes towards gains and losses together with attitudes towards probabilities. These results indicate that the biological study of decision making and attitudes toward risk can greatly benefit from an economic perspective.

Keywords: risk, losses, decision making, gambling, economics, primates

Elucidating the neural circuitry underlying individual differences in response to reward-associated cues

Shelly B. Flagel, Ph.D.
Department of Psychiatry, Molecular and Behavioral Neuroscience Institute, University of Michigan, Ann Arbor, USA

In recent years, we have utilized an animal model that captures individual variation in response to reward-associated cues to examine the neural mechanisms that underlie different forms of reward learning that are relevant to addiction. When rats are exposed to a classical Pavlovian conditioning paradigm, wherein a lever (conditioned stimulus, CS) predicts the delivery of food reward (unconditioned stimulus), the conditioned response that develops varies between individuals. Some rats, termed "goal-trackers", go to the location of reward delivery upon presentation of the lever-CS; whereas others, termed "sign-trackers", approach and manipulate the lever-CS upon its presentation. Importantly, delivery of the reward is non-contingent upon a response, and both goal-trackers and sign-trackers learn their conditioned response at the same rate. Thus, the lever-CS serves as a predictive stimulus for all rats. For sign-trackers, however, the lever-CS becomes attractive and reinforcing in its own right, to the extent that these rats will work for presentation of the lever-CS in the absence of food reward. Thus, for sign-trackers, the discrete reward cue is attributed with incentive salience and becomes an incentive stimulus, and this is true for both food- and drug-associated cues. Using this animal model, we have shown that different neural circuits are "engaged" when a discrete reward cue is attributed with predictive vs. incentive value. The cortico-striatal-thalamic motive circuit is activated to a greater degree in sign-trackers relative to goal-trackers in response to food- and drug-associated cues. Within this circuit, the paraventricular nucleus of the thalamus (PVT) appears to be a central node, mediating both sign- and goal-tracking behaviors as well as the ability of a drug-associated cue to reinstate drug-seeking behavior in a phenotype-dependent manner. Using chemogenetic tools, we have shown that manipulation of inputs from the prelimbic cortex to the PVT can alter the behavioral phenotypes, suggesting that these inputs act to inhibit the attribution of incentive salience to reward cues. Taken together, these data highlight a role for the prelimbic-PVT circuit in regulating responses to both food- and drug-associated cues, implicating this circuit in maladaptive behaviors related to addiction.

Knowing that we know: the building blocks of self-knowledge in decision-making

Stephen M. Fleming
Wellcome Trust Centre for Neuroimaging, University College London

A remarkable feature of the human mind is its capacity for assessing or monitoring its own knowledge, known as metacognition. Self-evaluation of decision-making is particularly relevant for guiding behaviour when external feedback is sparse or absent. In the lab we can study this process by asking people to rate their confidence in simple decision tasks, and assess the correspondence between task performance and subjective confidence. In the first part of my talk I will focus on leveraging individual differences in this measure to shed light on the neural substrates of metacognition in perceptual decision-making. I will then ask whether the neural basis for metacognition is shared across different domains such as perception and memory, drawing on studies of patients with post-surgical brain lesions and studies of the healthy brain using functional MRI and multi-voxel pattern analysis. I conclude that there are both domain-general and domain-specific neural substrates supporting self-knowledge.

Striatum codes for the dynamics of decision urgency in the human brain

Birte Forstmann
Amsterdam Brain & Cognition Center, University of Amsterdam, Amsterdam, the Netherlands

Deciding between multiple courses of action often entails an increasing need to do something as time passes - a sense of urgency. This notion of urgency is not incorporated in standard theories of speeded decision-making that assume information is accumulated until a critical fixed threshold is reached, controlled through activation of the striatum. In two experiments, we investigated the behavioral and neural evidence for an "urgency signal" in humans. Experiment 1 found that as the duration of the decision-making process increased, participants made a choice based on less evidence for the selected option. Experiment 2 replicated this finding, and additionally found that variability in this effect across participants covaried with activation in striatum. We conclude that striatum plays a more general role in the decision-making process than previously reported. By dynamically updating the threshold, striatal activation represents a neural implementation of the urgency signal in humans.

The interpersonal impact of emotional displays on decision-making

Julie Grèzes, Marwa El Zein and Emma Vilarem,
Lab of Cognitive Neurosciences, INSERM U960, Ecole Normale Supérieure, Paris.

Evolutionary theoretical accounts suggest that emotional displays serve a communicative function, implying 1) that emotional signals have co-evolved with recipient's decoding skills and behavioral responses and 2) that the recipient's response should reflect the social function of the perceived expression. We experimentally address these assumptions in 3 experiments and reveal 1) that neutral structural facial features are encoded automatically in the human brain biasing emotion categorization toward specific emotional expressions evoked by these features (El Zein et al. in prep); 2) that the neural sensitivity to threat-signaling emotions is enhanced in both ventral face-selective cortices and in action preparation motor cortices 200 ms following face presentation (El Zein et al. 2015); and finally 3) that there is a selective impact of threat-signaling displays on action selection processes: anger elicits avoidance behaviors while fear prompts affiliative approach tendencies (Vilarem et al. in prep). Altogether, these results indicate that emotional displays promote the elaboration of adapted decisions and specific motor actions.

Neurocomputational insights into social decision making and self-control

Cendri Hutcherson
University of Toronto, California Institute of Technology

Selfish, unethical, and short-sighted decision making lies at the heart of some of society's most pressing problems, but it is unclear why people so often struggle to make virtuous choices. Here, I show how a simple neurally-informed computational model of choice can account for a wide range of complex social decisions. The model makes novel predictions, borne out by behavioral and neural data, about when and why some choices are more difficult than others. It also suggests a need to refine popular competitive dual-system models of choice in light of computational model predictions, and points to new ways to help people make better choices for themselves and others

Is the capacity for self-control a limited resource?

Veronika Job
University of Zurich

The strength model of self-control suggests that acts of self-control consume from a limited resource, leaving people in a state of ego-depletion and making them less able to exert self-control on subsequent tasks. In a series of studies we showed that the way people think about willpower (as consuming from a limited vs. as a non-limited resource) affects their ability to exert self-control on subsequent tasks. Exploring mechanisms that may explain these effects we found that people who think that willpower is a limited resource are motivated to preserve and replenish their resources after they experience a task as exhausting. People who view willpower as non-limited show no such motivational shifts. Taken together, the findings suggest that reduced self-control after a depleting task or during demanding periods may reflect people's beliefs about the availability of willpower and the consequential motivation to preserve resources rather than true resource depletion.

A computational account of the role of dopamine in model-free learning and exploration modulation.

Mehdi Khamassi[1, 2]
[1] *CNRS, Institute of Intelligent Systems and Robotics (ISIR), UMR 7222, F-75005 Paris Cedex, France*
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The model-free reinforcement learning (MFRL) framework, where agents learn cached implicit action values without trying to estimate a model of their environment, has been successfully applied to Neuroscience in the last two decades. It can account for most dopamine reward prediction error signals (RPEs) in Pavlovian and instrumental tasks. However, it is still not clear why in the Pavlovian autoshaping paradigm RPEs can been recorded in some individuals but not in others. Moreover, the role of dopamine in other functions not related to learning is still not understood.

Using a neurocomputational model of the basal ganglia, we have previously shown that changing the level of simulated tonic dopamine has an impact on the exploration-exportation trade-off. This predicted that, in addition to possible effects on learning, dopamine manipulations would also have impact on performance which could look like learning effects while only directly altering the trade-off.

We have then combined this computational principle with a model-based / model-free reinforcement learning model applied to Pavlovian autoshaping. In this model, in addition to MFRL, simulated agents also try to estimate a model of the consequences of their behavior on the environment (i.e. model-based, MBRL). This model can explain inter-individual differences by a different relative weight of MFRL and MBRL on behavior: The behavior of sign-trackers is mostly led by MFRL, displaying dopamine RPEs and pushing them towards reward predicting stimuli; In contrast the behavior of goal-trackers is mostly led by MBRL, where dopamine RPEs is absent, and pushing them towards the outcome of their behavioral responses. This model predicts that sign-trackers would be less sensitive to outcome devaluation than goal-trackers, which has recently been confirmed experimentally. Moreover, the model explains why injection of flupenthixol in goal-trackers impairs the exploration-exploitation trade-off and thus blocks the expression of a covert dopamine-independent MBRL learning process.

Finally, we have recently performed injections of different doses of flupenthixol in rats learning different reward probabilities associated to three levers and facing non-signaled block changes (non-stationary multi-armed bandit task). Using model-based analyses of behavioral data, we have found a dose-dependent effect of flupenthixol on the modulation of the exploration parameter but not on the learning rate.

Together these results suggest a variety of mechanisms on which dopamine can impact, which can be progressively better understood through to the tight collaboration between experimentation and computational modeling.

Comparison of Signal Detection Theory and accumulation of evidence models for visual confidence

Pascal Mamassian
Laboratoire des Systèmes Perceptifs
CNRS & Ecole Normale Supérieure, Paris, France

Visual confidence refers to an observer's ability to judge the accuracy of her perceptual decisions. Even though confidence judgments have been recorded since the early days of psychophysics, there are still some debates about whether some popular methods, such as the use of confidence ratings, genuinely reveal the observer's confidence. In this presentation, I will summarise some concerns generally raised with common confidence measures and present an alternative method based on the confidence forced-choice paradigm. This method has been used in a variety of tasks and, in particular, has led to the conclusion that perceptual confidence can be registered in a common currency. I will also summarise the two main theoretical framework offered to describe confidence that are based on Signal Detection Theory and accumulation of evidence models. Finally, I will discuss the consequences of having perceptual accuracy and confidence derived from not necessarily identical evidence. Overall, proper conjoint measurements of accuracy and confidence should offer us a deeper understanding of visual perception.

Joint work with Vincent de Gardelle, Simon Barthelmé, Alan Lee, and Baptiste Caziot

A Computational Framework for Goal-Driven Learning in the Brain

Randal O'Reilly
Department of Psychology and Neuroscience, University of Colorado Boulder, Boulder CO USA.

We explore the idea that active goals guide behavior in a very proactive manner: we are not passively reacting to options presented to us — instead we are actively seeking desired outcomes. As such, there are two basic modes of goal-driven behavior: goal selection and goal pursuit, and they appear to have very different value functions. We are developing computational models of these dynamics, focusing on the roles of the OFC, ACC, and DLPFC along with corresponding areas of the basal ganglia and the subcortical dopamine systems. Specifically, I will show how predictive error-driven learning in the OFC can learn representations that guide proactive goal selection processes, to favor beneficial outcomes.

Executive fatigue and decision-making in the long run

Mathias Pessiglione
Motivation, Brain & behaviour (MBB) team
Institut du Cerveau et de la Moelle épinière, Hôpital de la Pitié-Salpêtrière, Paris

While we understand quite well why muscles ache after prolonged exercise, the origins of mental fatigue still appear totally mysterious. Existing theories remain at a psychological level, with scarce supporting evidence. Mental fatigue typically occurs after long episodes during which humans exert control on motor or cognitive processes, instead of executing routine or stimulus-driven behaviours.

In this talk, I will suggest a concept of executive fatigue based on the following core assumptions (supported by preliminary data):

a) Fatigue arises from the prolonged use of a specific brain system dedicated to executive control, in the lateral prefrontal cortex.

b) Recruitment of the executive control system is the result of an arbitrage between expected benefits and costs, the latter increasing with fatigue.

c) Fatigue may not manifest as performance decrease with time-on-task but as a bias in unrelated choices, due to lack of executive control during decision-making, which might condition socio-professional success.

d) Fatigue develops over much longer time scales (from hours to weeks) than usually explored, and in severe cases result in major health issues known as overtraining or burnout syndromes.

Exploring the single-trial dynamics of neural activity in parietal cortex during decision-making

Jonathan Pillow, Kenneth Latimer, Jacob Yates, Miriam Meister, & Alex Huk
Princeton University

Abstract: Neural firing rates in the macaque lateral intraparietal (LIP) cortex exhibit gradual "ramping" that is commonly believed to reflect the accumulation of sensory evidence during decision-making. However, ramping that appears in trial-averaged responses does not necessarily indicate that the spike rate ramps on single trials; a ramping average rate could also arise from instantaneous steps that occur at different times on each trial. In this talk, I will describe an approach to this problem based on explicit statistical latent-dynamical models of spike trains. We analyzed LIP spike responses using spike train models with: (1) ramping "accumulation-to-bound" dynamics; and (2) discrete "stepping" or "switching" dynamics. Surprisingly, we found that three quarters of choice-selective neurons in LIP are better explained by a model with stepping dynamics. We show that the stepping model provides an accurate description of LIP spike trains, allows for accurate decoding of decisions, and reveals latent structure that is hidden by conventional stimulus-aligned analyses. Finally, I will discuss more recent insights into the coding of decisions using simultaneous multi-neuron recording in areas MT and LIP during decision formation.

Mapping the dynamic properties of confidence

Timothy J. Pleskac, Shuli Yu, and Peter D. Kvam
Max Planck Institute for Human Development & Michigan State University

How confident are you in your choice? Such a simple question for people to answer. Yet, modeling how people answer that question has proven challenging. Part of the challenge has been that it has been unclear what information is used to make a choice and what information is used to make a confidence judgment. Another part of the reason is that confidence is conceptualized as a static variable that does not change over time. In this talk, I will review recent empirical work from my group addressing both of these challenges. In the first part of the talk, I will show that choice and confidence are based on the same evidence, but in contrast to recent neuro-computational models of confidence this evidence does not conform to what would be expected if the evidence reflected the likelihood of the data for the given hypotheses (i.e., the evidence accumulation process does not conform to a Bayesian optimal process). Instead for both choices and confidence people over-emphasize the strength of the information relative to the weight. Importantly though the confidence people express in their choice is not a simple snapshot of the accumulated evidence at the time of a choice. Instead, in the second part of my talk, I will map the dynamics of confidence as it changes over even very brief periods of time. I will show that part of its dynamic nature is due to the contribution of post decisional processing of evidence. But, that is not the entire explanation. Its dynamics are also due to its reflection of other aspects including the feedback people are given as well as new incoming information. Together these results support an overall hypothesis that choice and confidence are the product of the same evidence accumulation process. Understanding this interrelationship can help us not only understand the cognitive and neural processes of evidence accumulation, but also understand how and why and when people are accurate and inaccurate in their choices and judgment they make in the world.

Evolutionary economics: Decision-making under uncertainty in chimpanzees, bonobos, and humans

Alexandra G. Rosati
Department of Human Evolutionary Biology
Harvard University

Human decision-making is marked by systematic biases, but the origin of these biases is unclear. They may stem from our species' unique cultural experiences with money, markets, and exchange—or they maybe be shaped by biological dispositions that are shared with other species. Comparative studies of decision-making in our closest living relatives—chimpanzees (*Pan troglodytes*) and bonobos (*Pan paniscus*)—are critical to disentangle the roots of human economic behavior. I will present evidence that nonhuman apes exhibit many human-like biases when faced with foraging decisions, including their responses to risk (variability in payoffs), ambiguity (lack of knowledge about payoff probabilities), and framing (identical outcomes presented as a loss versus a gain). However, human decision-making is also modulated by reward currency: people respond differently to choices about evolutionarily-novel rewards such as money, compared to choices about biologically-central rewards such as food. Together, this indicates that human economic behavior has evolutionary roots as far back as the last common ancestor with nonhuman apes, but humans may also have specialized psychological skills for thinking about novel abstract rewards.

A computational and neural model of momentary subjective well-being

Robb B Rutledge, Archy O de Berker, Svenja Espenhahn, Nikolina Skandali, Peter Dayan, Raymond J Dolan
University College London

The subjective well-being or happiness of individuals is an important metric for societies, but we know little about how the cumulative influence of daily life events are aggregated into subjective feelings. Using computational modeling, I show that momentary happiness in a decision-making task is explained not by task earnings, but by the combined influence of past rewards and expectations. The robustness of this account was evident in a large-scale smartphone-based replication. I use a combination of neuroimaging and pharmacology to investigate the neural basis of mood dynamics, finding that it relates to neural responses in the striatum and to dopamine. I then show that this computational approach can be used to investigate the link between mood and behavior.

Neural circuits associated with behavioral flexibility in humans and macaques

Jérôme Sallet
University of Oxford

The human prefrontal cortex has been associated with the most sophisticated aspects of cognition, including those that are thought to be especially refined in humans.
First of all I will first present data obtained using diffusion-weighted magnetic resonance imaging (DW-MRI) and functional MRI (fMRI) in humans and macaques to infer and compare the organization of prefrontal cortex in the two species.
Secondly I will focus on structural and functional changes associated with learning rules in macaques. In discrimination reversal (DisRev) learning tasks animals learn that one choice leads to reward while another does not. Animals also learn that when the reward assignments are switched, the previously unrewarded choice has become the one followed by reward. Behavioural flexibility in DisRev has often been thought to rely on a brain circuit centered on the orbitofrontal cortex (OFC). This view has been challenged because fiber-sparing lesions do not impair discrimination reversal learning in macaques. On the basis of longitudinal changes in grey matter and activity coupling during DisRev training, we identified a neural network associated with behavioral flexibility

The role of brain bioenergetics on the effects of stress and anxiety in coping behaviors

Carmen Sandi. Brain Mind Institute,
Ecole Polytechnique Federale de Lausanne (EPFL), Switzerland.

Stress and anxiety are strong modulators of behavior and decision-making. Importantly, individual differences in stress effects are largely related to the personality trait anxiety. I will present our recent work implicating mitochondrial function in the nucleus accumbens in coping behaviors, including the establishment of social hierarchy, and its critical involvement in the low social competitiveness associated with high trait anxiety. I will also discuss recent evidence implicating the accumbal dopaminergic system in the modulation of social competitiveness and accumbal bioenergetics by acute stress or benzodiazepine treatment.

Dynamic tracking of social relationships in the human brain

Daniella Schiller
Icahn School of Medicine at Mt. Sinai

How do we place ourselves within a social structure? Social encounters provide opportunities to become intimate or estranged from others and to gain or lose power over them. The locations of others on the axes of power and intimacy can serve as reference points for our own position in the social space. The goal of our research is to uncover the neural encoding of these social coordinates. In my talk I will describe recent experiments tracking the online neural encoding of the perceived locations of others relative to ourselves, beginning with the first impression and proceeding through dynamic interactions with multiple peers.

The Attraction and Costs of Choice

Amitai Shenhav[1, 2], Uma Karmarkar[3], Randy Buckner[4, 5]

[1] *Princeton University*
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[3] *Harvard Business School*
[4] *Harvard University*
[5] *Harvard Medical School*

The past few decades of research have confirmed that we have a complicated relationship with win-win choices. We seek out choices that offer us more good options yet also find such choices particularly stressful. We explored this choice paradox across two neuroimaging studies. In the first study, participants undergoing fMRI made incentivized time-pressured choices between pairs of products that varied in subjective value. They then retrospectively rated positive and anxious experiences for each choice pair, and were offered an (unanticipated) opportunity to reevaluate earlier choices. Participants reported feeling both most positive and most anxious when choosing between similarly high-valued options. Crucially, we found that dissociable networks tracked these two competing experiences. Ventral versus dorsal regions of medial PFC and striatum differentially tracked positive and anxious states, consistent with their proposed roles in evaluating potential rewards versus the response costs required to obtain them (e.g., choice conflict). This study also revealed a second and unexpected dissociation: whereas a network including rostral cingulate (rACC) and ventral striatum (VS) tracked the positive experience associated with one's options, a network including medial orbitofrontal cortex (mOFC) was sensitive to both the value and the difficulty of a choice. These and other features of the results suggested that this dissociation reflected a distinction between an rACC/VS-related circuit involved in signaling (perhaps automatic) affective associations for our options versus an mOFC-related circuit involved in the integration/comparison process required to make a choice. We tested this in a second study by manipulating people's goals when evaluating a set of valuable items. Participants were presented with sets of products and instructed to either determine how much they like the set or to choose which product they liked best. As expected, we found that the mOFC network was more active during choice comparison than evaluation of liking. Conversely, the rACC/VS network was associated with how much participants liked a given choice set, with components of the network (VS in particular) signaling liking irrespective of whether the participant was prompted to evaluate the set or compare between the options. Collectively these findings are consistent with the possibility that somewhat separate neural circuits are involved in (1) signaling the overall value of stimuli in the environment (perhaps reflexively biasing our approach towards such options), (2) directly comparing these stimuli in order to identify the best one, and (3) signaling the costs of choosing. These dissociations may set the stage for our paradoxical attraction to win-win choices in spite of the costly decision-making process that may ensue.

Moral decision-making across primates

Mark Sheskin
Yale University

Research into the evolutionary origins of human morality has often involved research with nonhuman primates. Unfortunately, behavioral decision-making tasks with a wide variety of species have provided conflicting results. One the one hand, many studies have revealed potential nonhuman motivations that seem parallel to human moral concerns regarding both harm and fairness. On the other hand, other studies have failed to find similar results. One possible consensus statement is that nonhuman motivations related to harm and fairness are *at most* very limited compared to human moral concerns. Most recently, several proposals have been made for *why* such motivations might vary across different primate species. I focus on a Life History approach that was recently applied to variation in prosocial motivation across the human lifespan and that might be analogously applied phylogenetically. More generally, I will suggest that comparative investigations into the origins of human morality should focus less on establishing merely that effects exist (at some nonzero effect size, $p < .05$), and more on testing hypotheses about the origin of human morality that are informed by an analysis of the potential functions of morality.

Neural circuits that distinguish memory processes in the fly brain

Mai Kanno, Toshiharu Ichinose, Hiromu Tanimoto
Tohoku University, Graduate School of Life Sciences

Memory acquired from salient experiences guides future behavior. Fruit flies Drosophila melanogaster bidirectionally adapt the response to an odor based on appetitive and aversive memories of sugar reward and electric shock punishment, respectively. Accumulating evidence suggest that the output from a brain structure called the mushroom body (MB) is necessary for acquisition, consolidation, and retrieval of appetitive and aversive memories. However, it is largely unclear how the common MB circuit operates these distinct memory processes. To comprehensively characterize the organization of the MB output, we anatomically identified all the MB output neuron types in Drosophila. By measuring the behavioral importance of each output pathway, we found that the different sets of the MB output neurons are recruited in appetitive and aversive memories. Furthermore, our comprehensive behavioral analysis revealed acquisition, consolidation and retrieval of memories are characterized by the combinatorial functions of MB output neurons.

Change-Point Detection without the Need to Detect Change-Points

Angela Yu, Chaitanya Ryali
University of California San Diego

In recent years, there has been much progress in understanding how humans and animals learn about statistical regularities in the environment and to track changes based on noisy data. Broadly speaking, this problem has been studied using two kinds of data, those that are continuous or ordinal-valued, and those that are binary or categorical. The first kind has often been modeled using variants of the Kalman filter, while the latter kind has been studied using algorithms like the Dynamic Belief Model (DBM), a variant of a Bayesian hidden Markov model that assumes the generative distribution to undergo abrupt resetting with a constant hazard rate. Although we have shown that DBM can explain a variety of behavioral phenomena, its complexity represents a challenge for neural plausibility. Here, I show that DBM is well approximated by a linear exponential filter for binary data, or n independent linear exponential filters for n-nary data, resulting in tremendous computational and representational savings. I will also present the parameters of this approximation to the equivalent DBM generative parameters, as well as a bound on the approximation error. Our results show that Bayesian change-point detection based on categorical data can be done well without the need to explicitly compute the probability of change, i.e. via a fixed learning rate in the linear exponential filter, or equivalently a fixed gain using leaky integrating dynamics. Indeed, the results imply that not much can be gained by tracking the posterior probability of change, nor is it ideal to use categorical data in a change-point detection task if the goal is to discern behavioral and neural changes in response to detecting a true change in the environment. This work has obvious implications for the neural and psychological study of change-point detection, as well as experimental design.

Re-exploring the psychophysiology of mental effort

Alexandre Zénon
Université catholique de Louvain; Bruxelles, Belgium

SBDM 2016 // Posters

Authors by poster order

Session 1 (Wednesday, May 25; 12:30-14:30)

[ ]: poster number

[1] Influence of other's choice behavior on observational learning.

Nadège **Bault**[1], Tobias Larsen[1], Alexander Vostroknutov[1] and Giorgio Coricelli[1,2]
[1]Center for Mind/Brain Sciences (Cimec), University of Trento
[2] Department of Economics, University of Southern California, Los Angeles, CA USA

[2] The Brain Uses Reliability of Stimulus Information when Making Perceptual Decisions

Sebastian **Bitzer** and Stefan J. Kiebel
Department of Psychology, Technische Universität Dresden, 01062 Dresden, Germany

[3] Neural correlate of selective integration during multi-attribute decision-making

Annabelle **Blangero**[a], Fabrice Luyckx[a], Konstantinos Tsetsos[b], Christopher Summerfield[a]
[a] Department of Experimental Psychology, University of Oxford, UK;
[b] Department of Psychological Sciences, Birkbeck, University of London, London, UK

[4] Noradrenaline as a cognitive booster: evidence from systemic medication in monkeys

Nicolas **Borderies**[1], Sophie Gilardeau[2], Mathias Pessiglione[1], Sébastien Bouret[1]
[1]Motivation, Brain and Behavior team (MBB), Institut du Cerveau et de la Moelle épinière (ICM), Paris, France
[2]Primate Phenotype Platform (PRIM'R), Institut du Cerveau et de la Moelle épinière (ICM), Paris, France

[5] Doubt and checking behavior in monkey

M. **Bosc**[1, 2], B. Bioulac[1, 2], N. Langbour[3], TH. Nguyen[1, 2], M. Goillandeau[1,2], B. Dehay[1,2], P. Burbaud[1,2,4], T. Michelet[1,2]
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[3] Centre Hospitalier Henri-Laborit, Poitiers, France;
[4] Service d'explorations fonctionnelles du système nerveux, CHU de Bordeaux, Bordeaux, France.

[6] Hebbian mechanisms for contextual learning in a complex environment

Flora **Bouchacourt**[1], Etienne Koechlin[2], Srdjan Ostojic[1]
[1]Group for Neural Theory, Laboratoire de Neurosciences Cognitives, ENS, Paris
[2] Frontal Lobe Function Group, Laboratoire de Neurosciences Cognitives, ENS, Paris

[7] Substance P and enkephalin enhance the striatum's ability to switch between actions in a sequence

D. **Buxton**, E. Bracci, P. G. Overton, K. Gurney
University of Sheffield, Department of Psychology

[8] Deciding to Know: Information Prediction Errors and Value in the Human Brain

Caroline J. **Charpentier**[a], Ethan Bromberg-Martin[b], Tali Sharot[a]
[a]Affective Brain Lab, Department of Experimental Psychology, University College London, London, UK;
[b]Department of Neuroscience and Kavli Institute for Brain Science, Columbia University, New York, NY, USA

[9] Dopamine blockade affects exploration but not learning rate in a non-stationary 3-armed bandit task

François **Cinotti**[1, 2], Virginie Fresno[3, 4], Nassim Aklil[1, 2], Etienne Coutureau[3, 4], Benoît Girard[1, 2], Alain R. Marchand[3,4], Mehdi Khamassi[1,2]
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[4] Université de Bordeaux, INCIA, UMR 5287, F-33076 Bordeaux, France

[10] Chaotic Neural System: An Approach Towards Synchronization by Using Impulsive Control

Amitava Kundu[a], Pritha **Das**[a]
[a]Department of Mathematics, Indian Institute of Engineering Science and Technology

[11] The role of the error positivity in confidence-based decision-making

Kobe **Desender**[1], Annika Boldt[2], & Nick Yeung[3]

[1]Vrije Universiteit Brussel [2]. Cambridge University [3]. Oxford University

[12] Chronic nicotine increases value-sensitivity in a multi-armed bandit task.

M.L. **Dongelman**s, N. Torquet , S. Tolu, J. Naudé & Ph. Faure[1]
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[13] Pervasive influence of idiosyncratic social biases in the expression of first impressions about others

Marwa **El Zein**[1], Valentin Wyart1, [‡], and Julie Grèzes[1], [‡]
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[14] Domain-generality of adaptive processes in human perceptual decision-making.

Andreea **Epure**[1] and Christopher Summerfield[1]
[1]Computational Neuroscience Lab, Department of Experimental Psychology, University of Oxford.

[15] Effects of learning-induced categorical representations upon dynamics of visual evidence processing in behaviour and EEG-recordings

Timo **Flesch**, Hamed Nili, Christopher Summerfield
Department of Experimental Psychology, University of Oxford

[16] Human noise blindness and decision suboptimality

Santiago **Herce** Castañón[1], Dan Bang[1], [2, 3, 4], Jacqueline Ding[1], Tobias Egner[5],[6], and Christopher Summerfield[1]
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[5]Center for Cognitive Neuroscience, Duke University, Durham, North Carolina, USA
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[17] Decision-making in a neural network model of the basal ganglia

Charlotte **HERICE**[1], [2], Radwa KHALIL[1], Marie MOFTAH[3], Thomas BORAUD[1],[2],
Martin GUTHRIE[1], [2] and André GARENNE[1],[2]
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[3] Zoology Department, Faculty of Science, Alexandria, Egypt

[18] Across-trial dynamics of stimulus priors in an auditory discrimination task

A. **Hermoso**-Mendizabal[1], A. Hyafil[2], P.E. Rueda-Orozco[3], S. Jaramillo[4], D. Robbe[5] and J. de la Rocha[1]
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[3] Universidad Nacional Autónoma de México, México
[4] University of Oregon, USA
[5] Institut de Neurobiologie de la Méditerranée, Marseille, France

[19] Social Status and self-image shape the attempt to influence others

Uri **Hertz** [1], [2], Stefano Palminteri [1], [3], Silvia Brunetti [1], Chris D Frith [2],[4], Bahador Bahrami [1]
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[20] Modelling history-dependent perceptual biases in rodents

Alexandre **Hyafil** [1],[2], Ainhoa Hermoso-Mendizabal [2], Jaime de la Rocha[2]
[1] University Pompeu Fabra, Barcelona, Spain;
[2] IDIBAPS, Barcelona, Spain

[21] Computational approaches to emotional decision-making

Mauricio **Iza**
University of Malaga

[22] Noradrenaline in motivation and decision-making: a pharmacological study in monkey

Caroline **JAHN**[1]-[2], Sophie GILARDEAU[3], Jérôme SALLET[4], Mark WALTON[4], Sébastien BOURET[1]

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[3] Institute for Translational Neuroscience of Paris IHU-A-ICM, 75013 Paris, France

[4] Department of Experimental Psychology, University of Oxford, Oxford, UK

[23] Novelty and generalisation in value-guided learning

Andreas **Jarvstad**; Jacqueline Ding; Christopher Summerfield

University of Oxford

[24] Managing a zoo with the medial prefrontal cortex

Keno **Jüchems**[1], Jill O'Reilly[1], and Chris Summerfield[1]

[1] Department of Experimental Psychology, University of Oxford

[25] Lateral hypothalamus inactivation affects cost-benefit decision making

Sara **Karimi**[1], Gholam Ali Hamidi[1], Abbas Haghparast[2], Zahra Fatahi[2]

[1] Physiology Research Center, Kashan University of Medical Sciences, Kashan, I.R. Iran.

[2] Neuroscience Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran

[26] Temporal expectation biases duration judgment

Tadeusz W. **Kononowicz**[1] & Virginie van Wasshenove[1]

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[27] Task to investigate the effects of exogenous and endogenous spatial attention on perceptual confidence

Phillipp **Kurtz**[1], Katharine Shapcott[1], Michael Schmid[1,2]

[1] Ernst Strüngmann Institute (ESI) for Neuroscience in Cooperation with Max Planck Society;

[2] Institute of Neuroscience, Newcastle University

[28] Behavior-dependent gating and extraction of task-relevant auditory signals in ferret frontal cortex

Jennifer **Lawlor** [1,2] , Bernhard Englitz [1,2,3] , Arne Meyer [4] ,Urszula Górska [3] , Shihab Shamma [1,2,5] , Yves Boubenec [1,2]

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[4] Gatsby Computational Neuroscience Unit, Sainsbury Wellcome Centre, 25 Howland Street, London W1T 4JG

[5] Electrical and Computer Engineering & Institute for Systems Research, University of Maryland in College Park, MD 20742, USA

[29] Perceptual uncertainty, conflict, and gain control in human decision-making

Vickie **Li**[1], Elizabeth Michael[2] and Christopher Summerfield[1]

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[2]Dept. Psychology, University of Cambridge

[30] Sleep Deprivation Alters the Integration of Affect in Subsequent Evaluations

Aiqing **Ling**[1,2], Irma Kurniawan[3], Michael Chee[3], Hilke Plassmann[1,2]

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Session 2 (Thursday, May 26; 12:30-14:30)

[ ]: poster number

[31] When there is a will, there is a way? Paradoxical effects of motivation on motor performance

Delphine **Oudiette**[1], Fabien Vinckier[1] and Mathias Pessiglione[1]
[1] Motivation, Brain and Behavior (MBB) Team, Institut du Cerveau et de la Moelle Épinière - ICM CNRS UMR 7225 - UPMC-P6 UMR S 1127, Paris, France

[32] Intracranial EEG investigation of the Brain Valuation System: Revealing the dynamics underlying value-based decision-making.

Alizée **Lopez-Persem** [1, 2], Julien Bastin [3,4], Mathias Pessiglione [1, 2]
[1]Team Motivation, Brain and Behavior (MBB), Institut du Cerveau et de la Moelle épinière (ICM), F-75013 Paris, France.
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[3] University of Grenoble Alpes, F-38000 Grenoble, France
[4] Inserm, U1216, F-38000 Grenoble, France

[33] Heart rate variability is associated with increased resistance to tempting foods

Silvia U. **Maier**, Todd A. Hare
University of Zurich, Department of Economics, Laboratory for Social and Neural Systems Research

[34] If only I had chosen differently! EEG manifestations of comparison between received and alternative outcomes

Deborah **Marciano-Romm**[1, 2], Sacha Bourgeois Gironde[3, 4], Leon Y. Deouell[1, 5]
[1] Department of Psychology, The Hebrew University of Jerusalem, Israel
[2] Federmann Center for the Study of Rationality, The Hebrew University of Jerusalem, Israel
[3] Department of Economics, LEMMA, Université Paris 2, Paris, France
[4] Institut Jean-Nicod, École Normale Supérieure, Paris, France
[5] Edmond & Lily Safra Center for Brain Sciences, The Hebrew University of Jerusalem, Israel

[35] Goal-action transformation in the primate prefrontal cortex

Encarni **Marcos**, Aldo Genovesio
Department of Physiology and Pharmacology, Sapienza University of Rome, Rome, Italy

[36] Change point models and hierarchical Gaussian filters: Bayesian model comparison

Dimitrije **Marković**, and Stefan J. Kiebel
Technische Universität Dresden, Dresden, Germany

[37] Allocating attentional effort over time in sustained attention: a value-based decision making approach

Stijn A.A. **Massar** & Michael W.L. Chee
Centre for Cognitive Neuroscience, Duke-NUS Medical School, Singapore

[38] Memory decision confidence interacts with reward history in the ventral striatum.

Ewa A. **Miendlarzewska**[a, b, c, f], Kristoffer Abergc,[f], Daphne Bavelier[b, d, e], Sophie Schwartz[b, c, f]
[a] Geneva Finance Research Institute, University of Geneva, Geneva, Switzerland
[b] Swiss Center for Affective Sciences, University of Geneva, Geneva, Switzerland
[c] Geneva Neuroscience Center, University of Geneva, Geneva, Switzerland
[d] Psychology Section, FPSE, University of Geneva, Geneva, Switzerland
[e] Brain & Cognitive Sciences, University of Rochester
[f] Department of Neuroscience, University of Geneva, Geneva, Switzerland

[39] A novel protocol to assess Dual Task Cost as a measure of Cognitive Reserve

Coelho, I.L.R.[1], **Moura**, A. R.[1], Paixão, V.[1], Barahona-Corrêa, B.[1], Oliveira-Maia, A.[1],
[1]Neuropsychiatry Unit, Champalimaud Centre for the Unknown, Lisbon, Portugal;

[40] Sex Differences in Decision Making and Frontal Lobe Activity under Diazepam

Zeidy **Munoz-Torres**[1, 2] María Corsi-Cabrera[1]
[1]Laboratory of Sleep, Faculty of Psychology, Universidad Nacional Autonoma de Mexico,
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[41] Cholinergic modulation of dopaminergic activity and exploration

Naudé Jérémie[1]*, Didienne Steve[1]*, Takillah Samir[1], Prévost-Solié Clément[1], Faure Philippe[1].
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[42] Irrational sub-goal selection to subdue complexity in a learning task

Arsham Afsardeir[1], Yasaman Razeghi[1], and Majid Nili **Ahmadabadi** [1, 2]
[1] Cognitive Robotics Lab., School of ECE, University of Tehran
[2] School of Cognitive Science, Institute for Research in Fundamental Science (IPM), Tehran, Iran

[43] Implication of a minimal information and limited computational abilities on money emergence: An experimental approach with humans and artificial agents

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[44] Investigating the neural mechanisms underlying abstract category learning

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[45] Asymmetric reinforcement learning: computational and neural bases of positive life orientation

Germain Lefebvre, Mael Lebreton, Florent Meyniel, Sacha Bourgeois-Gironde, Stefano **Palminteri**

[46] Muscular fatigue causes flexible preference reversals in an effort-based decision making task

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[47] Modulation of inference by the temporal statistics of stimuli

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[48] The dopamine signal in decision making tasks with temporal uncertainty

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[49] Does Red Bull give you wings? Placebo effects of commercially available cognitive enhancers on performance motivation

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[50] Reward related suppression in visual area V4 during a discrimination task o ignored

Katharine **Shapcott**[1], Ricardo Kienitz[1], Kleopatra Kouroupaki[1], Joscha T. Schmiedt[1], Michael C. Schmid[1, 2]
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[51] Flexible adaptation of reward-guided learning to the correlation structure of choice alternatives

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[52] Neural correlates of the Decision Variable: Comparison of evidence accumulation signal to decision-related ERPs

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[53] To infer the correctness of an action from the reward it delivered, brain uses a linear heuristic as transfer function

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[54] Poster title: Believing in one's power: a counterfactual reinforcement-learning account of instrumental causation

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[55] Selective integration of decision evidence in the human brain

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[56] Who's the teacher and who's the pupil?

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[57] Robust Sampling of Decision Information During Perceptual Choice

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[58] Effects of social threat on attention and action-related decisions

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[59] How do you see your chances? Neuro-computational account of mood effects on risky decision-making

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[60] Crucial role of right frontopolar cortex in directed exploration

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[61] Orexinergic OX1 receptors in the Orbitofrontal cortex regulate delay-based decision making

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[42] Irrational sub-goal selection to subdue complexity in a learning task

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Reinforcement learning (RL) is a powerful tool for discovering the optimal decision however; it suffers from low learning speed in face of curse of dimensionality commonly present in the real world applications. Decomposing a complex task into a set of proper subtasks and then learning each in a hierarchical manner is a prominent way to fight the curse of dimensionality and increasing the learning speed. In hierarchical reinforcement learning (HRL), the key component is detection of subtasks; specially, when the task model is not known a prior. Effectiveness of HRL heavily depends on the selection of suitable sub-problems. Sub-goal detection and identification of highly visited states are commonly used in artificial HRL to form subtasks. Subtask detection is straightforward when the tasks structure is known.
The literature reports some evidences on using HRL by humans through decomposing task based on sub-goals. Our question is if we decompose a task into sub-problems when the decomposition does not match the task's nature. In other words, we investigate if we decompose a task even in absence of distinct sub-goals, where the breakdown is not rational in terms of finding the optimal solutions. In addition, we investigate if decomposing strategy and task complexity are related.

The experimental data from a minimum cost routing task in a directed acyclic graph confirmed that the subjects decompose the task even when no distinct sub-goal is present. Moreover, the subjects took some ordinary nodes at the middle of graph as sub-goals when the graph was complex. Tendency to sub-goal selection behavior increased for more complex graphs. Finally, as it was guess allowed, we observed that sub-goal-selector subjects were less successful in finding the optimal path. The data points at presence of a heuristic for sub-goal selection. Seemingly, the hypothetical heuristic serves the subjects by reducing the task complexity by breaking it down to a set of subtasks in order to make the learning problem simpler and faster at the cost of gaining less reward. The data is more in favor of complexity role in sub-goal selection than a tradeoff between complexity reduction and reward maximization.

[1] Influence of other's choice behavior on observational learning.

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When making decisions in an uncertain environment, individuals may learn by observing the choice behavior of others. We tested the hypothesis that the learning rate and exploration/exploitation tradeoff of the person being observed (the observee) would influence how and how much the observer would imitate when choosing. We measured brain activity using functional MRI while participants made decisions in a repeated two-armed bandit task. In some trials, they observed the choice of two individuals before making their own choice. They were told that the others were choosing in the same environment; however participants never saw the others' outcome. The two observees' behavior was simulated using a Q-learning algorithm with varied parameters, resulting in one observee switching options more often than the other. We found that the type of observee influenced the observer participants both in their ability to choose the best option and in the probability that they would switch options. Preliminary neuroimaging results indicate that the lateral prefontal cortex was more activated when choosing differently from the observee than when imitating. Moreover, during the feedback phase, the activations in the striatum and insula were stronger in the observation than the no-observation condition. These findings suggest that brain areas implicated in decision-making and reward processing keep track of how imitating different persons influence one's own learning.

[2] The Brain Uses Reliability of Stimulus Information when Making Perceptual Decisions

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In simple perceptual decisions the brain has to identify a stimulus based on noisy sensory samples from the stimulus. Basic statistical considerations state that the reliability of the stimulus information, i.e., the amount of noise in the samples, should be taken into account when the decision is made. However, for perceptual decision making experiments it has been questioned whether the brain indeed uses the reliability for making decisions when confronted with unpredictable changes in stimulus reliability. We here show that even the basic drift diffusion model, which has frequently been used to explain experimental findings in perceptual decision making, implicitly relies on estimates of stimulus reliability. Our analysis is based on a rigorous discrimination between the concepts of measurements (sensory samples), evidence (measurements specifically related to the decision) and likelihood (evidence weighted by its reliability). We then show that only those variants of the drift diffusion model which allow stimulus-specific reliabilities are consistent with neurophysiological findings. Our analysis suggests that the brain estimates the reliability of the stimulus on a short time scale of at most a few hundred milliseconds.
Sebastian Bitzer and Stefan J. Kiebel. The Brain Uses Reliability of Stimulus Information when Making Perceptual Decisions. In: *Advances in Neural Information Processing Systems 28* (NIPS 2015), 2015, 1045-1053

[3] Neural correlate of selective integration during multi-attribute decision-making

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Most real-world economic decisions involve options that have multiple attributes. For example, when looking for a new apartment, the decision will not only depend on the rent, but the size and location will also be taken into account. Normatively, the overall value of each property is a weighted combination of the value of its different attributes. Descriptively however, for each attribute, subjects favour the best alternative by down-weighting the element that is less favoured the local competition (lowest value for that attribute) [Tsetsos et al. 2016]. Thus, if one apartment is more expensive than its rivals, its momentary value on the dimension of "expense" is integrated with a lower than optimal weight. Here we sought to investigate the neural correlates of this selective integration and to investigate the processing stage at which the down-weighting occur?

We recorded both behaviour and electroencephalographic (EEG) activity of 17 participants while they were performing a multi-attribute decision-making task. Participants maintained central fixation whilst viewing a sequence of 9 pairs of bars that ocurred in two streams on the left and right of the screen. The height of each bar varied at each presentation frame (every 500ms) and the subjects indicated whether, overall, the average bar from the left or the right stream was the tallest or the shortest in alternate framings of the task performed on different days.

Behaviorally, our subjects showed evidence for selective integration. Choices were biased towards the stream that won more often the local competition, even if it was not always the option with highest integrated value. Using the selective integration model [Tsetsos et al. 2016] we are able to quantify the down weighting factor of the local loser (w) for each subject. A strong inter-subject correlation between the two sessions shows that subjects are consistent in their integration strategy, irrespective of the framing of the task.

Analyses of phase-locked electrophysiological markers of visual processing, and oscilatory activity in the alpha (8-13 Hz) band showed a posterior lateralised encoding of the difference between the two bars. Interestingly, the sign of the lateralisation switched depending on the session (tallest/shortest) indicating that this contralateral signal encoded the stimuli in the frame of reference of the task (tallest vs. shortest) rather than coding for pure sensory information. Critically however, we also observerd neural evidence for selective integration in the electrophysiological contralateral posterior encoding of the single bar size. There was weaker encoding of the bar size when it was loosing the local competition than when it was winning. This finding demonstrates the prevalence of selective integration in the neural computation of multi-attributes decision-making.

Tsetsos K, Moran R, Moreland J, Chater N, Usher M, Summerfield C. Economic irrationality is optimal during noisy decision making. Proc Natl Acad Sci U S A. 2016 Mar 15;113(11):3102-7

[4] Noradrenaline as a cognitive booster: evidence from systemic medication in monkeys

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Noradrenaline (NA) is a major neuromodulator that has been implicated in several neurological and psychiatric disorders (e.g., Parkinson's disease, major depression). Yet its cognitive role is still poorly understood: NA is generally thought to increase arousal or attention. Here, we assessed the causal role of NA in decisions that involve weighing costs and benefits, using a pharmacological approach.

Two monkeys (macacca mulatta) were trained to make choices between two options associated with different levels of liquid reward (number of water drops) and physical effort (amount of handgrip force). Monkeys were treated with either systemic administration (0.5 mg/kg) of the selective reuptake inhibitor Atomoxetine (ATX) or a saline solution. The two treatments (ATX and placebo) were alternated on a weekly basis and behavioral performance was assessed on 4-5 days within each week.

We considered three behavioral measures: the rate of choices performed versus declined (participation), the choice response time (RT), and which option was chosen (preference). Participation increased with the overall net value over the two options of a choice, and decreased with position of the trial within a session. Preference was positively influenced by reward level and negatively influenced by effort level.

ATX treatment induced several changes: (1) it increased participation, (2) it reduced RT, particularly when the two dimensions were in conflict (higher reward paired with higher effort), (3) it improved discrimination of the best option and (4) it enhanced precision of squeezing, particularly for low force levels. However, ATX did not change the total amount of reward obtained, the total force produced or the total duration of a task session.

Overall, these preliminary results suggest that ATX boosted the allocation of cognitive resources (but not motor resources) to the choice task, such that the behavior was both more efficient (increased participation and reduced RT) and more accurate (more consistent choices and more controlled force).

[5] Doubt and checking behavior in monkey

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Checking compulsions is among the most common behavioral features of obsessive-compulsive disorder (OCD), an anxiety disorders reaching 2-3% of the population. Checking compulsion derives and escalates from once-functional behavior. It is thought to be a behavioral attempt to relieve anxiety caused by high levels of doubt and uncertainty. Numerous studies suggest that alteration of prefrontal cortices would lead to abnormal cognitive control of action (e.g. conflict monitoring or error detection) and could be related to compulsive checking behavior. However the physiology of checking behavior remains poorly understood and no concrete and reliable model of physiological checking has been developed so far. The present behavioral study tends to characterize physiological doubt and checking behavior in non-human primates (NHP). To do so, we designed a novel behavioral task to study electrophysiological correlates of decision making, doubt and checking in NHP. We trained two rhesus monkeys (Macaca mulatta) on the Check-or-Go task while recording their frontal EEG activity. We also collected saliva samples to quantify cortisol concentration along sessions in order to correlate this biological marker of anxiety with checking behavior. Our behavioral paradigm allows the animal to multiple-check and potentially change the availability of the reward before taking the final decision leading to that reward. By manipulating the ambiguity of the visual cue embedding the reward status (reward operational cue), we successfully modulated animal uncertainty and created doubt. Behavioral results showed that the animal uncertainty level influenced not only performances and reaction times but also checking behavior rate. Fronto-central EEG potentials were also modulated by visual cues' ambiguity level and checking decision. Daily cortisol quantification revealed a positive correlation between monkeys' checking behavior and anxiety level. Taken together, our study demonstrated that the Check-or-Go task is a valid behavioral tool to study the impact of ambiguity on doubt and the subsequent adaptive checking behavior and will thereby help us provide new insights into OCD mechanisms.

[6] Hebbian mechanisms for contextual learning in a complex environment

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The human brain is able to adjust and exploit multiple strategies for the same task, depending on environmental demands. The mental representations of such stimuli-response mapping rules are called task-sets. Theoretical research on rule-guided behavior and the interdependence between learning and cognitive control mainly focuses on abstract computational models at the functional level, inspired by ideas from reinforcement learning theory and Bayesian statistics. Little is known however about the underlying neural implementation and mechanisms.

We have developed a candidate neural mechanism for the implementation and learning of task-sets as hebbian engrams, with the idea that long-term memory for events is associative and temporally ordered. The model is composed of two interacting neural circuits of mixed-selectivity neurons with bistable synapses. A reward-dependent associative module learns one to one associations between visual stimuli and motor responses. It encodes only one task-set. The activity in this module drives synaptic plasticity in a second unsupervised neural circuit encoding transition probabilities for the task. When hebbian engrams of task-set associations are detected in this circuit, an inference bias to the decision module guides future behavior.

We show that simple unsupervised hebbian learning in the second module is sufficient to learn an implementation of task-sets. Their retrieval in the decision module improves behavioral performance. It accounts for fast contextual switching and correction for environmental noise, reproducing noteworthy features of subjects' behavior.

The model predicts abrupt changes in behavioral responses depending on the precise statistics of previous responses. We fitted the model to human behavioral data, and highlighted learning facilitation or learning reduction predicted contingencies. The predictions of the model were borne out by the data, and enabled to identify from behavior alone subjects who have learned the task structure, confirming a post-test debriefing.

Preliminary results of our model-based fMRI analysis show a correlation between this hebbian-inspired inference signal and BOLD activity in medial prefrontal cortex regions, suggested to be biasing decision circuits when a stable behavior is retrieved.

These results suggest that simple hebbian mechanisms and temporal contiguity may underlie the learning of complex, rule-based behavior.

[7] Substance P and enkephalin enhance the striatum's ability to switch between actions in a sequence

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The striatum is the primary input nucleus for the basal ganglia, and receives glutamatergic afferents from the cortex. Under the hypothesis that basal ganglia perform action selection, these cortical afferents encode potential 'action requests'. Previous studies have suggested the striatum may utilise a mutually inhibitory network of medium spiny neurons (MSNs) to filter these requests so that only those of high salience are selected. However, the mechanisms underlying the ability of the striatum to perform clean, rapid switching between distinct actions that form part of a learned action sequence are still poorly understood.

Substance P (SP) and enkephalin are neuropeptides co-released with GABA in MSNs preferentially expressing D1 or D2 dopamine receptors respectively. SP has a facilitatory effect on subsequent glutamatergic inputs to target MSNs, while enkephalin has an inhibitory effect. Additionally, blocking the action of SP in the striatum is known to affect behavioural transitions.

We hypothesize that SP boosts the effective salience of inputs to the striatum that form part of a sequence, thus allowing for rapid switching between such actions. We further hypothesize that enkephalin may serve to modulate this behaviour.

The current research uses a hybrid model – comprising a spiking striatal microcircuit and rate-coded nodes representing other basal ganglia structures and motor cortex – to demonstrate that switching between actions in a sequence takes place more efficiently with patterned neuropeptide connectivity. Specifically, for an action sequence of the form A-B, the model shows a selection advantage for a structured projection scheme in which SP is released from MSNs encoding action A that project to MSNs representing action B. The model shows a further selection advantage when low levels of enkephalin are present in the striatum, though no directional projection scheme for enkephalin is assumed.

This supports the hypothesis that SP and enkephalin play a combined role in action sequence execution and suggests that formation of directional SP projections may be part of action sequence automatisation.

[8] Deciding to Know: Information Prediction Errors and Value in the Human Brain

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How do we decide what to know and what to remain ignorant of? Answering this question is important because knowledge guides action. Yet, the mechanism underlying information seeking in humans is largely unknown. Here, we characterize the neural basis and computational principles of how people decide what to know. We show that the decision to receive information is driven both by the resolution of uncertainty and the likelihood of receiving good news. Participants were more eager to know about outcomes with higher expected value, a strong effect that was also modulated by outcome uncertainty. We identify two sets of Information Prediction Errors (IPE) in the human brain, which represented these two motives. One set of IPEs were independent of expectations of reward and loss (in OFC/vmPFC) and the other (in ventral striatum) were modulated by such outcome expectations. Our results identify the components that give rise to information seeking decisions and their respective encoding in the human brain.

[9] Dopamine blockade affects exploration but not learning rate in a non-stationary 3-armed bandit task

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Deciding in an uncertain and changing environment involves a balance between accumulating rewards using known strategies (exploitation) and acquiring knowledge through less rewarding but potentially adaptive strategies (exploration). Under uncertain situations, a larger amount of exploration may be required. According to recent theories, tonic levels of dopamine may control the balance between exploitation and exploration. To assess this hypothesis, we tested rats under flupenthixol, a dopamine D1, D2 receptor antagonist, in a probabilistic task involving two levels of uncertainty. During blocks of trials, rats had to identify which of three levers yielded the highest probability of reward. The correct lever changed every 24 trials in an unsignalled manner. Under drug-free conditions, the rats reached over 70-80% accuracy by the end of a block. Uncertainty reduced accuracy and selectively increased the probability of shifting choice after a rewarded trial (win-shift), an index of exploration. Additionally, the percentage of win-shift was found to slowly decrease across training sessions as well as within a block, suggesting that rats do in fact dynamically modulate their level of exploration. To further assess this possibility and the possible role of uncertainty, we conducted a series of computational analyses based on simple Q-learning models with distinct parameters for phases (early vs. late trials) within a block and for different uncertainty levels. These analyses revealed no effect of uncertainty on learning rate and exploration parameters, but an effect of phase. This suggests that rats perform meta-learning during this task, and in particular dynamically regulate their exploration-exploitation trade-off. Moreover this implies that this regulation is largely independent of uncertainty. We then proposed a mechanistic computational model of the behaviour of the rats based on a Q-learning algorithm augmented with a modulation mechanism of the exploration-exploitation trade-off, driven by an average RPE signal, intended to represent tonic dopamine activity. Model comparison established that this model fits rat choices better than simpler reinforcement learning or Bayesian models. After training, flupenthixol was injected i.p. (Experiment 1: 0, 0.1, 0.2 or 0.3 mg/kg) prior to behavioural testing, according to a latin square design with at least 72 h recovery between injections. Systemic flupenthixol dose-dependently increased the percentage of win-shift, irrespective of the level of uncertainty or of the degree of learning within a block. Flupenthixol also reduced accuracy in the low uncertainty condition, but not in the high uncertainty condition. Further analyses suggest that these effects on performance were a consequence of the increase in exploration and that flupenthixol and uncertainty had separate effects on exploration.
Altogether, these results indicate that low levels of dopaminergic activity favour exploration without affecting the learning rate.

[10] Chaotic Neural System: An Approach Towards Synchronization by Using Impulsive Control

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Impulsive control is characterized by the abrupt changes in the system dynamics at certain time moments. It is an efficient method to deal with dynamical systems which cannot be regulated by continuous control. This paper introduces this idea of impulsive control and synchronization of a chaotic model system. Computer simulation results based on an artificial five dimensional neural network model with impulsive effects is discussed in this paper. By applying the Lyapunov technique, the aggregated effects of impulse and stability properties for the non-linear system to be globally exponentially and asymptotically stable have characterized theoretically. Impulsive synchronization of chaotic system is also being done theoretically in this paper. Results are shown through numerical simulation showing with and without impulse to control chaotic behavior.
Keywords: chaos; impulsive control; impulsive synchronization; stability

[11] The role of the error positivity in confidence-based decision-making

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A rapidly increasing number of studies are examining the neural correlates of subjective confidence. Using human electrophysiology, it has been shown that the amplitude of the error positivity (Pe), which has previously been linked to error awareness, increases monotonically with our degree of confidence. However, whether this neural correlate of confidence is predictive of actual changes in behavior remains unexposed so far. Mainly, this results from the close association between first-order performance and confidence, which prevents a clear delineation of both variables' contribution. Here, we were able to create conditions that were matched in accuracy but differed in the subjective evaluation of accuracy. In a perceptual decision-making task, human observers could choose to sample more information before making their decision. The data showed that low Pe amplitude, indicating low levels of confidence, was associated with sampling additional information from the environment before making a decision. Crucially, this was found while controlling for differences in accuracy. In sum, our data show that the error positivity, reflecting subjective confidence, serves as a cue that influences subsequent decision-making.
Keywords: confidence, decision making, error positivity, eeg

[12] Chronic nicotine increases value-sensitivity in a multi-armed bandit task.

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Dopamine acts as a modulator in a variety of value-based choice behaviors. Nicotine, the reinforcing compound in cigarettes, can modulate dopaminergic activity by binding onto nicotinic acetylcholinergic receptors (nAChRs). Long-term nicotine administration has been linked to a decreased sensitivity in the mesocortiolimbic dopaminergic (DA) "reward" system that is composed out of the ventral tegmental area (VTA) with its projections to the nucleus accumbens and prefrontal cortex. Behaviorally, this manifests in an increased effort to obtain rewards, but also in an increased exploitation of highly expected rewards. Firstly, we show that chronic nicotine administration alters spontaneous dopaminergic activity in the VTA mostly by enhancing bursting activity. It has been suggested that a dopaminergic overdrive diminishes prediction error learning and therefore biases action selection toward previous rewarded options in dynamic tasks.

We use a novel multi-armed bandit task for mice to demonstrate the implications of nicotine treatment on value-sensitivity without behavioral flexibility. In this task, three locations in an open field are associated with different probabilities (1; 0.5; 0.25) for intracranial self-stimulation (ICSS). Exploration is essential to reactivate previous visited locations. This task implements a Markov Decision Process. No significant increase in speed and choice behavior was observed after acute administration of nicotine (I.P., 500, µg/kg). In contrast, chronic administration of nicotine via osmotic mini pumps (10 mg/kg/day) during the acquisition of the task increased both the velocity and the value-sensitivity compared to saline-treated mice. The increases in velocity and value-sensitivity were independent and are therefore suggested to rely on different mechanisms.

We demonstrate an increase in value-sensitivity after chronic nicotine. This increase is developed during training and suggests decreased sensitivity in the DA reward system by means of exploitation of higher probabilities of reinforcement. Therefore, nicotine-induced phasic DA may bidirectionally amplify the contingency of reward probabilities.

[13] Pervasive influence of idiosyncratic social biases in the expression of first impressions about others

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In social environments, we spontaneously form opinions about others' moods and thoughts which deeply influence our interpersonal interactions. As a prominent example, inferring someone's emotion depends not only on his or her facial expression, which is often ambiguous, but also on several contextual factors such as invariant facial traits and previous interactions with this person. However, the mechanisms by which these first impressions are acquired and expressed in human behavior remain unclear.
Here we aimed at characterizing the distinct sources of bias which shape social judgments during facial emotion recognition. Computational modeling revealed that associations between a face and an emotion prompted by invariant facial traits and past experience coexist with an idiosyncratic yet highly consistent source of bias to shift participants' decision criterion about displayed emotions.
Neural correlates of the decision variable in electrical brain activity were found to encode invariant facial traits earlier than the strength of the displayed emotion. Furthermore, the strength of this encoding predicts the expression of idiosyncratic biases in subsequent behavior, showing that the automatic processing of characteristic facial features triggers purely subjective face-emotion associations which in turn bias social decisions.
Together, these findings highlight the previously underestimated influence of idiosyncratic biases in the acquisition and expression of first impressions about others.

[14] Domain-generality of adaptive processes in human perceptual decision-making.

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Recent studies have shown that human choice processes adapt to background levels of decision-related information, just as sensory systems adapt to average levels of stimulation. In the visual domain, evidence from tasks involving serial integration of category information have revealed two suboptimal biases in choice behaviour, whereby (i) expected and (ii) later occurring samples of evidence are over-weighted in the decision process. These findings are explained by an "adaptive gain" account of decision-making in humans. An adaptive gain model of perceptual choice shows that the gain of information rapidly adapts to the ever-changing statistics of the environment.
The adaptive gain model states that each sample of evidence is characterised by a scalar decision update value that is transformed nonlinearly via a sigmoidal transfer function. The inflection point of the transfer function adjusts based on the running mean of the evidence, hence expected evidence comes to fall within the maximal gain section of the function (consistency bias). In other words, samples of evidence carrying similar decision information to their predecessors have a greater influence over choice independently from the stimuli physical appearance. Additionally, early samples will be less predictive of choice than late occurring samples because early samples will drift away from the point of maximal gain due to the effect of late-occurring evidence on the inflection point of the transfer function (recency bias).
Here, we replicated these findings in the auditory domain, using a task in which observers judged the average pitch provided by a rapid succession of tones. As in the visual domain, more variable sequences led to less accurate decisions, and both biases predicted by the adaptive gain model were present during the encoding of decision information. These findings show the domain-generality of adaptive processes in human perceptual decision-making.

[61] Orexinergic OX1 receptors in the Orbitofrontal cortex regulate delay-based decision making

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Orexinergic neurons are discretely localized within the lateral hypothalamus and have widespread projections to the whole brain. In addition, several lines of evidence specify that orexins may also participate in the regulation of a variety of affective and cognitive processes. Orexin-1 receptor (OX1R) is distributed extensively throughout the prefrontal cortex (PFC). Delay based decision making is mediated largely by the orbitofrontal cortex (OFC). Hence, in the present study, we conducted a series of experiments to clarify the role Orexinergic OX1 receptors in the OFC regulate delay-based decision making. Sixteen adult male Wistar rats (Pasteur Institute, Iran) were used in this study. The rats had been trained in a delay-based form of cost-benefit T-maze decision making task. The two goal arms were different in the amount of accessible reward. The animals could choose high reward arm (HR arm) and pay delay cost to achieve large reward or obtain a low reward in the other arm immediately (LR arm). Before surgery, all animals were selecting the HR arm on almost every trial. During test days, the rats received local injections of either DMSO 20% /0.5µl, as vehicle, or SB334867 (3,30,300 nM/0.5µl), as selective OX1-receptor antagonist, within the OFC. Our results demonstrate profound effects of OFC's OX1-receptors on delay based decision making, due to bilateral microinjection of SB334867, at the doses of 30 nM/0.5µl into the OFC changed the animal's preference to a low but immediately available reward. This was not caused by a spatial memory because the same rats returned to selecting the HR arm when the amount of cost needed to be expended to obtain reward in either arm was equalized.OX1-receptor inactivation changed decision policy, such that animals tended to make suboptimal decisions by avoiding decision costs. These results imply that OX1-receptor has a crucial role for allowing the animal to be patient to acquire greater rewards.

[15] Effects of learning-induced categorical representations upon dynamics of visual evidence processing in behaviour and EEG-recordings

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Humans have the remarkable ability to rapidly learn new categories composed of arbitrary groupings of stimuli. Recent single-cell recordings have suggested that neurons in the lateral intraparietal area (LIP) of the macaque brain play a key role in this function. When classifying two successive psychophysical stimuli (sample and probe) characterised by distinct directions of motion according to whether they belong to the same or different category (delayed match-to-category [DMC] task; Sarma et al 2016), LIP neurons encode task-relevant category information during the delay period intervening between sample and probe, instead of purely low-level sensory orientation information. Here, we investigated the learning of arbitrary categories in human participants using scalp EEG recordings.

Human observers performed a DMC task that involved matching the category of two successive, fully coherent random dot motion stimuli according to their direction of motion. Category boundaries in motion direction space were assigned randomly but remained stationary for each participant over the course of the experiment, and were learned via trial-and-error feedback.

Behaviourally, we observed that accuracy depended on the distance of both the probe and the sample to the boundary. However, response times (RTs) were shorter both when the probe was closer to the sample, and when the probe was closer to the boundary, with the latter effect becoming stronger over the course of the experiment. In other words, participants used a mixture of stimulus- and category-based strategies for performing the task, but use of the latter grew during learning.

We analysed the neural data by regressing the (absolute) distances between sample, probe and category boundary against single-trial estimates of EEG activity across the brain. This revealed that EEG signals encoded the distance between both the sample and the category boundary, and the probe and the category boundary, at ~300 ms post-stimulus over parietal electrode sites.The latter effect became stronger in the timecourse of the experiment. Consistent with behavioural data, this suggests that both sample and probe were encoded in the frame of reference of the category, and that this categorical signal is supported by the human parietal cortex.

Next, in order to disentangle low-level perceptual and high-level task relevant quantities in the EEG recordings, we applied representational similarity analysis (RSA, Kriegeskorte et al, 2008) to the data. Both, for sample and probe, we were able to decode both the stimulus orientation and the category from around 300ms, continuing after stimulus offset.

Taken together, the behavioural results suggest that the participants are relying on a mixture of the angular distance between sample and probe and their category membership in order to solve the task, and that categorical uncertainty is reflected in accuracies and reaction time measurements. Further analyses are targeted at identifying timepoints were neural signals reflect a potential transformation of sensory information into an abstract categorical variable.

[16] Human noise blindness and decision suboptimality

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Human judgments about sensory stimuli are well described by optimal inference models in which the different sources of decision-relevant information are weighted according to their reliability. For example, during sensorimotor judgments, humans rely more on information about stimulus base rates (prior probability of occurrence) when the stimulus quality is experimentally degraded, e.g. when it is harder to perceive. Conversely, in cognitive tasks, humans show systematic deviations from optimality. For example, when asked to guess an individual's profession, participants neglect the base rate of occurrence of different professions. Understanding this discrepancy in optimality between perceptual and cognitive tasks is a major challenge for the cognitive sciences.

Here, we tested and confirmed one explanation: that decision optimality is driven by differences in human metacognitive sensitivity to (i) noise that arises "early", e.g. during the encoding of information, and (ii) noise that arises "late", e.g. during the integration of different pieces of information. We asked human observers to categorize the average orientation of set of gratings as clockwise or counterclockwise of the horizontal axis, providing fully informative feedback after each decision. We independently manipulated the impact of early and late noise on choices. Higher early noise was achieved by lowering the contrast of each grating (poor encoding); higher late noise was achieved by increasing the variability of orientations within a set of gratings (harder to integrate). Both manipulations lead to a significant drop in decision accuracy by about 10%. We used 3 methods for testing observers' metacognitive sensitivity to early and late noise: (i) recording whether observers adjusted (according to their performance) their use of a cue about the base rate of each stimulus category, (ii) eliciting second-order confidence judgments, and (iii) offering observers the option to "opt out" out of making a decision for a fixed probability of receiving reward. In all three cases, humans adjusted their decision strategy optimally in response to increased early noise but failed to do so in response to increased late noise. We conclude that humans are relatively blind to noise arising from their imperfect integration of different sources of information. These findings offer an explanation for human decision suboptimality on cognitive and economic tasks.

[17] Decision-making in a neural network model of the basal ganglia

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Keywords: Decision-making, action selection, basal ganglia, spiking neurons

The mechanisms of decision-making are generally thought to be under the control of a set of cortico-subcortical loops involving basal ganglia and thalamic pathways. These structures include several parallel functional loops connecting back to distinct areas of cortex, processing motor, cognitive and limbic modalities of decision making. Due to convergence and divergence within the network, these loops cannot be completely segregated. We used these circuit properties to develop a computational model at a spiking neuron level of description. The model was implemented using leaky integrate-and-fire neuronal models connected by voltage-jump synapses and its architecture relied on commonly accepted data regarding the complex functional connectivity description between basal ganglia, cortex and thalamus.

This model was applied to a decision making task which was initially studied in primates. In this task, the animals were trained to associate reward probabilities to different cues they had to select in order to maximize their gain.

Combining behavioral and electrophysiological experimental data from this study and detailed circuit description, we developed a basal ganglia model in which we used two parallel loops, each of which performed decision making based on interactions between positive and negative feedback pathways. The loops communicate via partially convergent and divergent connections in specific basal ganglia sub-regions.

This neuronal network model was then trained to perform the same decision making task as in primates. This training resulted from the closed-loop interaction between the neural circuitry and its sensory-motor interface. The learning was implemented as a cortico-striatal synaptic weight variation modulated by phasic dopamine release following the presence or absence of reward delivery.

Thanks to this simple bottom-up approach the model was able to learn to select optimum reward cues in a similar manner as the monkey. Moreover, this model allows us (i) to avoid the arbitrary choice of a pre-existing machine-learning derivative model, (ii) to investigate lesional and pharmacological effects on learning and decision making and (iii) also provides the possibility to test for further hypotheses regarding cell-scale mechanisms effect on the whole model capacities

[18] Across-trial dynamics of stimulus priors in an auditory discrimination task

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Just as our experience has its origin in our perceptions, our perceptions are fundamentally shaped by our experience. How does the brain build expectations from experience and how do expectations impact perception?
We aim to understand how neural circuits integrate the recent history of stimuli and rewards to generate priors and how priors are combined with sensory information across the processing hierarchy to bias decisions. In order to achieve our goal we trained rats in a reaction-time two-alternative forced-choice (2AFC) task with stimuli consisting in a superposition of low and high frequency amplitude-modulated tones (6.5kHz and 31kHz). The relative weight of each tone was parameterized by the coherence c. Rats had to discriminate the dominant tone and seek reward in the associated port.
We presented partially predictable stimulus sequences that, once learned, could be used to generate adaptive priors that maximize the performance. These sequences were created using a two-state Markov chain whose stimulus transition probability was fixed in each 200 trials lasting block: In Repeating blocks the probability to repeat the previous stimulus category was 0.7 and in Alternating blocks the probability was 0.2.
We found that this design leveraged on the natural tendency of these animals to exhibit history dependent biases, they learned to recognize the changes in the sequence statistics of each block and adapted their behavior to them by developing a repeating choice bias after several correct repetitions and a weaker but reliable alternating bias after correct alternations. The magnitude of the bias built up after each correct response and it seemed to saturate after four consecutive correct responses, but reset to zero after error trials. In the transitions between the Repeating and Alternating blocks, rats took around five trials to modify their belief in the sequence rule.
Moreover, animals reaction time was longer for unexpected compared to expected stimuli, but comparable to trials without a define expectation.
Finally stimulus impact on choice was smaller when the choice matched the expectation, than when it went against it. Our findings show that priors show build-up-and-reset dynamics across trials allowing animals to capitalize on the predictability of the stimulus sequence.

[19] Social Status and self-image shape the attempt to influence others

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In the relationships in our lives we are constantly influenced by, and attempt influencing, others through exchange of information and advice. Two models suggest that we adapt our advice confidence according to our status, but in contradictive direction: a competitive model suggests we increase, while a defensive model suggests we decrease our confidence when our status is low. We examined these models' predictions using a paradigm in which two advisers competed to influence a client. Over three experiments, we found that the confidence with which advice is given depends upon the interaction between two kinds of status: social-status imposed externally by the client appraisal, and self-image tracked internally by comparison to rival adviser. Expressed confidence was dynamically adjusted to be highest when an adviser currently had low social-status, in line with the competitive model, and high self-image, in line with a defensive model. These two sources of social information were tracked in distinct parts of the social and valuation brain systems. Medial prefrontal area activity was modulated by internally tracked self-image, while temporo-parietal area was tracking social status. Both kinds of information modulated activity in ventral striatum.

[20] Modelling history-dependent perceptual biases in rodents

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Higher order cognition relies on selecting actions based on current sensory information and on the outcome of previous experiences. While humans can flexibly learn the statistical regularities of the sensory environment and use them to guide behavior, little is known about whether rodents display comparable abilities. We studied the capacity of rats to use the history of recent actions and outcomes to bias future perceptual decisions. Rats performed a novel acoustic discrimination two-alternative forced choice task in which we introduced correlations in the rewarded choice sequence that could be used to guide decisions. Specifically, blocks of trials in which the probability to repeat the previous stimulus category was Prep> 0.5 (repeating environment) alternated with blocks where it was Prep< 0.5 (alternating environment). Rats were able to use acoustic information across the stimulus duration, as well as recent history of rewards and errors to guide their choices and maximize performance. History-dependent choice biases based adapted to each environment.

Probit regression analyses showed that rats use recent history of response alternation and repetitions, as well as responses to left and right ports to guide action selection: they tended to favor both the response (left/right) and response transition (alternate/repeat) that lead to rewards in previous trials. While sequences of successful trials lead to gradual build-up of such history-dependent bias, importantly, errors lead to a reset of such biases.

We use fitting and comparison of computational models of behavior to detail the mechanisms at play in integration of sensory evidence with recent history. Our model includes build-up of both laterality (left/right) and transition (alternate/repeat) biases as latent (auto-regressive) variables. Fitting parameters indeed show opposing effects of correct left vs. right response onto the laterality bias, and opposing effects of correct alternate vs. repeat responses onto the transition bias, while errors lead to almost complete reset of such biases.

Our results show how history-dependent choice biases develop and and are integrated them a normative framework describing how organisms flexibly adapt to regularities in the environment.

[21] Computational approaches to emotional decision-making

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Findings on the role that emotion plays in human behavior have transformed Artificial Intelligence computations. Modern research explores how to simulate more intelligent and flexible systems. Several studies focus on the role that emotion has in order to establish values for alternative decision and decision outcomes. For instance, Busemeyer et al. (2007) argued that emotional state affects the subjectivity value of alternative choice.

However, emotional concepts in these theories are generally not defined formally and it is difficult to describe in systematic detail how processes work. In this sense, structures and processes cannot be explicitly implemented. Some attempts have been incorporated into larger computational systems that try to model how emotion affects human mental processes and behavior (Becker-Asano & Wachsmuth, 2008; Marinier, Laird & Lewis, 2009; Marsella & Gratch, 2009; Parkinson, 2009; Sander, Grandjean & Scherer, 2005).

As we will see, some tutoring systems have explored this potential to inform user models. Likewise, dialogue systems, mixed-initiative planning systems, or systems that learn from observation could also benefit from such an approach (Dickinson, Brew & Meurers, 2013; Jurafsky & Martin, 2009). That is, considering emotion as interaction can be relevant in order to explain the dynamic role it plays in action and cognition (see Boehner et al., 2007).

[22] Noradrenaline in motivation and decision-making: a pharmacological study in monkey

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Neuromodulatory systems are the targets of most drugs used in psychiatry and their alteration induces major disruptions in cognitive functions, such as decision-making. In particular, noradrenaline seems to play a key role in motivation and decision-making, but its specific function remains unclear. On one hand, it has been recently propose that it would be especially critical to face difficult situations, such as producing a physical effort. On the other hand, it has been associated with behavioural flexibility in decision-making.

To better characterize the role of noradrenaline in both motivation and decision-making, we studied the effect of clonidine, a selective alpha-2 noradrenergic receptor agonist that suppresses presynaptic noradrenaline release at the doses that we used (2.5-7.5µg/kg, IM), in force production and cost/benefit trade-off in monkeys. In our task, monkeys had to perform sequences of actions, i.e. clamp squeezes, to obtain rewards. Sequences of variable number of actions and different reward sizes were used. In most trials, as the animals were performing a sequence for a given reward, they were proposed to perform a different one. Therefore the animals had the possibility to either stay and complete the original sequence, or to switch and execute an alternative one.

Under clonidine treatment, the number of squeezes performed and the overall force produced decreased in a dose dependent way. We excluded a pure peripheral effect because the effect of doses on different measures of locomotor activity did not correlate. Reaction times were affected by difficulty: they were greater in choice compare to no choice conditions and in easy (congruent) compared to hard (incongruent) choices. Clonidine treatment did not alter this pattern but dose-dependently affected reaction times. At the time of choice, monkeys integrated both reward size and sequence length to guide their behaviour. There was no systematic bias to stay with the current option or switch to the alternative one across subjects. Model-based analysis of the behaviour showed that clonidine treatment affected the inverse temperature parameter beta depicting the randomness in choices. Indeed the higher the dose of clonidine administrated, the higher the beta, namely the less noisy the choices.

Overall, our findings suggest that there is a global energizing effect of noradrenaline on force production, with animals completing fewer trials and squeezing less hard under clonidine compared to saline. Noradrenaline seems to be also involved in decision-making, since clonidine induces a decrease in choice variability. These data provide a new insight into the causal role of noradrenaline in effort/reward trade-off.

[23] Novelty and generalisation in value-guided learning

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A large literature has investigated the neural mechanisms by which humans and other animals learn the value of stimuli and actions. However, in natural settings, novel stimuli are often composed of combinations of familiar elemental features, and much less is known about how human generalise existing value representations to make decisions about novel compound stimuli. Here, we addressed this question using a two-stage task in which human participants first learned the value of 4 elemental visual stimuli, and then made decisions about compound stimuli, composed of combinations of these elements.

On each trial, participants (N=18) viewed a 2x2 grid. In Stage 1, one of the 4 squares was black and the others were white. Each black square was associated with a unique probability of obtaining a reward (.22, .33, .67, .78), which remained unchanged across Stage 1. Above the grid, the number of points that could be won on the current trial were shown. Each stimulus thus represented a gamble, which participants could 'accept' or 'reject'. Accept decisions led to receipt of the indicated points with p(win|stimulus), and a fixed loss with 1-p(win|stimulus). Reject decisions incurred a small fixed cost, and participants received outcome feedback for both chosen and foregone options.

Subsequently, in Stage 2, participants made decisions about 2x2 grids with 2 black squares. There were two contexts: 'Bayes' and 'Shuffled' (signalled by different background colours). In 'Bayes', the objective reward probability for each 2-square grid was calculated via Bayes' rule as the posterior over the elemental probabilities from Stage 1. Thus, participants experience in Stage 1 could be used to infer the probability of reward for novel Stage 2 stimuli. In 'Shuffled', the mapping between stimuli and win probabilities was shuffled and participants' earlier experience was not useful. As before, participants learned the probabilities of reward by trial-and-error reinforcement through accept/reject decisions.

As expected, in Stage 2, participants increasingly chose to 'accept' as the probability of reward and the reward magnitude increased. However, participants were more sensitive to the probabilities in 'Bayes' compared to 'Shuffled', suggesting that participants made use of their Stage 1 experience to boost learning in 'Bayes'. As expected, no context dependence was evident for reward magnitude.

To understand the improved performance for 'Bayes', we fit a number of different computational models based on the reinforcement learning framework. Of key interest was whether participants learned the novel compound values from scratch more rapidly (different learning rates), or whether their Stage 2 decisions were best described by incorporating prior value estimates from Stage 1 (true vs. neutral priors). The best-fitting model was one in which reward probabilities for compound stimuli in Stage 2 were initialised as the true combination of their Stage 1 probabilities, rather than to neutral priors. Moreover, participants learned about the Stage 2 stimuli in a configural rather than elemental fashion, as demonstrated by better fits for configural models (which treat each Stage 2 stimulus as unique) compare to elemental models (which learn about the elements of each Stage 2 stimulus).

Together, these results show that participants used their experience in Stage 1 to form prior beliefs about Stage 2 stimuli which approximate the application of the Bayesian rule, and that these beliefs guided participants' choices. However, once exposed to the novel stimuli, participants appear to treat them as distinct from the elements that make them up. Forthcoming work will explore the limits of value generalisation and use functional neuroimaging to understand its neural mechanisms.

[24] Managing a zoo with the medial prefrontal cortex

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Animals tend to make decisions that lead to positive outcomes. Standard models assume that the brain integrates potentially incommensurable outcomes into a single common value function. However, in natural settings, survival depends on the ability to independently maximise multiple distinct assets. For example, a thirsty animal will value a liquid reward over a food reward, whereas the reverse is true for a hungry animal. Thus, in order to choose optimally between two distinct assets, animals must integrate the respective values on offer in the context of their internal resource levels.

Previous research in the biology of decision-making has identified neural structures, prominently including the medial orbitofrontal cortex (vmPFC), that are required for humans and other animals to choose stimuli that maximise a specific outcome, for example, when one of two assets is devaluated through selective satiation ('model-based' decision-making). However, much less is known about how the brain keeps track of resource levels associated with a given asset, and how these contextual representations guide model-based decisions. Here, we created a task that involved accumulating two assets (lions and elephants in a virtual zoo), which human participants performed in the fMRI scanner. Each trial involved an offer of a variable number of lions and elephants. Participants received trial-wise rewards that related to the category with the minimum number of accumulated animals in each category (i.e. they tried to maximise the minimum of either asset). Periodically, the accumulated resources were reset to zero, creating a predictable succession of "zoo contexts" that decoupled asset accumulation from the passage of time elapsed across the experiment. In line with previous studies, we asked how neural structures previously implicated in representing economic value responded to the magnitude of each offer, and the relative value of the chosen and unchosen option. However, the paradigm also allowed us to ask how these representations were modulated on a trial-by-trial level by ongoing resource levels.

Behaviour showed that although on average participants favoured the choice with more animals on offer (offer-based choices; i.e. choose 4 elephants over 2 lions) choices were strongly modulated by ongoing resource levels for either asset (resource-based choices; i.e. lions might be preferred if accumulated lions in the zoo were low). The tendency to make resource-based choices grew as the end of each zoo context approached.

In the neural domain, we observed a dissociation between offer and resource-based value encoding: while the ventral striatum encoded the value of the chosen relative to unchosen option, BOLD signals in the vmPFC scaled with the increase in resource value for the current minimum asset, as well as encoding the absolute level of resources as they accumulated over time. By contrast, more dorsal regions of the medial prefrontal cortex, peaking in the rostral anterior cingulate cortex (ACC) coded for the difference in the two cumulative resources. Finally, a yet more dorsal region overlapping with the pre-supplementary motor area coded inversely for the update to the minimum asset. One interpretation of these data is that the vmPFC encodes values in the context of overall goals, while also updating progress towards this goal, whereas ACC facilitates changes in context-based decision strategy.

[25] Lateral hypothalamus inactivation affects cost-benefit decision making

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Lateral hypothalamus (LH) is an important component of the networks underlying the control of feeding and other motivated behavior. Cost-benefit decision making is mediated largely by the prefrontal cortex (PFC) which strongly innervates the LH. Therefore, in the current study, we conducted a series of experiments to elucidate the role of the lateral hypothalamic nucleus (LH) in effort- and delay- based decision making.
A total of 30 male Wistar rats (Pasteur Institute, Iran) were used as subjects. We trained different groups of rats in a delay-based and an effort-based form of cost-benefit T-maze decision making task in which they could either choose to pay cost to obtain a high reward in one arm (HR arm) or could obtain a low reward in the other arm with no cost (LR arm). Before surgery, all animals were selecting the HR arm on almost every trial.During test days, the rats received local injections of either vehicle or lidocaine4% (0.5μl/side), in the LH.
Our results demonstrate profound effects of LH on cost-benefit decision making. In an effort-based decision task, LH inactivation led to decrease in high reward choice. Similarly, in a delay-based decision task animals' preference changed to a low but immediately available reward. This was not caused by a spatial memory or motor deficit because the same rats returned to selecting the HR arm when the amount of cost needed to be expended to obtain reward in either arm was equalized.In rats performing an effort or delayed -based decision task , animals choose to pay a cost to obtain a high reward.
LH inactivation modified decision behavior, such that animals tended to make suboptimal decisions by avoiding decision costs. These results imply that LH area is important for allowing the animal to pay a cost to acquire greater rewards.

[26] Temporal expectation biases duration judgment

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Timing processes in humans are typically classified into implicit and explicit timing: explicit timing requires explicit usage of the temporal dimension to estimate duration of a given time interval. On contraire, implicit timing entails the use of the temporal dimension to create temporal expectation with respect to the upcoming stimulus. The simplest form of temporal expectation is linked to the buildup of anticipation informed by the hazard rate function, that is the probability that an event will occur given that it has not yet occurred. As temporal expectation is known to affect sensory processing, we set out to test how temporal expectation affects duration perception in order to address the interplay between implicit and explicit timing processes which are rarely considered.

We asked participants to discriminate time intervals while recording brain signals using combined EEG and MEG. On each and every trial the standard duration (860ms) was presented, followed by the presentation of the comparison interval (770, 860, 950ms; 10%, 80%, 10% of all trials respectively). Crucially, the inter-stimulus intervals (ISI), that is interval between the SI offset and the CI onset, were uniformly distributed which allowed participants to build up a steady anticipation function with regard to the occurrence of the comparison interval, as evidenced by the proportion of 'short' and 'long' responses. To investigate how the expectation of the comparison interval affects duration perception, we split trials according to their short and long ISI ('early', 'late'). Within these two groups we investigated differences in the oscillatory power and inter-trial coherence (ITC) between trials subjectively perceived as 'short' and 'long'. For the 'late' trials the processing of the comparison interval has been associated with the modulation of alpha and beta power, and the modulation of the ITC, predominantly in the theta band. Specifically, the trials perceived as long exhibited larger alpha and beta desynchronization and increased ITC, suggesting increased expectation level in the 'longer' trials. Importantly, no difference between the 'short' and 'long' trials was observed for the 'early' trials. Together, these results demonstrate that temporal expectation modulated duration judgments by desynchronization of oscillatory power and enhancement of ITC.

[27] Task to investigate the effects of exogenous and endogenous spatial attention on perceptual confidence

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Whenever we make a decision we are able to easily evaluate and report the quality of that decision, e.g. as confidence ratings. Equally easily we can use attention to enable us to better process the attended stimulus. There are two forms of spatial attention: one that is voluntarily and slowly deployed (endogenous) and the other that is reflexively and fast deployed (exogenous). Both confidence and spatial attention have been subjected to extensive research but little is known about the interactions between these two phenomena. While it is known that attention has similar effects on improving discrimination of stimuli whether it is due to an exogenous or endogenous attention, we do not know whether these two types of attention have similar effects on the confidence of subjects' in their decision. Here we present a task to investigate this question. As two previous studies investigating the link between attention and confidence by Wilimzig et al., 20081 and Zizlsperger et al., 20122 found contradictory results we hope to additionally be able to use this task to support the conclusions of one of the two studies.
We designed the following orientation discrimination task: a sinusoidal grating is briefly presented after which subjects have to report their perceived orientation by changing the orientation of another identical grating to match it. Subjects are then asked to rate the quality of their response on a visual analogue scale. Before the stimulus a spatial pre-cue may be shown that is either a short Posner line pointing to the stimulus location (for endogenous attention) or a briefly presented small dot next to the stimulus location for exogenous attention. In control conditions the stimulus is presented without any pre-cue.
In preliminary data from 4 subjects we have found that both cue types lead to an improvement in performance but only endogenous attention, which in contrast to exogenous attention is a voluntary process, seems to shift confidence to overall higher values. This suggests that confidence might interact differently with endogenous and exogenous attention and therefore may include a metacognitive component, but more data is needed to confirm this hypothesis.

[28] Behavior-dependent gating and extraction of task-relevant auditory signals in ferret frontal cortex

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The frontal cortex has been previously associated with enhancement of relevant information for goal-directed behavior. Neuronal responses in the frontal cortex (FC) of the behaving ferret have been shown to be behaviorally gated and highly selective for target stimuli during auditory and visual discrimination tasks (Fritz et al., 2010). This suggests a selection in the flow of sensory information by frontal cortex in tasks in which ferrets rapidly categorize reference and targets. However, in a more natural and cluttered environment, accumulating relevant evidence to produce an adequate behavior is critical. Here we investigate how FC can extract targets embedded in continuous sound stream, and how FC is involved in a complex task demanding accumulation of sensory evidence. For this purpose we trained ferrets on a change detection paradigm where animals have to constantly monitor a stochastic and continuous acoustic stream to detect subtle statistical changes. In an attempt to characterize the role of frontal cortex in the extraction of relevant sensory information, we gathered electrophysiological data in the primary auditory (A1) cortex and the frontal cortex (dlFC) of the behaving ferret. Preliminary analysis show area-specific responses to changes, consistent of previous EEG findings. Specifically, A1 neurons exhibited strong onset responses and reduced change-related discharges, whereas dlFC neurons presented an enhanced response to change-related events during behavior, possibly being the signature of accumulation of sensory evidence. This suggest a behavior-dependent sensory 'gating' mechanisms leading to decision making.

[29] Perceptual uncertainty, conflict, and gain control in human decision-making

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When sensory stimuli provide conflicting information about how to respond, decisions are slower and less accurate. For example, in the Eriksen Flanker task, decisions are impaired when a central imperative stimulus is flanked by stimuli that are associated with an imcompatible response. This finding is explained by models in which response units compete for limited resources, and decisions are delayed until conflict is resolved.

However, in flanker tasks, compatible and incompatible stimuli also differ with respect to their level of perceptual variability. During binary categorisation tasks in which sensory information must be integrated across multiple sources, arrays characterised by more variable features also incur a cost to decision accuracy and latencies. For example, observers classifying an array of gratings as on average tilted clockwise or counterclockwise of vertical make poorer decisions when the gratings are drawn from a more variable orientation distribution. However, the relationship between the effects of conflict and perceptual heterogeneity on human decisions remains largely unexplored.

Here, we asked participants to judge the orientation of a centrally presented grating relative to vertical, whilst manipulating the mean and variance of the distribution from which 6 flanking gratings were drawn. In experiment 1, we observed that compatibility effects depended on the variance of the flanker distribution. Interestingly, stimuli flanked by congruent gratings with low variance elicited shorter RTs, but flanker variance had no influence when gratings were on average incongruent with the imperative stimulus. This finding is inconsistent with the view that the RT cost on incongruent trials arises from competition among rival response units alone.

This finding can however be explained by a simple model in which the statistics of the flanker distribution determine the allocation of resources across orientation space, acting as a gain control mechanism that helps or hinders processing of the imperative stimulus. For example, when the flankers are narrowly distributed around a counterclockwise angle, a counterclockwise stimulus is processed with heightened gain, but when they are more broadly distributed, less benefit is incurred on compatible trials. By contrast, the cost of incompatible flankers was independent of the variance of the distribution from which they were drawn.

This model predicted the existence of paradoxical “reverse compatibility” effects that should occur when the orientation of the target stimulus lies close to the category boundary. In experiment 2, we tested for, and confirmed, the existence of these effects. This finding provides strong support for the gain-control model of perceptual decision-making.

[30] Sleep Deprivation Alters the Integration of Affect in Subsequent Evaluations

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Objective: Affect plays a central role in judgment and decision-making processes. Previous behavioral research has suggested that people integrate their affective states as informational inputs to subsequently unrelated evaluations (i.e. affect-as-information effects, AAIE) (Schwarz & Clore, 1983). Research has further indicated that AAIE influence evaluations in an affect-congruency manner: more favorably evaluations of positive (negative) objects when the individual is in a positive (negative) affective state (Adaval 2001; Cohen et al., 2008). In this research, we investigated how the integration of affect on subsequent evaluations could be modified under sleep-deprivation. Sleep deprivation (SD) has been known to detrimentally influence cognitive systems that rely on affective inputs. More specifically, studies have shown that functional connectivity between limbic regions (e.g., amygdala) and the medial prefrontal cortex (mPFC) is dampened under SD (Yoo et al., 2007; Gujar et al., 2011). Accordingly, we hypothesized that the integration of affect will be altered under SD.
Methods: 21 participants (M=6, Age=22) participated in the study. They were instructed that the goal of the study was to investigate their affective reactions to different types of rewards. In each trial they either won or did not win a non-hypothetical monetary reward of S$15 as a manipulation of their affective states and then were asked to evaluate their enjoyment of viewing affectively positive, neutral or negative images on a 9-point scale. Participants completed the task once under rested wakefulness (RW) state and once after 24 hours total sleep deprivation (within-subject factor). A lottery determined which of the different trials counted for the pay-off of the S$15 at the end of each session.
Results: A multi-level regression analysis found a main effect of image and a main effect of RWSD state on reported enjoyment of viewing images as a seemingly unrelated evaluation task (βimg=2.71, $p<.001$; βRWSD=-1.12, $p=.023$). Though the main effect of reward was insignificant (βreward=-.721, $p=.145$), we observed that 1) there was a trend of affect-congruency effect on evaluations in RW such that receiving reward increased the evaluation of neutral and positive images and not receiving reward increased the evaluation of negative images; 2) in SD, the pattern was reversed such that not receiving reward increased the evaluation of neutral and positive images and receiving reward increased the evaluation of negative images. More importantly, this reversed pattern was qualified by a significant negative three-way interaction between reward, images and RWSD state (β3way=-.853, $p=.008$), and a significant two-way interaction between reward and RWSD state (β2way=1.529, $p<.03$). These results confirmed our hypotheses that SD altered the integration of affect to subsequently unrelated evaluations and revealed that the affect-congruent evaluation under RW was reversed under SD.
Discussions: Our results give first evidence that SD alters the congruency of how incidental affect is integrated into subsequent evaluations. This finding raises interesting implications for the putative neural mechanism at play: on the one hand, there is evidence suggesting that behavioral AAIE may underlie a physiological integration of affect in brain's valuation region (i.e., vmPFC) that "misattributes" incidental feelings to subsequent evaluations (e.g. Abitbol et al., 2015). On the other hand, in addition to the evidence that SD dampens functional connectivity between the limbic region and the mPFC, other neuroimaging studies have shown that value signals in ventromedial prefrontal cortex are attenuated following SD (e.g. Menz et al., 2012). Taken together, it seems possible that SD interrupts connectivity between limbic systems and valuation systems, and that in turn alters the vmPFC signal during evaluation.

[32] Intracranial EEG investigation of the Brain Valuation System: Revealing the dynamics underlying value-based decision-making.

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Estimating the value of outcomes is a key process in decision-making. According to numerous studies, the brain valuation system, mainly composed of the ventromedial prefrontal cortex (vmPFC), encodes hedonic values of objects in a subjective, automatic and generic manner. Most of these studies investigated this network using fMRI and the dynamics of the valuation process is still unknown. In our study, we recorded intracerebral electroencephalography signals in 35 epileptic patients while they performed rating and choice tasks. From our large dataset, including a total of 3970 recording sites, we showed that the brain valuation system was specifically involved in pleasantness valuation in the gamma band activity [50-150Hz], we also found an involvement of the lateral orbitofrontal cortex (lOFC), less commonly revealed in fMRI studies but often found in animal electrophysiological studies. Among the set of areas revealed by the pleasantness valuation task, the vmPFC was the only one to encode the pleasantness value of items independently of their category (food, faces and paintings) and independently of the task (even when the valuation was implicit). The study of the dynamics underlying this valuation process revealed that the hippocampus and the lOFC encoded the value just after the stimulus onset while the vmPFC encoded values until the response was made. The same distinction between vmPFC and lOFC was found during choices, with the decisional value encoded in the vmPFC until a response was made, while in the lOFC it was encoded transiently right after the stimulus onset. Our results confirmed the properties of the brain valuation system found in fMRI and bring new insights in the dynamics of value encoding during valuation and decision-making.

[33] Heart rate variability is associated with increased resistance to tempting foods

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Objective: Self-control has been linked to better psychosocial and physical health. Yet it is unclear through which channels this link may operate. A similar link to health outcomes has been reported for heart rate variability (HRV). We therefore tested in a dietary self-control task whether resting HRV can serve as a biomarker for the neurophysiological adaptability that putatively underlies self-controlled behavior, and whether individuals with higher HRV are more resilient to self-control temptations.

Methods: After 49 healthy men had rated food stimuli for health and taste aspects, we recorded their baseline ECG during 3 minutes at rest. They then made a series of choices between two food items, one of which was always healthier than the other, while BOLD fMRI was acquired. Self-control success was measured as the proportion of trials in which the participant overruled his taste preferences and chose the healthier, but less tasty food if the two attributes were in conflict.

Results: Total HRV (measured as standard deviation over all RR intervals, SDNN) correlated positively with the frequency of successful self-control use in the food choice task ($r = 0.36$, $p = 0.01$, CI = [0.07, 0.59]). Moreover, higher HRV was associated with decreased influence of taste attributes in self-control challenge choices (i.e. trials in which health and taste attributes were not aligned; $z = -2.81$, $p = 0.0049$). At the neural level, individuals with higher HRV showed higher activity and attenuated taste representations in the vmPFC ($r = -0.42$, $p = 0.002$, CI = [-0.60, -0.19]) in this region when facing self-control challenges compared to choices that did not require self-control to override taste preferences. Lastly, our multiple regression analyses demonstrated that accounting for HRV improves predictions of self-control levels as HRV explains unique variance in choice patterns across participants that is not captured by standard self-reports measuring cognitive regulation of eating behavior.

Conclusions: Heart rate variability is an index of cardiovascular and psychological health that has been associated with improved performance in executive function tasks and may reflect an organism’s readiness and ability to adapt to changes in the environment. Our results indicate that participants with a greater HRV are better able to flexibly incorporate health and taste in food value computations in order to maintain dietary health goals.

[34] If only I had chosen differently! EEG manifestations of comparison between received and alternative outcomes

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Behavioral research shows that following a choice, the outcome of the unchosen (alternative) option influences people's evaluation of their received outcome. Upward comparison - realizing the Alternative's Outcome (AO) was better than the Received Outcome (RO) - diminishes satisfaction; downward comparison increases it. ERPs studies tested if the Feedback-Related Negativity (FRN) and P3 are sensitive to outcomes comparison but methodological limitations hindered clear conclusions. Presenting both outcomes simultaneously at different locations didn't ensure that subjects paid attention to both stimuli. Presenting the AO first might have created biased expectations regarding the RO (Marciano et al., 2016). We overcame these issues using a novel paradigm, the Matrix Game, in which a single stimulus conveys both options' outcomes. We expected the FRN and P3 elicited by this stimulus to be more positive if the RO is a gain vs. a loss and less positive if the AO is a gain vs. a loss.
Methods: 25 subjects saw a 2X2 matrix (Columns: +/-; Rows: +/-), and had to bet on Columns/Rows while EEG was recorded (66 electrodes). A coin then appeared in one of the matrix' cell. If subjects bet on Rows, they won 0.5 NIS if the coin appeared in the "+" row or lost 0.5 NIS if it appeared in the "-" row. If they bet on Columns, losing or gaining was based on the column in which the coin appeared. Thus, the location of the coin in the matrix simultaneously conveyed information on the AO and the RO.
The amplitudes of the FRN and P3's were each subject to a 2 (AO: gain/loss) × 2 (RO: gain/loss) × 5 (electrodes – FRN: Fz, FCz, Cz, CPz, Pz; P3: Cz, CPz, Pz, POz, Oz) repeated-measure ANOVA.
Results
FRN: The FRN was more positive when the AO was a loss vs. a gain. However, the FRN was not sensitive to the valence of the RO. These results, quite surprising given the literature on the FRN, could be explained by the complexity of the feedback, possibly requiring more time to be processed.
P3: As expected, received gains elicited more positive responses than received losses, while alternative gains elicited less positive P3s than alternative losses.
Conclusions
Using a novel task in which the RO and the AO were presented as a single stimulus, we found that the P3 was modulated by both outcomes. Importantly, the RO and the AO modulated the P3 in opposite directions, which suggests that the P3 doesn't reflect a mere summation of the two options' outcomes, but rather a downward/upward comparison process between what a subject received and what he could have received had he chosen differently.

[35] Goal-action transformation in the primate prefrontal cortex

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During natural behavior multiple processes need to be coordinated so that specific goals can be obtained. Due to its large number of connections with many other areas of the brain, the prefrontal cortex (PF) plays a fundamental role on this matter (Desimone and Duncan, 1995). Several studies have shown that neurons in PF represent different task-related information that goes from the coding of sensory stimuli to the specific goals and actions. However, how PF neurons transform the goals into specific actions is still matter of debate. To study the goal-action transformation we used a task design resembling a situation in which we need to hold in memory an object and then perform a motor action to reach it (Genovesio et al., 2011). Imagine, for instance, that you are asked to buy an apple after work. To successfully do it, you need to keep your goal in memory so that later you can perform the proper action to get it. How is the transformation of goal into action made by PF neurons?
In our task, monkeys were trained to discriminate which of 2 stimuli (goals) sequentially presented on a screen was farther from the center. A delay period separated the end of the second stimulus presentation from the reappearance of the two goals (“go” signal). Similar to the previous example, during the delay period the monkeys had to remember the goal (blue or red) and then to select it by touching the corresponding switch below. Importantly, during the delay period the monkeys could not predict the future goal location. Our results show that while one population of PF neurons encoded the goal only in the delay period, another started to represent it only around 200ms after the “go” signal. Interestingly, one subpopulation of neurons encoded the goal both during and after the delay period either keeping the same goal preference (non-switch) or changing (switch) it. We observed that neurons that switched preference had a significantly greater number of bursts and pauses during the delay period. This result suggests that this kind of neurons tends to oscillate between “up” and “down” states and probably due to this stability they are more likely to change preference in subsequent periods when fundamental information (goals location) is provided. Furthermore, some of the neurons showing a goal preference after the “go” signal also encoded the final action. The encoding of the action emerged ~100ms after the goal representation.
Altogether our results show that goal information kept in working memory does not directly lead to the action, but instead there is a transition to a new scheme of goal encoding occurring only at the moment of goal-action transformation when the goal location can be determined and the action specified.

[36] Change point models and hierarchical Gaussian filters: Bayesian model comparison

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Behavioral models based on approximate Bayesian inference were in recent years successfully applied in model-based fMRI studies to identify the functional properties of several brain areas typically involved in the decision making under uncertainty, e.g. [1,2]. However, as different studies considered different models of decision making under uncertainty, it is unclear which of these computational models provides the best account of the behavioral and neuroimaging data. This is an important issue, as not performing model comparison may tempt researchers to over-interpret results based on a single model.
Here we describe how one can perform such model comparison, which is highly relevant for the identification of the computational processes that underlie decision making under uncertainty, both in behavioral and neuroimaging studies. We focused on two well-established hierarchical probabilistic models that capture the evolution of beliefs in changing environments: (i) Hierarchical Gaussian Filters (HGF) [3], (ii) and Change Point Models (CPM) [4]. To perform Bayesian model comparison, we have formulated both perceptual models within a meta-Bayesian framework [5]. This allowed us to assess using a Bayesian model comparison whether it is in principle possible to disambiguate between the two models in behavioral or neuroimaging experiments.
To test the accuracy of the Bayesian estimation we have simulated large number of behavioral experiments. We found that meta-Bayesian inference achieves high accuracy of model identification, and parameter estimation. Furthermore, we found Bayesian estimation and model comparison to be essential for an accurate estimate of hidden belief states (e.g. posterior expectations and uncertainty, prediction error) of simulated agents. Importantly, the estimation accuracy drops significantly if we base the model comparison and parameter estimation on Maximum-Likelihood schemes (e.g. the Akaike Information Criterion). These results stress the relevance of Bayesian model comparison for model-based neuroimaging analysis [6].

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[37] Allocating attentional effort over time in sustained attention: a value-based decision making approach

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Maintaining vigilance over time in sustained attention tasks is an effortful process. Performance in such tasks is hypothesized to be constrained by limited cognitive resources that deplete with sustained performance. Recent theories describe how the allocation of such resources depends on a value-based decision process, in which the costs of effortful performance are weighed against the benefits of expected rewards.
In order to examine the validity of this decision making view of sustained attention we tested whether performance subjects would improve performance and increase attentional effort when performance was incentivised with higher rewards. In addition, we examined whether rewards would be devalued if they were contingent on longer (more costly) task performance. Participants performed a sustained attention task under three different levels of reward. Following these task blocks a reward-discounting task was performed to measure the extent to which subjects experienced task performance as a cost. Behavioural choices in the discounting task were used to determine how long the participants had to perform the attention task for the remainder of the experiment.
Results showed that task runs with higher incentives were characterised by improved behavioral performance (Exp1, N=25), and increased attentional effort, as indexed by larger pupil diameter (Exp2, N=25; Exp3, N=23). Furthermore with longer task duration, both behavioral performance and pupil diameter decreased as a function of time. Importantly, in the subsequent choice task subjects consistently discounted rewards that came at the cost of sustaining attention for a longer duration.
These data suggest that the allocation of attentional resources in sustained attention is modulated based on reward prospects; and that sustained performance is regarded as a cost against which reward value is discounted.

[38] Memory decision confidence interacts with reward history in the ventral striatum.

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Expectation of reward produces a state of motivation that enables reward-predictive learning (Adcock et al., 2006). Yet, it is unclear whether memory advantage for rewarded stimuli is maintained when stimuli are first rewarded and then used in an unrelated and unrewarded memory task. We designed an fMRI experiment to test whether reward conditioning influences hippocampus-dependent learning in a subsequent task, and whether reward value may transfer from the specific rewarded cues to semantically related ones. Here we report the results of the recall test implemented 24h later.
In a first phase, participants underwent a monetary reward conditioning procedure with 2 levels of reward (high and low) respectively associated with photographs from 2 distinct semantic categories. In a second phase, participants performed a picture-location learning task (after van Dongen et al., 2011) with the same high and low reward pictures, and with new semantically-related pictures. In a third phase, occurring 24h later, participants returned for a re-test that additionally tested confidence of recall and source memory (i.e. stimuli presented in the first or second half of the picture-location task).
At retrieval 24h after learning, spatial location memory was worse for associations retrieved with some confidence for high-reward stimuli compared to low-reward, but a reverse pattern was observed for guesses. Response confidence did not differ between conditions. However, we found that parametrically modeled decision confidence activated the hippocampus and the ventral striatum (putamen) for stimuli that had previously been conditioned with high (vs. low) reward as well as for their semantically-related counterparts. This striatal activation may reflect the influence of incentive-memory on the subjective satisfaction with the attainment of a recollection goal, which was higher in the case of pictures with high-value history and generalized to similar stimuli. This result demonstrates that initial stimulus-reward association exerts a lasting effect on later unrelated learning and post-consolidation recall confidence, independent of actual memory performance.

[39] A novel protocol to assess Dual Task Cost as a measure of Cognitive Reserve

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Introduction: The ability to resist neurological decline associated with disease is difficult to quantify and compare. Reserve is a term used in neuroscience for a quantitative and functional description of this individual ability. This is an important and useful concept to explain how the same degree of brain damage does not always lead to identical outcomes in every patient. The tools to measure reserve remain limited, and both passive (static) and active (dynamic) models to assert it have been proposed. Cognitive Reserve (CR) is an active model where functional variability in task processing is evaluated. Higher CR is associated with delayed appearance of dementia symptoms only when presence of cumulative lesions has already occurred. Dual tasking (DT) is the concurrent performance of two tasks that can be performed and measured independently. The simultaneous use of the same processing resources for different tasks in the brain occurs in DT. DT Cost (DTC) is the decrement in scores obtained in this dual task situation versus each task performed individually. Gait is a motor task affected by cognitive domains such as executive function and attention. Dual Tasking Cost can be measured when subjects perform a cognitive task while walking. DTC is found in healthy adults of any age group but seems to increase with advancing age. Patients with Alzheimer's disease show a greater DTC. It has also been shown that decision-making while performing a second cognitive task shows a poorer performance because of interference. We still do not know much about the memory processes involved in decision-making but different levels of cognitive reserve may play a part. DTC is thought of as a possibly robust method of quantifying CR. There are, however, no fully validated measures of DTC yet, either for scientific or clinical use. Objectives: We are trying to validate a simplified way of measuring DTC in a population of healthy volunteers for comparison and application in clinical settings as a measurement of CR. Methods: We tested a sample of 39 healthy young adults asking them to subtract a given number by 7's (cognitive task) while walking (motor task). For the cognitive task, we recorded the number of correct and incorrect subtractions, as well as the latency between subtractions. Gait parameters were recorded on a tri-axial accelerometer fixed to the left ankle. Both tasks were performed separately (single task) and simultaneously (double task). A battery of neuropsychological assessment and questionnaires to assess quality of life and affective symptoms were also applied, to measure possible correlations with DTC scores. We are currently also conducting a retest protocol with the same healthy subjects to learn about test-retest reliability of this measure. Results: Subtracting 7's while walking caused significant changes in gait parameters and in cognitive task performance. A significant decrease in the autocorrelation of the accelerometer signal (a measure of gait periodic pattern) during the dual task vs. single task was also found (DTC=37.9±7.56%; $p < .0001$). This algorithm had not been previously used and may be a more sensitive measure than previously used gait parameters. Correlations between DTC and the measures of cognitive function used were not significant which was expected in healthy subjects. We are finishing asserting test-retest reliability and results seem positive. Conclusion: Our study explores an effective, portable and non-intrusive Dual Task Cost experimental protocol that can be easily used in healthy and patient populations to investigate cognitive reserve. Decision-making systems are compromised in cognitive decline and dementia and cognitive reserve may be a useful measurement to explore in this context.

Keywords: Cognitive Reserve, Dual Task Cost, Gait and Dementia

[40] Sex Differences in Decision Making and Frontal Lobe Activity under Diazepam

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Frontal cortex plays a key role in decision making when selection between competing possibilities and generation of flexible responses are needed according to novel, abstract and arbitrary rules. Sedative drugs such as benzodiazepines (BDZ) modulate the GABAA receptor by increasing Cl- conductance across the membrane. Major sex differences in the physiological mechanisms of the GABAergic system have been reported. The prevalence of mood disorders and the prescription use of BDZ are significantly higher among women than men. Enhancement of inhibition with diazepam (DZ) can have important effects at the cognitive level, including executive functions such as decision making. To investigate the neural correlates of these effects, we explored the ability of healthy volunteers to select responses following complex rules, and brain correlates were measured with fMRI under the administration of DZ and a placebo (PL). Eighteen healthy volunteers participated in a single-blind study. BOLD activity was measured 2 hours after a single-dose (10 mg) of DZ or placebo PL administration in two counterbalanced sessions during the decision making task. We found that a single dose of DZ was enough to increase reaction times and reduce accuracy in the complex-rules with greater effects in women than in men. The activity of frontal regions involved in decision making increased in men, while in women decreased under DZ, and in comparison to PL. These findings could have important consequences in understanding the differential influences of DZ involved in complex daily life situations More importantly, this study emphasizes the importance of understanding the differential effects on men and women of drugs widely employed by society, pointing out the necessity of searching for an adequate doses for each gender, and not using the same treatment for both men and women, and thereby achieve better therapeutic results.

[41] Cholinergic modulation of dopaminergic activity and exploration

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The dopamine (DA) system is involved in motivation and reinforcement. DA neurons from the ventral tegmental area (VTA) encode a reward prediction error (RPE) as a phasic burst of action potentials, corresponding to the difference between the actual and expected rewards. It is postulated that this RPE allows learning the expected (mean) value of actions, and/or motivating ongoing decision-making. Previous work has suggested that spontaneous bursting in DA neurons depends on nicotinic acetylcholine receptors containing the β2-subunit (β2*-nAChRs), in anesthetized mice. However, we have recently shown that VTA nAChRs were not involved in reinforcement learning and motivation for certain rewards. VTA nAChRs would rather be involved in exploration and decision-making under uncertainty. To investigate the links between nAChR-dependent DA activity and exploration, we recorded DA neurons from freely-moving mice. We compared DA activity from wild-type and knockout (for the β2*-nAChRs) mice, in different environments (home cage, open field) and in a mice-adapted spatial version of the bandit task.
At rest, spontaneous bursting was observed in DA neurons from awake β2KO animals, showing that β2*-nAChRs is not necessary for the generation of bursting activity. Rather, these receptors seem involved in the temporal structure of these bursts, and in their synchrony, as shown by simultaneous recordings of pairs of DA neurons. We did not observe differences (on average) between firing rates, bursting activity, and synchrony, between the home cage and open-field conditions, both in WT and β2KO animals. By decomposing behavioral activity in the open-field based on velocity, we found that DA neurons were more active during low-speed exploration than during high-speed navigation. Moreover, β2*-nAChRs seem necessary for this modulation, which is consistent with the known role of β2*-nAChRs in exploration and related behaviors (scanning, rearing, sniffing). Finally, in a bandit task based intra-cranial self-stimulation (ICSS) DA activity was consistent with the classical encoding of RPE in an instrumental setting, with a burst at the beginning of the action leading to a reinforced location. This bursting activity was proportional with reward probabilities. In β2KO animals, DA neurons also encoded RPE, but we found differences in the encoding of reward uncertainty. Overall, our results suggest that β2*-nAChRs are involved in the encoding of exploration and reward uncertainty by DA neurons.
Irrational sub-goal selection to subdue complexity in a learning task

[43] Implication of a minimal information and limited computational abilities on money emergence: An experimental approach with humans and artificial agents

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Most of the theoretical models in economics proposed so far to describe money emergence are based on three intangible assumptions: the omniscience of economic agents, an infinite time and an extremely large number of agents (not bounded). The goal of our study is to investigate the condition of apparition of a monetary economy in a more ecological framework starting with the assumption that the market is made up of a finite number of agents having a bounded rationality and facing a time constraint.

Monetary economics recently developed tools to test experimentally the theoretical and behavioral assumptions that govern the emergence of money as a medium of exchange. These models, called search-theoretical models allow to define economic structures (mode of interaction, agent specialization in terms of production and consumption, cost structures, etc.) easily implementable within a computer simulation or a laboratory experiment.

Simulations with artificial agents are used as a mean to assess the relevance of high-level learning processes in order to achieve money emergence. In particular, it permits to highlight at which extent learning rules by trial and error without sophisticated environment representation and deep strategic anticipation can support money emergence.

In the other hand, the results obtained with our artificial agents in terms of economic structure and cognitive features that are suitable to money emergence, allow us to define the relevant environmental constraints to use during our manipulations in the laboratory with human subjects. Furthermore, it provides us with predictions about the human behavior in such context.

Conversely, our experimental results allow us to ``humanize" our artificial agents and to reveal the plausible decision-making mechanisms that could lead to achieve a monetary equilibrium.

By this constant moving between works with artificial agents and works with “living” agents, we hope to shed light on structural conditions (as trading organization and agents’ specialization) as well as cognitive conditions (as learning skills, memory and strategic anticipation abilities, and adequate tradeoff exploration/exploitation) for money emergence.

[44] Investigating the neural mechanisms underlying abstract category learning

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Visual categorisation tasks have been extensively used to investigate neural mechanisms underlying sensorimotor behaviour. However, most studies have used a small number of familiar stimuli. Much less is known about how we form novel abstract categories composed of items that cannot be defined on the basis of physical similarity. Single-cell studies have suggested that during category learning, neurons in parietal cortex come to code for one abstract category over another, and that the dimensionality of this coding is remarkably low (Fitzgerald et al., 2013). For example, within a given monkey, most of the neurons code for one abstract category with a common “biased” firing rate (e.g. high vs. low), rather than exhibiting diverse preferences. Low-dimensional coding may be useful for generalisation of abstract information to novel learning contexts (Ganguli et al., 2007).

Here, in an fMRI study, we measured BOLD fMRI while subjects learned abstract categories. We asked humans to perform a delayed match-to-category task using visual stimuli (images of cartoon characters) that were assigned randomly to two categories. Subjects learned the categories through trial-and-error feedback. Furthermore, in separate scanning sessions, each subject viewed the same images before and after training, enabling us to probe the effects of learning on brain response-patterns explicitly. This whole procedure was repeated three times for each participant, each block with a different set of images. Participants were able to accurately learn the categories in the scanner and showed stable categorisation performance across blocks.

We used representational similarity analysis (RSA) to investigate the similarity structure of locally distributed patterns using a searchlight approach (Kriegeskorte et al., 2006). Comparing similarity structure in pre-training and post-training data revealed that representations of abstract categories evolved during learning in the prefrontal cortex. However, item representations remained stable in early stages of visual processing, irrespective of their category membership. This reshaping of the similarity space is concordant with a low-dimensional categorical structure in those brain areas.

[31] When there is a will, there is a way? Paradoxical effects of motivation on motor performance

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A commonly established belief is that high motivation is beneficial for performance. However, several studies have challenged this assumption by showing that high stakes can actually have a detrimental effect on performance in various types of tasks, particularly in sportive settings. Why motivation can have such a paradoxical effect on performance is still hotly debated. We propose that motivation impacts force production through an automatic mobilization of motor resources. While these additional resources are clearly helpful when performance depends on the amount of force developed (e.g., in weight lifting), they can be detrimental in precision tasks when fine motor control is necessary (e.g., for putting in golf).

To test this hypothesis, we asked 24 participants to perform a task that involves squeezing a handgrip with a specific force to be as close as possible to a target. The target force differed between sessions, consisting in 20%, 45% or 70% of the subject's maximal voluntary contraction (MVC). We also manipulated the motivation to perform well by varying the reward at stake, on a trial-by-trial basis. Potential gains went from very low (5c) to high (50€) compared to the usual financial compensation for participating in an experiment. Participants knew that their payoff would be a fraction of the reward inversely proportional to the distance between their peak force and the target force.

In agreement with our hypothesis, we found that participants squeezed harder with higher gains for all target forces. This motivation effect was beneficial in the 70% MVC condition, where subjects were globally undershooting the target, but detrimental in the 20% MVC condition, where it drove subjects to overshoot the target.

Thus, our study revealed a paradoxical effect of motivation, which result in too much force being invested in motor precision tasks. We speculate that in more complex gestures such as putting in golf, an excessive force at the beginning of movement might result, through compensations, in a more erratic trajectory of the ball – a phenomenon that sport journalists may call "choking under pressure".

[45] Asymmetric reinforcement learning: computational and neural bases of positive life orientation

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While forming and updating beliefs about future life outcomes, people tend to consider good news and to disregard bad news. This tendency is supposed to support the optimism bias. Whether learning bias is specific to high-level abstract belief update or a particular expression of a more general low-level reinforcement learning process is unknown. Here we report evidence in favor of the second hypothesis. In a simple instrumental learning task, participants incorporated worse-than-expected outcomes at a lower rate compared to better-than-expected ones. This asymmetry was correlated across subjects with standard measure of dispositional optimism. Multimodal imaging indicated that inter-individual variability in the expression of asymmetric update relies on the dorsomedial prefrontal cortex at both morphological and functional levels. Our results constitute a new step in the understanding of the genesis of optimism bias at the neurocomputational level.

[46] Muscular fatigue causes flexible preference reversals in an effort-based decision making task

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In both the wild and the laboratory, animals' preferences for one course of action over another reflect both the value of action goals and the cost or effort that must be invested in pursuing them. Despite physical exercise and fatigue significantly affect the levels of effort that an animal can - or is willing to - exert to obtain a reward, their role in effort-based choice are incompletely known. One pressing question is whether fatigue influences decision strategies flexibly (model-based choice) or only post-decision action execution and learning. To answer this question, we trained mice on a T-maze task in which they choose between a high-cost, high-reward arm, which included a barrier, and a low-cost, low-reward arm, with no barrier. The animals were physically fatigued, as they ran on a treadmill with progressive intensity load (that varied parametrically from 40% to 60% and 80% of their maximal power load), immediately before the behavioral tasks. We found a sharp choice reversal, from the high- to low-reward arm, at 80% of maximal power load, followed by another sharp choice reversal, from the low- to the high-reward arm, when the animals were successively tested at 60% of maximal power load or in a two-barrier task. We also observed increased subcortical, but not cortical, dopamine levels in fatigued mice: a marker of individual bias to use model-based action choice in humans. Our results indicate that fatigue levels can be incorporated in flexible cost-benefits computations that improve foraging efficiency.

[47] Modulation of inference by the temporal statistics of stimuli

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Bayesian models integrating sensory cues in a probabilistic fashion have been shown to satisfactorily explain human behavior in various visual, auditory, and haptic-based estimation tasks. Time, in those tasks, takes no significant part. Yet the natural environment, often, is changing, causing time to be a critical factor, all the more as natural mechanisms introduce specific temporal structures in the course of events. There are, for instance, patterns in animal motor activity, in animal gait, in the delivery of speech, and in circadian cycles. Are temporal statistics used to improve the inference of the (hidden) state of the environment?

To investigate this question we use a simplified changing environment, consisting in a random visual stimulus whose mean position changes occasionally and abruptly. This kind of signals is known as a "change-point" process. The literature on inference problems for this class of signals mainly focuses on history-independent, Poisson temporal statistics which are characterized by the absence of temporal structure, i.e., where the probability of occurrence of an event is constant and does not depend on past history. Alongside with such a signal, we use a history-dependent stimulus that contains a strong temporal structure. Using these two classes of stimuli, we design a change-point inference task that allows us to compare directly the behaviors of human subjects in the presence and in the absence of a temporal structure, as well as to compare the behavior of subjects with the prediction of various models.

We measure the 'learning rate' of subjects, a quantity that indicates how strongly their inference is impacted by each new signal. In agreement with our theoretical results, when the probability of a change point grows due to the temporal structure in the (hidden) state, the learning rate of subjects increases proportionately. This shows that human subjects adapt their inference behavior to the temporal statistics of the signal. Another notable observation is that the variability of the subjects' responses is not constant over the course of inference: when the signal provides only scarce information on the state, responses are more widely scattered; this suggests that there exists a link between the inferred uncertainty on the state and the variability in the measured responses.

We compare our experimental results to the outputs of an optimal Bayesian model and of a family of suboptimal models that relax various assumptions in the optimal model. In particular, we examine the role of prior beliefs and memory capacity. Furthermore, we contrast the optimal model, which yields a deterministic strategy, to a model based on a sampling hypothesis, whereby subjects sample the posterior distribution instead of maximizing it. This strategy, sometimes referred to as "probability matching", reproduces the experimental observations on the variability in the response of human subjects. Hence, by exploring the uncharted, yet omnipresent, class of history-dependent signals, our work provides both theoretical results and experimental insights on human inference and probabilistic accounts thereof.

[48] The dopamine signal in decision making tasks with temporal uncertainty

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Animals live in uncertain environments where they have to make decisions based on noisy sensory information to maximize possible rewards. Ideas from the field of reinforcement learning (RL) have played an important role in neurobiological theories of reward-motivated behaviour. In particular, it has been suggested (Schultz et al, 1997) that the phasic activation of midbrain dopaminergic (DA) neurons resembles a temporal difference (TD) prediction error, used by the brain as a teaching signal to learn reward expectations and optimize action selection. Although RL successfully explained DA activity in classical and operant conditioning, its potential in understanding the role of dopamine in decision-making tasks with uncertain temporal and sensory information has not been investigated.

To obtain further insight on this problem we used a vibrotactile detection task in which the time of a possible stimulation is random (de Lafuente & Romo, 2011). We reanalyzed midbrain neurons recordings and proposed a dopamine-mediated RL model. The model coupled a Bayesian inference module with an actor-critic architecture. The first module estimated joint beliefs about stimulation and timing of the task events. Using these beliefs an actor-critic module learned to evaluate and select actions. Importantly, following recent experimental an theoretical results concerning interval timing in the striatum (Adler et al, 2012 ; Mello, Soares & Paton, 2014), the critic component represented time in a scale invariant manner (Shankar & Howard, 2012).

The model matched the animal performance and, most interestingly, it was able to catch the phasic response of midbrain DA neurons. In particular, the model explained the condition-dependent phasic response to the go cue observed in the data in terms of a belief reflecting the level certainty of the animal about its perception and thus about the future decision. Moreover the model correctly predicted that DA neurons are phasically activated by the subjective perception of the relevant stimulus. On the one hand in hit trials the detection of the vibration produced a large phasic response. On the other hand, detection events responsible for false alarms (Carnevale et al, 2015) were distributed over the possible stimulation window, generating a weak positive modulation of the tonic activity. Finally, before the go cue, both data and model presented a decreasing tonic activity. In correct rejection trials it resulted from the variable duration of the trial. In hit trials it came mainly from the finite resolution in the estimation of time intervals. According to the model this tonic activity represented a form of negative reward prediction error generated by the temporal expectation of an event that failed to occur.

This study showed that RL procedures can be a powerful tool to study decision-making tasks with a complex temporal structure. Our results suggest how, not only the standard phasic reward prediction error signals, but also the slow modulations of dopamine activity were affected by both sensory and temporal uncertainty.

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[49] Does Red Bull give you wings? Placebo effects of commercially available cognitive enhancers on performance motivation

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Placebo effects are a famous example for the power of expectancies on human behavior and judgment. Prior clinical research has suggested that placebo effect is a kind of anticipated reward response boosting, via the recruitment of dopaminergic motivation pathways, the brain's ability to suppress pain and symptoms of many diseases. Parallel research from consumer psychology has suggested that placebos such as price tags or branding can also color non-aversive perceptions such as consumption utility. Yet, less is known about how a placebo translates into non-aversive behavior. Here we tested whether effects of energy drinks, frequently consumed to enhance performance under pressure, can stem from a placebo effect. We hypothesized that, through marketing actions of the manufacturer and prior experiences of the product, a person forms positive expectations about learning performance that translate into enhanced motivation. We manipulated label and drink in a 2x2 between-subject design that involved two tasks: a cognitive effort task designed to assess performance motivation and a memory task that served as a control task. Our results (88 participants, mean age: 23.6±2.6) revealed a main effect of label on performance motivation ($F(1,86)=11.9$, $p<0.001$), operationalized as the sensitivity to the number of points at stake in a given trial. There was no drink effect, meaning that motivation and performance were similar whether participants were having Red Bull or lemonade. Our results provide evidence for a robust placebo effect of energy drinks that is selective to motivation. This placebo effect could be mediated by dopaminergic pathways that are known to enhance performance motivation in similar effort tasks. It points toward the possibility that positive expectancies can facilitate drug effects by enhancing motivational processes. Such a potential mechanism of placebo effects provides the promise of a powerful tool for a broad range of implementations from the treatment of disease to enhancing quality of life.

Acknowledgements:
We thank the staff of the Centre Multidisciplinaire de Sciences Comportementales Sorbonne-Universités-INSEAD for their support with data collection.

[50] Reward related suppression in visual area V4 during a discrimination task o ignored

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Reward related activity has been intensively studied with electrophysiology in high-level areas such as LIP and FEF in the visual system. However, recent evidence has shown that early visual areas also show reward related activity. As reward biases the decision criteria of subjects performing discrimination tasks, we wanted to investigate how reward affected the neural activity in the visual cortex during a discrimination task.

To this end we implanted 64 channel Utah arrays in visual area V4 of macaques previously trained on a motion discrimination task. V4 is a mid-level visual area that shows responses to visual stimuli, which can be strongly modulated by higher-level features like attention. On each trial a colored reward cue informed the subject of the reward value of each motion direction, however, only when the correct motion direction was chosen would the reward be given. When the reward amounts were uneven, macaques were biased towards choosing the option with higher reward as has been reported previously.

Our hypothesis was that area V4 would use reward information to enhance the representation of the rewarded motion direction. However, unexpectedly when we examined the time period immediately after the reward cue onset, what we found was a suppression of the response to the stimulus. The size of this suppression was dependent on the amount of reward signaled by the cue. Surround suppression is thought to allow the brain to efficiently represent stimuli and can be enhanced with attention to a stimulus. As it is likely that the macaque would attend to the cue to ascertain the amount of reward available this may be the reason for the observed surround suppression. However, that the amount of reward predicted can scale the amount of suppression is more difficult to explain. As these results mean that learned stimulus value can enhance surround suppression, it may be that high value stimuli are therefore more favorably represented than low value stimuli in the visual cortex.

[51] Flexible adaptation of reward-guided learning to the correlation structure of choice alternatives

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Learning from trial-and-error has been well characterized at the behavioral, computational and neurobiological levels, and shown to play an important role in human decision-making. However, the extent to which the underlying reinforcement learning process adapts to long-term correlations in the environment remains unclear. While learning rates adapt to the overall volatility of choice-outcome contingencies during reversal learning, do learning rules change depending on the presence or absence of the correlations between choice alternatives?
To answer this question, we asked healthy subjects (N = 30) to play a repeated two-armed bandit game where: a) rewards which could be obtained from the two levers were either uncorrelated or anti-correlated over time, and b) rewards from the unchosen lever on each trial were either shown or hidden (complete or partial feedback information), in which case they could only be inferred. This design allowed us to ask two interrelated questions. First, do subjects apply the same learning scheme when they have to infer, rather than observe, the reward from the unchosen lever? Second, do subjects adapt this 'fictive' learning process to the correlation between rewards from the two levers?
Bayesian model selection revealed that subjects apply different learning schemes in complete and partial feedback conditions, and adapt learning rules depending on the presence or absence of reward correlations between levers. When both chosen and unchosen rewards were shown, a reinforcement learning scheme which tracks the relative preference for one lever over the other outperformed learning schemes using separate value representations of the two levers (exceedance probability pexc > 0.999). The opposite pattern was observed in the partial feedback condition, where a learning scheme which tracks the absolute values of the two levers better accounted for the human data (pexc ≈ 0.99). In this condition, subjects adopted a 'normalization' learning rule by updating the value of the unchosen lever with the negative prediction error for the chosen lever when rewards from the two levers were anti-correlated, and a 'regression-to-the-mean' learning rule when rewards were uncorrelated (anti-correlated: pexc ≈ 0.88, uncorrelated: pexc ≈ 0.89). These results were confirmed by model-free analyses of human choices and transient changes in pupil diameter in response to chosen and unchosen rewards recorded simultaneously.
Together, these findings show that human subjects encode the correlation structure of their environment through fictive learning rules which change flexibly as a function of the presence or absence of correlations between choice alternatives. This 'computational flexibility' has important implications for real-life economic environments (e.g., stock markets) which feature complex correlation structures.

[52] Neural correlates of the Decision Variable: Comparison of evidence accumulation signal to decision-related ERPs

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While driving, walking, or even playing our favourite computer game, we constantly need to perform speeded decisions, the outcomes of which can be of major importance. It is now widely acknowledged that such fast decisions rely on accumulation processes, in which evidence in favour of the different response alternatives is accumulated across time, until a decision threshold is reached. Different formal models have been developed within this framework, and we focus here on the linear ballistic accumulator (LBA) model, the leaky competing accumulator (LCA) model, and the drift diffusion model (DDM). These three models can all reproduce both response times and accuracy in simple decision making tasks, but they rely on different mechanisms, and hence predict different decision accumulation signals. In order to compare the models, and eventually refine the constraints usually applied on them, we directly compared the accumulation profiles they predict to the recently described centro-parietal positivity (CPP), an event-related potential thought to reflect evidence accumulation in the brain. EEG was recorded while subjects performed a standard decision-making task (discriminating random dot motion) in which the amount of sensorial evidence was varied between trials (Easy Vs Hard trials), under either the instruction to emphasize response accuracy, or response speed (Accuracy Vs Speed instruction). As expected, CPP slope was steeper in Easy compared to Hard trials; more surprisingly however, the CPP amplitude was not higher in Accuracy compared to Speed instruction. Best-fitting parameters for the three models (LBA, LCA and DDM) were then determined, and mean accumulation signals predicted by each model in each condition were obtained and compared to CPP. Our results indicate that, under certain constraints, the models predict accumulation signals presenting the same modulation pattern than EEG-recorded CPP.

[53] To infer the correctness of an action from the reward it delivered, brain uses a linear heuristic as transfer function

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In an unknown environment, standard modeling assumes that performing an action leads to a reward drawn from a reward distribution. These reward distributions depend of the action and can also depend of a hidden state of the environment. Maximizing reward on the long term asks to use obtained rewards as information to compute the distributions and infer the current hidden state. Then the “best” choice can be performed.
Since rewards are usually represented on an infinite scale, theoretically optimal Bayesian inference is impossible on a finite time period. But the fact that we manipulate reward scales authorizes to exploit two usual properties of reward scales.
Continuity: Close rewards usually bring close information concerning the environment.
Linearity: When performing the best choice, high rewards are frequent and low rewards rare.
From these properties derive two approximations which could be used by the brain to simplify the problem
Gaussianity: The brain could represent all reward distributions as Gaussian distributions. It would just have to track a mean and a standard deviation for each of them (rather than a complete distribution).
Reinforcement: The brain could give up distribution learning. It would just reinforce highly rewarded choices and avoid low rewarded choice.
We conducted a series of behavioral experiments where we varied the number of hidden states and the shape of the reward distributions. Our results could not be explained by the first approximation (Gaussian representation).
We instead exhibit a Bayesian mechanism which adds a simple reasonable hypothesis to the optimal algorithm: If the best available action is performed, any other action would have led to a smaller reward.
Our algorithm explains all behavioral data, and adapt way faster than an optimal algorithm while performing better than a simple reinforcement learning algorithm.

[54] Believing in one's power: a counterfactual reinforcement-learning account of instrumental causation

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We live in an uncertain and changing world that requires the ability to flexibily adjust behavior. This capacity requires to continously assess ongoing actions and the outcomes of these actions. Therefore to find the most adapted action, we need to find out which events in the outside world are consequences of our actions, and which are not. This requires to be able to calculate and monitor causal relationships between our actions and events occurring in the outside world. The ability to envision oneself as an causal agent is classically referred to as "sense of control" and has been poorly investigated in adaptive behavior experiments.
We used a reversal-learning task, in which participants were instructed to find the bandit machine they controlled under diverse conditions. Our aim was to understand on which mechanisms instrumental causation is built. Two dominant approaches to causation can be distinguished, upon which causal relationships are either explicitly calculated (generative approach) or retrospectively inferred (associative approach). To implement these two hypotheses, we built an optimal Bayesian learner, updating its beliefs about the hidden structure of the environment with the exact underlying structure of the task, and a reinforcement-learning model updating the value associated with each action through the Rescorla and Wagner rule.
We showed that participants' behaviour cannot be explained neither by an associative, nor a generative model. Critically, the model that best fitted participants' data in every condition was a reinforcement-learning model that updated the counterfactual (non-chosen) actions in the opposite direction of the chosen action. Thus, we found that a simple rule that symmetrized the observed reward to compute a reward "that-could-have-happened" best accounted for the participants' ability to flexibly adapt their actions after reversals. Surprisingly, in the condition where participants had no control over the obtained reward, the counterfactual update weights were as high as in the condition where the participants' choices influenced the outcomes.. Such a similarity in subjects' strategies across conditions suggests that people rely on a strong prior of control to make decisions, as illustrated in the psychology literature by the so-called (and pervasive) 'illusion of control".

[55] Selective integration of decision evidence in the human brain

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The best decisions are made when all available evidence is taken into account, weighted by its reliability. Canonical theories argue that human observers performing sensorimotor tasks behave optimally in this way, weighting evidence by its inverse uncertainty, and integrating without loss. However, recent research has challenged this view showing that decision evidence that is more frequent or expected may be processed with enhanced gain, whilst less prevalent information is downweighted or ignored. Here, we examined the behavioural and neural underpinnings of this mechanism using EEG recording during a probabilistic 'urn and ball' decision making task in which participants viewed series of draws each consisting of multiple coloured balls, and had to state whether these were drawn from an urn in which green and orange balls predominated, or an urn in which blue and pink balls predominated. We varied the prevalence of one of the within-category colours, so that, for example, within a trial pink balls might occur more frequently than blue balls, and measured their relative influence on choices (pink/blue vs. green/orange). In line with our predictions, participants downweighted the less prevalent (less expected) colour within each category, even though it provided equivalent evidence to its more prevalent counterpart.

Furthermore, single-trial analysis of scalp electroencephalographic (EEG) data recorded during performance of the task revealed that whilst all colours were encoded in occipital (visual) areas, in parietal regions – which have commonly been associated with decision-relevant evidence integration – there was only a significant correlation with the prevalent subcategory in the neural activity, and not the less prevalent subcategory. This provides neural evidence for a 'selective integration' mechanism, whereby a subset of more prevalent evidence is a stronger driver of human decisions. Whilst apparently suboptimal, this selectivity can be understood as the most useful policy when agents' limited processing capacity is taken into account. Given limited resources, an efficient system should process the information is more likely to be decision-relevant (such as consistent or expected information) with enhanced gain, in order that the most diagnostic stimuli have the greatest impact on choice with the smallest computational expense. This work thus describes a new limit on human decision-making, and supports the view that gain is allocated dynamically during sequential integration of decision information.

[56] Who's the teacher and who's the pupil?

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Abstract: Even though there was early interest in the neural basis of automatic behavior in the beginning of the previous century, it is still unclear how we obtain and express habits. The dominant view of the 20th century was that novel behaviors are generated by cortex, because they require attention and flexible thinking. Contrary, habits are automatic, so they are primarily mediated by subcortical structures, more precise basal ganglia (BG). Nowadays, there is arising bibliography that argues exactly the opposite position. So the essential question is "Who's the teacher and who's the pupil?". In attempting to give an answer, we developed a theoretical model that predicts a novel explanation for the formation and the expression of habits in the cortex of primates by considering basal ganglia as an implicit supervisor. Our model implements the cortical-basal-thalamic closed loop, using reinforcement learning and explicit valuation of the outcome (Guthrie et al. (2013)). Hebbian learning has been added at the cortical level such that the model learns each time a move is issued, rewarded or not. Then, by inhibiting the output nuclei of the model (GPi), we show how learning has been transferred from the basal ganglia to the cortex, simply as a consequence of the statistics of the choice. Because best (in the sense of most rewarded) actions are chosen more often, this directly impacts the amount of Hebbian learning and lead to the formation of habits within the cortex. Our theory was also tested on monkeys, which confirmed our predicted results.

[57] Robust Sampling of Decision Information During Perceptual Choice

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When making decisions, humans and other primates move their eyes freely to gather information about their environment. A large literature has explored the factors that determine where the eyes fall during natural scene perception and visual search, concluding that deviant or surprising perceptual information attracts attention and gaze. However, saccadic sampling has largely been explored in paradigms involving search for a lone target in a cluttered array or natural scene. Here, we investigated the policy that humans use to overtly sample information during a perceptual categorisation task that required information to be combined from across multiple spatial locations.
Participants (n=60), viewed spatial arrays of 8 numbers and judged whether the average was greater or smaller than a reference value. We developed a new analysis approach ("landscape analysis") for eye-tracking data that quantifies the decision information available to the participant at each time point, based on the spatial coordinates of their fixations. In contrast to conventional approaches, this approach allows us to infer a probabilistic relationship between whether an item is integrated or not and its distance from fixation.

In this study, we show that gaze was directed preferentially to items that were less diagnostic of the correct answer ("inlying" elements, that were closer to the reference value, rather than "outlying" elements). This bias was linked to decisions, in that a preference for sampling inlying elements drove a tendency to give more weight to inlying over outlying elements in the final choice ("robust averaging"). These findings contrast with a large body of evidence indicating that gaze is directed preferentially to deviant information during natural scene viewing and visual search, and suggest that humans may sample information "robustly" with their eyes during perceptual decision-making.
Critically, we show that under an optimal observer model, performance of the model linearly decreased as the sampling policy changed from a bias to sample outlying information first to a bias to sample inlying information. Thus, the sampling bias to preferentially sample inlying information is suboptimal in our task in that it fails to maximise performance. Finally, we determined the best fitting parameter values for the sampling policy per subject and show that simulated evidence accumulation curves closely resemble the evidence trajectories obtained from our landscape analysis approach. This and other control analyses provide strong support for the use of this new analysis approach.

In conclusion, participants sample decision information robustly, viewing by preference those samples that are near, not far, from the category boundary.

[58] Effects of social threat on attention and action-related decisions

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Evolutionary theories suggest that emotional displays serve a communicative function by providing information about the individuals expressing them, or the surrounding environment. Consequently, individuals who more efficiently detect and respond to these signals have a survival advantage. This evolutionary framework implies that 1) emotional signals have co-evolved with recipient's behavioral responses, and 2) that the recipient's response should reflect the social function of the perceived expression.

Here, we set out to experimentally address these assumptions. In two experiments, participants faced stimuli reproducing a social environment, i.e. a waiting room with four seats, where the two middle seats are occupied by two individuals, one displaying a neutral expression and the other expressing either anger or fear of varying intensity. We selected these emotions as they both signal the presence of potential threat in the environment, but they differ in terms of their social functions and were suggested to be associated with different approach-avoidance reactions (Marsh et al., 2005). In our first experiment, participants were requested to detect a "T" appearing on either of the two outer seats as we recorded their reaction times. This experiment capitalized on the knowledge that observers' current potential actions impact the appraisal of their environment, notably by enhancing the perception of relevant spatial information (Kirsch, 2015). Thus, if emotional displays are perceived as opportunities for action, and if fearful and angry expressions prompt different motor actions by conveying different signals, the observers' appraisal of space should be differently impacted. Moreover, the observer's choice of action should also be differently impacted, as tested in our second experiment, wherein participants were asked to freely decide where they want to sit by moving their cursor on the screen; here, movement kinematics and pupil dilation were recorded.
Results from both experiments indicate that fearful and angry expressions induced opposite effects: anger, by signaling a potential direct threat, resulted in a better "T" discrimination in the opposite side of the scene and avoidance behaviors; in contrast, fear, by warning the observer about a danger in the environment, elicited better "T" discrimination in the same side of the scene and affiliative approach behaviors. Movement kinematics and pupil dilation further support the governance of these behavioral tendencies by distinct mechanisms. Overall, our data suggest that emotional displays promote elaboration of adapted decisions and emotion-specific motor actions.

[59] How do you see your chances? Neuro-computational account of mood effects on risky decision-making

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Objective: The effect of mood on decision making is a well established phenomenon in clinical practice. However, the mechanisms underlying such an effect remain obscure. In this study, we tested the hypothesis that mood fluctuations induced by the history of positive and negative feedbacks might be reflected in the baseline activity of choice-related brain areas, which in turn would influence decision under risk.

Methods: In our behavioral task, mood fluctuations were induced by the feedbacks provided to subjects after they answered a general knowledge question. Unbeknownst to them, quiz difficulty and feedbacks were biased so as to create episodes of high and low correct response rate. The effects of this induction procedure were observed on both subjective mood ratings and risky choices. In the choice phase subjects decided whether or not to take the risk of performing a motor precision task of a certain difficulty level, depending on the expected gain (in case of success) and the expected loss (in case of failure). We first developed a computational model that integrated the history of feedbacks so as to account for mood ratings. Then we examined, using model-based fMRI, how this theoretical mood level affected the baseline brain activity preceding the choices. Last we characterized the impact of baseline activity on the integration of gain and loss prospects into a computational model of decision making.

Results: We found that distinct, specific aspects of mood fluctuations were encoded in the baseline activity of the ventromedial prefrontal cortex (vmPFC) and anterior insula (AI). Crucially, we observed a double dissociation between vmPFC and AI baseline activity, which respectively modulated the representation of gain and loss prospects. As a consequence, higher VMPFC activity during high mood state promoted risk taking, whereas higher AI activity during low mood state tempered risk taking.

Conclusions: Our neuro-computational model suggests that irrelevant positive and negative feedbacks have long-lasting effects (for several minutes) on VMPFC and AI baseline activity, which in turn might bias how gain and loss prospects are weighted when making a decision.

This research has received funding from the ERC Starting Grant 'BioMotiv'. FV has been supported by the Groupe Pasteur Mutualité.

[60] Crucial role of right frontopolar cortex in directed exploration

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Effective adaptation in a dynamic and ever-changing environment requires optimizing the balance between exploiting well known options and exploring new ones. Recent behavioral evidence suggests that people use at least two distinct strategies while exploring the environment: directed and random exploration (Wilson et al, 2014). Directed exploration is driven by uncertainty and the need of obtaining essential information about the less known option while random exploration is driven by mechanisms related to behavioral variability. However, it has not yet been shown that these two types of behaviors have separate neural origins.
In this study we present first causal evidence of the involvement of right frontopolar cortex (RFPC) in directed exploration. We designed a within-subject experiment using continuous theta bursts TMS protocol and a modified, sequential version of the Horizon Task (Wilson et al, 2014). We examined 16 participants in two conditions: vertex (control) and RFPC stimulation (experimental). Inhibiting the RFPC significantly reduced directed exploration while not affecting random exploratory behaviors nor ambiguity preference. This finding establishes the uniquely human role RPFC plays in exploration and inspires the creation of more detailed, mechanistic models of higher cognitive functions.