Eighth International Symposium on Biology of Decision Making

SBDM 2018
May 21-23, Paris, France
PARTNERS AND FUNDERS

Institut du Cerveau et de la Moelle Epinière (ICM)

Institut des Neurosciences Translationnelles de Paris (IHU-A-IC)

Ecole Normale Supérieure (ENS)

Sorbonne Université (SU)  
(formerly UPMC)

Institut National de la Santé et de la Recherche Médicale (INSERM)

Centre National de la Recherche Scientifique (CNRS)

Team Motivation, Brain, and Behavior (MBB)

Okinawa Institute of Science and Technology (OIST)
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PART 1 – GENERAL INFORMATION
INTRODUCTION

The Symposium on Biology of Decision-Making (SBDM) is an international conference annually held in Paris or Bordeaux in France. The objective of this three-day symposium is to gather researchers that investigate decision-making through the lens of different fields: economics, ethology, psychiatry, and neural and computational approaches. To this end, we welcome 27 speakers who will be presenting their research in 30-minute talks, grouped into 6 sessions:

1. Decision-making across species
2. Constructing and deconstructing subjective value
3. Moral decision-making
4. Learning about the structure of the world to make decisions
5. Development and decision-making
6. Dealing with uncertainty: exploration and curiosity

We are also delighted to welcome 100 poster presenters, distributed over 4 poster sessions to be held on Monday 21 May and Tuesday 22 May.

Two venues will host the conference: the Institut du Cerveau et de la Moelle Epinière (ICM) in the Pitié-Salpêtrière hospital on Monday and Tuesday, and the Ecole Normale Supérieure (ENS) on Wednesday. During all days, lunch as well as warm and soft drinks will be provided. On Tuesday evening, there is a social event on the top floor of the Zamanski Tower on the campus of the Sorbonne Université (formerly the Université Pierre et Marie Curie). During this event, drinks and dinner will be provided.

ORGANIZERS

The scientific committee hosting the speakers consists of:

Kenji Doya
(Okinawa Institute of Science and Technology, Japan)
Lesley Fellows
(McGill University / Montreal Neurological Institute and Hospital, Montreal, Canada)
Mehdi Khamassi
(CNRS / Sorbonne Université / UPMC, Paris, France)
Etienne Koechlin
(CNRS / Ecole Normale Supérieure, Paris, France)
Mathias Pessiglione
(INSERM / ICM, Paris, France)
Chris Summerfield
(University of Oxford / Google Deepmind, Oxford/London, UK)
Miriam Teschl
(Ecole des Hautes Etudes en Sciences Sociales, Paris, France)

The local organizers responsible for the event are:

Mehdi Khamassi
(CNRS / Sorbonne Université)
Mathias Pessiglione, Roeland Heerema, Fanny Lachat
(ICM)
Etienne Koechlin, Marine Magne
(ENS)
PARTICIPANT STATISTICS

All 200 participants (attendees, poster presenters, speakers, organizers) together represent scientific institutions from 14 different countries of all continents:
### Monday, 21 May (Venue: Institut du Cerveau/ICM)

Registration opens at 08:30

#### Decision-making across species (chair: Mathias Pessiglione)

<table>
<thead>
<tr>
<th>Time</th>
<th>Speaker</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:00 – 09:30</td>
<td>Matthew Rushworth</td>
<td><em>Temporal-frontal interactions in memory-guided decision making</em></td>
</tr>
<tr>
<td>09:35 – 10:05</td>
<td>Charlie Wilson</td>
<td><em>Frontal oscillatory bursts underlie adaptive cognitive control in the monkey</em></td>
</tr>
<tr>
<td>10:10 – 10:30</td>
<td></td>
<td><strong>Coffee Break</strong></td>
</tr>
<tr>
<td>10:30 – 11:00</td>
<td>Léon Tremblay</td>
<td><em>The role of anterior striatum to value-based decision making: the power of translational investigation between human and non-human primate</em></td>
</tr>
<tr>
<td>11:05 – 11:35</td>
<td>Armin Lak</td>
<td><em>Neuronal signals for reward learning under perceptual uncertainty</em></td>
</tr>
</tbody>
</table>

#### Lunch and Poster Session (posters 1-25): 11:40 – 13:15

#### Constructing and deconstructing subjective value (chair: Lesley Fellows)

<table>
<thead>
<tr>
<th>Time</th>
<th>Speaker</th>
<th>Title</th>
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</thead>
<tbody>
<tr>
<td>13:15 – 13:45</td>
<td>Lesley Fellows</td>
<td><em>Carving value at its joints: insights from patients with prefrontal damage</em></td>
</tr>
<tr>
<td>13:50 – 14:20</td>
<td>Dana Small</td>
<td><em>Gut feelings: metabolic signals regulate food reinforcement</em></td>
</tr>
<tr>
<td>14:25 – 14:55</td>
<td>Alizée Lopez-Persem</td>
<td><em>Testing the core properties of the brain valuation system: an intracranial EEG investigation</em></td>
</tr>
<tr>
<td>15:00 – 15:20</td>
<td></td>
<td><strong>Coffee Break</strong></td>
</tr>
<tr>
<td>15:20 – 15:50</td>
<td>Shinsuke Suzuki</td>
<td><em>Food value computation in the human orbitofrontal cortex</em></td>
</tr>
<tr>
<td>15:55 – 16:25</td>
<td>David Smith</td>
<td><em>Constructing value: understanding the role of corticostriatal connectivity</em></td>
</tr>
</tbody>
</table>

#### Poster Session (posters 26-50): 16:30 – 18:00
### Tuesday, 21 May (Venue: Institut du Cerveau/ICM)

#### Moral decision-making (chair: Miriam Teschl)

<table>
<thead>
<tr>
<th>Time</th>
<th>Speaker</th>
<th>Title</th>
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<tbody>
<tr>
<td>09:00 – 09:30</td>
<td>Lasana Harris</td>
<td>Law on the brain: the role of the social cognition and deductive reasoning during legal decision-making</td>
</tr>
<tr>
<td>09:35 – 10:05</td>
<td>Rima-Maria Rahal</td>
<td>Eyes on morals: investigating the cognitive processes underlying moral decision making via eye-tracking</td>
</tr>
<tr>
<td>10:10 – 10:20</td>
<td></td>
<td>Coffee Break</td>
</tr>
<tr>
<td>10:30 – 11:00</td>
<td>Molly Crockett</td>
<td>The value of moral action</td>
</tr>
<tr>
<td>11:05 – 11:35</td>
<td>Drazen Prelec</td>
<td>Self-signaling and the actor-critic model</td>
</tr>
</tbody>
</table>

#### Lunch and Poster Session (posters 51-75): 11:40 – 13:15

#### Learning about the structure of the world to make decisions (chair: Chris Summerfield)

<table>
<thead>
<tr>
<th>Time</th>
<th>Speaker</th>
<th>Title</th>
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</thead>
<tbody>
<tr>
<td>13:15 – 13:45</td>
<td>Chris Summerfield</td>
<td>Conceptual scaffolding for decision values</td>
</tr>
<tr>
<td>13:50 – 14:20</td>
<td>Brad Love</td>
<td>Selective attention for dimensionality reduction</td>
</tr>
<tr>
<td>14:25 – 14:55</td>
<td>Helen Barron</td>
<td>Memory engrams as a basis for decision making</td>
</tr>
<tr>
<td>15:00 – 15:20</td>
<td></td>
<td>Coffee Break</td>
</tr>
<tr>
<td>15:20 – 15:50</td>
<td>Zeb Kurth-Nelson</td>
<td>Learning to experiment</td>
</tr>
<tr>
<td>15:55 – 16:25</td>
<td>David Badre</td>
<td>Learning and transfer of working memory gating policies (Cortico-striatal mechanisms for cognitive control)</td>
</tr>
</tbody>
</table>

#### Poster Session (posters 26-50): 16:30 – 18:00

19:00 – 22:00 Social Event at the Zamansky Tower (Jussieu Campus of the Sorbonne University)

The Jussieu Campus is situated at approximately 20 minutes’ walking distance from the ICM.
<table>
<thead>
<tr>
<th>Time</th>
<th>Speaker</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:00 – 09:30</td>
<td>Monique Ernst</td>
<td>Development of neural systems underlying changes in motivated behaviors across adolescence</td>
</tr>
<tr>
<td>09:35 – 10:05</td>
<td>Coralie Chevalier</td>
<td>Social cognition in harsh and unpredictable environments</td>
</tr>
<tr>
<td>10:10 – 10:40</td>
<td>Berna Güroglu</td>
<td>Adolescent decision-making in the peer context</td>
</tr>
<tr>
<td>10:45 – 11:15</td>
<td>Coffee Break</td>
<td></td>
</tr>
<tr>
<td>11:15 – 11:45</td>
<td>Iroise Dumontheil</td>
<td>Enhancement of cognitive control in rewarding contexts in adolescence and adulthood</td>
</tr>
<tr>
<td>11:50 – 12:20</td>
<td>Wouter van den Bos</td>
<td>Navigating uncertainty in adolescence</td>
</tr>
</tbody>
</table>

Lunch break: 12:25 – 14:00

<table>
<thead>
<tr>
<th>Time</th>
<th>Speaker</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:00 – 14:30</td>
<td>Alireza Soltani</td>
<td>Learning and decision making in a changing world</td>
</tr>
<tr>
<td>14:35 – 15:05</td>
<td>Rava da Silveira</td>
<td>Various approaches to online inference — human behavior and theoretical models</td>
</tr>
<tr>
<td>15:10 – 15:40</td>
<td>Pierre-Yves Oudeyer</td>
<td>Computational theories of curiosity-driven learning</td>
</tr>
<tr>
<td>16:15 – 16:45</td>
<td>Etienne Koechlin</td>
<td>(TBD)</td>
</tr>
</tbody>
</table>
On Monday 21 and Tuesday 22 May, SBDM takes place in the auditorium of the ICM, a research institute located within the Pitié-Salpêtrière hospital. You can enter the hospital through one of two entries:

- From **83 Boulevard de l'Hôpital** (main entry) : just next to stop Saint-Marcel on metro line 5. Alternatively, walk 10 minutes from Gare d’Austerlitz (metro line 5, RER C) or take bus 57 or 91.

- From **Rue Bruant** (small side entry) : just next to metro stop Chevaleret on metro line 6. As you walk from this entry to the ICM, you will have to climb a flight of stairs.
The third conference day, Wednesday 23 May, takes place at the ENS. Note that the venue is not accessible at its usual address of 29 Rue d’Ulm, but has to be entered at 24 Rue Lhomond. From there, arrows will indicate the way to the Salle Jaurès where the conference is held. The ENS is situated at a few minutes’ walking distance from metro stop “Place Monge” on line 7, or RER station “Luxembourg” on line B.

On Tuesday evening, a social event takes place at the top floor of the Zamansky tower on the Jussieu campus of the Sorbonne university. The venue is situated at a 20-minute walking distance from the ICM. It is one of the few tall buildings in Paris’ inner city, granting a stunning view over the River Seine and the city center. The entry to the Jussieu Campus is just next to the metro exit “Jussieu” on lines 7 and 10.
**Accessing the Internet on Site**

To access the Wi-Fi, both at the ICM and at the ENS, you will need to log in using personalized codes that you will find on your badge (unless you are from those very institutions, in which case we have not requested a guest account for you).

- **At the ICM**
  Simply connect to "ICM-GUEST" with the login name and password you received. Once logged in, deactivate and reactivate your Wi-Fi and the connection should be established.

- **At the ENS**
  There are two ways of connecting to the Wi-Fi at the ENS. If you have Eduroam set up on your device, there is no need to enter any additional codes to access the internet. If you do not have Eduroam set up, you can connect to "wifiens". First, a WPA key is requested: enter "louis pasteur" (all lowercase and with a space in between). Once connected, you need to launch your web browser. (Note that for Internet Explorer, versions 9.0 and up are supported; other versions may not be.) To get to the Wi-Fi access page, load an http address (not https). Then use the ID and password printed on your badge to connect to the Wi-Fi.
# POSTER SCHEDULE

## SESSION 1: POSTERS 1-25 (MONDAY 21 MAY, 11:40 – 13:15)

<table>
<thead>
<tr>
<th>Poster Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjectivity in preference-based decision-making: do neural responses to heartbeats impact value encoding?</td>
<td>Damiano Azzalini, Stefano Palminteri, Catherine Tallon-Baudry</td>
</tr>
<tr>
<td>A spiking neural network for goal-directed behaviour with partially learned world models</td>
<td>Ruggero Basanisi, Andrea Brovelli, Emilio Cartoni, Gianluca Baldassarre</td>
</tr>
<tr>
<td>Reference-point centering and range-adaptation enhance human reinforcement learning at the cost of irrational preferences</td>
<td>Sophie Bavard, Maël Lebreton, Mehdi Khamassi, Giorgio Coricelli, Stefano Palminteri</td>
</tr>
<tr>
<td>Decisions to explore are preceded by increased baseline arousal</td>
<td>Anjali Raja Beharelle, Marcus Grueschow, Rafael Polania, Marius Moisa, Todd Hare, Christian C. Ruff</td>
</tr>
<tr>
<td>Computational bases of behavioral unpredictability</td>
<td>Marwen Belkaid, Malou Dongelmans, Etienne K. Duranté, Jérémie Naudé, Olivier Sigaud, Philippe Faure</td>
</tr>
<tr>
<td>Cortical and Thalamic Influences on Striatal Involvement in Human Behavioural Flexibility</td>
<td>Tiffany Bell, Angela Langdon, Michael Lindner, Anastasia Christakou</td>
</tr>
<tr>
<td>Perceptual decision-making: Attractor dynamics explains post-error adjustments</td>
<td>Kevin Berlemont, Jean-Pierre Nadal</td>
</tr>
<tr>
<td>Dichotomous organization of the Globus Pallidus externa reproduces long pauses in a spiking model of the monkey basal ganglia</td>
<td>Grégoire Berthelon, Jean Liénard, Kenji Doya, Benoît Girard</td>
</tr>
<tr>
<td>Are you positive? A two-way misattribution bias between value and confidence judgments</td>
<td>Bioud E., Abitbol R., Pessiglione M.</td>
</tr>
<tr>
<td>Novel choices in the macaque monkey: Imaging and causal approaches to novel stimuli valuation and multidimensional decision-making in a non-human primate</td>
<td>Alessandro Bongioanni, Miriam Klein-Flügge, Davide Folloni, Matthew F.S. Rushworth</td>
</tr>
<tr>
<td>Brains without values: computational phenotyping of fronto-temporal dementia</td>
<td>Nicolas Borderies, Guilhem Carle, Raphael Le Bouc, Fabien Vinckier, Jean Daunizeau, Carole Azuar, Richard Levy, Mathias Pessiglione</td>
</tr>
<tr>
<td>Exploring the relationship between decision thresholds and confidence</td>
<td>Joshua Calder-Travis, Rafal Bogacz, Nick Yeung</td>
</tr>
<tr>
<td>Multisensory decision unfolds in time as causal inference</td>
<td>Yinan Cao, Christopher Summerfield, Hame Park, Robin Ince, Bruno L. Giordano, Christoph Kayser</td>
</tr>
<tr>
<td>The use of confidence when choosing between different types of information</td>
<td>Naomi Carlebach, Nick Yeung</td>
</tr>
<tr>
<td>Testing the role of the limbic thalamic nuclei during reinforcement learning: evidence from LFP in epileptic patients</td>
<td>Romane Cecchi, Maëlle Gueguen, Stephan Chabardès, Vincent Navarro, Jean Regis, Mathias Pessiglione, Julien Bastin</td>
</tr>
<tr>
<td>Arbitration between Imitation and Emulation during Human Observational Learning</td>
<td>Caroline J. Charpentier, Kiyohito Iigaya, John P. O’Doherty</td>
</tr>
<tr>
<td>Dopamine regulation of the exploration-exploitation trade-off in rats</td>
<td>François Cinotti, Virginie Fresno, Nassim Akil, Etienne Coutureau, Benoît Girard, Alain R. Marchand, Mehdi Khamassi</td>
</tr>
<tr>
<td>The effort of choosing: neural correlates of deliberation during value-based decision-making</td>
<td>Nicolas Clairis, Mathias Pessiglione</td>
</tr>
<tr>
<td>Multiple-value systems in the brain: Asymmetry between Dorsal Anterior Cingulate Cortex and Ventromedial Pre-Frontal cortex when solving decisions problems under multiple choice dimensions</td>
<td>Irene Cogliati Dezza, Axel Cleeremans, William Alexander</td>
</tr>
<tr>
<td>Computational neuropharmacology of human impulsive decision-making</td>
<td>David M. Cole, Lionel Rigoux, Andreea O. Diaconescu, Christoph Mathys, Zoltan Nagy, Daniel Müller, Andrea E. Steuer, Erich Seifritz, Boris B. Quednow, Klaas E. Stephan</td>
</tr>
<tr>
<td>Poster Title</td>
<td>Authors</td>
</tr>
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<td>----------------------------------------------------------------------------</td>
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</tr>
<tr>
<td><strong>21</strong> The Influence of social Pressure for Movement Precision: A Computational Approach</td>
<td>Ignasi Cos, Gustavo Dec</td>
</tr>
<tr>
<td><strong>22</strong> Investigating the origin and consequences of endogenous default-options in repeated economic choices tasks</td>
<td>Couto, J, van Maanen, L, Lebreton, M</td>
</tr>
<tr>
<td><strong>23</strong> Neural Modelling of Antisaccade Performance of Healthy Controls, Schizophrenia and Obsessive-Compulsive Disorders Patients</td>
<td>Vassilis Cutsuridis</td>
</tr>
<tr>
<td><strong>24</strong> CANCELLED</td>
<td></td>
</tr>
<tr>
<td><strong>25</strong> Determinants of transfer and curriculum learning in human categorisation</td>
<td>Ronald Dekker, Jan Balaguer, Timo Flesch, Christopher Summerfield</td>
</tr>
</tbody>
</table>

**SESSION 2: POSTERS 26-50 (Monday 21 May, 16:30 – 18:00)**

<table>
<thead>
<tr>
<th>Poster Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>26</strong> Models that learn how humans learn: the case of depression and bipolar disorders</td>
<td>Amir Dezfouli, Kristi Griffiths, Fabio Ramos, Peter Dayan, Bernard W. Balleine</td>
</tr>
<tr>
<td><strong>27</strong> Groups of unfair individuals benefit from decreased social punishment</td>
<td>Marwa El Zein, Chloe Seikus, Lee De-Wit, Bahador Bahrami</td>
</tr>
<tr>
<td><strong>28</strong> Challenge preference: Behavioural demonstration and a computational model</td>
<td>Greta M. Fastrich, Shinsuke Suzuki, Anastasia Christakou, Kou Murayama</td>
</tr>
<tr>
<td><strong>29</strong> The adaptive virtues of inferential noise in changing environments</td>
<td>Charles Findling, Margaux Romand-Monnier, Etienne Koechlin</td>
</tr>
<tr>
<td><strong>30</strong> Neural Mechanisms of Rapid Category Learning in Humans</td>
<td>Timo Flesch, Hamed Nili, Christopher Summerfield</td>
</tr>
<tr>
<td><strong>31</strong> Reversible disruption of amygdala and anterior cingulate cortex using focused ultrasound neurostimulation</td>
<td>Davide Folloni, Lennart Verhagen, Rogier Mars, Elsa Fouragnan, Charlotte Constans, Pierre Pouget, Jean-François Aubry, Matthew Rushworth, Jerome Sallet</td>
</tr>
<tr>
<td><strong>32</strong> Dissociable effects of valence and information on response times during reinforcement learning: A diffusion decision model account</td>
<td>Laura Fontanesi, Stefano Palminteri, Maël Lebreton</td>
</tr>
<tr>
<td><strong>33</strong> The macaque anterior cingulate cortex translates counterfactual choice value into actual behavioral change</td>
<td>E Fouragnan, BKH Chau, D Folloni, N Kolling, M Klein-Flügge, L Verhagen, L Tankelevitch, GK Papageorgiou, JF Aubry, J Sallet, MFS Rushworth</td>
</tr>
<tr>
<td><strong>34</strong> Mechanisms of suggestion: Cognitive regulation propensities mediate the effect of appetite suggestions on hunger.</td>
<td>Solène Frileux, Philippe Fossati, Liane Schmidt</td>
</tr>
<tr>
<td><strong>35</strong> Predicting Risk Attitudes from the Precision of Mental Number Representation</td>
<td>Miguel Barretto Garcia, Marcus Grueschow, Rafael Polania, Michael Woodford, Christian C. Ruff</td>
</tr>
<tr>
<td><strong>36</strong> Loss Aversion for Monetary and Food Rewards in Healthy Controls and Women with Anorexia</td>
<td>Alexia GERARDIN, Charles-Alexandre JOLY, Guillaume SESCousse, Stéphanie ROGUES-LEFEBVRE, Michel PUGEAUT, Jean-Claude DREHER</td>
</tr>
<tr>
<td><strong>37</strong> Goal-directed imagination and cognitive flexibility: A computational model of the Wisconsin Sorting Card Test</td>
<td>Giovanni Granato, Gianluca Baldassarre</td>
</tr>
<tr>
<td><strong>38</strong> Rewards and punishment learning differentially modulates intracerebral brain dynamics</td>
<td>Maëlle Camille Marie Gueguen, Jean-Philippe Lachaux, Philippe Kahane, Pablo Billeke, Mathias Pessiglione, Julien Bastin</td>
</tr>
<tr>
<td><strong>39</strong> Understanding why rewards improve cognitive performance using multivariate analyses of EEG data</td>
<td>Sam Hall-McMaster, Nicholas Myers, Paul Muhle-Karbe, Mark Stokes</td>
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<tr>
<td><strong>40</strong> Stochastic satisficing account of confidence in uncertain value-based decisions</td>
<td>Uri Hertz, Bahador Bahrami, Mehdi Keramati</td>
</tr>
<tr>
<td><strong>41</strong> Motivational effects on action selection and memory</td>
<td>Stephanie T. Hirschbichler, Jaime Ibáñez, Lorenzo Rocchi, Richard Greenwood, John Rothwell, Sanjay G. Manohar</td>
</tr>
<tr>
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<td>-----------------------------------------------------------------------------</td>
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</tr>
<tr>
<td><strong>51</strong> Neural Computations in the Temporoparietal Junction during Strategic Interactions</td>
<td>Arkady Konovalov, Christopher Hill, Jean Daunizeau, Christian Ruff</td>
</tr>
<tr>
<td><strong>52</strong> Learning about other person’s character traits relies on a combination of reinforcement learning with representations of trait distributions and similarities</td>
<td>Christoph Korn, Gabriela Rosenblau, Jan Gläscher</td>
</tr>
<tr>
<td><strong>53</strong> The Role of Testosterone in Strategic Prosociality</td>
<td>Hana H. Kutlikova, Michael Naef, Christoph Eisenegger, Claus Lamm</td>
</tr>
<tr>
<td><strong>54</strong> Why did Pandora open the box: When curiosity supersedes in risk-related decision</td>
<td>Johnny King LAU, Hiroki OZONO, Anthony HAFFEY, Kei KURATOMI, Asuka KOMIYA, Kou MURAYAMA</td>
</tr>
<tr>
<td><strong>55</strong> Comparison of model-free and model-driven analysis to detect early signs of cognitive decline in small cohort of neurodegenerative patients</td>
<td>Lorna Le Stanc, Katia Youssov, Agnès Sliwinski, Maria Giavazzi, Anne-Catherine Bachoud-Lévi, Charlotte Jacquemot</td>
</tr>
<tr>
<td><strong>56</strong> Outcome valence bias confidence and impact decision strategies in reinforcement learning tasks.</td>
<td>Maël Lebreton, Karin Baciły, Stefano Palminteri, Jan Engelmann</td>
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<tr>
<td><strong>57</strong> The motivational control of mental effort allocation during decision-making</td>
<td>Douglas Lee, Jean Daunizeau</td>
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<tr>
<td><strong>58</strong> Reinforcement learning confirmatory bias in the human brain</td>
<td>Lefebvre Germain, Joffily Mateus, Giorgio Coricelli, Palminteri Stefano</td>
</tr>
<tr>
<td><strong>59</strong> Action selection and reinforcement learning in a Basal Ganglia model</td>
<td>Jean Liénard, Benoît Girard, Kenji Doya</td>
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<tr>
<td><strong>60</strong> The effects of exogenous testosterone on the preference to compete for status in repeated Real Effort-based Competitions</td>
<td>Annabel Losecaat Vermeer, Isabelle Krol, Christoph Eisenegger</td>
</tr>
<tr>
<td><strong>61</strong> Magnitude provides a conceptual scaffold for the neural encoding of value</td>
<td>Fabrice Luyckx, Bernhard Spitzer, Hamed Nili, Christopher Summerfield</td>
</tr>
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Visiting Paris

Public Transport

For detailed information about your journey to and from the airport, see [this page](#) on the SBDM website.

You can move around in Paris using the metro, bus, tram, or RER (something in between a metro and a train: faster than metro, but with fewer stops). To plan your trip, simply use Google Maps or the official [public transportation website](#).

The easiest way to move around is by metro, as Paris has a dense network and a regular service (see map below). However, many stations are only about 250 meters apart, so you may want to also consider walking (note that it does not matter whether you cross the entire city or just hop off after two stations - you pay the same price of a single ticket). Do not forget that there are many pickpockets active on the metro, whom you can avoid by keeping hold of your bags at all times, or by not looking like a tourist.

For each journey, you have to buy a “T+ Ticket” (shown above) that you hold on to during your trip to move through the gates, and then dispose of once you leave the station. Tickets get date-stamped once you enter a station or a bus and cannot be used anymore afterwards. You can use the same ticket if you transit from the metro to the RER or vice versa, but if you transit from metro or RER to a bus or tram, you have to use a new ticket. So, as you can imagine, you will use up many tickets rapidly if you move around a bit. Therefore, it may be more economical to buy a set of 10 or more tickets at once. Note that there are
different price categories: if you only move around in Paris, you can get the “dans Paris” ticket for 1,90€ (or 14,90€ per 10), but if you are going outside Paris (this includes the suburbs), you need a ticket that includes the banlieues, which is a little bit more expensive. Be sure to buy the correct ticket at the vending machines. If you get inspired by the many people who fare-dodge by jumping over the gates, consider that the fine to pay if you get caught is 35€, or the amount of 24 separate tickets.

**Food and Drinks**

Needless to say that France, in theory, is known for its exquisite cuisine. This does, however, not mean that your every meal will be delicious, served by gentle waiters, and represent good value for your money. Be critical of the restaurant or brasserie you select, or make an informed choice based on recommendations from LeFooding or TimeOut Paris.

As it may be nice to get food and drinks after the conference as a group, we suggest for **Monday 21 May** to walk (15 minutes) from the ICM to the quays of the River Seine (Quai de la Gare), where several pop-up bars and little restaurants on boats will allow us to enjoy some sun at the end of the day.

On **Tuesday 22 May** our social event takes place in the Tour Zamansky, offering a beautiful view over Paris’ city center. The event finishes at 22:00, which may be a bit early for some. For a potential afterparty, the brasserie “Le Nouvel Institut” seems particularly suited. Located at just 5 minutes’ walking distance, this bar sells pints of beer for 3€.
SIGHTSEEING

If the Tour Zamansky doesn’t give you enough of a view of the city, you can see the Paris from above from the Eiffel Tower, the Tour Montparnasse, the Notre Dame, the Arc de Triomphe, and the Centre Pompidou. For all of these you will have to pay (and probably queue...), so consider the view from the Sacré-Cœur basilica in the elevated area of Montmartre.

Paris also has an impressive amount of musea to offer. Famous, of course, are the Louvre, the beautiful Musée d’Orsay, or the permanent and temporary exhibitions of the Grand Palais. But do also consider having a look at the more specific musea dedicated to movies, magic, ethnology, Picasso, contemporary art, modern art, or photography. And there’s more...

Less intellectual but ever so friendly on the eye are the glamorous Opéra Garnier, the most beautiful leaded windows in the world in the Sainte Chapelle, or the macabre Catacombs of Paris.

If you are an under-26 European, you are lucky and you will get into most of these places for free. Important for everyone: be sure to buy your tickets (even if they are free of charge) online to avoid queueing.

More commercial ways of spending your money are amply available at Paris’ well-known department stores Le Bon Marché, Le Printemps, and the Galeries Lafayette, or the large Les Halles mall.

And if you really just want to see the city without standing in line or paying for entry, take a stroll and be sure not to miss the Place des Vosges (4th arrondissement), Place Vendôme (1st), the gardens of the Palais Royal (1st), Rue Montorgeuil (2nd), and the many little streets and passages. Consider taking a guided tour, some of which are free.
Part 2 – Talk abstracts
**MATTHEW RUSHWORTH (9:00 – 9:30)**

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

*Temporal-frontal interactions in memory-guided decision making*

Decision making is not just guided by immediately available sensory evidence but by information held in memory. In two experiments with macaques we have found that decision making depends on interactions between temporal and frontal cortical regions. In the first experiment animals chose between two options while retaining information about a third option that could become available to choose on a future trial. Activity in the medial temporal lobe, in the hippocampus, tracked the value of currently unavailable options - counterfactual choices - and was predictive of accuracy in future decisions concerning that option. Anterior cingulate cortex activity also tracked counterfactual choice value but in a distinct framework linked to the best alternative. Temporary disruption of anterior cingulate cortex compromised translation of counterfactual values into actual choices. In a second experiment monkeys learned that attributes of visual stimuli predicted either reward magnitude or probability. After extensive training activity in anterior temporal and perirhinal cortex tracked the value of the stimuli. Animals were, however, also able to combine information about both attributes when they encountered novel stimuli comprising features of both original stimulus sets. The ability to make such novel decisions was related to activity in entorhinal cortex and ventromedial prefrontal cortex. Some features of the activity suggested a grid-like encoding of an abstract value space occurred in these regions. Temporary disruption of ventromedial prefrontal cortex compromised monkeys’ ability to make novel decisions.

**CHARLIE WILSON (9:35 – 10:05)**

Stem Cell and Brain Research Institute INSERM U1208, Université de Lyon

*Frontal oscillatory bursts underlie adaptive cognitive control in the monkey.*

Beta and gamma oscillations may have a pivotal role in coordinating cognitive control in frontal cortex. We have shown that average prefrontal beta power tracks trial-by-trial levels of cognitive control between periods of exploration and exploitation, in monkeys using ECoG recordings (Stoll, Wilson et al 2016 Cerebral Cortex). The same oscillations also reflect the attentional effort of the animals across the time of a session (Wilson et al 2017 PLoS Biology). These oscillations are generally studied as a sustained activity averaged across trials. But in fact in the raw data their true occurrence is as circumscribed bursts. I will show that analysis of the properties of the individual bursts is essential to decoding cognitive control from oscillatory phenomena within frontal cortex. Single trial burst analysis of frequency domain data provides a high frequency resolution, and indication that frequency variation (inside the beta band) within and between trials is indicative of cognitive features of the trial. In prefrontal cortex, the number and power of bursts at beta frequencies reflects cognitive control for that trial, similarly to trial-by-trial mean beta power. By contrast changes in burst duration but not power reflect the within session change in mean beta power, providing a form of double dissociation across burst properties. As such burst analysis is essential to decoding cognitive control, and more generally it is essential for a precise understanding of the role of oscillatory phenomena.
**LÉON TREMBLAY (10:30 – 11:00)**

Institute of Cognitive Science Marc Jeannerod, Lyon, France

*The role of anterior Striatum to value-based decision making: The power of translational investigation between human and non-human primate.*

Based on a broad range of Brain imaging studies in humans, neuronal recordings in behaving monkeys and pharmacological perturbation studies mainly in rodents, the role of the ventral striatum and his dopamine modulation in appetitive motivation, value-based decisions and reward seeking is largely accepted. Growing evidences from brain imaging studies in human suggest that the anterior striatum could be also involved in aversive motivation (Jensen et al. 2003), learning of avoidance behaviors (Delgado et al. 2009) and anxiety-related disorders (Radua et al. 2010). Moreover, recent study with Parkinson’s disease patients which expressed negative psychiatric symptoms such as apathy, depression and anxiety, suggests that serotonin inside the anterior striatum might be important to modulate negative value encoding and anxiety-relative behaviors (Maillet et al. 2016). How is the encoding of negative values in the anterior striatum? Is there a subgroup of neurons or a specific striatal territory that encodes the negative values and induce avoidance behaviors or anxiety disorders? Finally, can serotonin modulate these negative value encoding by an action on the anterior striatum since we know that the serotonergic system projects in this territory? These are 3 fundamental questions that cannot be answered by Brain imaging in humans and that requires a complementary and translational investigation in animal, especially in non-human primate. In this talk, I will focuses on recent investigation that we performed to answer these questions by neuronal recording on monkeys trained to perform an approach-avoidance task before and during serotonin treatment. The results of this study shown that the anterior striatum has the neural bases to encodes separately negative values as well as positive values and the integrity of their activities is essential to value-based decision making which lead to context adapted behaviors. An imbalance between these two opposed populations that can lead to the overexpression of the negative-value neurons could be behind the striatum involvement in large spectrum of anxiety-related disorders. Interestingly, our results with fluoxetine suggest that an opposite action between these two striatal populations may explain the therapeutic effects of the serotonin reuptake inhibitors: an increase of incentive motivation associated to an anxiolytic effect. All together, these results highlight the power of preclinical investigation in nonhuman primate to unravel and understand the role of a specific structure like the anterior striatum, in value-based choices in normal and pathological states.

**ARMIN LAK (11:05 – 11:35)**

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

*Neuronal signals for reward learning under perceptual uncertainty*

Efficient decision making requires combining immediate sensory evidence with reward values, which must be learned over time. How does the brain perform this combination and learn from the outcome of the resulting decisions? We trained mice in a task that requires combining sensory evidence and past rewards, and we developed a model that describes their behavior. The model makes key predictions for the underlying neural signals and computations. We confirmed these predictions by recording from populations in prelimbic frontal cortex and through imaging and optogenetic manipulation of midbrain dopamine neurons. The results reveal key neuronal computations that enable mammals to learn and make efficient choices when challenged with internal and environmental uncertainty.
Lesley Fellows (13:15 - 13:45)

Professor, Dept. of Neurology & Neurosurgery, Montreal Neurological Institute, McGill University, Montreal, Canada

Carving value at its joints: Insights from patients with prefrontal damage

Subjective value is a central concept in neuroeconomics. It is tracked in ventral fronto-striatal circuits, and variation in ventromedial prefrontal (vmPFC) value-related signals can predict choice. Real-world options are typically characterized by multiple attributes, some or all of which could contribute to a global value estimate. What brain mechanisms underpin value “construction” from multiple attributes? I will present studies of patients with focal damage to vmPFC that suggest that this region plays a much more specific role in subjective valuation than the wider literature suggests. These patients can provide consistent value estimates for a range of complex stimuli, ranging from faces to food to artworks. However, they seem to draw on different information to inform those value judgements. I argue that they may be showing a kind of “value neglect”, ignoring or underweighting specific value-predictive information. This may reflect a difficulty in inferring value from multiple attributes in context, an ability that may be needed for appreciating more abstract aspects of value. Alternatively, the problem may stem from impairment in recognizing value that emerges from the conjunction of attributes rather than being calculable on the basis of each attribute alone. Either way, these findings argue that we need a more nuanced understanding of the role of vmPFC in appreciating the value of decision options.

Dana Small (13:50 - 14:20)

Professor of Psychiatry and Associate Professor of Psychology; Director, Modern Diet and Physiology Research Center

Gut Feelings: Metabolic signals regulate food reward

The ubiquity of energy-dense “hyper-palatable” food is often blamed for fueling the obesity epidemic. Although this explanation includes three variables: availability, energy and pleasure, the primary focus of the lay, industrial and scientific communities alike has been on pleasure. The intuitive assumption is that the pleasure derived from eating overrides homeostatic circuits leading to positive energy balance and weight gain. In this talk data will presented showing that this framework is not entirely en pair with what is currently known about the neural circuits underlying feeding behavior. Instead, it will be argued that physiological signals functioning independently of conscious processes - such as the sensation of pleasure -are the driving force accounting for ingestive decision-making. More specifically, findings from rodent and human studies will reveal that post-ingestive signals regulate neural circuits in the dopaminergic meso-striato-prefrontal system independently of other food characteristics that could influence reward such as liking, to guide reinforcement learning and food valuation.

Alizée Lopez-Persem (14:25 - 14:55)

Post-doctoral research associate, Department of Experimental Psychology, University of Oxford, United Kingdom.

Testing the core properties of the Brain Valuation System: an Intracranial EEG investigation

Estimating the value of alternative options is a key process in decision making. fMRI studies have identified a brain system, with the ventromedial prefrontal cortex (vmPFC) as a central component. Here, we examined the properties of this brain valuation system using a different recording technique, intracranial electroencephalography (iEEG), which offers direct access to the electrophysiological activity supposed to underpin hemodynamic responses, with much better temporal resolution. We recorded iEEG signals in 36
epileptic patients while they performed judgment tasks that involved rating different kinds of items (food, face, painting) and different features (age, likeability). We identified several brain regions in which High-gamma activity (50-150 Hz) positively correlated with likeability ratings, including not only the vmPFC but also the lateral orbitofrontal cortex (lOFC) and the hippocampus. Focusing on these three regions, we characterized the dynamics of value coding across time and frequency bands. Then we investigated their functional properties of valuation in the high frequency bands. All properties derived from fMRI results were replicated in the vmPFC: likeability ratings could be decoded in pre-stimulus activity (anticipation of value judgment), for both food and non-food items (generality), during both explicit and distractive tasks (automaticity), with both linear and quadratic functions (aggregation of value and confidence). Overall, our findings provide a bridge between two literatures on the neural underpinnings of subjective values: one based on electrophysiological studies in non-human primates and one based on fMRI studies in humans.

Shinsuke Suzuki (15:20 – 15:50)
Assistant Professor, Frontier Research Institute for Interdisciplinary Sciences, Tohoku University, Sendai, Japan.

Food value computation in the human orbitofrontal cortex

How do we compute value of an available option for decision-making? There is accumulating evidence to suggest that the brain represents the expected value or utility of options at the time of decision-making. However, much less is known about how it is that value signals are constructed. In this presentation, I will discuss how valuations for food rewards are constructed in the brain. Using a food-based decision task combined with multivariate analysis of fMRI data, I will demonstrate that values of food items can be predicted from beliefs about constituent nutritive attributes of food (e.g., fat, carbohydrate etc). I will then show, while food value is represented in patterns of neural activity in both medial and lateral parts of the orbitofrontal cortex (OFC), only the lateral OFC represents the elemental nutritive attributes. These results suggest a key role for the lateral OFC in encoding the precursor representations subsequently used to compute integrated subjective values.

David Smith (15:55 – 16:25)
Assistant Professor, Department of Psychology, Temple University, USA

Constructing Value: Understanding the Role of Corticostriatal Connectivity

Understanding the mechanisms of decision making and valuation is a core goal in decision neuroscience. A growing corpus of findings suggests that activation within the ventromedial prefrontal cortex (VMPFC) encodes the subjective value of different goods and experiences on a common scale. Yet, our decisions are sensitive to contextual factors -- including the presence of other people and the way information is presented -- that are likely represented outside of VMPFC. In this lecture, I will present studies that highlight the importance of considering brain connectivity, and particularly corticostriatal interactions, during decision making. Building on these findings, our recent work suggests that dysregulated corticostriatal connectivity may play a key role in in psychopathologies involving aberrant reward processing. Taken together, our findings suggest that multiple brain regions interact to construct value and enable flexible decision making.
**LASANA HARRIS (9:00 – 9:30)**
Senior Lecturer, Department of Experimental Psychology, Division of Psychology and Language Sciences, University College London, London, UK.

*Law on the brain: The role of the social cognition and deductive reasoning during legal decision-making.*

Legal systems punish people for bad behaviour motivated by bad minds. These legal and related moral decisions depend on a Bayesian inference of the person’s mind as well as deductive reasoning processes. Here, I examine the interplay of deductive reasoning and social cognition during legal decision-making. In the first study, participants decide responsibility and punishments after reading vignettes that either make a person’s mind salient or not. We find reduced engagement of brain regions active during deductive reasoning when the perpetrator’s mind is less salient, suggesting that social cognition is necessary to trigger deductive reasoning processes crucial for legal decision-making. In the second study, we inactivate social cognition (right temporal parietal junction (rTPJ)) and deductive reasoning (dorsolateral prefrontal cortex (DLPFC)) brain regions using TMS while people make decisions about torture intensity for a terror suspect. Consistent with our brain imaging findings, inactivating DLPFC escalates torture intensity and severity, not rTPJ. This suggests that DLPFC engagement is necessary for more human treatment. We discuss the implication of these results for legal and moral decision-making.

**RIMA-MARIA RAHAL (9:35 – 10:05)**
Research Associate, Cognitive Psychology II, Goethe University Frankfurt, Frankfurt (Main), Germany

*Eyes on Morals: Investigating the Cognitive Processes underlying Moral Decision Making via Eye-Tracking*

How are moral decisions such as sacrificing the life of one to rescue the lives of many others formed? The Dual Process Theory (Greene et al., 2001) proposes that decisions driven by utilitarian vs. deontological moral principles are preferentially supported by deliberate vs. intuitive processes. A competing account proposes that choices would be least effortful when the choice options are readily discriminable depending on individual preferences (Kim et. al, 2018). Investigating the implications of both theoretical propositions, we report an eye tracking study, showing decision makers’ attentional foci, their decision effort and conflictedness during the decision process. To study deontological vs. utilitarian decision making, we used incentivized third-party helping dilemmas, where participants decided whether to leave donations for cataract operations with a predetermined child (deontological option) or to reallocate the donation to operate a group of other children (utilitarian option). Moral preferences determined via choices in classical hypothetical trolley-type dilemmas predicted choices in the third-party helping dilemmas. Surprisingly, deontologists fixated more on operation costs than utilitarians, and less on information about the original allocation of the operation. Decision effort measured via reaction times, number of fixations and number of inspected information was lowest for participants with strong utilitarian moral preferences, while more deontological decision makers made their decisions more effortfully. Gaze patterns over the course of the decision process indicated that deontological decisions were accompanied by higher conflictedness than utilitarian choices, and that preference-consistent choices were made with less decision conflict. Implications for the theories of moral judgment are discussed.
**Molly Crockett (10:30 – 11:00)**

Assistant Professor of Psychology, Yale University

**The value of moral action**

Classical models of antisocial behaviour propose that violence arises out of a failure of lateral prefrontal cortex (LPFC) to “put the brakes” on selfish impulses originating in subcortical regions such as the amygdala and striatum. A new, alternative model proposes that LPFC does not directly inhibit selfish impulses, but instead flexibly modulates the value of selfish acts via cortico-striatal circuits. Here I will present empirical evidence directly supporting the alternative model. In a series of behavioural, pharmacological and neuroimaging experiments we observed healthy adults as they decided whether to anonymously inflict pain on themselves or strangers in exchange for money. We found that most people would rather harm themselves than others for profit. This moral preference correlated with neural responses to profit, where participants with stronger moral preferences had lower dorsal striatal responses to profit gained from harming others. LPFC tracked the blameworthiness of harmful choices and showed stronger functional connectivity with the profit-sensitive region of dorsal striatum during moral decisions. Increasing central dopamine levels with levodopa eliminated moral preferences. The findings suggest moral behaviour is linked to a neural devaluation of reward realized by a prefrontal modulation of striatal value representations. This mechanism implies that the moral value of actions is flexibly guided by neural representations of social norms. If norms change, so then do the values that guide actions. Supporting this view, changing norms via framing and social influence modulated moral preferences. Implications for theories of value representation in social decision-making will be discussed.

**Drazen Prelec (11:05 – 11:35)**

Professor, Sloan School, Dept. of Economics, Dept. of Brain & Cog. Sciences MIT, Cambridge MA, USA

**Self-signaling and the actor-critic model**

Self-signaling refers to actions taken to obtain positive or avoid negative information about one's internal characteristics. It is a natural model for some aspects of moral motivation, such as avoidance of shame or the preservation of self-esteem. Computational (behavioral economic) accounts of self-signaling generally presuppose two interacting modules: An ‘actor’ and an ‘observer’ or ‘critic.’ I will present some behavioral and imaging results relevant to this framework, and discuss how it would have to be modified to account for moral luck and guilt.
Conceptual scaffolding for decision values

As they develop, humans learn about the conceptual structure of the world. One simple concept is numerical magnitude, e.g. that four is greater than three. Here we show that neural codes for number provide a conceptual scaffold for reward-guided learning. Humans first viewed streams of symbolic digits, and then learned the reward probabilities associated with six novel visual images (bandits). Multivariate neural signals were more similar for consecutive numbers (e.g. three and four) and after reward learning, neural patterns elicited by each bandit mapped onto neural codes for the number that denoted its inverse rank (e.g. higher values onto larger numbers and vice versa). We argue that in humans, number is a conceptual basis function for understanding other one-dimensional stimulus spaces, such as reward probability.

Selective Attention for Dimensionality Reduction

How do we learn to categorise novel items and what is the brain basis of these acts? For example, after a child is told an animal is a dog, how does that experience shape how she classifies future items? In this talk, I will discuss work using model-based fMRI analyses to understand how people learn categories from examples. Results indicate that the medial temporal lobe (MTL) plays an important role in both learning and recognition. Successful cognitive models, which explain both behavioural and fMRI data, learn to selectively weight (i.e., attend) to stimulus aspects that are task relevant. This form of weighting, or top-down attention, can be viewed as a compression process. I will discuss how the medial prefrontal cortex (mPFC) and the hippocampus coordinate to build low-dimensional representations of learned concepts, as well as how the dimensionality of visual representations along the ventral stream is altered by the learning task.

Memory engrams as a basis for decision making

Memories for past experience play a critical role in flexible decision making. They facilitate explicit representation of potential outcomes which, at the time of choice, can be used to guide action selection. Here I will explore the mechanisms that govern the storage and retrieval of memory engrams, and discuss how insight into these mechanisms may explain decision biases. In the first set of studies I will discuss how overlapping memories are stored to minimise interference. Using ultra-high field 7T MRI and brain stimulation, I will show that in addition to the hippocampus, neocortical inhibition plays a key role in separating stored information. Therefore, when neocortical inhibition is reduced, interference between overlapping memories is observed at both a neural and behavioural level. In the second set of studies I will discuss mechanisms that support sampling of memory during decision making. Using a parallel cross-species approach in mice and humans, I will show that during inferential reasoning a competitive interaction can be observed between memories in the hippocampus. Together, these studies provide insight into the physiological mechanisms for memory storage and retrieval that provide a foundation for flexible decision making.
Learning to experiment

Recurrent neural networks (RNNs) can in principle be trained to execute any program. An interesting phenomenon emerges when RNNs are trained on a spectrum of tasks that each require within-task learning: the network learns to learn. After training, the network's acquired capacity for within-task learning can also be applied to novel tasks. We recently proposed that this phenomenon explains the emergence of model-based decision making in the brain. In this talk, I will explore the application of "learning to learn" to the problem of AI science. I show that an RNN can learn to perform informative causal interventions, learn from the results of those experiments, and combine the results of multiple experiments to solve a task.

Learning and transfer of working memory gating policies (Cortico-striatal mechanisms for cognitive control)

Rapid adaptation to novel tasks requires abstract task knowledge that can apply across multiple circumstances. A number of recent studies have focused on how people leverage the shared structure in stimulus-response (S-R) relationships across task contexts as one such form of abstract task knowledge. In this talk, I will focus on a line of studies that test how gating policies that govern internal control over working memory can also be learned as a form of abstract, transferable task knowledge. I will first provide behavioral evidence for the transfer of WM gating policies across changes of task context, as distinct from shared S-R structure. I will then provide behavioral and neuroimaging evidence that learning gating policies occurs over two timescales: a rapid adjustment of gating policies, supported by cortico-striatal circuits, accompanied by a slower process of adaptation that is driven by changes in the geometry of cortical representations. Overall, these studies highlight the importance of control policies, such as those related to working memory gating, as a key component of the task knowledge required for rapid, flexible behavior in novel environments.
Neural Systems Model of Decision-Making in Adolescence

Adolescence is a remarkable transition period, paved with obstacles. Indeed, the shift to independence requires embracing novel experiences, rejecting and losing old habits, and “recreating” the self. To achieve this feat, changes in “motivated behaviors” are essential. Since decision-making is the cornerstone of motivated behaviors, understanding how this complex process uniquely navigates throughout adolescence is critical to inform ways (e.g., public policy, education, media, mental health) to ensure successful transitions. This presentation will approach this question from the perspective of a heuristic mechanistic model, the Triadic Neural Systems model. This model proposes a shift in the functional balance among three core neural systems that govern emotion, motivation and executive control. Neuroimaging studies will illustrate how these neural systems may present different equilibria as a function of the environmental context (positive, negative), shaping decision-making in unique ways. First, event-related fMRI findings will suggest the nature of the networks involved, and then resting-state functional connectivity studies will address more directly networks affected by age, puberty and sex.

Social cognition in harsh and unpredictable environments

It has become a trope in cognitive sciences to say that humans are a uniquely cooperative species. At the same time, prosocial behaviours vary hugely between cultures, social groups and individuals. How can we reconcile these two facts? How can prosociality be universal yet so highly variable? The goal of the presentation is to examine the impact of individuals’ environment on their cognitive and behavioural strategies through the lens of behavioural ecology. The fundamental premise of our approach is that organisms have limited resources that must be allocated optimally to maximise survival and reproductive success. Our specific hypothesis is that prosociality is a special case of resource allocation and that it should therefore be highly susceptible to ecological influences.
Being able to form and preserve social bonds with others is essential for well-being. Successful navigation through the complex web of social relationships relies on separable but interconnected networks within the social brain. We can distinguish between neural networks related to emotion processing, regulation of behavior and understanding of oneself and others, all which contribute to our social functioning. Social behavior is highly influenced by the context of decision-making, such as the presence of peers or who the interaction partner is. Knowledge on adolescent brain development is crucial for a better understanding of social behavior and functioning of adolescents in the peer context. Here I will present findings from several studies where we examine the role of peer relationships in social decision-making and their underlying neural basis. Doing so, I will also discuss the challenges of ecologically valid paradigms that aim to combine real life relationships with neuroimaging methods.

Enhancement of cognitive control in rewarding contexts in adolescence and adulthood

Developmental studies of cognitive control have suggested that adolescents typically rely more on a reactive strategy (recruiting resources transiently in response to a cue) than a proactive strategy (sustaining these resources in anticipation of the cue), and that the balance between these two strategies shifts towards a more proactive strategy in adulthood. However, previous neuroimaging studies have not explored how these dynamics are influenced by rewards during development. The present study compared changes in performance in a working memory task as a function of monetary rewards in 30 adolescents (aged 12 to 16 years old) and 20 adults (aged 22 to 30). After a baseline working memory run without rewards, participants performed the same working memory task in a run in which they expected some trials to be rewarded. A mixed blocked/event-related functional magnetic resonance imaging design enabled separation of transient and sustained neural activity associated with reactive and proactive cognitive control. Participants’ accuracy for both rewarded and non-rewarded trials of the second run increased with age. Across age groups, participants were faster for the non-reward trials of the second run than the first run, indicating engagement of proactive control, and even faster for reward trials, suggesting an additional reactive engagement of cognitive control. Increased activity in the anterior insula and dorsolateral prefrontal cortex was observed in both adolescents and adults in the reward run compared to the non-reward run. Furthermore, increased activity in the anterior insula and the anterior cingulate cortex as well as subcortical areas was observed in response to reward trials within the reward run across age. These results suggest that in the context of sporadic rewards, both adolescents and adults adopt a combination of proactive and reactive strategy to maximise performance.
Wouter van den Bos (11:50 – 12:20)

Center for Adaptive Rationality, Max Planck Institute for Human Development, Berlin, Germany & Department of Psychology, University of Amsterdam, the Netherlands

Navigating Uncertainty in Adolescence

Despite the increased prevalence of adolescent risk-taking behavior in the real world, laboratory evidence of adolescent specific risk taking propensity remains scarce. In contrast with the lab, adolescents in the real world often have only incomplete information about risks. There is currently very little known about how adolescents make decisions under these uncertain conditions. To address this issue, we studied how adolescents search for information before making decisions. In a large behavioral study (N=105, ages 8-22) we found adolescents searched for less information before making a decision, were less averse of uncertainty, and made more risky decisions. In a follow-up fMRI study, comparing adults (N=25, ages 18-25) and adolescents (N=30, ages 11-15), we used a Bayesian updating model to track the processes involved in learning probabilities and decision-making. Again, we found that adolescents were less skilled in learning probabilities and were more risk-seeking compared to adults. In addition, we find that adolescents reported level of confidence is less well calibrated to level of uncertainty associated with the stimuli. Finally, our results suggest that adults, but not adolescents, consistently take estimation uncertainty into account when making choices. This was supported our finding that the VMPFC is encoding the uncertainty in adults but not for the adolescents. Finally, I will present novel behavioral studies on how adolescents use social information to reduce uncertainty and guide their choices in uncertain environments.

Alireza Soltani (14:00 – 14:30)

Assistant Professor, Department of Psychological and Brain Sciences, Dartmouth College, Hanover, USA

Learning and Decision Making in a Changing World

To successfully learn from reward feedback in real-world situations, the brain must adjust how it responds to and incorporates reward outcomes because the relationship between reward outcomes and real-world options or their many features can unpredictably change over time and at different timescales. At the heart of this learning problem is a tradeoff between adaptability and precision (adaptability-precision tradeoff). On one hand, the brain must rapidly update reward values in response to changes in the environment, and on the other hand, in the absence of any such changes, it must slow down learning to obtain accurate estimates of those values. First, I show experimental evidence for how humans and monkeys tackle the adaptability-precision tradeoff. Second, I show plausible neural mechanisms for how these adjustments could be instantiated in the brain. Finally, I discuss the implications of these findings for studying adaptive learning in dynamic environments.

Rava Azeredo da Silveira (14:35 – 15:05)

Ecole Normale Supérieure

Various approaches to online inference – human behavior and theoretical models

In natural settings, we make decisions based on streams of partial and noisy information. Arguably, we summarize the perceived information into a probabilistic model of the world, which we can exploit to make decisions. This talk will explore such ‘mental models’ in the context of idealized tasks that can be carried out in the laboratory and modeled quantitatively. The starting point of the talk will be a sequential inference task that probes inference in changing environments, in humans. I will describe the task and an experimental finding, namely, that humans make use of fine differences in temporal statistics when making inferences. While our observations agrees qualitatively with an optimal inference model, the data exhibit
biases. What is more, human responses, unlike those of the optimal model, are variable, and this behavioral variability is itself modulated during the inference task. In order to uncover the putative algorithmic framework employed by humans, I will go on to examine a family of models that break away from the optimal model in diverse ways. This investigation will suggest a picture in which humans carry out inference using noisy mental representations. More specifically, rather than representing a whole probability function, human subjects may manipulate probabilities using a (possibly modest) number of samples. The approach just outlined illustrates a range of possible computational structures of sub-optimal inference, but it lacks the appeal of a normative framework. If time permits, I will discuss recent ideas on a normative approach to human inference subject to internal ‘costs’ or ‘drives’, which can explain various biases. While different in its formulation, this approach shares conceptual commonalities with the rational inattention theory and other constrained optimization frameworks in cognitive science.

Pierre-Yves Oudeyer (15:10 – 15:40)

Research director, Inria, France

Computational theories of curiosity-driven learning

What are the functions of curiosity? What are the mechanisms of curiosity-driven learning? I will approach these questions about the living using concepts and tools from machine learning and developmental robotics. I will argue that curiosity-driven learning enables organisms to make discoveries to solve complex problems with rare or deceptive rewards. By fostering exploration and discovery of a diversity of behavioural skills, and ignoring these rewards, curiosity can be efficient to bootstrap learning when there is no information, or deceptive information, about local improvement towards these problems. I will also explain the key role of curiosity for efficient learning of world models. I will review both normative and heuristic computational frameworks used to understand the mechanisms of curiosity in humans, conceptualizing the child as a sense-making organism. These frameworks enable us to discuss the bidirectional causal links between curiosity and learning, and to provide new hypotheses about the fundamental role of curiosity in self-organizing developmental structures through curriculum learning. I will present various developmental robotics experiments that study these mechanisms in action, both supporting these hypotheses to understand better curiosity in humans and opening new research avenues in machine learning and artificial intelligence.

Etienne Koechlin (16:15 – 16:45)

Director of the Frontal Lobe Functions Group, Ecole Normale Supérieure, Paris, France

TBD
Part 3 – Poster abstracts
SESSION 1: MONDAY 21 MAY, 11:45 – 13:15
(POSTERS 1-25)

[Poster # 1]
SUBJECTIVITY IN PREFERENCE-BASED DECISION-MAKING: DO NEURAL RESPONSES TO HEARTBEATS IMPACT VALUE ENCODING?

Damiano Azzolini, Stefano Palminteri & Catherine Tallon-Baudry
Laboratoire de Neurosciences Cognitives, Département d’études cognitives, ENS, PSL, Research University, INSERM, Paris France

Subjectivity lies at the core of preference-based decision in two respects: the values on which the choice is based are idiosyncratic in nature and their access is available - via internal scrutiny - only to the person that holds them. A wealth of neuroscientific studies has focussed on first aspect of the question, namely the mechanisms of value representation and comparison, highlighting the pivotal role of ventromedial prefrontal cortex (vmPFC) (Clithero & Rangel, 2014). Less attention has been devoted to the second aspect, that is how those values can be made available and bound to oneself. A recent theory (Park & Tallon-Baudry, 2014) has put forth that neural responses to heartbeats (or heartbeat evoked responses, HERs) may generate a self-centered reference frame, to which ongoing cognitive processes can be referred. Several experimental results have provided support for this theory (Park et al, 2014; Babo-Rebolo et al., 2016; Park et al 2016; Sel et al 2016 and 2017). In the current study we tested (1) whether HERs distinguish between decisions that are based on internally available evidence, hence self-centered, as compared to evidence available in the outside world, and (2) whether HERs play a functional role in self-centered decisions. 21 healthy participants performed preference-based and perceptual choices on pairs of movie titles while their brain and cardiac activities were recorded with magneto-encephalography (MEG) and electrocardiography (ECG), respectively. Which decision type had to be performed was indicated at the beginning of each trial by a geometrical cue (a square or a diamond) presented at the center of the screen for a fixed delay of 1.5 s. After the cue, two movie titles were displayed on the screen. In preference-based choices, subjects had to indicate which of the two movies they liked more. We also manipulated the luminance of each character in the title so that the overall luminance of the two titles was slightly different. This was the relevant characteristic for perceptual choices in which participants had to indicate which title looked darker. After response and a variable delay, the next trial began. The exact same pairs of titles were presented twice, once per decision type. Our results show that while subjects have to prepare for preference judgment (i.e., during cue presentation), and thus before options are displayed, neural responses to heartbeats in the rostral part of vmPFC are larger as compared to preparation for perceptual choice. These results provide additional evidence supporting the idea that the amplitude of neural responses to heartbeats characterizes cognitive processes that are self-centered.

But do neural responses to heartbeats have functional relevance in subjective decision-making? In accordance with previous (fMRI) decision-making literature, we find that the caudal portion of vmPFC encodes the value of the chosen option during stimulus presentation in preference decisions. Our analyses further reveal that value encoding is enhanced for trials in which neural responses to heartbeats during task preparation are larger. Therefore, beyond characterizing self-centered processes, we reveal that HERs have a functional influence in subjective decision-making, in that they modulate the strength of value encoding.

[Poster # 2]
A SPIKING NEURAL NETWORK FOR GOAL-DIRECTED BEHAVIOUR WITH PARTIALLY LEARNED WORLD MODELS

Ruggero Basanisi*+, Andrea Brovelli+, Emilio Cartoni*, Gianluca Baldassarre*
+Institut de Neurosciences de la Timone, Unité Mixte de Recherche 7289, Aix Marseille Université, Centre National de la Recherche Scientifique, 13385, Marseille, France
*Institute of Cognitive Sciences and Technologies, National Research Council, Rome, Italy

Automatic and deliberate actions are essential components of human behavior. In mammals, the acquisition and consolidation of instrumental behaviour are known to engage two distinct decision-making processes. Acquisition relies on flexible goal-directed actions selected according to expected outcomes as well as current goals and motivational states. Consolidation is characterised by the gradual formation of stimulus-
driven habitual responses. At the neural level, goal-directed behaviours are thought to be controlled by the associative fronto-striatal circuit including the lateral and medial prefrontal cortices and the caudate nucleus. With increasing automaticity and consolidation, motor responses become habitual and recruit brain circuits involving the sensorimotor and premotor areas coupled with the sensorimotor territories of the striatum, the putamen in primates. In this work, we present a computational model addressing the operation of the goal-directed system during the acquisition of deterministic associations between stimuli, actions and outcomes by trial-and-error. The task requires human participants to find the correct associations between 3 colored circles and 5 finger movements, a task known as arbitrary visuomotor learning.

The computational model is composed of: (a) an input region encoding stimuli, actions (as afferent copies), and feedback; (b) a central associative network, able to represent the input patterns and to learn their temporal relations; (c) an output component, able to produce actions executed in the environment; and (d) a goal component encoding the pursued goal and able to bias the dynamics of the associative network so as to perform the correct actions. All components are formed by spiking neurons having an integrate-and-fire dynamics simulated as a non-homogeneous Poisson process. The associative network, the core of the model, is characterised by a learning rule that tends to form winner-take-all circuits that mirror the lateral inhibition and within-population excitation typical of cortical circuits.

The activation of neurons is such that can be formally interpreted as a probabilistic process, in particular as a Hidden Markov Process (HMP) that, through learning, progressively acquires the capacity to internally represent the observed dynamics sequences of input-action-feedback, and hence to form a forward model of the world. This mechanism has been taken from previous models. A further internal novel process, running on the forward model and guided by the successful matching of goals, instantiates a one-step planning process that allows the system to acquire a bias from the goal to the HMP. This results in a goal-directed action selection when the goal is internally activated ("desired") by the agent. The model is able to reproduce the behaviour of the participants of the target experiment. In this respect, the model represents a novel operational hypothesis on how such behaviour might be produced on the basis of goal-directed mechanisms relying on planning as probabilistic inference directly implemented by the stochastic spiking of neurons. Moreover, contrary to other works, the model proposes a model of human planning that performs in parallel the acquisition of the model of the world and its use for planning although still partial.

Taken together, our findings indicate that rapid category learning in humans over a timescale of hours is not accompanied by changes in the neural representation of stimuli, as occurs over longer timescales in NHPs. Instead, choices rely on the flexible computation of a decision signal in the frame of reference of the stimulus space and with respect to the category boundary. Further studies are necessary to investigate how this process might support generalisation ability or the formation of novel categorical representations over longer time courses.

**[Poster # 3]**

**REFERENCE-POINT CENTERING AND RANGE-ADAPTATION ENHANCE HUMAN REINFORCEMENT LEARNING AT THE COST OF IRRATIONAL PREFERENCES**

Sophie Bavard$^{1,2,3}$, Maël Lebreton$^{4,5}$, Mehdi Khamassi$^{6,7}$, Giorgio Coricelli$^{8,9}$, Stefano Palminteri$^{1,2,3}$

1 Laboratoire de Neurosciences Cognitives Computationnelles, Institut National de la Santé et Recherche Médicale, Paris, France
2 Département d’Etudes Cognitives, Ecole Normale Supérieure, Paris, France
3 Institut d’Etudes de la Cognition, Université de Paris Sciences et Lettres, Paris, France
4 CREED lab, Amsterdam School of Economics, Faculty of Business and Economics, University of Amsterdam.
5 Amsterdam Brain and Cognition, University of Amsterdam.
6 Institut des Sciences de l'Information et de leurs Interactions, Sorbonne Universités, Paris France
7 Institut des Systèmes Intelligents et Robotiques, Centre National de la Recherche Scientifique, Paris, France
8 Departement of Economics, University of Southern California, Los Angeles, USA
9 Centro Mente e Cervello, Università di Trento, Trento, Italia

*Equal contribution

In economics and in perceptual decision-making contextual effects are well documented, where decision weights are adjusted as a function of the distribution of stimuli. Yet, in reinforcement learning literature whether and how contextual information pertaining to decision states is integrated in learning algorithms has received comparably little attention. Here, in an attempt to fill this gap, we investigated reinforcement learning behavior and its computational substrates in a task where we orthogonally manipulated both outcome valence and magnitude, resulting in systematic variations in state-values. Over two experiments, model comparison indicated that subjects’ behavior is best accounted for by an algorithm which includes both reference point-dependence and range-adaptation - two crucial features of state-dependent valuation. In addition, we found state-dependent outcome valuation to progressively emerge over time, to be favored by increasing outcome information and to be correlated with explicit understanding of the task structure. Finally,
out our data clearly show that, while being locally adaptive (for instance in negative valence and small magnitude contexts), state-dependent valuation comes at the cost of seemingly irrational choices, when options are extrapolated out from their original contexts.

[Poster # 4]

Decisions to Explore are Preceded by Increased Baseline Arousal

Anjali Raja Beharelle, Marcus Grueschow, Rafael Polanía, Marius Moisa, Todd Hare*, and Christian C. Ruff*

Department of Economics, Laboratory for Social and Neural Systems Research, University of Zurich
Neuroscience Center Zurich, University of Zurich, Swiss Federal Institute of Technology Zurich
* denotes shared senior authorship

Subjectivity lies at the core of preference-based decision in two respects: the values on which the choice is based are idiosyncratic in nature and their access is available - via internal scrutiny - only to the person that holds them.

A wealth of neuroscientific studies has focussed on first aspect of the question, namely the mechanisms of value representation and comparison, highlighting the pivotal role of ventromedial prefrontal cortex (vmPFC) (Clithero & Rangel, 2014). Less attention has been devoted to the second aspect, that is how those values can be made available and bound to oneself. A recent theory (Park & Tallon-Baudry, 2014) has put forth that neural responses to heartbeats (or heartbeat evoked responses, HERs) may generate a self-centered reference frame, to which ongoing cognitive processes can be referred. Several experimental results have provided support for this theory (Park et al, 2014; Babo-Rebelo et al., 2016; Park et al 2016; Sel et al 2016 and 2017). In the current study we tested (1) whether HERs distinguish between decisions that are based on internally available evidence, hence self-centered, as compared to evidence available in the outside world, and (2) whether HERs play a functional role in self-centered decisions.

21 healthy participants performed preference-based and perceptual choices on pairs of movie titles while their brain and cardiac activities were recorded with magnetoencephalography (MEG) and electrocardiography (ECG), respectively. Which decision type had to be performed was indicated at the beginning of each trial by a geometrical cue (a square or a diamond) presented at the center of the screen for a fixed delay of 1.5 s. After the cue, two movie titles were displayed on the screen. In preference-based choices, subjects had to indicate which of the two movies they liked more. We also manipulated the luminance of each character in the title so that the overall luminance of the two titles was slightly different. This was the relevant characteristic for perceptual choices in which participants had to indicate which title looked darker. After response and a variable delay, the next trial began. The exact same pairs of titles were presented twice, once per decision type.

Our results show that while subjects have to prepare for preference judgment (i.e., during cue presentation), and thus before options are displayed, neural responses to heartbeats in the rostral part of vmPFC are larger as compared to preparation for perceptual choice. These results provide additional evidence supporting the idea that the amplitude of neural responses to heartbeats characterizes cognitive processes that are self-centered.

But do neural responses to heartbeats have functional relevance in subjective decision-making? In accordance with previous (fMRI) decision-making literature, we find that the caudal portion of vmPFC encodes the value of the chosen option during stimulus presentation in preference decisions. Our analyses further reveal that value encoding is enhanced for trials in which neural responses to heartbeats during task preparation are larger.

Therefore, beyond characterizing self-centered processes, we reveal that HERs have a functional influence in subjective decision-making, in that they modulate the strength of value encoding.

[Poster # 5]

Computational Bases of Behavioral Unpredictability

Marwen Belkaïd1, Malou Dongelmans2, Etienne K. Duranté2, Jérémie Naudé2, Olivier Sigaud1,3,* and Philippe Faure2,*

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2 Sorbonne Université, CNRS UMR 8246, INSERM U1130, Institut de Biologie Paris Seine, IBPS, F-75005 Paris, France.
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* These authors have jointly directed this work.

Numerous studies have delved into the neurobiological mechanisms by which individuals use past experience to repeat successful actions. Typically, reinforcement learning is conceived as a process that
makes individuals behavior more repetitive and predictable by increasing the propensity to perform actions that proved successful in the past [1, 2]. However, in certain cases, behaving in an unusual, variable, or unpredictable way can constitute a strategic advantage even when repeatedly facing the same situation - e.g. for humans playing competitive games or preys escaping a predator [3, 4]. It remains unknown whether and how the brain is able to actively implement an unpredictable strategy. Our work takes an integrative approach to these questions, mixing animal experiments with computational modeling.

On the experimental side, we captured the necessity to behave in a variable way by confronting mice with a virtual competitor (VC) [5]. More specifically, VC strives to predict mice future choices based on their past behavior. The animals are rewarded only when they elude the prediction of VC, i.e. when they generate variability. As a result, we observed that under this adversarial setting mice are able to adopt a more unpredictable behavior than in a deterministic setting. In particular, mice performance and the complexity of their choice sequences increased over sessions against the virtual competitor. Interestingly, throughout learning, mice behavior tended toward (pseudo-)random action selection while being statistically different from true randomness.

On the computational modeling side, we simulated this task as a Markov Decision Process using classical reinforcement learning algorithms. In particular, the representation of the state contains a memory of the previous choices. In this framework, two solutions can be implemented: 1) increasing the agent’s memory to allow for detecting and repeating patterns that counteract VC predictions, 2) increasing the exploration factor to approach random selection. Using this model, we can evaluate whether mice behavior is better fit by memory-based counteraction strategy or exploratory, quasi-random action selection. We can also assess how animals depart from these extreme models of decision-making.

References

**[Poster # 6]**

**Cortical and Thalamic Influences on Striatal Involvement in Human Behavioural Flexibility**

Tiffany Bell1,2, Angela Langdon3, Michael Lindner1, Anastasia Christakou1

1. School of Psychology and Clinical Language Sciences, Centre for Integrative Neuroscience and Neurodynamics, University of Reading, RG6 6AL, UK
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Introduction: Behavioural flexibility is a key adaptive ability for complex organisms. Evidence from animal studies points to a critical role for cortico-basal ganglia-thalamocortical circuits. Specifically, dorsal striatal regions, ventral prefrontal and cingulate cortical regions have been implicated in behavioural flexibility, as indexed in paradigms such as reversal learning. Reversal learning depends both on identifying changes in response contingencies, as well as on learning and expressing a new response (Bradfield & Balleine 2017). More recently, animal studies of reversal learning have shown a specific role in this latter process for the dorsal striatum and its interactions with the centromedian parafascicular (CM-Pf) thalamus. This thalamostriatal pathway makes a contribution to reversal learning that seems to build on the detection of contingency violation in cortical and thalamic regions. This system is not as well understood in humans. To bridge this gap, this study was designed to measure distinct corticostralial and thalamostriatal contributions to human reversal learning.

Methods: We used whole-brain functional magnetic resonance imaging (fMRI) during performance of a probabilistic, multi-alternative learning task, incorporating a protracted reversal learning phase. We analysed sub-components of behaviour based on a simple reinforcement learning model that disentangles the relative influence of positive and negative prediction errors over time. We used psychophysiological interaction (PPI) analysis of fMRI data, to measure task-dependent changes in connectivity between striatal, cortical and thalamic functional subdivisions. We defined these subdivisions (our regions of interest, or ROIs) using activation coordinates from independent studies (Morris et al. 2016; Metzger et al. 2010) and resting-state connectivity-based parcellation methods (Choi et al. 2012).

Results: Our results show a functional dissociation between corticostralial and thalamostriatal interactions, with specificity of involvement during initial learning compared to reversal learning. Specifically, we show that
medial orbitofrontal cortex (mOFC) connectivity with the ventral striatum increased during the late stages of initial learning, and lateral OFC (lOFC) connectivity with the putamen increased during reversal learning. By contrast, connectivity between the dorsal striatum and the centromedial parafascicular (CM-Pf) thalamic complex was increased during reversal, but not initial, learning. The strength of this connectivity was associated with the ability to flexibly alter behaviour; specifically, connectivity was associated not with resistance to perseveration, but rather with resistance to regressive errors, which are understood as an index of interference between old and new learning.

Conclusion: These findings are in line with evidence from the animal literature for functionally distinct inputs from the cortex and the thalamus to distinct striatal regions that contribute to specific components of reversal learning. The study helps to bridge the gap between animal studies of this system, and human studies of reversal learning and cognitive flexibility more generally, and highlights the contribution of thalamostriatal connectivity.

References:

[Poster # 7]
Perceptual decision-making: Attractor dynamics explains post-error adjustments

Kevin Berlemont, Jean-Pierre Nadal

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Perceptual decision-making is the subject of many experimental and theoretical studies. Whereas most modeling analyses are based on statistical processes of accumulation of evidence, less attention is being devoted to the modeling with attractor network dynamics, even though they describe well psychophysical and neurophysiological data. In particular, very few works confront attractor models’ predictions with data from continuous sequences of trials.

Recently however, numerical simulations of a biophysical competitive attractor network model have shown that such network can describe sequences of decision trials and reproduce repetition biases observed in perceptual decision experiments. Here we get more insights into such effects by considering an extension of the reduced attractor network model of Wong and Wang (2006), taking into account an inhibitory current delivered to the network once a decision has been made. We make explicit the conditions on this inhibitory input for which the network can perform a succession of trials, without being either trapped in the first reached attractor, or losing all memory of the past dynamics. We study in details the reaction times properties during a sequence of decision trials. Quite remarkably, we show that, in the absence of any feedback about the correctness of the decision, the network exhibits, qualitatively and with the correct orders of magnitude, post-error slowing and post-error improvement in accuracy, two subtle effects observed in behavioral experiments.

[Poster # 8]
Dichotomous organization of the globus pallidus externa reproduces long pauses in a spiking model of the monkey basal ganglia

Grégoire Berthelon¹, Jean Liénard², Kenji Doya², Benoît Girard¹

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The basal ganglia (BG) are a complex assembly of nuclei assumed to be involved in action selection and reinforcement learning. Among them, the globus pallidus externa (GPe) has a major impact on the basal ganglia because it projects to all the BG nuclei and has a strong looped connection with the subthalamic nucleus (STN). Some neurons of the monkey GPe exhibit long pauses in activity , that have not been
explained so far. Our work aims at understanding the mechanism of the pauses by a spiking neural network model constrained by anatomical and physiological data. In rats, Mallet et al. showed that rat’s GPe is composed of 2 populations. The Arkypallidal population (GP-TA) projects only to the Striatum and to local neurons. The rest of the neurons (GP-TI) projects to the entopeduncular nucleus (EPN), the Substantia Nigra pars reticulata (SNr), the STN and the striatum. However, the connections with the striatum are weak compared to the GP-TA population. Single axon tracing studies on the primate GPe showed that this nucleus can be separated into 4 different populations, depending on their target nuclei (Striatum, STN, Globus Pallidus interna or GPi, and SNr). If we consider the GPe and SNr to be one entity, we denominate only 2 populations, one projecting to the striatum and the other projecting to the STN and the GPi/SNr. Thus, we notice that the 2 populations of the GPe are similar in rats and primates.

Most models of the BG have considered the GPe as composed of a uniform population of neurons. We present here an extended version of our BG spiking model integrating the separation of the GPe into two separate populations projecting to the striatum and the other nuclei. We explore the minimal parameter modifications sufficient to transform uniform-GPe model into a split-GPe model that still passes the same firing rate tests as the initial model. We found that some of those models exhibited pauses in the GPe with similar characteristics as the recorded ones. This result shows that pauses could be related to the segregated organization of the GPe. Using the same set of parameters, neurons of both GPe populations in our model experienced longer maximum inter-spike intervals after the separation while the general firing frequencies remained intact. This suggests that the pauses can be explained as a network driven phenomenon rather than an intrinsic specificity of the GPe cells. The possible functional role of these pauses in monkey remains to be explored, in the light of the latest related rat results.


**[Poster # 9]**

ARE YOU POSITIVE? A TWO-WAY MISATTRIBUTION BIAS BETWEEN VALUE AND CONFIDENCE JUDGMENTS

Bioud E., Abitbol R., Pessiglione M.

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Current models of decision-making rest upon the assumption that healthy individuals seek to maximize their expected utility, which is computed by multiplying the subjective value of possible outcomes with their probability. Specifically, it is assumed that judgments of value and probability are made independently from each other. Yet, many cases of misattribution between these two decisional variables have been established behaviourally. For example, yielding to the so-called ‘desirability bias’, healthy adults have been shown to judge highly-valued (i.e. desirable) events as relatively more likely. Here, we focused on a subtype of probability judgment particularly relevant for action selection: confidence, defined as the subjective probability of being correct. Recent neuroimaging findings have shown a same brain region, the vmPFC, to be encoding both first-order value judgments and the second-order confidence judgment associated to them, which makes this region a good candidate substrate for a value-confidence signal spillover.

Until now, this misattribution phenomenon had only been demonstrated in situations where the two judgments concerned the same object. However, the genericity and automaticity of value and confidence encoding in the vmPFC suggests that a misattribution could occur even between distinct objects, so we investigated whether a modulation of context could have an incidental impact on a supposedly unrelated judgment. We also sought to test the extent to which subjects were able to reduce such a bias when incited to provide accurate judgments.

In two behavioural experiments (N = 52), we had participants answer general-knowledge quiz questions while listening to musical extracts, and subsequently rate either their confidence in having given the correct answer to the quiz, or how much they liked the musical extract. In experiment 1, we observed a reciprocal positive influence between confidence and pleasantness judgments: participants trusted their answer more
when the musical background was more pleasant, and reciprocally, they liked more the musical background when they were confident in their answer. In experiment 2, we tested whether this double bias would still be present if the accuracy of the ratings given by the participants was incentivized (monetarily or hedonically). In this motivationally stringent setting, we again observed a positive effect of confidence on pleasantness judgments, but not the reciprocal effect of contextual pleasantness on confidence judgements. This result suggests that, under sufficiently high incentives, healthy subjects may be able to correct for the influence that context may exert on their confidence. However, the impact of confidence on value judgments seemed harder to suppress, possibly because confidence signals are automatically generated whenever a response is given that can be correct or incorrect.

Overall, we found evidence for a two-way value-confidence misattribution bias in healthy subjects, which occurred incidentally, between contextual features and behavioural responses that were unrelated. The value-to-confidence bias could nevertheless be suppressed when subjects were financially motivated to form accurate judgments.

[Poster # 10]

**Novel choices in the macaque monkey: Imaging and causal approaches to novel stimuli valuation and multidimensional decision-making in a non-human primate**

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

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

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

In a separate analysis of the same data, we looked for a BOLD effect consistent with a grid-like coding of the position and movement across the abstract 2-dimensional reward space, in analogy to grid cells’ hexagonal symmetry in physical space encoding. We found such an effect in the medial prefrontal cortex and this became stronger across sessions, as monkeys became more familiar with the 2-dimensional reward space. We subsequently ran a causal experiment, disrupting the neural activity in the medial prefrontal region identified with fMRI, using Focused Ultrasound Neurostimulation and we observed an alteration in the activity in the frontopolar region, not only for identical stimuli, but also for stimuli with different magnitude, different probability but similar expected value, indicating that the region can encode the expected value of complex novel stimuli.

In conclusion, we showed that macaques can make inferential decisions when facing novel stimuli, analogously to humans, but the brain activity that we observed to underlie this ability is not present for overlearned decisions.

[Poster # 11]

**Brains without values: computational phenotyping of fronto-temporal dementia**

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Apathy is a very common and detrimental symptom in neuro-psychiatric disorders. Despite its importance, current measurement tools are limited to subjective clinical scales that do not offer any mechanistic understanding. In contrast, the computational approach provide generative models of the behavior, with a set of parameters that can capture specific motivational deficits. Here, we illustrate this approach in the example case of fronto-temporal dementia (behavioral variant), which is induced by atrophy in the medial prefrontal cortex and anterior insula and associated with symptoms of apathy and disinhibition. We recruited a group of consecutive bv-FTD patients (N=20) and matched healthy relatives (N=20) in a hospitalization unit. All participants performed a battery of motivational tasks targeting various cognitive processes (valuation, decision-making, effort allocation, instrumental learning) and manipulating critical dimensions of motivation (reward, punishment, effort, delay). We developed computational models to fit behavioral responses in the different tasks and compared fitted parameters between the two groups. The main finding was a general disruption of the valuation process that affected action costs (effort) and action outcomes (reward and punishment), but not the impact of delay. This computational could explain several behavioral patterns, such as more binary judgments, more stochastic decisions, more impulsive choices and hyposensitivity to reinforcement. In turn, it could account for clinical features such as apathy and disinhibition. The same tasks and models could be used to better specify motivational deficits in other neurological or psychiatric diseases. In the future, computational phenotyping could improve prediction of clinical outcome and help with personalizing treatment.

**[Poster # 12] Exploring the relationship between decision thresholds and confidence**

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There is substantial agreement that the drift diffusion model (DDM) accounts well for the speed and accuracy of two-alternative perceptual decisions, however this model struggles to explain variability in confidence reports. The problem is that, according to the DDM, deliberation involves tracking the difference in evidence between alternatives until this difference crosses a fixed threshold. Hence, decisions are always made with the same balance-of-evidence between the chosen and unchosen alternatives. In a variant of the DDM, decision thresholds are allowed to vary with deliberation time, such that as deliberation time increases, the balance-of-evidence required to trigger a response decreases. This may provide a unified account of perceptual decisions and confidence, as decisions are no longer made with the same balance-of-evidence. It has been suggested that the DDM with decreasing thresholds may be optimal in a variety of situations, however, modelling of decision thresholds via fits to choice and reaction times has so far produced ambiguous results. We describe a novel approach based on an application of ordinal regression to confidence data, that is applicable when decisions are made on the basis of time-varying evidence. Via simulation, we show that this approach can determine whether confidence follows from the process that led to the initial decision and, if it does, what the shape of the decision threshold is. We applied the analysis to a dataset in which participants had to make a quick decision regarding which of two flickering boxes contained the most dots on average. Results suggest that confidence does indeed follow from the same process that leads to the initial decision, and that the threshold for this decision decreases over time. Current limitations are discussed.

**[Poster # 13] Multisensory decision unfolds in time as causal inference**

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Multisensory perceptual decision has often been modelled based on the assumption that the brain implements a reliability-weighted fusion of the available sensory evidence. However, more recent work suggests that to understand multisensory decision making more elaborate models are required to explain the brain’s flexibility of weighing sensory segregation against fusion according to an inferred belief about
common vs. separate cause(s) among incoming sensory streams. A key open question concerns where and when these multisensory inference processes are represented in the brain during decision making. We probed for the spatio-temporal evolution of various candidate neural representations underlying the inference processes, such as the representations of unisensory evidence, of reliability-weighted sensory fusion and of sensory causal inference using a combination of behavioural modelling and multivariate pattern analysis of source-localised magnetoencephalographic (MEG) responses.

Fifteen human participants categorised (4-choice task) the temporal rate of stochastic pulsatile stimuli in unisensory and multisensory conditions, focusing on either visual or auditory pulses (focused modality-specific attention). The pulse-trains (duration 550 ms) consisted of 17-ms visual flicker (Gaussian annulus) and auditory flutter (depth-modulated noise) with congruent or incongruent rates (9, 13, 16 or 20 Hz). The auditory and visual rates, auditory reliability (modulation depth) and the attended modality (task relevance) were manipulated factorially.

The behavioural data demonstrated a nonlinear, rate- and congruency-dependent effect of the task-irrelevant stimulus on categorisation performance. This multisensory partial integration is a behavioural signature of causal inference, resulting in the breakdown of reliability-weighted fusion for highly discrepant cues (e.g., 9-Hz auditory vs. 20-Hz visual). Indeed, modelling confirmed that a Bayesian causal inference model with a flexible prior of common-cause probability provided a significantly better explanation for the observed data compared to models without the causal inference step.

We analysed the MEG data using cross-validated representational similarity analysis (Walther et al., 2016) and variance decomposition to uncover the spatio-temporally selective neural encoding of different candidate model-driven rate estimates (segregated auditory or visual unisensory rates, reliability-weighted fusion and causal inference). This revealed a gradual progression of neural representations from sensory segregation to fusion to causal inference. An initial representation of unisensory rates was observed as early as 100 ms after stimulus onset within the respective sensory cortices. Reliability-weighted fusion was represented in associative cortices at mid latencies (left superior temporal sulcus around 220 ms and bilateral intraparietal sulcus, IPS, around 500~540 ms post stimulus onset). Finally, stimulus representations predicted by a causal inference process weighting inter-sensory congruency and task relevance emerged at 620 ms in the bilateral inferior frontal cortex (IFG), in the insula and in the anterior cingulate, and were sustained until a choice was made.

Our results manifest a spatio-temporal unfolding of the cerebral processes that refine early unisensory representations into multisensory decision variables that embody sensory attributes, task relevance and the posterior probabilistic beliefs about common cause underlying the sensory attributes. Further, they suggest that a common parietal-frontal circuit (bilateral IPS/IFG) may underpin the updates of causal structure during both sensory and cognitive/inductive causal inference (Tomov et al., 2017).

References:


[Poster # 14]

The Use of Confidence When Choosing Between Different Types of Information

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Upon making a decision we typically have a sense of the likelihood that the decision we reached was a good one, i.e. a degree of confidence in our decision. Usually, people are highly accurate at evaluating their performance, with reported confidence ratings strongly reflecting objective performance. Despite the evident connection between confidence judgements and decision-making, the functional importance of confidence judgements and how they affect decisions remains largely unknown.

Here, we study how people use confidence when choosing between different types of information before making a decision. 25 participants performed a perceptual decision making task, in which they reported which of two boxes presented briefly on the screen contained more dots, and how confident they are in their decision. After giving an initial response, participants chose between viewing the stimulus again for a longer period or receiving advice from a virtual adviser. Following reception of this additional information, they gave their final response and confidence on which box contained more dots. Participants were incentivised to maximise performance, and told advisers and their accuracy rates varied between blocks, but were not given any information about the quality of each adviser.

We hypothesized that people will use confidence strategically when deciding between the different types of information, depending on their immediate goal. More specifically, we expected people to request advice more often when extremely unconfident in their response, hence trying to improve their accuracy by using external help, but also when extremely confident, allowing them to learn how good the adviser is. Surprisingly, our results indicate that participants chose to view advice more often when confidence was...
high, but not low. We suggest this reflects the use of confidence to learn about the environment, specifically the quality of advice in this instance, and propose an additional experiment to further support this hypothesis.

[Poster # 15]
**Testing the role of the limbic thalamic nuclei during reinforcement learning: evidence from LFP in epileptic patients**

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The dorsomedial (DMTN) and anterior thalamic nucleus (ATN) are thought to play a critical role within the brain network enabling human memories formation (Sweeney-Reed et al., 2014). However, DMTN and ATN are also strongly connected with medial prefrontal cortex, cingular and insular cortices (Vertes et al., 2015). This connectivity pattern explains partly why both nuclei are also believed to be involved during decision-making (Chakraborty et al., 2016; Parnaudeau et al., 2015), and an emerging view proposes that these limbic thalamic nuclei could have dissociable functional roles. This hypothesis is mainly supported by animal electrophysiological and lesion studies (Bradfield et al., 2013; Corbit et al., 2003; Mitchell, 2015) and deep brain stimulations in patients (Sun et al., 2015). Yet, given the lack of circumscribed lesion data associated with the fact that noninvasive neuroimaging methods cannot distinguish signals that originate from small and deep areas within the thalamus, the exact functional role of human DMTN and ATN during decision-making remains unclear. To clarify this issue, we recorded local field potentials (LFPs) data during a reinforcement learning paradigm designed to dissociate reward-based learning from punishment avoidance. Nine patients with intra-thalamic depth electrodes implanted to treat severe refractory epilepsy (Fisher et al., 2010) were included in the study. Depth electrodes were bilaterally implanted and had multiple contacts (4/hemispheres) that sampled both ATN and DMTN. We found significant evidence of instrumental learning: patients were able to seek rewards or to avoid punishments. At the neural level, we found an outcome-related decrease of 5-10 Hz power in both nuclei (DMTN and ATN); this decrease of power was marginally modulated by outcome valence. Taken together, these results suggest that the dorsomedial and anterior thalamic nuclei are critical part of a brain network that is important for learning and updating the value of choice options.

REFERENCES


[Poster # 16]
**Arbitration between imitation and emulation during human observational learning**

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In order to navigate our social world, it is crucial for people to learn from others. However, we often have to learn from observing the behavior and actions of others without directly observing the outcomes and consequences of these actions. Here we aim to investigate the behavioral and neural computations underlying two strategies that people can implement in such observational learning situations: (1) action imitation, where one learns by copying the action tendencies of other agents, and (2) emulation or social inference, where one learns by inferring the goals and intentions of others. We developed a novel fMRI task in which participants have to learn to identify valuable tokens by observing another agent choosing between explicit slot machines, while manipulating volatility (frequency of switches in valuable token) and entropy (perceptual ambiguity about token probabilities). Critically, participants can learn this task by learning about the actions performed by the other agent (imitation), or by inferring which token (goal) the agent is aiming for (emulation). Various computational models were fit to participants’ data: (1) imitation-only models, which incorporate learning about the other agent’s action via computation of an action prediction error; (2) emulation-only models, which rely on Bayesian inference over token values; and (3) an arbitration model, in which the likelihood of relying on one strategy over the other varies over time as a function of each strategy’s relative reliability. This latter arbitration model was found to be the best predictor of behavior in an out-of-sample analysis. Specifically, volatility decreased the reliability of imitation, while entropy decreased the reliability of emulation. Thus, participants were found to emulate more in volatile, low entropy environments, but to imitate more in stable, high entropy environment. Current work is investigating how these computations are implemented in the brain. Together, these findings provide novel insights on how people learn from others in the absence of outcomes, and how they adaptively modulate their learning strategy depending on the environment.

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**[Poster # 17]**

**DOPAMINE REGULATION OF THE EXPLORATION-EXPLOITATION TRADE-OFF IN RATS**

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In an environment where the reward rate of different actions can change, it is adaptive for an organism to maintain a balance between selecting what seems to be the best option and keeping track of alternatives. This exploration-exploitation trade-off could be modulated simply by changing the bias favouring better actions over other randomly selected actions. Thus exploitation is characterized by an action probability distribution with low entropy (the best action is almost certainly selected) and exploration by a high entropy probability distribution (action selection tends to be equiprobable). A theoretical prediction based on a model of the basal ganglia is that tonic dopamine, the average level of dopamine activity in the striatum, contributes to setting this balance, specifically that the higher this level is, the more exploitation is favoured. We therefore investigated the relationship between dopamine and the exploration-exploitation trade-off within rat subjects in a novel non-stationary bandit task and showed that pharmacological inhibition of D1 and D2 dopamine receptors greatly increased the proportion of random choices without seemingly affecting learning abilities. Simulations of an extended Q-learning model fitted on each individual accurately reproduced the rats’ behaviour under the various pharmacological conditions and demonstrated that decreasing dopaminergic activity is equivalent to increasing exploration rate without interfering with the learning rate. This computational approach was further validated using artificial data sets to ensure its ability in capturing variations in either one or the other parameter. This study opens the door to the possibility that fluctuations of tonic dopamine in a healthy rat dynamically regulates the exploration-exploitation trade-off.

**[Poster # 18]**

**THE EFFORT OF CHOOSING: NEURAL CORRELATES OF DELIBERATION DURING VALUE-BASED DECISION-MAKING**

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When deciding about which action to take, people must weigh the costs against the benefits associated with alternative options. FMRI studies have identified a brain network whose activity correlates positively with the appetitive value of potential outcomes. This network, coined Brain Valuation System (BVS), mainly includes the ventromedial prefrontal cortex (vmPFC), the ventral striatum and the posterior cingulate cortex. Less is known about the existence of an opponent brain system that would correlate positively with the aversive value of effort costs, although some brain regions, such as the dorsomedial prefrontal cortex (dmPFC) have been repeatedly implicated. One critical issue is to disentangle between brain activity linked to effort associated with the envisaged options and to effort invested in the decision-making process.

To tease apart these neural representations, we scanned healthy participants (n=38) while they performed tasks involving valuation of virtual reward and effort items. More precisely, they performed 3 tasks that required 1) rating of reward appetitive value and effort aversive value on an analog scale, 2) choosing the most appetitive of two rewards, or the least aversive of two efforts, 3) deciding whether or not to make a given effort for a given reward. Reward appetitive values and effort aversive values were simply the ratings assigned by participants to the different items. Response time was taken as a proxy for the amount of effort invested in every task trial. We verified that response time was correlated to the amplitude of pupil dilation, which is considered a valid marker of mental effort.

As expected, the appetitive value of reward items were signaled in all tasks by increased activity in the BVS, including the vmPFC. Activity in this brain region was also sensitive to the aversive value of effort items, but with a negative correlation, consistent with the idea of a net value representation. Activity in the putative opponent regions, notably the dmPFC, did not correlate with aversive value but with response time, whatever the task.

Thus, we established a dissociation between effort costs attached to choice options, which are (negatively) integrated in the vmPFC, and the effort cost entailed by the very process of decision-making, which is (positively) reflected in the dmPFC. Further research is needed to precise whether this activity participates to the decision-making process or simply signals the amount of resource that is consumed by the process.

[Poster # 19]

**Multiple-value systems in the brain: Asymmetry between Dorsal Anterior Cingulate Cortex and Ventromedial Pre-Frontal Cortex when solving decisions problems under multiple choice dimensions**

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Dorsal Anterior Cingulate Cortex (dACC) and ventromedial Pre-Frontal Cortex (vmPFC) are two brain regions that subserve decision-making processes in a variety of decision tasks and their basic functions are still a matter of intensive debate. Converging researches appear to suggest that these regions work symmetrically but in opposition along a choice dimension. However, in their daily life, humans and animals are often confronted with decisions that require integration of different choice dimensions (i.e., information, reward, probability etc.) in order to guide actions. In this study, we investigated to what extent the symmetrical opposition between dACC and vmPFC is maintained after increasing the number of choice dimensions (i.e., reward and information). To do so, we asked participants to undergo an FMRI session while performing a modified version of standard multi-armed bandit task that has previously been adopted in order to discern between choice dimensions in foraging-like scenario. A model-based analysis was then performed in order to investigate the neural correlates of reward and information computation. Results showed that activity in dACC was correlated with the information value of the chosen option, but not with its relative reward value. On the contrary, activity in vmPFC was correlated with the relative reward value of the chosen option, but not with its information value. After introducing additional choice dimensions, the symmetrical opposition between dACC and vmPFC appears to break. The results of this study make troubling the interpretation of the decision-making process as controlled by a single-value system suggesting instead that multiple, parallel and independent value systems may account for decision-making in foraging-like scenario.

[Poster # 20]

**Computational neuropharmacology of human impulsive decision-making**

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Introduction. The behavioural construct of impulsivity is multifactorial, with broad relevance for neuropsychiatric conditions including addiction, psychosis and ADHD. The serotonin (5-HT) and dopamine (DA) neuromodulatory systems are hypothesised to serve complementary roles in the expression, specifically, of the ‘premature responding impulsivity’ (PRI) behavioural subtype of impulsive decision-making. However, PRI remains under-researched in humans. We provide a computational neuroimaging assessment, using a novel decision-making task and model-based functional magnetic resonance imaging (fMRI) approach, of the serotonergic and dopaminergic bases of PRI in healthy volunteers. We hypothesised interactions between 5-HT and DA-promoting drugs and reward/punishment task effects on behaviour and neural encoding of computational quantities under environmental uncertainty.

Methods. Ninety-three males (24.9±4.3 years) enacted probabilistic decision-making during fMRI in double-blind, placebo-controlled, crossover designs with either the selective 5-HT reuptake inhibitor escitalopram (15mg; n=50), or the DA reuptake inhibitor methylphenidate (20mg; n=43). The task embodied reversal learning procedures wherein the likelihood of which binary cue was the correct, rewarding (or non-punitive) choice varied across trials, with an additional pseudo-block modulation or environmental uncertainty (‘volatility’) across trials. Within trial, participants opted to either wait longer to receive more accurate choice information, or respond sooner to maximise reward/minimise loss if correct. Behavioural analysis used hierarchical Bayesian modelling, computing PRI parameters during the decision-making period and prediction error (PE) signals during feedback. We acquired blood oxygenation-level dependent (BOLD) fMRI data at 3T and adopted standard procedures for pre-processing and physiological noise correction. Computational neuroimaging analysis regressed PRI and PE trajectories against each fMRI run, followed by group analyses examining main effects and interactions of drug and task ‘win/loss’ condition (significance P<0.05).

Results. Relative to placebo, escitalopram significantly increased the number of cues viewed before making a decision, specifically during loss avoidance periods in high uncertainty/volatility. Similarly, fMRI analyses revealed a significant drug (escitalopram > placebo) × task context (avoid loss > gain reward) interaction in the encoding of outcome-related PEs in the serotonergic dorsal raphe. Conversely, a computational ‘baseline urgency’ parameter, representing trait-level PRI, was reduced under methylphenidate, relative to placebo, across win/loss task contexts. Moreover, methylphenidate reduced the neural representations of (i) a computational PRI parameter describing evidence accumulation rate and (ii) volatility-related PEs, respectively, in bilateral frontopolar cortex and left putamen.

Conclusions. Our findings suggest greater nuance to PRI associations with DA/5-HT than hypothesised. We observed 5-HT increase to primarily affect non-computational (‘model-free’) PRI behaviour measures, along with very subtle, context-specific modulation of serotonergic brain activity. Conversely, we identified comparatively broad effects of DA in attenuating the encoding of computational (‘model-based’) PRI- and uncertainty-related variables in regions important for managing competing task goals. Further investigations may combine this computational pharmaco-imaging approach with genetic testing to elucidate the relative contributions of phasic/tonic monoaminergic mechanisms to PRI in health and disease.

[Poster # 21]

The Influence of Social Pressure for Movement Precision: A Computational Approach

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Reward prospect is a foundation of behaviour: we move to attain valuable states. However, moving towards those states implies investing a certain amount of effort and deploying motor strategies that require specific parameters. Although the relationship between reward, motivation and behaviour has been extensively studied, the specifics of how effort relates to the selection of movement parameters under social pressure, it all remains largely controversial.

To investigate whether and how motor parameters and decisions between movements were influenced by different levels of social pressure, we performed a decision-making experiment in which human volunteers, under different movement control conditions, had to make choices between reaching movements. Their goal was to gain maximum reward by selecting one of two reaching movements of opposite biomechanical cost,
and to perform their selected reaching towards the target. Maximum reward was contingent upon the movement to reach the centre of the target, and decreased proportionally with error. All trials had fixed duration to oblige participants to work on a single trial basis, and to prevent them from maximizing reward rate across trials.

We manipulated the participants’ state via social pressure. Each experimental session was composed of six blocks, during which subjects could either play alone or accompanied by a simulated player. Within this illusion, the amount of reward obtained by the participant and by his/her companion was reported at the end of each trial. The ranking between players was shown briefly every nine trials. However, no specific mention to competition was ever made to the subjects in the instruction, and any such assumption reported by the player was immediately rejected by the experimenter.

The results show that despite the experimenter’s denial on competition, the subjects end-point error diminished proportionally to the skill of the accompanying player subjects cared about their performance and about their skill with regard to the other players. The main behavioural result was an increase of the time to peak velocity and global movement time between the baseline (play alone) condition and any accompanying condition, irrespective of the opponent’s skill. This could be viewed as a simple adaptive process of trade-off between precision and time, however, other effects on the movement amplitude became significant when the skill of the companion player was clearly unattainable, such as a reduction of the amplitude, therefore escaping the traditional context of the speed-accuracy trade-off.

To further investigate the dynamics of adaptation across conditions, we developed a computational model based on the optimization of the trade-off between the benefits and costs associated to a movement. Remarkably, the predictions of this model show that this optimization depends on the context where the movements and the choices are performed. Although further research remains to be performed to understand their specific intricacies, this suggests that the inter-relation between internal physiological dynamics and motor behaviour is richer than a simple modulation of the vigour of movement.

[Poster # 22]

**Investigating the Origin and Consequences of Endogenous Default-Options in Repeated Economic Choices Tasks**

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Dominant value-based decision-theories initially stated that economic choices are solely based on the value of available options. Experimental evidence, however, has suggested that individuals are susceptible to the framing of decisions, which creates default-options and biases choices. Yet, little is known about how such default-options endogenously emerge, and how they impact decision-making in classical economic choices. In order to investigate this, we designed two experiments (n = 2*36), adapted from a standard economic task involving binary choices between lotteries with varying monetary amounts and probabilities. In the first task, monetary amounts featured potential gains (gain task), while in the second task featured potential losses (loss task). Lotteries were generated in the same way in both experiments, such that there was always a choice between a risky (small probability/high amount) and a safe lottery (high probability/small amount). In addition, three experimental factors were orthogonally manipulated and analyzed: time-pressure, time spend on the task, and most-frequently chosen option - manipulated by the theoretical probability of subjects choosing (~70%) the safe or the risky lotteries.

Using general linear mixed-effect regressions, we dissociate two main default-option dimensions which bias individuals’ choices: a natural tendency to prefer certain types of options (natural-default), and the tendency to implicitly learn a default-option from past choices (learned-default). Specifically, with increasing time-pressure, individuals' choices are increasingly naturally biased towards the safe option in the gain task, and towards the risky option in the loss task. In both tasks, individuals also tend to be increasingly biased towards the most-frequently chosen option - the learned safe or risky option, respectively - with increasing task duration.

With this study, we provide experimental evidence of how individuals build endogenous default-policies in economic decision-making and how this biases their choices in the domains of potential gains and losses. Importantly, we also provide an important note to the development of carefully designed experimental setups by considering some currently neglected experimental features in research (time-pressure, task duration).
In the antisaccade paradigm subjects are instructed to perform eye movements in the opposite direction from that of a peripheral visual stimulus, while fixating to a central stimulus. The paradigm requires the parallel programming of two decision processes: the suppression of an erroneous prosaccade towards the peripheral stimulus and the initiation of a volitional antisaccade to the mirror position. Although healthy controls (CTL) typically make few errors, patients suffering from schizophrenia (SCZ) and obsessive-compulsive disorder (OCD) make more errors and display increased and more variable latencies of error prosaccades and antisaccades. Deficits in the antisaccade performance of these patients are generally interpreted as an impaired top-down inhibitory signal that fails to suppress the erroneous responses. Neural network models with mutual inhibition implementing non-linear accumulation of information prior to decision making (eye movement) are presented. Two decision signals representing the volitional antisaccade from the Frontal Eye Fields (FEF) and the reactive prosaccade from the Lateral Intraparietal Area (LIP) are integrated in an one-dimensional competitive neural network of the intermediate layer of the superior colliculus. The model accurately reproduces the error rates and latency distributions of error prosaccades, antisaccades and corrected antisaccades of CTL, SCZ and OCD cohorts of subjects. The model predicts that antisaccade performance of SCZ patients is due to more noisy rate of accumulating information, but they are as confident as CTL subjects. On the other hand, the antisaccade performance of OCD patients is due to noise in the accumulation of information process, although they are less confident about their decisions than the controls. Finally, competition between the two decision processes in the superior colliculus and not a third top-down inhibitory signal that suppresses the erroneous response accounts for the antisaccade performance in healthy, schizophrenia and OCD subjects.

**[Poster # 23]**

**Neural Modelling of Antisaccade Performance of Healthy Controls, Schizophrenia and Obsessive-Compulsive Disorders Patients**

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In the antisaccade paradigm subjects are instructed to perform eye movements in the opposite direction from that of a peripheral visual stimulus, while fixating to a central stimulus. The paradigm requires the parallel programming of two decision processes: the suppression of an erroneous prosaccade towards the peripheral stimulus and the initiation of a volitional antisaccade to the mirror position. Although healthy controls (CTL) typically make few errors, patients suffering from schizophrenia (SCZ) and obsessive-compulsive disorder (OCD) make more errors and display increased and more variable latencies of error prosaccades and antisaccades. Deficits in the antisaccade performance of these patients are generally interpreted as an impaired top-down inhibitory signal that fails to suppress the erroneous responses. Neural network models with mutual inhibition implementing non-linear accumulation of information prior to decision making (eye movement) are presented. Two decision signals representing the volitional antisaccade from the Frontal Eye Fields (FEF) and the reactive prosaccade from the Lateral Intraparietal Area (LIP) are integrated in an one-dimensional competitive neural network of the intermediate layer of the superior colliculus. The model accurately reproduces the error rates and latency distributions of error prosaccades, antisaccades and corrected antisaccades of CTL, SCZ and OCD cohorts of subjects. The model predicts that antisaccade performance of SCZ patients is due to more noisy rate of accumulating information, but they are as confident as CTL subjects. On the other hand, the antisaccade performance of OCD patients is due to noise in the accumulation of information process, although they are less confident about their decisions than the controls. Finally, competition between the two decision processes in the superior colliculus and not a third top-down inhibitory signal that suppresses the erroneous response accounts for the antisaccade performance in healthy, schizophrenia and OCD subjects.

**[Poster # 24] - CANCELLED**

**[Poster # 25]**

**Determinants of Transfer and Curriculum Learning in Human Categorization**

Ronald Dekker1, Jan Balaguer1, Timo Flesch1 & Christopher Summerfield1

1. University of Oxford, Medical Sciences Division, Department of Experimental Psychology

In novel environments, humans are often faced with the problem of learning to categorize complex, naturalistic stimuli with minimal prior knowledge of the relevant decision criteria. Past studies of category learning have typically employed settings where the relevant dimensions are instructed or intuitively obvious, so little is known about category learning in the wild. Here, we asked humans to categorise naturalistic stimuli (trees) according to one of two uninstructed criteria, that depended on their “leafiness” and “branchiness”. Our research questions concerned (i) the nature of the training regime that promotes learning about naturalistic stimuli, and (ii) how learning about a stimulus dimension that is irrelevant in one task (e.g. branchiness during leafiness classification) aids or abets learning on a subsequent transfer task in which that dimension is decision-relevant. These questions were investigated in two experiments. In the first experiment, human participants learned to classify naturalistic trees according to either their leafiness or branchiness, without instruction and from trial-and-error feedback alone. To address question (i), during training we varied the heterogeneity of the examples along both relevant and irrelevant dimensions. To assess learning, we interspersed training trials with test trials in which exemplars were drawn uniformly from across the leafiness by branchiness space, but no feedback was offered. Our first finding is that when trained with exemplars that lay far from the decision boundary, humans performed better at test, even on those exemplars that were close to the boundary (interpolation), relative both to the converse condition (extrapolation) and to a full uniform control condition, where each combination of leafiness and branchiness had an equal probability of occurring. To address question (ii), we conducted a new experiment in which during training, the relevant dimension was sampled uniformly but the irrelevant dimension had either low or high heterogeneity (source task). We then transferred participants to a new task in which the previously irrelevant dimension became relevant (transfer task). Contrary to our predictions, we found that participants performed best both at source and transfer when features on the irrelevant dimension were less heterogeneous in the source task. Comparison to a full uniform control condition reveals that this difference is driven by an improvement in the low heterogeneity condition rather than by attenuated learning in the high heterogeneity condition.

**[Poster Abstracts: Monday 21 May]**

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In the antisaccade paradigm subjects are instructed to perform eye movements in the opposite direction from that of a peripheral visual stimulus, while fixating to a central stimulus. The paradigm requires the parallel programming of two decision processes: the suppression of an erroneous prosaccade towards the peripheral stimulus and the initiation of a volitional antisaccade to the mirror position. Although healthy controls (CTL) typically make few errors, patients suffering from schizophrenia (SCZ) and obsessive-compulsive disorder (OCD) make more errors and display increased and more variable latencies of error prosaccades and antisaccades. Deficits in the antisaccade performance of these patients are generally interpreted as an impaired top-down inhibitory signal that fails to suppress the erroneous responses. Neural network models with mutual inhibition implementing non-linear accumulation of information prior to decision making (eye movement) are presented. Two decision signals representing the volitional antisaccade from the Frontal Eye Fields (FEF) and the reactive prosaccade from the Lateral Intraparietal Area (LIP) are integrated in an one-dimensional competitive neural network of the intermediate layer of the superior colliculus. The model accurately reproduces the error rates and latency distributions of error prosaccades, antisaccades and corrected antisaccades of CTL, SCZ and OCD cohorts of subjects. The model predicts that antisaccade performance of SCZ patients is due to more noisy rate of accumulating information, but they are as confident as CTL subjects. On the other hand, the antisaccade performance of OCD patients is due to noise in the accumulation of information process, although they are less confident about their decisions than the controls. Finally, competition between the two decision processes in the superior colliculus and not a third top-down inhibitory signal that suppresses the erroneous response accounts for the antisaccade performance in healthy, schizophrenia and OCD subjects.

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**[Poster # 24] - CANCELLED**

**[Poster # 25]**

**Determinants of Transfer and Curriculum Learning in Human Categorization**

Ronald Dekker1, Jan Balaguer1, Timo Flesch1 & Christopher Summerfield1

1. University of Oxford, Medical Sciences Division, Department of Experimental Psychology

In novel environments, humans are often faced with the problem of learning to categorize complex, naturalistic stimuli with minimal prior knowledge of the relevant decision criteria. Past studies of category learning have typically employed settings where the relevant dimensions are instructed or intuitively obvious, so little is known about category learning in the wild. Here, we asked humans to categorise naturalistic stimuli (trees) according to one of two uninstructed criteria, that depended on their “leafiness” and “branchiness”. Our research questions concerned (i) the nature of the training regime that promotes learning about naturalistic stimuli, and (ii) how learning about a stimulus dimension that is irrelevant in one task (e.g. branchiness during leafiness classification) aids or abets learning on a subsequent transfer task in which that dimension is decision-relevant. These questions were investigated in two experiments. In the first experiment, human participants learned to classify naturalistic trees according to either their leafiness or branchiness, without instruction and from trial-and-error feedback alone. To address question (i), during training we varied the heterogeneity of the examples along both relevant and irrelevant dimensions. To assess learning, we interspersed training trials with test trials in which exemplars were drawn uniformly from across the leafiness by branchiness space, but no feedback was offered. Our first finding is that when trained with exemplars that lay far from the decision boundary, humans performed better at test, even on those exemplars that were close to the boundary (interpolation), relative both to the converse condition (extrapolation) and to a full uniform control condition, where each combination of leafiness and branchiness had an equal probability of occurring. To address question (ii), we conducted a new experiment in which during training, the relevant dimension was sampled uniformly but the irrelevant dimension had either low or high heterogeneity (source task). We then transferred participants to a new task in which the previously irrelevant dimension became relevant (transfer task). Contrary to our predictions, we found that participants performed best both at source and transfer when features on the irrelevant dimension were less heterogeneous in the source task. Comparison to a full uniform control condition reveals that this difference is driven by an improvement in the low heterogeneity condition rather than by attenuated learning in the high heterogeneity condition.
Together, these findings suggest that categorisation performance improves with heterogeneity along the relevant dimension, and declines with heterogeneity along the irrelevant dimension. We propose a model by which dimension weighting during credit assignment depends on an unsupervised surprisal signal, possibly through modulation of selective attention.
[Poster # 26]
Models that learn how humans learn: the case of depression and bipolar disorders

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Computational models of learning and decision-making processes in the brain play an important role in many domains. Such models typically have a constrained structure and make specific assumptions about the underlying human learning processes; these may make them underfit observed behaviours. Here we suggest an alternative method based on learning-to-learn approaches, using recurrent neural networks (RNNs) as a flexible family of models that have sufficient capacity to represent the complex learning and decision-making strategies used by humans. In this approach, an RNN is trained to predict the next action that a subject will take in a decision-making task, and in this way, learns to imitate the processes underlying subjects’ choices and their learning abilities. We demonstrate the benefits of this approach with a new dataset containing behaviour of unipolar depression (n=34), bipolar (n=33) and control (n=34) participants in a two-armed bandit task. The results indicate that the new approach is better than baseline reinforcement-learning methods in terms of overall performance and its capacity to predict subjects’ choices. We show that the model can be interpreted using off-policy simulations, and thereby provide a novel clustering of subjects’ learning processes - something that often eludes traditional approaches to modelling and behavioural analysis.

The results are reported in the figure below. The left-panel of the figure shows prediction accuracy in terms of negative log-probability (NLP; averaged over leave one-out cross-validation folds; lower values are better) and the right-panel shows the percentage of actions predicted correctly (%correct; higher values are better). Across all groups, RNN provided the highest mean performance (Healthy [β=0.090, SE=0.040, p=0.030], Depression [β=0.126, SE=0.021, p<0.001], Bipolar [β=0.180, SE=0.032, p<0.001], which shows that RNN is able to predict subjects’ choices better than the other models (QL, QLP and GQL are three variants of reinforcement-learning models).

[Poster # 27]
Groups of unfair individuals benefit from decreased social punishment

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In the last few decades, research on collective decisions has focused on the accuracy of collectives, ignoring an important aspect of collective behaviors: the diffusion of responsibility. In a group, individuals share responsibility for their actions, which may protect them against negative consequences of these actions. In particular, when actions could trigger punishment (unfair behaviors, crimes), being in a group could decrease this punishment, as it is shared among several individuals.

While it has been shown in previous studies that people in a group show increased free riding, no study has looked at how groups vs. individuals are punished. Following our reasoning that groups share responsibility for harmful acts, we predicted that a group would be punished less than an individual for the same act.

We tested this hypothesis using two well-known cooperation games: the ultimatum and the dictator game (with third party punishment). One (individual condition) vs three (group condition) proposers made offers to recipients in several rounds of the games. Unknown to participants who came in groups of ten, offers were experimentally manipulated and ranged from 0 to 5 out of 10, such that the majority of proposals were unfair splits. In the ultimatum game, recipients had to decide whether they reject (i.e. social punishment) or accept the offer. In the dictator game, a third party could decide to punish the proposer or proposers for their unfair offer at his/her own cost. In both games, groups were punished less than individuals who made the same unfair offers. Our results demonstrate a most useful adaptive value of collective actions: two heads are better off than one.
Previous work of the motivation literature suggests that people have intrinsic inclination to overcome negative feedback and monetary loss in favour of challenging tasks. This stands to contrast to a great body of studies on decision-making, neuroscience and economics, where an important assumption is that people prefer positive feedback and try to avoid effort where possible. This study aims to establish the phenomenon in an experimental setting and disentangle different motivations for choosing a more or less challenging task with the help of a computational model. Participants were asked to select the meaning of rare English words and given feedback about their performance. For each trial, participants first saw a reward or no-reward cue. Afterwards, two out of three different difficulty levels of the word were presented, and they were asked to choose the difficulty level that they prefer to answer. In a reward trial, participants were able to gain 5 pence for a correct answer. Results showed that when rewards are provided easier options were preferred in comparison to no reward condition, whereas more difficult options were chosen more frequently when no reward was provided. Through computational modelling we identified multiple components that influenced decision-making: a) a general preference for difficult decisions; b) a preference for moderately difficult decisions (50% expected success rate) and c) a preference for maximising the monetary reward. Further, we investigated how individual difference measures are related to the importance of these different challenge components.

Reference
[Poster # 30]

NEURAL MECHANISMS OF RAPID CATEGORY LEARNING IN HUMANS

Timo Flesch, Hamed Nili, Christopher Summerfield

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A rich body of research has investigated the cognitive and neural underpinnings of category learning in non-human primates (NHPs), suggesting that categorical representations emerge in the lateral intraparietal area (LIP) after extensive training (~1 year). For example, when macaques are trained to classify two successive random dot motion stimuli (sample, probe) according to whether or not their motion direction falls on the same side of a linear boundary (delayed match to category task, hereafter DMC), LIP neurons change their firing patterns from orientation encoding towards a binary code that maintains category membership of the sample during the delay period (Sarma et al., 2016). Comparably little is known about the neural substrates of category learning in humans, who appear to learn novel categories much quicker, usually on a timescale of hours. Here, we investigated whether similar neural mechanisms might underlie category learning in human participants, using the DMC paradigm and multichannel EEG recordings. Participants learned to match the category of two successive random dot motion stimuli via trial-wise feedback. The orientation of the category boundary was never explicitly signalled, and randomised across participants. Unlike NHPs, human participants achieved high categorisation performance already after the first 20 minutes of the experiment. We first tested whether humans performed the task by relying on the angular distance between the sample and probe (distance-based strategy, which would have yielded a classification accuracy of ~70%) or by learning the orientation of the boundary and basing their decision on the binary category membership of the sample and probe (boundary-based strategy). Logistic regression on choice revealed that participants used both strategies, but relied more on the boundary-based strategy the longer they engaged in the task. Surprisingly, even towards the end of the experiment, the angular distance between sample and probe was still used to inform choices.

Next, we tested whether changes in the choice strategy were accompanied by changes in the neural representation of the stimulus information, using Representational Similarity Analysis (RSA, Kriegeskorte et al., 2008). Surprisingly, although we could reliably decode and even reconstruct motion direction information of the sample and probe as early as 150ms post stimulus onset, no evidence was found for a binary category code during the delay period, during the ~1.5h of training received on the task.

Finally, we investigated whether univariate EEG signals scaled with decision variables predicted by the distance and boundary-based strategies. Univariate signals at parietal electrodes (PZ; after 300ms) scaled negatively with sample-probe distance and positively with probe-boundary distance. Consistent with behavioural observations, only the latter probe-boundary distance signal increased over the time course of the experiment. Lastly, a univariate encoding-decoding approach (Wyart et al 2014) suggested that encoding both of the angular distance (distance-based strategy) and the category match (boundary-based strategy) between sample and probe at parietal electrode sites informed choices.

[Poster # 31]

REVERSIBLE DISRUPTION OF AMYGDALA AND ANTERIOR CINGULATE CORTEX USING FOCUSED ULTRASOUND NEUROSTIMULATION

Davide Folloni, Lennart Verhagen, Rogier Mars, Elsa Fouragnan, Charlotte Constans, Pierre Pouget, Jean-François Aubry, Matthew Rushworth, Jerome Sallet

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Introduction: In order to establish the functional roles of brain areas and establish their connectivity it is often necessary to look at the impact of disrupting the brain area. This can be done reversibly using neuromodulation methods such as TMS and tDCS. However, their spatial resolution is limited and the depth of stimulation below the dorsolateral surface of the brain they can reach is very limited. We show, however, that with focused ultrasound neurostimulation (FUN; Deffieux et al., 2013; Legon et al., 2013) it is possible to transcranially and reversibly modulate neural excitability with relatively high spatial resolution and high inter-subject reproducibility even in relatively deep brain structures. Here we report a study into the effects of FUN on the resting-state activity of a relatively deep cortical region, the anterior cingulate cortex, and a subcortical region, the amygdala, in the macaca mulatta.
Methods: A single-element ultrasound transducer, geometrically focused at ~5cm, was used with region-specific coupling cones filled with degassed water for stimulation of either amygdala (n=4) or anterior cingulate cortex (ACC; n=3). The transducer resonance frequency was set to 250 kHz and 100 ms bursts of ultrasound waves were generated. Registration of each animal’s structural image to a neuronavigation system (RogueResearch) was used for brain spatial navigation and targeting of the ultrasound (US) beam to the region of interest. The US was directly applied to previously shaved skin. Resting state functional MRI (rs-fMRI) data were acquired for up to 90 minutes at 3T under anesthesia for each subject and preprocessed using FSL software and in-house tools (MrCat toolbox). The anesthesia protocol we used has previously been shown to preserve regional functional connectivity that is measurable with functional magnetic resonance imaging (fMRI) (Sallet et al., 2013; Neubert et al., 2014). The rs-fMRI results of each group of animals were averaged and compared with a control group (n=10).

Results: We investigated the focal effects of FUN targeted at ACC and amygdala by measuring the functional connectivity between each stimulated region and regions with which they are interconnected. We found dissociable and spatially focused effects of FUN in both cases. Primarily, we observed that FUN induced a reduction of otherwise strong coupling with regions both proximal and distal to the targeted site. These effects were spatially specific to the site of stimulation. In each case the effects were most prominent in brain regions known to be strongly interconnected with the stimulated area. Compared to control animals, transcranial FUN applied bilaterally to the amygdala decreased transiently and reversibly the connectivity of this region with ventrolateral, orbital and medial prefrontal cortices. Consistently, FUN targeted at ACC markedly reduced short- and long-range cortical connectivity with middle and posterior cingulate, and lateral prefrontal cortex compared to control animals. Notably, ACC stimulation resulted in a disruption of ACC connectivity sub-cortically with the amygdala. This connectional perturbation was mirrored by FUN targeted at the amygdala. Together, these results show the high spatial focality of ultrasound stimulation and its capacity to transiently and non-invasively stimulate relatively deep brain structures such amygdala and ACC. Moreover, they additionally suggest the effects we see on the functional connectivity of the targeted area may depend on the strength of its underlying structural connectivity; changes in coupling with areas that are anatomically strongly connected with the stimulated region are particularly prominent.

Conclusions: In summary, ultrasound stimulation can non-invasively modulate the activity of both deep cortical and subcortical regions with high spatial specificity in a transient and reversible fashion. We have shown the potential of FUN as a novel technique to investigate the functional connectome and allow precise causal inference on local neural computations.

References:

[Poster # 32]

**Dissociable Effects of Valence and Information on Response Times During Reinforcement Learning: A Diffusion Decision Model Account**

Laura Fontanesi1, Stefano Palminteri2,*, Mael Lebreton3,*
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Performance is shaped by the history of past reinforcement, as we learn, by trial-and-errors, to select actions that maximize the occurrence of rewards and minimize the occurrence of punishments. A century-long history of experimental investigation of reinforcement processes has shown that learning is concurrently accompanied by an increase of the frequency of the most advantageous action and by a decrease of the time necessary to implement this action. However, these two fundamental variables (accuracy and response times, RTs) have been mostly investigated in isolation, and little is known about how contextual factors influence these measures in a coherent framework (Summerfield & Tsetsos, 2012; Pedersen, Frank and Biele, 2017).

We recently demonstrated that two contextual factors interact to shape important features of human reinforcement learning: whether the outcome of the non-chosen option is provided (information factor) and whether individuals are engaged in reward seeking or in loss-avoidance (valence factor) (Palminteri, Kilford, Coricelli, & Blakemore, 2016; Palminteri, Khamassi, Joffily, & Coricelli, 2015). In this paper, we analyzed
data from four independent experiments, realized in different sites, in which the feedback information (partial vs. complete) and valence (reward vs. punishment) were manipulated. Using a Bayesian meta-analytical approach, we investigated the modulating effects of these two factors on the two main dimensions of learning performance: accuracy and RTs. We found that, across all experiments, feedback information affected performance in terms of both accuracy and RTs, while valence exclusively affected RTs. We also found an interaction of information and valence on RTs. We then provided a comprehensive computational account of those results in the frame of the diffusion decision model by applying Bayesian hierarchical modeling fitting to both choice and RT data. Across the four experiments, we found that contextual factors (feedback information and valence) have dissociable effects on the DDM parameters: while feedback information increases the drift-rate, valence induces a prolongation of the non-decision time. Both contextual manipulations increase the threshold. Finally, we interpret these results in the light of current psychobiological theories of learning and decision-making. While the positive effect of valence on the threshold (increased cautiousness), can be explained in the frame of a general - evolutionary sound - ‘negativity bias’ aimed at putting more attention in avoiding threat, we hypothesize that the positive effect of valence on NDT could be explained within the framework of a Pavlovian bias, where positive valence favors motor execution (and vice-versa). Since in the partial and full feedback conditions the objective choice difficulty (in terms of difference in expected outcome between the two alternatives) was the same, the positive effect of feedback information on the drift-rate could be explained by a reduced uncertainty induced by the additional feedback information (meta-cognitive effect).

References

[Poster # 33]
THE MACAQUE ANTERIOR CINGULATE CORTEX TRANSLATES COUNTERFACTUAL CHOICE VALUE INTO ACTUAL BEHAVIORAL CHANGE
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1Wellcome Integrative Neuroimaging (WIN), Department of Experimental Psychology, University of Oxford, Oxford, UK; 2Wellcome Integrative Neuroimaging (WIN), Centre for Functional MRI of the Brain (MRI), Nuffield Department of Clinical Neurosciences, John Radcliffe Hospital, University of Oxford; 3Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong; 4McGovern Institute for Brain Research and Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology, Cambridge, MA, USA; 5Institut Langevin, National Scientific Research Center (CNRS), Paris, France * Authors contributed equally to the work

The neural mechanisms mediating sensory-guided decision-making have received considerable attention but animals often pursue behaviors for which there is currently no sensory evidence. Such behaviors are guided by internal representations of choice values that have to be maintained even when these choices are unavailable. We probed the ability of four macaque monkeys to maintain representations of the value of counterfactual choices - choices that could not be taken at the current moment but which could be taken in the future. Using functional magnetic resonance imaging (fMRI), we found two different patterns of activity co-varying with values of counterfactual choices in a circuit spanning hippocampus, anterior lateral prefrontal cortex, and anterior cingulate cortex (ACC). ACC activity also reflected whether the internal value representations would be translated into actual behavioral change in the future so that a different choice would be taken. To causally test our main hypothesis of ACC function, we used a novel technique, focal ultrasound neurostimulation, to reversibly disrupt ACC activity; ACC disruption impaired the translation of counterfactual choice values into actual behavioral change.

[Poster # 34]
MECHANISMS OF SUGGESTION: COGNITIVE REGULATION PROPENSITIES MEDIATE THE EFFECT OF APPETITE SUGGESTIONS ON HUNGER.
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Research across domains from consumer psychology to clinical trials indicates that suggestion about the efficiency of a consumer good (e.g., quality or price) or a medical treatment (e.g., a doctor’s words) is underpinned by activation of a set of frontal cortex regions associated to the cognitive regulation of affective states. Cognitive regulation can be defined as directing attention away from and/or assigning less weight on specific attributes of a condition or state. Here we aimed to provide direct behavioral evidence for the contribution of such psychological processes to suggestion effects. We tested 50 participants who had fasted for 12 hours, and combined appetite suggestions (i.e., water labeled as either enhancing or diminishing appetite) with a behavioral paradigm from decision neuroscience that quantified cognitive regulation propensities of food choices. Our results showed that suggestion about diminished appetite decreased hunger ratings ($t(49)=-2.65$, $p=0.01$) indicating that our experimental manipulation of appetite worked. We next defined cognitive regulation in terms of regulatory success characterized by rejecting unhealthy, tasty food and assigning less weight on the taste attribute of food. We found that participants under the diminished appetite suggestion displayed more regulatory success than participants under the enhanced appetite suggestion ($r(50)=0.43$, $p=0.03$). Importantly, mediation analysis revealed that regulatory success fully mediated the direct effect of appetite suggestion on hunger ratings ($ab=0.63$, $p=0.03$, path $c'=0.62$, $p=0.16$). These findings indicate that the mere suggestion about appetite generate cognitive regulation processes that lead participants to perceive less hunger. These results provide insights into how suggestions get translated into an effect on behaviour, and open the window toward a better understanding of the psychological processes that contribute to placebo effects.

**[Poster #35]**

**Predicting Risk Attitudes from the Precision of Mental Number Representation**

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Marcus Grueschow, University of Zurich
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A novel model of risky choice behavior (Khaw, Li and Woodford, 2017) proposes that risky choice behavior is determined by the noise of mental number representations of magnitude. The model proposes that risky choice arises from an optimal Bayesian encoding of values similar to perceptual bias seen in numerical cognition (Dehaene, 2008). However, it is unknown whether the noisy representations of a simple numerical cognition task can predict risky choice behavior, assuming that this noise arises from the same optimal Bayesian encoding mechanism. To test this, subjects ($n_{total}=64$, $n_{included}=52$) performed both a magnitude comparison task involving two piles of one-franc coins and a lottery task involving sure and probabilistic lotteries. We also tested whether noise truly arises from the representation of numerical magnitude and not simply by mere stimulus representation by having two representations of the monetary amounts in the risky choice task: as numbers or as a pile of one-franc coins. We derived noise measures for both tasks for every subject using the proposed model. Our results show that the noise derived from the magnitude comparison task correlates with the noise arising from the risky choice task, regardless of the stimulus representations of the monetary amounts ($r(50)=0.407$, $p=0.002$ (two-sided) overall, $r(50)=0.434$, $p=0.001$ for numbers and $r(50)=0.402$, $p=0.003$ for coins). We also replicate behavioral and psychometric results that confirm the assumptions on the model on optimal Bayesian value encoding. Overall, these results show that the noise in both number cognition and risky choice domains arises from the same optimal Bayesian encoding of numerical magnitude representation. These findings indicate that our apparent risk attitudes may arise from the perceptual biases arising from the mental processing of numerical values and not necessarily from utilities associated with risk.

**[Poster #36]**

**Loss Aversion for Monetary and Food Rewards in Healthy Controls and Women with Anorexia**

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Introduction. Loss aversion is defined by a greater sensitivity to losses than gains when facing a risky decision. Here, we conducted a new event-related fMRI study on loss aversion using both primary (food) and secondary (money) reward in healthy controls and in women with Anorexia Nervosa (AN). Women with AN are known to have an altered reward processing and poorer decision making capacities than healthy controls. Yet, it is still unknown whether: (i) in healthy controls, behavioral loss aversion can be extended to primary rewards, and whether similar brain networks are engaged for both reward types; (ii) in women with AN, behavioral loss aversion is present for secondary rewards (money), but gain aversion is present for food reward, and whether distinct brain systems are engaged relative to controls.

Methods. We scanned 18 women with AN and 16 matching controls while they accepted or rejected a gamble presenting 169 mixed bets offering 50% chance of gaining or losing different amounts of money or fruit juice. During practice, subjects were informed that they may receive a glass filled with 18 cL of fruit juice and payment of 30 € at the end of the experiment but that these amounts might change given their responses to the task. At the end of the experiment, a trial was chosen randomly and the outcome was given to the participant. If this random bet was accepted, an equiprobable draw would inform of the amount received by the subject.

Results. Behaviorally, healthy controls provided the same loss aversion pattern for both the primary and secondary rewards. As for the women with AN, the behavioral pattern for money was identical to healthy controls but the pattern for juice reward appeared reversed, reflecting a ‘gain aversion’ for food. At the brain imaging level, a similar mesocorticolimbic network was engaged for monetary and food loss aversion with bidirectional responses (positive correlation for gains and negative correlation for losses) in the Anterior Cingulate Cortex (ACC), the Dorso-Lateral Prefrontal Cortex (DLPFC) and the striatum in healthy controls. The same brain network was observed for monetary reward in AN patients, but with lower levels of activities (DLPFC and striatum). In contrast, areas responding to the food stimuli in AN patients, showed a reverse pattern of activity (positive correlation with losses and negative correlation with gains) in the DLPFC and the striatum and revealed the engagement of the bilateral Insula.

Discussion. This study established three major results: (i) Behaviorally, in healthy subjects, loss aversion is not restricted to secondary rewards but can be extended to primary rewards. (ii) For healthy subjects, loss aversion involves similar brain network independently of the reward types. (iii) Women with anorexia showed a reversed pattern of loss aversion for food compared to money with an increased activation of the DLPFC, which might reflect a higher cognitive control to avoid food intake.

[Poster # 37]

GOAL-DIRECTED IMAGINATION AND COGNITIVE FLEXIBILITY: A COMPUTATIONAL MODEL OF THE WISCONSIN SORTING CARD TEST

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In mammals, habitual behaviour involves rigid stimulus-response associations relying on brain motor cortices and dorsal basal ganglia. Instead, goal-directed behaviour, relying on an ample network of fronto-striatal and parietal areas, allows mammals to produce a flexible course of action based on top-down processing of internal representations related to possible world states and to actions.

We present a computational model of how the goal-directed system might solve the Wisconsin Sorting Cards Test (WSCT), an important neuropsychological test used for measuring cognitive flexibility in humans. The test requires to sort cards drawn from a deck of 64 cards according to one of three criteria/classes (“color”, “form”, “number”). This is done by putting each card near one of four target cards each exhibiting one of four different attributes from each class (e.g., for the class colour: “red”, “blue”, “green”, “yellow”). For each drawn card, the participant chooses a sorting rule, matches the card with one target card, and listens to a “success”/”failure” feedback. The key elements of the test, probing cognitive flexibility, are that: (a) the sorting rule is not told to the participant who has to infer it on the basis of the feedback; (b) the sorting rule changes every ten drawn cards without being told.

The model acts within a simulated 2D environment showing the card to be sorted and the four target cards. The model is endowed with a mobile visual sensor mimicking overt attention that after focussing on the deck card randomly scans the target cards, and with a hardwired action that can move the deck card onto the foveated target card (“move-card action”). The model control part is formed by various components pivoting on a deep belief neural network and working as follows: (a) a first Restricted Boltzmann Machine (RBM) module learns, by unsupervised learning, an internal hidden representation of the foveated card sensation and can generate the image back onto its input units; (b) a second RBM module takes as input the output of the previous module and learns, in a supervised fashion, the attributes of card; this allows it to generate back onto its input units the features corresponding to the selected attributes; (c) a module compares the two
reconstructed images (depending on the selected sorting rule) of the deck card and of the foveated target card, and triggers the move-card action if they match; (d) a reinforcement learning module uses the feedback to learn to select one of four units representing the card classes: the selected unit selects, in a top-down fashion, the group of attribute hidden units of component ‘b’ corresponding to the selected card unit.

The system infers hidden causes in the world (the correct sorting rule) by applying a mental manipulation of the way it perceives and reconstructs the input, and by adjusting such manipulation based on the feedback for the performed action that relies on the reconstruction. The novelty of the model resides in the active search of the correct mental manipulations to perform, and in the use of the outcome of this search to perform a suitable input reconstruction (imagination), based on the RBM modules. This is at the basis of the flexibility exhibited by the goal-directed processes of the system.

The performance of the system, and its errors resulting from two types of lesions, are comparable those of healthy participants and patients with frontal impairments. This represents a first validation of our hypothesis, operationalised in the model, on the mechanisms that might underlie the flexibility goal-directed behaviour needed to solve the WSCT.

[Poster # 38]
REWARDS AND PUNISHMENT LEARNING DIFFERENTIALLY MODULATES INTRACEREBRAL BRAIN DYNAMICS

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Whether learning to maximize rewards and learning to avoid punishments rely on different brain systems remains unclear. To elucidate the neural signatures of reward-based and punishment-based learning, we recorded intracerebral activity from patients with refractory epilepsy while they performed a reinforcement learning task. We found that predictions errors estimated from computational modeling modulated parametrically broadband gamma activity in the ventromedial prefrontal cortex (vmPFC), anterior insula (aIns), dorsolateral prefrontal cortex (dPFC) and lateral orbitofrontal cortex (LOFC). Furthermore, intracerebral recordings also revealed a clear double dissociation: vmPFC activity was related to reward prediction errors whereas aIns and dPFC neural responses correlated with punishment prediction errors. Neural responses directly recorded within aIns predicted both inter-trial behavioral adaptations following punishments and also inter-subjects’ learning performances. These results provide critical support for the hypothesis that opponent brain systems are recruited depending on the outcome valence – gain or loss – that has to be learned to reinforce behavior.

[Poster # 39]
UNDERSTANDING WHY REWARDS IMPROVE COGNITIVE PERFORMANCE USING MULTIVARIATE ANALYSES OF EEG DATA

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Research studying the interaction between motivation and cognition has amassed a substantial body of evidence that rewards tend to enhance cognitive performance, decreasing the reaction time and increasing the accuracy of appropriate responses. While this finding has been represented in many areas of cognitive control research, including selective attention (Padeska & Pessoa, 2011), inhibitory control (Leotti & Wager, 2010) and task switching (Kleinberge & Rikhenauer, 2012), it remains unclear how rewards impact neural coding to bring about performance benefits. One possibility is that rewards increase task encoding in prefrontal regions of the brain (Etzel et al., 2015). Under this account, phasic dopamine signals produced in response to reward associated cues permit greater sensory information into prefrontal cortex, which in turn sharpens the representation of abstract task rules (Etzel et al., 2015; Westbrook & Braver, 2016). Here we present preliminary results from an EEG experiment aiming to test the task representation hypothesis. Participants were instructed to make simple cognitive judgements about the colour and shape
of stimuli, while rewards for fast and accurate responses were manipulated dynamically, on a trial-by-trial basis. Behaviourally, we found that this manipulation modulated cognitive performance, eliciting faster reaction times and greater accuracy under high reward conditions. We then used Representational Similarity Analysis (RSA) to quantify neural coding patterns represented within subjects’ EEG data. By examining RSA confusion matrices over time, we found that reward coding, task coding, visual coding and motor coding dominated neural activity patterns sequentially within trials. Corresponding coding models all showed significant model fit with the RSA confusion matrices at defined time periods. Intriguingly, we found that visual differences between stimuli during the response phase were significantly correlated with participant reaction time and accuracy. These results may begin to shed light on which components of information processing are impacted by reward and how these modulations contribute to performance benefits in high reward scenarios.

References

[POSTER # 40]
STOCHASTIC SATISFICING ACCOUNT OF CONFIDENCE IN UNCERTAIN VALUE-BASED DECISIONS

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Every day we make choices under uncertainty; choosing what route to work or which queue in a supermarket to take, for example. It is unclear how outcome variance, e.g. uncertainty about waiting time in a queue, affects decisions and confidence when outcome is stochastic and continuous. How does one evaluate and choose between an option with unreliable but high expected reward, and an option with more certain but lower expected reward? Here we used an experimental design where two choices’ payoffs took continuous values, to examine the effect of outcome variance on decision and confidence. We found that our participants’ probability of choosing the good (high expected reward) option decreased when the good or the bad options’ payoffs were more variable. Their confidence ratings were affected by outcome variability, but only when choosing the good option. Unlike perceptual detection tasks, confidence ratings correlated only weakly with decisions’ time, but correlated with the consistency of trial-by-trial choices. Inspired by the satisficing heuristic, we propose a “stochastic satisficing” (SSAT) model for evaluating options with continuous uncertain outcomes. In this model, options are evaluated by their probability of exceeding an acceptability threshold, and confidence reports scale with the chosen option’s thus-defined satisficing probability. Participants’ decisions were best explained by an expected reward model, while the SSAT model provided the best prediction of decision confidence. We further tested and verified the predictions of this model in a second experiment. Our model and experimental results generalize the models of metacognition from perceptual detection tasks to continuous-value based decisions. Finally, we discuss how the stochastic satisficing account of decision confidence serves psychological and social purposes associated with the evaluation, communication and justification of decision-making.

[POSTER # 41]
MOTIVATIONAL EFFECTS ON ACTION SELECTION AND MEMORY

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Objective: Studying eye movements can provide important insights into the pathophysiology of neurological disorders. For this study two experimental paradigms were devised to quantify the differential effects of motivation by reward and loss on motor control and decision making.
Background: The speed-accuracy trade-off is a well-studied law obeyed by a broad variety of behavioral tasks including saccadic eye movements. This law can be overcome by monetary reward, which simultaneously invigorates movements and improves response precision (Manohar et al. 2015). Dopamine may be a key neuromodulator in such motivational effects and have asymmetric effects in situations which involve the prospect of obtaining reward, versus the need to avoid loss. Here we asked whether motivational control costs extend to two tasks which are limited by decision noise and memory noise respectively. We measured effects of monetary incentives on oculomotor action selection and spatial working memory.

Methods: 20 healthy controls performed two saccadic tasks recorded by an infrared eye tracker. In experiment 1 we studied effects of motivation on action selection. When we have to choose between a larger number of options, our responses become slower; healthy volunteers therefore were asked to make a saccade to one target indicated by an arrow, while monetary incentives and the number of possible targets varied. In experiment 2, we studied memory guided saccades as either a single saccade to a remembered target or a sequence of saccades to locations held in working memory.

Both tasks involved three incentive levels indicated by an auditory cue before the start of each saccade (“lose”: max loss of 50 pence, “nil”: 0p independent of performance or “win”: max gain of 50 pence). Reward was calculated as a fraction of the maximum depending on the performance (accuracy and speed).

Results: In the motivated Hick’s law experiment, reaction times were faster with both reward and loss. Saccade amplitudes decreased with larger numbers of possible targets, and peak velocity was correspondingly slower, indicating that motor vigour is reduced by target uncertainty. Reward increased movement velocity, but this was strongest when just two potential targets were shown - i.e. the condition with least uncertainty.

In the study of memory-guided saccades, single saccades were slower in loss and faster in reward conditions compared to “nil” conditions, while both incentives sped up saccades when a sequence of saccades was performed but at the cost of diminished accuracy. As expected, latencies were longer and error was larger with longer sequences.

**[Poster # 42]**

**Does dopamine modulate the subjective value of cognitive control?**

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Brain dopamine has long been implicated in working memory and cognitive control (Sawaguchi & Goldman-Rakic, 1991; Cohen et al., 2001). Moreover, dopamine is important for motivation and cost-benefit decision making, as evidenced by effects of dopaminergic drugs on physical effort-based decision making (Salamone et al., 2016; Treadway et al). We aim to integrate these lines of evidence and ask whether dopamine also plays a role in cost-benefit decision making about cognitive control. To address this question, we combined dopamine PET, psychopharmacology and a cognitive effort-discounting choice procedure with a classic delayed response task of working memory. In this placebo-controlled, double-blind, cross-over design, 50 participants completed a working memory task as well as a subsequent preference task on 3 separate sessions: once after intake of placebo, once after a low oral dose (20mg) of the catecholamine reuptake blocker methylphenidate and once after intake of a low oral dose (400mg) of the selective dopamine receptor antagonist sulpiride. All participants also underwent an [\textsuperscript{18}F]DOPA PET scan to quantify their baseline dopamine synthesis capacity. This allowed us to ask whether the subjective value of a cognitively demanding working memory task varies with (i) individual differences in striatal dopamine synthesis capacity and (ii) dopaminergic drug administration, perhaps in a baseline dopamine-dependent manner. Analyses of unblinded data, irrespective of drug, fail to demonstrate a relationship between individual variation in dopamine levels and cognitive control value, when data are collapsed across all three sessions. However, preliminary exploratory analyses revealed an interesting pattern of results as a function of session, with the value of control declining with session, despite, if anything, increases in performance. Critically, dopamine synthesis capacity predicted the degree to which the subjective value of cognitive control decreased from the first to the last session. Participants with higher levels of dopamine synthesis capacity exhibited a greater reduction in value across sessions than did low dopamine participants, perhaps in line with dopamine’s putative role in cognitive control avoidance (Frobose et al., 2017 BioRxiv).


[Poster # 43]
HOW VALUES CHANGE DURING SEQUENTIAL INFORMATION SAMPLING IN MULTIPLE OPTION CHOICES

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When people make choices in real life, options do not present themselves simultaneously. Even if all options are side by side, as in supermarkets, decision makers can only pay attention to and valuate one option at a time. How such sequential sampling process affects option values is still poorly understood.

Here, we build on two lines of research to propose a model of how sequential sampling affects the valuation process. First, it has been observed that items selected during binary choice benefit from an increase in value, as shown by likeability rating. Second, it has been suggested that a natural frame of comparison is opposing a default option to alternatives. We therefore hypothesized that during sequential sampling, every new option is covertly compared to the current default option. The option that wins this covert comparison then receives a fixed bonus in value and becomes the new default. Symmetrically, the value of the defeated option is diminished by the same extent.

In this study, we tested this hypothesis by fitting model on choice behavior collected in a group of healthy participants (n = 23). Options were items drawn from a same category (either food, magazine or DVD) and presented side by side on a computer screen. Prior to the choice task, participants rated the likeability of every item on a visual analog scale, in order to obtain subjective values that were used by computational models to predict choices. During information sampling, options were transiently unmasked one after the other, when participants pressed a key. The number of options varied from 3 to 6, such that the end of the sequence remained unpredictable in most cases. When all options had been seen subjects were prompted to make a choice, and to report their confidence that they had made the best choice (for their own sake).

We used choice, confidence rating and response time data to compare our model (bonus by competition) to memory models with primacy or recency effects (bonus is given to items early or late in the sequence), in addition to the null hypothesis (no change in value). All models predicted choice through a softmax function of option values. Group-level Bayesian model comparison favored our hypothesis (exceedance probability > 95%), that values are changed depending on the outcome of a covert value comparison (between new and default options). These results extend the notion of cognitive dissonance to implicit binary choice, and more generally provide further evidence that the sequence of option sampling is not neutral for value-based decision-making.

[Poster # 44]
TEMPORAL INTEGRATION IS A ROBUST FEATURE OF PERCEPTUAL DECISIONS

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Current theories in human decision-making emphasize the capacity of the brain to integrate information over different time scales to reach best informed decisions. For perceptual decisions, this temporal integration of sensory evidence is conceptualized by the drift-diffusion model (DDM). Nevertheless, the presence of temporal integration has scarcely been tested experimentally. Here we compare how perceptual choices from monkeys performing a motion perception task can be accounted for by a discrete-time DDM model as well as two alternative models that do not rely on temporal integration. In the first alternative model (extrema detection model), responses simply report the motion of the first sensory frame that surpasses a certain threshold. In the second model (snapshot model), responses correspond to the motion of a randomly selected sensory frame. Strikingly, both alternative models, despite relying on the motion of a single sensory frame, could achieve accuracy level similar to highly trained animals, as well as for the observed primacy
effect. However, further analyses clearly rule out that monkeys use either of these strategies. First, while the extrema detection model predicts an exaggerated influence of sensory frames with large net motion onto decisions, we found that the decision weight of sensory frames scaled sublinearly with net motion. Second, the probability of right responses depended on the sum of the net motion in the first samples and the net motion in the late samples, consistently with the DDM model but inconsistently with the snapshot model. Overall, our results show that in fixed-duration settings, even though the timing of decisions cannot be accessed experimentally, psychophysics analyses provide strong support in favor of temporal integration in perceptual decisions.

[Poster # 45]
THE VENTROMEDIAL PREFRONTAL RESPONSES TOWARD FACES AUTOMATICALLY REPRESENT BELIEF ABOUT “BEING-LIKED”

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Previous psychological studies have clarified cognitive processes involved in representing beliefs about how much we are liked by others. In the present study, we investigated whether the brain valuation system (BVS) codes such belief automatically in addition to subjective preference using functional magnetic resonance imaging (fMRI). During the fMRI, participants were asked to simply press a button when presented with photographs of opposite gender faces. After the scanning, they were unexpectedly asked to perform three impression ratings for each face: 1) attractiveness, 2) preference, and 3) willingness-to-talk (WTT) ratings. They were also asked to predict 4) how attractive each person would think the subject is, and 5) preference by each person for the subject. A factor analysis revealed that the former three types of ratings (i.e., impressions to others) and the latter two types of ratings (i.e., belief about impressions of others to self) were classified into distinct factors. Parametric modulation analysis based on data of the former three ratings showed significant positive correlation in several brain regions including the ventromedial prefrontal cortex (vmPFC), anterior cingulate cortex, and the anterior insula (p < 0.001 uncorrected at peak, p < 0.05 FWE corrected at cluster level). Parametric modulation analysis based on the latter two ratings revealed significant positive correlations in the vmPFC, dorsomedial prefrontal cortex, and posterior cingulate cortex. An overlapping cluster within the vmPFC was found. These results may suggest that the vmPFC automatically codes belief about “being-liked” as well as subjective preference.

[Poster # 46]
EMOTIONALLY INTERACTIVE AGENTS

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Models in language processing have researched how words are interpreted by humans. Many models presume the ability to correctly interpret the beliefs, motives and intentions underlying words. The interest relies also on how emotion motivates certain words or actions, inferences, and communicates information about mental state. As we will see below, 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.

As these experimental data show, activating accessible constructs or attitudes through one set of stimuli can facilitate cognitive processing of other stimuli under certain circumstances, and can interfere with it under other circumstances. Some of the results support and converge on those centered on the constructs of current concern and emotional arousal.

Future research has to take seriously into account this question: how to develop models where emotion interacts with cognitive processing. One example could be the work of Pitterman et al. (2010) where it is combined speech-based emotion recognition with adaptive human-computer modeling. With the robust recognition of emotions from speech signals as their goal, the authors analyze the effectiveness of using a plain emotion recognizer, a speech-emotion recognizer combining speech and emotion recognition, and multiple speech-emotion recognizers at the same time. The semi-stochastic dialogue model employed
relates user emotion management to the corresponding dialogue interaction history and allows the device to adapt itself to the context, including altering the stylistic realization of its speech.

Interpreting the mix of audio-visual signals is essential in human communication. Researchers have to take into account the advances in the development of unimodal techniques (e.g., speech and audio processing, computer vision, etc). In traditional human-computer interaction, the user faces a computer and interacts with it via a mouse or a keyboard. In the new applications (e.g., multiple agents, intelligent homes) interactions are not explicit commands. Some of the methods include gesture, speech (Potamianos et al., 2004), eye movements (Grauman et al., 2003), etc.

We can interpret the suggested selection mechanism as an information filter. This information filter only selects the measurement for the required features and passes them to the memory system. Features that do not contribute in solving a given task are discarded. This also requires a dynamical and flexible system architecture that allows for a demand-driven combination of processing modules. We have proposed such architecture for the congruent emotion of word processing. To acquire more complex information, the system needs to combine those procedures in a suitable way within memory representation. Beside this, the system has to decide which properties it has to measure for solving the current task. The resulting representation is demand related, as only the pieces of information to solve the task is acquired. This task driven representation can serve as a foundation for learning new relations between words and emotions and for interpreting current interactions.

Zhanj & Barnden (2012) addressed the problem of the detection and revealing of the relevant “context” to inform affect detection. They implemented a context-based affect detection component embedded in an improvisational virtual platform. The software allows up to five human characters and one intelligent agent to be engaged in one session to conduct creative improvisation within loose scenarios. Some of these conversations reveal personal subjective opinions or feelings about situations, while others are caused by social interactions and show opinions and emotional responses to other participant characters. In order to detect affect from such contexts, first of all a naïve Bayes classifier is used to categorize these two types of conversations based on linguistic cues. A semantic-based analysis is also used to further derive the discussion themes and identify the target audiences for the social interaction inputs. Then, two statistical approaches have been developed to provide affect detection in the social and personal emotion contexts. The emotional history of each individual character is used in interpreting affect relating to the personal contexts, while the social context affect detection takes account of interpersonal relationships, sentence types, emotions implied by the potential target audiences in their most recent interactions and discussion themes. The new development of context-based affect detection is integrated with the intelligent agent.

In this context, a psychological framework of emotional language processing is needed to describe the steps humans take when they interact with other computer systems or agents (e.g., Parkinson, 2009). This framework can be used to help evaluate the efficiency and naturalness of a user interface (e.g., design principles, emotional inferences, etc.). So, the key question is to represent, reason, and exploit various models of word processing to more effectively process input, generate output, and manage the dialog and interaction between different agents. The input data (words) should be, cognitive and emotionally, processed in a joint feature space according to a context-dependent model.

[Poster # 47]

Exploration for Information in Monkeys

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The dilemma between exploiting a know resource and exploring an unknown or less know one is critical for survival in an uncertain and changing environment. Primates are thought to be able to solve this dilemma by adapting their exploration strategy to the environment. However, the distinction between purposely exploring and simply making a mistake is rarely made in studies in monkeys. Here, we present a new experimental paradigm, based on work in humans, to study exploration in monkeys. We dissociated errors from exploratory choices by manipulating the value of information and the nature of the feedback. We isolated two potential sources of exploration: the reward-based exploration and the uncertainty-based exploration. The former allows the sampling of an option, which does not have the highest expected reward. The latter allows the sampling of the most uncertain option when the expected values of the options are similar. We showed that monkeys (rhesus macaques) could identify situations in which acquiring information by exploring was beneficial. Our results suggest the use of both types of exploratory strategies, although with, in our experimental paradigm, a bias for reward-based exploration. We also determined additional factors that influenced their tendency to stay committed to a course of action. Overall, this suggests that monkeys have a representation of the significance of the information and used it to plan future actions.
[Poster # 48] Reliance on model-free and model-based learning relates quadratically to severity of obesity

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Obesity is the result of consuming more energy than is expended, and often of compulsive overeating despite negative consequences. Observed alterations in reinforcement learning in obesity have been suggested to underlie such failures of behavioural control. Behavioural control is thought to arise from a balance between two dissociable strategies of dopamine-mediated reinforcement learning: model-free and model-based. Previous studies investigating reinforcement learning in obesity either did not systematically disentangle between the two strategies 1,2, or found no differences when comparing lean and obese participants 3. A recent proposal suggests the existence of a quadratic relationship of the severity of obesity with tonic dopamine 4. We therefore hypothesized that weight status relates to the degree to which individuals rely on model-free vs. model-based learning and that it does so in a quadratic manner. We tested 91 healthy participants in a wide BMI range (lean (n=31): BMI=18.5–24.9 kg/m², overweight (n=30): BMI=25–29.9 kg/m², obese (n=30): BMI≥30 kg/m²) using a sequential decision-making task designed to dissociate model-free and model-based control 5,6. The weight groups differed significantly in their relative balance between model-free and model-based control, and this was characterized by an inverted U-shape such that the balance between model-based and model-free control was lower for obese relative to lean and overweight participants, and it was in fact highest for overweight participants. Preliminary analyses to separately test for the contribution of model-free and model-based control to this balance suggest that the observed quadratic relationship is driven by increased model-free control in the obese group. These findings confirm our hypothesis and suggest that obesity may be related to an imbalance in learning strategies driven by increased model-free rather than decreased model-based learning.

References

[Poster # 49] Obsessions and Compulsions: Rational consequences of irrational beliefs?

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Obsessive Compulsive Disorder (OCD) is a mental disorder characterized by the presence of obsessions and/or compulsions. Obsessions are recurrent and persistent thoughts, urges, or images that are experienced as intrusive and unwanted, whereas compulsions are repetitive behaviors or mental acts that an individual feels driven to perform in response to an obsession or according to rules that must be applied rigidly.
Multiple – and sometimes contradictory - theories have been proposed to explain the emergence of those symptoms: overpowering habit formation, extreme susceptibility to doubt, fear of failure to act properly, perceptual memory deficits, and others. Understanding and testing the predictions of those theories is particularly difficult as they rely on complex interactions between covert beliefs, sequential actions, and motivational aspects. Discriminating between potential causes of the disease is rendered even more difficult by the fact that patients themselves generally perceive their pathological behaviors as unreasonable (egodystonia).

To try and better understand the mechanisms at play in OCD, we adopt a computational approach to ask the question: under what circumstances an otherwise rational agent would develop compulsions? We start from a simplified description of the OCD symptoms, here a washing / checking compulsion that form one of the most prevalent manifestation of the pathology. We then build a minimal model, formally relying on Partially Observable Markov Decision Processes, that can capture the phenomenology of this simplified disorder. Defining compulsion as an abnormal (consecutive) repetitions of washing and/or checking actions, we can explore through simulation the conditions of emergence of compulsive behaviors, and pinpoint the potential causes at the origin of the symptoms.

Quite surprisingly, our results suggest that a lack of confidence in the success of some actions is the most likely and sole source of the compulsions. Interestingly, this misrepresentation of action success also yields in our simulations pathological belief updating (chronic doubt) and a distortion of the motivational landscape we interpret in the perspective of obsession formation.

Albeit simple, our model shed a new light on OCD by identifying a specific mechanism from which could emerge multiple symptoms. This model further makes predictions that we hope could help better target future experiments and treatments.

[Poster # 50]
**DEVELOPMENTAL TRAJECTORIES OF PROBABILISTIC REVERSAL LEARNING: A COMPUTATIONAL MODELING APPROACH**

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In an ever-changing environment it is essential to shift strategies or adapt response patterns based on obtained feedback. Such cognitive flexibility is linked to executive functioning, cognitive control and decision-making, but it has also been shown to be highly implicated for social interactions. Recent studies have used probabilistic reversal learning tasks to examine cognitive flexibility in adolescents and adults. By means of computational modeling (e.g., Hierarchical Gaussian filter modelling, using individual volatility and meta-volatility estimates in concert with an adaptive learning rate to explain behavior), the underlying processes could be examined more systematically than using simple reaction time and error rate data. Although such models are increasingly used in cognitive neuroscience, developmental approaches are still scarce. Additionally, though most RL paradigms have a comparable design regarding timing and feedback contingencies, the type of feedback differs substantially between studies.

We included 28 typically developing (TD) children (8 - 12 years of age) and 25 TD adolescents (13 - 18 years of age) who completed three runs of a probabilistic reversal learning task with either social, individualized or control feedback to assess cognitive flexibility. Behavioral responses were modelled in two variants of a HGF model and a simple Rescorla-Wagner learning model in concert with a softmax decision function using maximum-likelihood estimation and Bayesian model selection. First, the results suggest that children make more overall and regressive errors, while less perseverative errors than adolescents. Second, behavioral responses in children and adolescents were best explained by a HGF model containing the volatility parameter omega (which was significantly smaller in children than in adolescents), but with fixed meta-volatility parameter theta, in comparison to a simple Rescorla-Wagner learning model. This may indicate that children have a bias towards updating their estimation of the prediction strength for a rewarding outcome slower than adolescents, resulting in less efficient learning in the context of an unstable, switching environment. Third, the decision parameter β (reflecting the steepness of the probabilistic decision function translating internal value representations into responses) was correlated with
a subclinical index of repetitive, stereotypical behavior (parent-questionnaire SRS-RBB), suggesting a relation between inflexible behavioral patterns and reduced exploration behavior within a reversal learning task. Taken together, this study provides first-time data on the development of the underlying processes of cognitive flexibility using computational modeling and underlines the usefulness of such approaches to assess typical and atypical developmental effects in the general population and in neuropsychiatric conditions.
SESSION 3: TUESDAY 22 MAY, 11:45 – 13:15
(POSTERS 51-75)

[Poster # 51]
NEURAL COMPUTATIONS IN THE TEMPOROPARIETAL JUNCTION DURING STRATEGIC INTERACTIONS

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Competition is ubiquitous in social settings. Strategic interactions require tracking of rewards as well as predicting the opponent’s actions and updating higher-order beliefs (“what does my opponent think I will do?”). Previous work has demonstrated that predicting opponent beliefs causally depends on activity in the temporoparietal junction (TPJ¹). However, it is unclear whether TPJ involvement is triggered by social context (belief that one faces another human) or by computational demands of interacting with any reactive process. Here we present an fMRI experiment (N = 60) that teases apart these two competing accounts.

We used a game requiring subjects to guess on each trial which of two cards was selected by the opponent. Two different groups of subjects played this game in either a social (matching pennies against a presumed human opponent) or a non-social (guessing a draw from a card deck) context. In both contexts, subjects actually alternated between facing two computer opponents: one that reacted to the subject's actions according to a reactive algorithm¹ and one that generated a noisy sequence. This allowed us to test whether TPJ activity reflects social context or the nature of the predictive computations.

The behavioral data were best explained by a learning model that continuously arbitrates between a sequence-learner and an influence-learner via prediction error-based updating. Neurally, BOLD activity in the TPJ and other nodes of the mentalizing network was driven by any opponent reacting to subjects’ choices, irrespective of whether this occurred in the social or non-social context. Moreover, activity in the TPJ correlated with the relative confidence estimate assigned to the influence model (which was optimal against a reactive opponent). Thus, our results suggest that the TPJ’s involvement in strategic behavior might not reflect functional specialization for social interactions per se, but rather computations that detect and deal with interactive processes.

Acknowledgements: The project is supported by the ERC consolidator grant BRAINCODES.

[Poster # 52]
LEARNING ABOUT OTHER PERSON’S CHARACTER TRAITS RELIES ON A COMBINATION OF REINFORCEMENT LEARNING WITH REPRESENTATIONS OF TRAIT DISTRIBUTIONS AND SIMILARITIES

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Introduction: Most social interactions entail that the interaction partners learn continuously about each other’s character traits (e.g., how polite, helpful, and reliable is the other person?). Formal models that capture such complex social learning processes are currently lacking. Reinforcement learning models can successfully describe human learning in several social contexts and therefore constitute good candidates. However, we surmised here that reinforcement learning per se is not sufficient to account for learning about character traits since humans may additionally rely on their knowledge about the distributions of different traits and the similarities between them (e.g., most people are moderately to very polite and polite persons tend to be helpful).

Methods: In two behavioral studies, participants (n=36; n=41) were asked to consecutively predict how four other persons had previously rated themselves on a series of 60 trait words. After each prediction, participants received veridical feedback (but they never met the other persons). The two studies used
different sets of trait words. Distributions and similarities of all traits were derived from self-ratings of independent laboratory and online samples (total n=835). Additionally, we aimed at providing converging evidence that humans represent the similarities between different character traits. Therefore, we applied representational similarity analyses on a published fMRI study (Korn et al, 2012), in which participants (n=27) were asked to rate themselves on 80 traits words.

Results: Bayesian model comparison shows that the winning behavioral models combine reinforcement learning with reliance on the distributions and similarities of the employed character traits. Crucially, the winning models generalize across traits according to their similarities. That is, when receiving information about a given trait the estimates of all other traits are updated according to how similar these are to the trait at hand. A comparison of the two studies shows that the implemented similarity metric depends on the range of traits to be learned about. Representational similarity analyses of fMRI data in a non-learning task provided converging support for the plausibility of using the similarities between traits since these similarities were reflected within the medial prefrontal cortex, a region classically associated with reflecting about character traits.

Conclusions: Overall, our results indicate that variants of reinforcement learning algorithms which incorporate the distributions and similarities of character traits describe crucial aspects of the dynamics at play when persons interact each other.

[Poster # 53]
THE ROLE OF TESTOSTERONE IN STRATEGIC PROSOCIALITY

Hana H. Kutlikova, Michael Naef, Christoph Eisenegger, Claus Lamm

Testosterone has repeatedly been reported to enhance status-seeking behaviours such as dominance and aggression in a variety of species. It has been suggested, however, testosterone may also promote nonaggressive behaviour, in situations where displaying prosociality would lead to status enhancement. We tested this hypothesis using a single-dose placebo-controlled testosterone administration and a reinforcement learning task, in which male participants learned to obtain rewards for themselves or charitable organizations. Participants performed the task either in the presence of observers or in private. Using computation modelling, we show that participants, whether observed or not, learnt to obtain rewards for themselves faster than for charitable organizations. Moreover, testosterone increased learning for charitable organizations when the participant’s behaviour was visible to others. Conversely, testosterone decreased prosocial learning in situations where the behaviour was private. These findings contradict a simple testosterone-aggression link and demonstrate instead that testosterone’s effects on male behaviour are highly dependent on the social context, further supporting the hypothesis that testosterone flexibly promotes behaviours that enhance social status. Our study is the first to reveal the computational bases of human strategic prosociality and its underlying endocrinological mechanisms.

[Poster # 54]
WHY DID PANDORA OPEN THE BOX: WHEN CURIOSITY SUPERSEDES IN RISK-RELATED DECISION

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Curiosity, as a fundamental part of human motivation, supports an enormous variety of intellectual behaviours such as scientific discovery. Recent findings also show that curiosity facilitates long-term memory consolidation [1]. Surprisingly, there is little attention given to one of the most essential nature of curiosity: its seductive power to influence behaviours. This study examined how curiosity biases decision-making, even in the face of physical risk (e.g. potential electric shock), and evaluated relevant underlying neural mechanisms using fMRI. To induce curiosity, we have pilot-tested a set of videos of magic tricks performed by professional magicians. A magic trick shows an event that appears impossible, thus an ideal material to create strong knowledge gap as a source of curiosity.
Thirty-one right-handed healthy participants were presented with videos of magic tricks (n=36) as well as images of food in a 3-Tesla Siemens scanner. In every trial, after viewing a trick, participants were shown a wheel of fortune which visualised the probability of winning (and losing), and were asked to decide whether to gamble. If they gambled and won, they were provided with a ticket to see the solution. They were instructed that if they lost, they would receive a mild electric shock after the experiment. Participants could also skip the gamble. For each trick, participants rated how curious they were to know the solution.

Based on a generalised linear mixed-effects model, increased probability of expecting no shock, as well as curiosity, increased an individual’s tendency to take risk. Neuroimaging analysis compared the neural activations of the ‘accepted’ and ‘rejected’ trials at the time of decision making. In both magic and food trials, the acceptance (versus rejection) of the risky gamble was associated with greater activity in striatum and ventral tegmental area, indicating that decision making driven by curiosity and extrinsic rewards are both supported by the brain’s reward system [2]. A further functional connectivity analysis using a beta-series correlation approach revealed that during rejection (versus acceptance) of the gamble, striatal activity was strongly coupled with amygdala, a structure that has been implicated in loss aversion and risk evaluation in gain/loss contexts [3,4].

REFERENCES

[Poster # 55]
COMPARISON OF MODEL-FREE AND MODEL-DRIVEN ANALYSIS TO DETECT EARLY SIGNS OF COGNITIVE DECLINE IN SMALL COHORT OF NEURODEGENERATIVE PATIENTS
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Huntington’s Disease (HD) is a rare neurodegenerative disease due to a single gene mutation and characterized by progressive cognitive, psychiatric and motor symptoms. Premanifest gene carriers (preHD) can be identified by genetic diagnosis and infraclinical signs of cognitive deficits are detectable in large cohorts of preHD long before clinical diagnosis (1). The premanifest stage is emerging as a window of opportunity to reduce the effects of HD using treatments preserving neural function and delaying disease progression (1,2). However, detecting infraclinical signs in small cohort is still a medical challenge hampering clinical trials opportunity. The aim of this study is to assess whether new computational models can be used to detect early cognitive signs in small cohort of preHD.

To address this issue, we compared two ways of analysing behavioural data: model free and model-driven analyses. We tested early HD patients (N=28), preHD participants (N=20) and matched control groups (N=26, N=19), with a phonological discrimination task in which they had to judge whether two pseudowords were identical or not. We used evidence accumulation models (3) assuming that, at each trial, one accumulates evidence until a decision threshold is reached. This model decomposes responses and reaction times into the decision threshold representing the quantity of evidence needed before taking a decision, the speed rate of accumulation, the decision bias toward one of the alternatives and the non-decision time accounting for non-decision process (stimulus encoding, motor preparation...).

Model-free analyses of accuracy and reaction times were performed using linear mixed effect models. They show normal performance in preHD participants [all p-values>.05] but impaired performance in early HD patients compared to controls (slower response [β=-.26, SE=.05, p<.001], worse accuracy [β=.94, SE=.21, p<.001]).

The model-driven analyses were performed using Bayesian statistics. We observed significant differences between earlyHD and controls but remarkably also between preHD and controls: both early HD [P=0.96>0.95] and preHD [P=0.99>0.95] show a higher decision threshold compared to controls. In addition, we found a lower rate of accumulation in early HD [P=0.99>0.95] but a higher one in preHD [P=0.99>0.95] compared to controls.
As opposed to the model-free analyses, the model-driven analyses reveal differences between preHD participants and controls. They have an increased decision threshold but seem to compensate with a faster rate of accumulation explaining why their accuracies and reaction times are similar to controls (4). The model-driven analysis also shows an impaired decision component in early HD patients (increased decision threshold and rate of accumulation) leading to elongated reaction times. These results highlight the benefits of formal computational analysis to identify infraclinical symptoms in a small cohort of preHD participants (N=20). This paradigm is thus a powerful tool to detect early symptoms in neurodegenerative disease, to follow disease progression and to monitor the effect of therapy.

References: 1-Tabrizi et al., 2009; 2-Tabrizi et al., 2011; 3-Wiecki et al., 2013; 4-Ratcliff & McKoon, 2008.

[Poster # 56]
Outcome valence bias confidence and impact decision strategies in reinforcement learning tasks.

Maël Lebreton, Karin Bacily, Stefano Palminteri & Jan Engelmann

A confidence judgment is a subjective prediction of the probability of one's action being correct. Unbiased and accurate confidence judgments are critical to optimally arbitrate between different decision strategies. We recently demonstrated that incentivizing confidence accuracy paradoxically biases confidence judgments: prospects of gains (resp. losses) increase (resp. decrease) confidence in a perceptual decision. Here, we hypothesized that this bias would replicate in reinforcement-learning tasks, and would have important consequences on learning performances when competing decision strategies are available.

Methods. We used variants of an instrumental probabilistic reinforcement-learning task. Participants repeatedly faced pairs of abstract symbols probabilistically associated with monetary outcomes (gains or losses). Participants could maximize their payoffs by learning to choose the most advantageous symbol of each pair, i.e. the highest expected gain or the lowest expected loss. At each trial, participants also reported their confidence in their choice.

Results. In two variants of this experiment, although learning performance was unaffected by the outcome valence, confidence judgments were significantly lower in the loss conditions. Using computational modelling, we show that this bias is driven by the learned context-value associated with a pair of symbols. In a third experiment, the probabilistic associations between symbols and outcomes reversed halfway through learning in half of the pairs, requiring participants to switch decision strategy. Before the reversal, results were similar to the previous experiments: although learning performance was unaffected by the outcome valence, confidence judgments were lower in the loss condition. Critically, after the reversal, the behavioral switch was more pronounced and faster in the loss than in the gain conditions.

Discussion. Confirming our hypothesis, we replicated the valence bias on confidence in simple reinforcement-learning tasks: confidence is lower when individuals learn from losses rather than gains despite identical performances. We showed that individuals are consequently more prone to switch decision strategies when probabilistic contingencies change in loss contexts. These results have fundamental implications for the neural and computational basis of goal-directed behavior.

References

[Poster # 57]
The motivational control of mental effort allocation during decision-making

Douglas Lee and Jean Daunizeau, MBB, ICM

In our daily lives, we make multitudes of decisions, yet we do not handle every decision in the same way. Sometimes we choose quickly and effortlessly, sometimes we think long and hard before choosing. Why do we invest resources in some decisions but not others? We propose that mental effort is strategically deployed—the amount of executive resources (e.g., attention, working memory) that a decision-maker (DM) will allocate to a task will be proportional to the expected value of that allocation. We developed a computational model to demonstrate the mechanics of the allocation process. According to our model, the decision-making process starts with a default assessment of option values, which is progressively refined through allocating executive resources. Such cognitive effort investment thus increases the expected value of the allocation. We specifically implemented this model in the context of a probabilistic decision-making task and demonstrated that individuals who are higher in executive capacity allocate more resources to the decision process, which improves their performance.
probability of making the right choice (it may eventually change one’s -default- mind), but carries a cost. The optimal effort allocation will be the level at which the marginal cost equals the marginal benefit (beyond which the cost would outweigh the benefit). Critically, the benefit of effort is determined, at least partly, by decision difficulty. In brief, a difficult decision occurs when the default values are similar (i.e., if the default probability of making the right choice is low). In turn, difficult decisions induce a demand for allocating resources. Interestingly, the model predicts that the relationship between optimal resource allocation and decision difficulty is not trivial and depends upon effort cost and the efficacy of value reassessment.

To validate our model predictions, we conducted a behavioral experiment. Participants rated items, then chose between pairs of the items, then again rated the items. The second rating is motivated from the frequency of “changes of mind” (chosen item was initially rated lower than rejected item) for more difficult decisions, as well as for choices where item values were initially more uncertain. Difficult or uncertain decisions also yielded longer response times, consistent with the idea that more time was needed to more carefully assess the items. Controlling for difficulty, higher rating change corresponded with higher choice confidence. In sum, our findings support our claims about the mental effort allocation process during decision-making tasks.

[Poster # 58]
REINFORCEMENT LEARNING CONFIRMATORY BIAS IN THE HUMAN BRAIN

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Previous studies suggest that factual learning, that is, learning from obtained outcomes, is biased, such that participants preferentially take into account positive, as compared to negative, prediction errors whereas counterfactual learning, that is, learning from outcomes that could have been obtained but were not, is biased, such that participants preferentially take into account negative, as compared to positive one. These effects are supposed to be the two sides of a unique confirmation bias, such that participants preferentially take into account confirmatory, as compared to disconfirmatory one, and that independently of their obtainment. However, whereas the positivity bias observed in factual learning has been demonstrated to rely on the ventromedial dopaminergic system, the neural underpinning of this more general confirmation bias remains unknown. To address this question, we analysed the neural activity of participants learning reward contingencies in an instrumental task similar to those previously used, and fitted behavioural data with different reinforcement learning algorithms. We first replicated the computational results indicating that a learning model with two learning rates, one for confirmatory and one for disconfirmatory outcomes, explained better the behavioural data than standard reinforcement learning models. Additionally, functional imaging results corroborated this hypothesis indicating an enhanced encoding in the ventromedial dopaminergic circuitry of both obtained positive outcomes and forgone negative ones. Beyond the understanding of the confirmation bias, this result has the potential to shed light on the question to know whether or not learning from factual and counterfactual feedback relies on the same neural network. Indeed, it tends to show that outcomes are processed differentially according to their confirmatory aspect instead of according to their actual obtainment.

[Poster # 59]
ACTION SELECTION AND REINFORCEMENT LEARNING IN A BASAL GANGLIA MODEL

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In this computational study, we analyze action selection mechanisms in an integrate-and-fire model of the basal ganglia. This spiking model was derived from a mean-field model parameterized in a previous work (Liénard and Girard, 2014), which was developed as a theory-agnostic model with the sole goal of matching to a large body of anatomical and electrophysiological constraints obtained in macaque monkey. Here we first show that the spiking version of this model exhibits selection properties in the context of an arm-reaching task, as was the case in the previous mean-field model. A comparison to the neural activity
recorded in monkeys performing this task further shows that the amplitude and time courses of the modeled firing rates match the experimental data obtained from basal ganglia nuclei. We then carry out a systematic assessment of the functional roles of the glutamatergic inputs to the basal ganglia. These inputs arise from the cortico-striatal pathway (CSN, originating mostly from cortical layer 5a), the pyramidal tract (PTN, originating from layer 5b), and from the centromedian/parafascicular (CM/Pf) nuclei of the thalamus. Varying the relative importance of these pathways in a selection task shows that (a) the CSN and PTN, acting alone or together, can act as conveyors of the information to be successfully selected, and (b) CM/Pf inputs can prevent selection of multiple actions by narrowing selection to the best one even in the case of ambiguous cortical inputs. In this model, the cortical inputs from CSN and PTN thus act in accordance to the hypothesized role of feeding action saliences to the basal ganglia, whereas thalamic inputs modulate the discrimination capabilities and affects how actions are selected under ambiguous inputs. We finally study reinforcement learning at the level of glutamatergic inputs to the striatum, using dopaminergic-modulated spike-time dependent plasticity (DA-STDP). The exact effect of dopamine in modulating STDP, which depends on tonic and phasic DA concentration and on the dopaminergic receptors expressed by striatal medium spiny neurons, is still uncertain. We thus test different models of DA-STDP and compare the resulting learning capabilities. We also test different overlaps of D1 and D2 receptors in medium spiny neurons of the striatum, from a few percent (conservative estimate) to up to 60% (highest estimate reported in the literature), and likewise assess the resulting learning capabilities. We conclude by highlighting the range of tested parameters that are functionally consistent with reinforcement learning.


**[Poster # 60]**

**THE EFFECTS OF EXOGENOUS TESTOSTERONE ON THE PREFERENCE TO COMPETE FOR STATUS IN REPEATED REAL EFFORT-BASED COMPETITIONS**

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Competition can be a means to achieve and maintain a high social status in a hierarchy that allows access to rewards such as food and money (Mazur & Booth, 1998). Testosterone is assumed to boost competitive behaviours in order to keep or improve one’s social status (Eisenegger et al., 2011). These effects may depend on the social status position itself. Interestingly, testosterone effects on motivation to compete may depend on the context. The stability of one’s status level or closeness to others in relation to one’s status position have been found to differentially influence testosterone responses following victories or defeats, and has been theorized to potentially motivate competition behaviour in unstable hierarchies and to reduce when it is stable (Zilioli et al., 2014). We tested this theory by examining whether testosterone causally influences individuals’ motivation to compete for social status, and whether this is modulated by one’s social rank position and status stability.

We tested 172 male participants in a randomized double-blind placebo-controlled design, receiving either Testosterone (150 mg) or placebo. Participants played multiple real-time repeated competitions against multiple players in the same room. In this novel paradigm participants had to provide actual physical effort to gain points in the competition and influence their rank position, providing a continuous measure of competitiveness and performance. Following the competition, rank feedback was given in a ranking list that was either only visible to the participant (private) or also visible for his peers (public). Status of individuals was manipulated by placing subjects in a high or low rank, between-subjects. In a second part, participants played a public competition where their rank was held either stable or unstable.

We found a significant effect of rank feedback on motivation to compete, showing that when rank information was made public participants provided more effort than when it was kept private (p<.01). Testosterone administration modulated motivation to compete over time, which depended on rank position (p<.05). Participants with high testosterone but low in rank were more motivated to compete as compared to placebo. In line with prior literature on hierarchy stability, we found that when their rank was held unstable testosterone increased preference to compete, whereas when their rank was stable testosterone administration decreased their preference to compete (p<.05).

To conclude, using a real effort-based design to assess competitive behavior we show that motivation to compete is higher when concerns of social reputation is present as compared to when it is held private. Testosterone influences competitive motivation when there is an opportunity to improve one’s status, whereas it decreases motivation to compete when there is no opportunity to improve, potentially to avoid further loss.
**[Poster # 61]**

**Magnitude provides a conceptual scaffold for the neural encoding of value**

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The decisions we make in everyday life usually do not occur in a void. Rather they can be based on schemas we have learnt from similar situations, allowing us to function more flexibly in different contexts. For example, changing currencies when travelling from the UK to France should not impair our understanding of how payments work. One very basic schema that develops from an early age and is ubiquitous in daily life is magnitude judgement, for example when estimating the height of a car or solving simple maths problems.

Research using M/EEG has demonstrated it is possible to decode the representational geometry of relative magnitude from neural signals evoked by symbolic and non-symbolic numbers. Similarly, value-based choices can often be reduced to a comparison of magnitudes, such as comparing prices or quality. If this is the case and we employ abstract schemas for more efficient behaviour, then we would predict that our brain also relies on the pre-existing structure of magnitude when making value-guided choices. Building on previous work, we hypothesized that if numerical and value encoding share a representation of magnitude, (1) we should find a similar neural geometry evoked by either type of stimuli and (2) idiosyncratic patterns in numerical magnitude representation should predict the patterns in valuable items.

We tested 46 participants on two tasks, a numerical task and a value task, during the same EEG recording session. In the numerical task, participants viewed a stream of 10 consecutive symbolic digits (1-6) in orange and blue font and decided which colour category had the lowest (n = 24) or highest (n = 22) average. In the subsequent value task, all participants first learned about six bandits, presented as colourful images each associated with a reward probability linearly spaced between .05 and .95. In the test phase, they were then given the choice between two bandits. Crucially, no aspect of the bandit task was explicitly associated with numerical values.

Using representational similarity analysis (RSA), we first tested for a magnitude representation in both tasks. Indeed, we could reliably decode numerical magnitude and value magnitude from ~100 ms after stimulus onset. Second, we asked whether the representational geometry in the numerical task could explain the geometry in the bandit task within the same participant. We found that again from around 100 ms after stimulus onset, we could cross-validate from the numerical to the bandit task. These results could not be explained by factors such as probability correct or task instructions. And although both higher numbers and more valuable bandits also elicited a larger average centro-parietal positivity, multivariate decoding was significant even after this univariate signal had been partialled out.

Our findings suggest that value-based decisions rely on a more abstract, low-level scaffold of numerical magnitude. Utilizing a pre-existing structure could allow the brain to learn faster and make computations more efficiently.

**[Poster # 62]**

**A generic probabilistic inference mechanism for the detection of sequential regularities in humans**

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Real-life processes, from weather to traffic lights, produce structured times series of events. Indeed, because these processes unfold across time, they produce sequences of observations that are characterized by some hidden regularities. Importantly, there exists regularities of different kinds. Some regularities are stochastic: there is a given probability for an event to occur, and this probability is different from chance. For instance, dark clouds often precede rain, but sun may also follow. Other regularities are deterministic: the event occurs for sure. For instance, at a French traffic light, only the red light (stop signal) can follow the orange one (warning signal). Theoretically, deterministic regularities are a limit case of stochastic ones in which the probability of occurrence is one (or zero). In practice, however, this distinction is key since both types of regularities afford different predictability power: uncertain predictions (stochastic regularity) versus sure predictions (deterministic regularity). Are stochastic and deterministic regularities detected by the same machinery in the brain? We designed a new regularity detection task in which human subjects were presented at each trial with one of three types of binary auditory sequence (with items A and B). All sequences started fully randomly (A and B are equally likely to occur). In two conditions, there was a change point: the second part of the sequence contained either a stochastic (e.g. overall more repetitions than alternations) or deterministic (e.g. the repetition of AABB) regularity. In the last condition, the sequences...
remained random. Subjects were asked to guess and report those conditions on-line during sequence listening, by continuously moving their index finger inside a triangle whose summits corresponded to the three conditions. We compared subjects’ reports to a Bayesian ideal observer of the task that detects and assigns credence to each condition. Finger trajectories reflected several qualitative properties of this ideal probabilistic inference. First, detection of deterministic regularities was faster than detection of probabilistic regularities. Second, the build-up of confidence was gradual for stochastic regularities while it was abrupt for deterministic ones. Third, within regularities, distinct quantities dictated the detection speed: the entropy in case of stochastic regularities and the pattern size for deterministic ones. Overall, our results suggest that the brain may use a core probabilistic inference system to detect and compare very different kinds of regularities.

[Poster # 63]

**Social Conformity in Destructive Behaviour Towards Strangers: Measurement and Modulation by Interpersonal Similarity**

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Research has shown that increasing the sense of social connection between individuals in a group enhances cooperative and prosocial behaviours - not only towards other individuals within the social group, but also towards strangers. This has been taken to suggest that strong group bonds may foster a general prosocial orientation in individuals. However, there is also abundant evidence that strong group identification makes individuals more prone to social influence, and may decrease self-monitoring which facilitates behavioural disinhibition. Since prosocial behaviours are usually in line with highly internalized group norms, a stricter test of the role of genuine prosocial orientation versus social influence in shaping social behaviour towards a third party would be to assess whether strongly bonded individuals also more easily engage in behaviours that align with the current group norm, but are clearly destructive rather than prosocial. In the present study, we developed a new paradigm to assess 1) whether individuals conform to their social group even if the behaviour is clearly destructive and does not produce any personal or group gain; and 2) whether the social connection between the individuals in a group, manipulated by interpersonal similarity, increases this tendency.

We tested 82 male participants, who engaged in groups of 4 in a social bonding manipulation, followed by a key-press task. In a 2x2 between-subjects design, we manipulated, firstly, the Similarity in personal preferences, beliefs and desires between the group members (SIMILAR versus DISSIMILAR) - a manipulation previously shown to promote a sense of social connectedness. After this, participants performed a key-press task: in some trials, they could gain a monetary reward for their group by making fast key presses (gain trials), while in other trials they could use key presses to destroy points from an unknown future group of participants (subtraction trials). The task consisted of three blocks: 1) an individual baseline block in which participants performed the task without feedback on the behaviour of their group members; 2) a group block, in which the alleged behaviour of the other players was shown on the screen and 3) a second individual block. Using pre-programmed stimuli, we manipulated the group members’ behaviour shown during the group block (factor Group Behaviour) to be either DESTRUCTIVE (involving a high number of key presses in subtraction trials) or NON-DESTRUCTIVE (no key presses). The change in participants’ key presses during the group block with respect to the individual baseline block was used as an index of social conformity and entered into a two-way ANOVA.

Behavioural ratings confirmed that participants in similar groups experienced stronger self-other overlap between themselves and their group members. In the key press task, participant did not differ in their tendency to engage in destructive behaviour towards a group of future participants when tested individually. However, a main effect of Group Behaviour confirmed that participants conformed to their group members’ destructive behaviour in the subsequent group block. This effects was also found for the second individual block, indicating that participants not just publicly complied with the group norm, but to some extent internalized it. We did not find a significant Similarity x Group Behaviour interaction though, indicating that group bonding did not significantly modulate the strength of conformity behaviour. Yet, explorative comparisons within both experimental groups revealed that only participants from similar groups adapted their behaviour if their group members behaved destructively, while participants from dissimilar groups did not adapt their behaviour. Conversely, only participants of similar groups showed a decrease in destructive behaviour if their group members behaved strictly non-destructively.

These data provide first evidence from a novel task that individuals in a group tend to conform to their group members if these engage in senseless destructive behaviour towards strangers. Although explorative testing indicated that this effect was only present in groups with high interpersonal similarity, we could not show a significant differential effect of interpersonal similarity on this behaviour.
In sum, our findings underline the powerful tendency of individuals to conform to their group members’ behaviour, even if this behaviour is harmful for unknown others and does not produce any material gain. Our novel task seems promising as a method for measuring destructive forms of social influence and behavioural contagion in a laboratory setting. Future research using a more salient group bonding manipulations and a larger sample might give more clear-cut answers to the question to what extent these behaviours are modulated by the strength of the social bond between individuals in a group.

[Poster # 64]
**Working memory provides a flexible context for reinforcement learning**

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Reinforcement learning allows us to update the rules we use to select actions, whereas working memory permits recently encountered information to be held online for short durations. How do these two cognitive systems interact to produce organised behaviour? One important situation in which these systems must interact in a structured way, is when our learning must be specific to the context in which it was learned. Here we investigate how this contextual control depends on working memory.

We developed a novel stimulus-response learning task in which both the stimulus and the response have two feature dimensions. Participants were shown one of four coloured shapes (2 possible colours, 2 possible shapes), and had to select one of four response locations (arranged along 2 spatial dimensions). They were instructed that just one response was correct for each of the four shapes, that reward was probabilistic, and that the rules might change periodically. Unknown to the participants, the rules could either be dimensional (consistent correspondences between the correct response dimensions and the stimulus dimensions), or non-dimensional (XOR-type rule governing the response given the stimulus). A fixed monetary reward was given on 80% of ‘correct’ responses and 20% of ‘incorrect’ responses.

In Expt 1, we demonstrated correlations across 40 participants, between working memory capacity and whole-stimulus to whole-response reinforcement learning. This did not correlate with dimensional learning. This finding demonstrates that the trait ability to retain and bind information is necessary to use whole bound objects as a learning context.

In Expt 2, we manipulated concurrent working memory load by introducing a background 1-back or 0-back task, during the learning task. Some contextual aspects of learning were selectively impaired by increasing working memory load, in particular whole-stimulus whole-response learning, and some aspects of dimensional learning. However contextual effects where stimuli changed completely (on both dimensions) between trials showed enhanced reinforcement effects. This may reflect a stronger separation effect between dissimilar contexts. Thus, rather than simply reducing the strength of context effects, working memory load can alter the kind of information used as context.

Finally in Expt 3, we showed that the contents of working memory dynamically alter learning. After each trial we included a memory-test for the original stimulus itself. This memory probe required participants to select the one of two options that matched the stimulus. This comprised a choice between either two isolated features, or two whole objects. This secondary task therefore biased participants to process the stimuli either in terms of their separate feature dimensions, or as bound objects - but kept constant the amount of information needed. In blocks where feature memory was being tested, reinforcement effects were stronger for the feature dimensions, whereas when object memory was being tested, reinforcement was stronger for the bound conjunctions. Thus the context for learning tracked the kind of representation required for the working memory response.

Together the experiments demonstrate that reinforcement of actions is contextualised by states at the time of learning, but that this context depends on working memory, is flexible, and can be biased by the type of representation held in memory. Our results help pin down the nature of ‘states’ that are often postulated for flexible learning.

[Poster # 65]
**Inference and planning with explicit representation of temporal structure**

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A series of recent studies have established that the perceived frequency of the changes in the environment modulates how human adjust their beliefs about the current state of the environment—comparable to a rational Bayesian agent. However, to fully understand computational and neuronal mechanisms that underlie human adaptive behavior in dynamic environments one should take into account our ability to represent complex temporal structure over multiple time scales (Harrington et al. 2004, Kiebel et al. 2008). In principle,
beliefs about an underlying change frequency as well as beliefs about specific moments of change allow us to perform complex everyday tasks with temporal precision.

Here we will present a behavioral model which incorporates explicit representation of state duration and is based on hidden semi-Markov models (Yu 2010) in which state duration is treated as a random variable. This approach allows us to incorporate prior beliefs about temporal regularities in a dynamic environment within a behavioral model and investigate how these priors shape both inference and planning processes. Using a probabilistic reversal learning task, we will illustrate the key properties of the behavioral model. Specifically, we will show how performance depends on the expectation about the regularities of intervals between reversals. Importantly, we will demonstrate both on simulated and experimental data (Reiter et al. 2017) that one can accurately determine individual differences in the representation of the task’s temporal structure. Interestingly, we find a heterogeneous distribution of the task representation across participants, where the behavior of some participants is explained by prior beliefs in semi-regular intervals between reversals.

The presented model opens new possibilities for the systematic investigation and cognitive phenotyping of individual beliefs about temporal structure in dynamic environments.


[Poster # 66]
A NEURAL NETWORK CENTERED ON POSTERIOR CINGULATE CORTEX COMPUTES THE VALUE OF AN OCCUPATION.

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Many people have some role in society (i.e., occupation). In addition, occupational choice affects well-being as well (Diener, 2000; İşgör & Haspolat, 2016). An international survey of occupation suggested that there are two key variables for computing willingness to do an occupation (i.e., “value of an occupation”: interest and income (MOW international research team, 1987). However, despite its importance, little is known about the neural mechanism underlying occupational choice. In neuroscience studies, it is suggested that posterior cingulate cortex (PCC), as well as ventromedial prefrontal cortex (vmPFC), is implicated in value computation in various contexts (Clithero and Rangel, 2014; Schacter et al., 2007; and Bartra et al., 2013). Given these findings, we hypothesized that interest and income of occupation are computed in the PCC. To test the hypothesis, in this study, we scanned human participants by functional MRI, while they reported willingness to do each of the 80 occupations. After the scanning session, they were asked to rate their belief about interest and income of the same set of the occupations. Consistent with the previous finding, by using linear regression, we found that willingness to do an occupation (i.e., “value of an occupation”) can be predicted by its interest and income. The fMRI analysis revealed that the two key computational variables, interest and income, were encoded in the same brain region: that is, BOLD signal in the PCC was correlated with the interest and income of an occupation. Furthermore, integrated value of the occupation was found to be encoded in the PCC and the vmPFC. The results provide supporting evidence that the value of occupation may be computed by a neural network centered on the PCC.

[Poster # 67]
SURPRISE ABOUT SENSORY EVENT TIMING DRIVES CORTICAL TRANSIENTS IN THE BETA FREQUENCY BAND

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Knowledge about the timing of relevant events in the sensory environment can benefit decision-making. Several subcortical brain regions seem to be driven by uncertainty about event timing, as well as violations of timing expectations (‘surprise’). Less is known about how temporal statistics of the environment affect the dynamics of cortical networks that mediate sensory-motor decisions. Here, we used magnetoencephalography (MEG) to exhaustively map the trial-to-trial correlation between variations in uncertainty or surprise about event timing and cortical dynamics in a simple decision task. Human subjects judged changes of a salient visual target. The intervals between changes varied randomly from trial to trial. We used a Bayesian learning model to update internal beliefs about event timings. From this we extracted two information-theoretic variables that varied from event to event: (i) entropy, a measure of uncertainty about the occurrence of the upcoming event; (ii) Shannon information, a measure of surprise elicited by the occurrence of the event. We found a positive relation to trial-to-trial variations in reaction time for both surprise and entropy. However, only surprise predicted reaction time better than the durations of the two previous intervals, showing that subjects indeed tracked the temporal structure of the task environment, as our model assumes.

We correlated both surprise and entropy with MEG activity, across the cortical power spectrum, time and MEG sensors. Surprise also correlated negatively to power modulations after perceptual events, peaking around 20 Hz. The distributions of these correlations were widespread and different between target on- and offsets, but most prominent in fronto-parietal areas. We did not find a robust correlation between entropy and MEG activity. We conclude that surprise about the timing of behaviorally relevant events shapes cortical population dynamics across widespread brain regions.

**[Poster # 68]**

**Prediction Errors Govern the Acquisition and Updating of Declarative Memory**

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The ability to acquire long-lasting memories is driven by the extent to which predictions about future states match actual outcomes. Computationally, predictions can be updated and optimized by the calculation of an error term associated with their accuracy in light of incoming information - the degree of mismatch between expectation and reality. Indeed, one of the most successful theories in neuroscience is the reward prediction error (RPE) theory of reinforcement learning (RL), whereby action- or stimulus-outcome contingencies are learned over trials in accordance with the principles of PE based updating. Despite the acclaim of this computational account, its applicability to the formation of long-term declarative memories has not been explicitly examined. We bridge this gap by a series of behavioural and neuroimaging studies of knowledge acquisition. By calculating two different error terms provided by subjective assessments and degrees of actual inaccuracies, we were able to compute trial-by-trial prediction error terms and assess their link to long-term memory strength. We demonstrate a striking relationship between PE and subsequent memory such that the larger the error upon initial retrieval, the better the learning from feedback in the long run. These data, supplemented by fMRI scanning, show that declarative learning follows similar rules to RL, sometimes with surprising and paradoxical consequences. Moreover, a network of brain regions, including ventral striatum and prefrontal cortex, known to govern non-declarative reinforcement learning, seem to similarly underlie the updating of declarative memory as a function of evaluated PE.

**[Poster # 69]**

**Uncertainty Exposure and its Influence on Framed Decision-making with Moral Dilemma**

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Introduction
Natural disasters are particularly uncertain and unpredictable threatening events, which lead to emotional reactions (i.e., fear, anxiety) (Adolphs, 2013) and possible decision-making biases (Lerner, Li, Valdesolo, & Kassam, 2015; Phelps, Lempert, & Sokol-Hessner, 2014). We examined how the sensitivity to the framing of the consequences (gain or loss) (Kahneman & Frederick, 2007) and to moral judgments (Greene et al., 2009) (e.g., evacuate or help an injured person) could be altered for exposed individuals. More specifically, we used a framed decision-making task with moral dilemma, and we investigated how uncertainty and a threatening context would influence the framing effect and personal intention effect of the moral acceptability of the choice. Considering the impact of uncertainty and fear on the processing of anticipatory emotions (Adolphs, 2013; Pabst, Brand, & Wolf, 2013) that underlies the framing effect (Kahneman & Frederick, 2007) and moral judgments (Greene et al., 2009), we hypothesized that uncertainty and threatening context would neutralize these two effects. For the needs of the study, we created a paradigm to elicit emotional and (un)certainty (uncertainty vs. certainty) responses by means of (un)predictable (unpredictable vs. predictable) stimuli either in a threatening or a neutral context. We used a visual presentation of the moral dilemmas, framed in terms of gain or loss, and divided into two degrees of personal intentions, namely intentional and unintentional actions.

Method
We recruited 131 undergraduate students (121 females, 10 males) with a mean age of 19.71±2.48 years from the University Clermont Auvergne in Clermont-Ferrand (France). Each participant was randomized into one of the four induction conditions: certainty/threatening, uncertainty/threatening, certainty/neutral, uncertainty/neutral. All participants first performed the induction task (10 min), then the moral dilemma task where they were instructed to give spontaneous answers (about 6 min), and finally they completed the STAI-Y (anxiety) task (about 5 min).

We conducted a repeated-measures ANOVA on the moral acceptability scores and RT, with context (threatening vs. neutral) and (un)certainty (certainty vs. uncertainty) as a between-subjects variable, and with framing (gain, loss) and personal intention (intentional, unintentional) as a within-subjects variable. Any significant interaction was followed by simple effect analyses with Bonferroni corrections.

Results
The results presented a marginal effect of the context (threatening vs. neutral) on the moral acceptability scores, in the threatening condition participants presented higher scores ($M = 53.56, SD = 21.42$) than in the neutral context condition ($M = 46.30, SD = 20.94$), $F(1, 116) = 3.49, p = .064, \eta^2 = .029$. However, we obtained no main effect of (un)certainty (certainty vs. uncertainty), $F(1, 116) = 0.017, p = .896, \eta^2 = .0002$.

We obtained that uncertain events led to the negation of the framing effect, but did not influence the moral acceptability and the effect of personal intention. More precisely, we observed an interaction effect between the framing (gain, loss) and the (un)certainty (certainty vs. uncertainty), $F(1, 116) = 9.62, p = .002, \eta^2 = .077$. In the certainty condition, the framing of gain involved higher moral acceptability scores ($M = 53.40, SD = 21.45$) than the framing of loss ($M = 45.95, SD = 21.35$), $F(1, 116) = 21.48, p < .001, \eta^2 = .22$. However, there was no difference between framings of gain and loss in the uncertainty condition, $F(1, 116) = .06, p = .81, \eta^2 = .002$. Yet, we obtained no significant interaction effects between the framing (gain, loss) and the context (threatening vs. neutral), and between the personal intention (intentional, unintentional) and the context (threatening vs. neutral), $F(1, 116) = 1.07, p = .3$ and $F(1, 116) = .02, p = .89$ respectively.

As far as the RT analysis is concerned, the analysis exhibited a main effect of the (un)certainty (certainty vs. uncertainty) condition, participants in the uncertainty condition presented longer RT ($M = 5328.27, SD = 1580.14$) compared to participants in the certainty condition ($M = 6153.55, SD = 2240.63$), $F(1, 116) = 4.06, p = .046, \eta^2 = .03$. We obtained no other significant effect ($p > .15$).

Discussion
By means of a framed decision-making task with moral dilemma, we examined whether uncertainty and a threatening context could be influencing the framing and personal intention effects on the moral acceptability of the choice. In the case of moral decision-making, the exposure to uncertainty can result in the negation of the framing effect. Such negation can be the result of a heightened systematic processing and the resulting reduction of the anticipatory emotional processing, which is supported by an increased RT in our results. Further researches are warranted to determine better solution for scientists and local population that constantly deal with uncertainty (e.g., in cases of impending natural disasters), such as focusing on how to use cognitive strategies to regulate emotions for appropriate decision-making in cases of crisis events.

BIBLIOGRAPHY
The dopaminergic system is implied to be the central culprit in many psychiatric disorders that are characterized by the inability to form satisfying social interactions (Meyer-Lindenberg & Tost, 2012). Yet despite the established role of dopaminergic neurons in approach and avoidance behavior in non-social settings (Frank, Seeberger, & Reilly, 2004), its role in social interactions is poorly understood. Neuroimaging studies suggest that brain areas densely innervated with dopaminergic neurons involved in basic reward processing overlap with brain areas responsible for social reward processing and facilitation of cooperative behavior (Ruff & Fehr, 2014).

We used a high dose of selective D2/3 dopamine receptor blocker to investigate the effects of the dopaminergic system on learning about and interacting with others. We administered either sulpiride or placebo to 80 participants that underwent several social interaction tasks. The pharmacological challenge had no robust effects on single round games, looking at positive and negative reciprocity, and general prosociality. However, blocking D2 transmission does seem to affect the consistency of choice behavior in a repeated trust game. Using a computational model to further dissect the underlying mechanisms we find, that these differences in behavior could be due to lower reward sensitivity in the treatment group thus supporting dopamine’s involvement in motivational circuits (Pessiglione, Vinckier, Bouret, Daunizeau, & Le Bouc, 2017).

References

[Poster # 71]
LEARNING THE PAYOFFS AND COSTS OF ACTIONS
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When deciding whether or not to take an opportunity, which aspects of it do we consider? Certainly, the most salient aspects are the payoff that we can expect, and the cost we must invest into pursuing the opportunity. Furthermore, we must ask ourselves how urgently we need the payoff, and how readily we could afford the costs.

There are two main sets of factors influencing our choices. On one side, there are internal, subjective factors - our need for payoff, and our resources available to invest. These factors together constitute the motivational state: our subjective tendency to engage with arising opportunities. We might not be aware of our motivational state explicitly, but full information about it is readily available to us at least in principle. On the other side, there are external factors, such as the typical payoff and the cost associated with the opportunity. In the absence of prior experience, these characteristic properties are unknown to us. Since they are nevertheless crucial for evaluating opportunities, it is in our best interest to build a reliable internal map of the payoffs and costs of frequently encountered opportunities.

Collins and Frank (2014) investigated a possible neural implementation of such a map of payoffs and costs, situated in the Basal Ganglia (BG), which is a subcortical structure common to all vertebrates. The BG features two pathways connecting cortical neurons (selective for the state of the environment) to thalamic neurons (selective for specific actions). These two pathways are famously known as Go and No-Go pathway; the Go pathway facilitates action, the No-Go pathway inhibits it (Kravitz et al., 2010). Collins and Frank hypothesized that the strengths G of trained Go connections might represent the expected payoffs of actions. The strengths N of trained No-Go connections, on the other hand, would then represent the costs of pursuing actions.

The theory of Collins and Frank explains how the payoffs and costs are represented, and how the brain makes use of them. It does not, however, explain how payoffs and costs are learned. How does experience transform an initially blank map into a reliable atlas of payoffs and costs? Our novel results suggest that in fact, a set of striatal plasticity rules proposed by Mikhael and Bogacz (2016) could allow the BG to infer accurate estimates of payoffs and costs for frequently encountered opportunities.

How do those rules operate? A large body evidence suggests that the BG implements reinforcement learning, with reward prediction errors (RPEs) as the driving force of plasticity. According to Mikhael and Bogacz, RPEs affect G and N differently. The impact of the RPEs further depends on whether the experienced reward exceeded or missed the expectation.

Throughout our recent work, it became apparent that these modifications of standard reinforcement learning allow for learning of payoffs and costs. We show, both analytically and through simulations, that Mikhael and Bogacz’ plasticity rules correctly infer payoff and cost from a single RPE signal. This holds in multiple reward scenarios, under the condition that investment of the cost and reception of the payoff occur at different moments in time.

Collins and Frank’s theory also assigns a neural equivalent in the BG to the motivational state: they suggest that tonic dopamine (DA) might correspond to the motivational signal. Indeed, DA amplifies activity in the Go pathway and inhibits activity in the No-Go pathway (Smith et al., 1998). According to Collins and Frank’s hypothesis, high DA corresponds to a strong craving for payoff and sufficient reserves to engage with an action. Low DA, on the other hand, encodes depleted reserves partnered with indifference towards the payoff. In line with this view, in further recent work we demonstrate that Mikhael and Bogacz’ learning mechanism can account for the effects of DA depletion on the willingness to exert effort. Salomone et al. (1991) demonstrated that DA is involved when rats balance payoffs against costs: hungry rats are much less willing to work for their preferred food when injected with the DA antagonist haloperidol. Using Mikhael and Bogacz’ plasticity rules in combination with Collins and Frank’s hypothesis about the role of DA in decision making, we successfully reproduce Salomone’s findings in simulations.

In summary, we demonstrate how learning of payoffs and costs in the BG could explain motivationally modulated decision making.

References

[Poster # 72]
Decision biasing or value updating: A computational account of imitation in social reinforcement learning
Humans have the capacity to learn autonomously by relying on their own experience, as well as socially by leveraging the knowledge of their peers. How autonomous and social learning relate to each other still raises several challenges in terms of computational modelling. One challenging question is to understand how these two different and complementary forms of learning can be combined within a single computational framework.

Recently, observational learning (learning from observing others’ choices and/or rewards) has been investigated within the reinforcement learning framework [Burke et al., 2010, Colette et al., 2017]. The model proposed in [Burke et al., 2010] is built upon two key ideas. First, it assumes that observing others actions has an effect on the learning process by biasing the decision on the next trial towards the observed action. Second, it stipulates that this imitation effect is overridden by the observation of others’ outcomes. We refer to this model as the “Decision-Biasing” model. This model has been adopted in several studies, where it has been shown to explain subjects learning behaviours [Selbing et al., 2014, Selbing and Olsson, 2017]. However, the first assumption presents one obvious limitation in that it allows only an indirect and immediate effect of imitation on the learning process. First, the observed action only biases the decision-making process without updating the subject’s model of the task, which is only updated through self-experienced outcomes following imitation. Second, this bias only affects the decision-making process on the next trial, so it does not have a persistent effect over time.

In this study, we tackle these limitations of the Decision-Biasing model, by proposing an alternative model in which the observed actions are used for updating the action value function. We evaluate this “Value-Updating” model, and compare its exceedence probability (EP) with respect to the Decision-Biasing model on three different datasets. The first dataset is part of one published study (N = 42) where the Decision-Biasing model has been adopted [Selbing et al., 2014]. In this dataset, observational trials were systematically followed by private trials and conditions where presented in blocks. This design is not appropriate for studying the extent of imitation over time. In order to address this limitation, we performed a lab-based experiment (N = 44) where conditions were randomized over trials, so that observations can be spaced by varying horizons. We also replicate the setting of the first dataset on a larger scale, in a web-based experiment (N = 102). We show that model comparison favors the Value-Updating over the Decision-Biasing model in the three datasets (EP = 0.8, EP = 0.99, EP = 1). These results support a deeper effect of imitation on the learning process than what has been classically considered in the literature.

References

[Poster # 73]
**Quantifying the Cost of Cognitive Stability and Flexibility**

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Cognitive control refers to the ability to ‘focus’ on a task. Exerting cognitive control is well known to be accompanied by a subjective effort cost and people are generally biased to avoid it. However, the mechanisms underlying this effort cost of cognitive control are currently unclear. To begin to address this question, we build on recent theorizing suggesting that the cost of cognitive effort represents a motivational signal that facilitates switching to alternative tasks, hence promoting flexibility (Cools, 2016; Kurzban, Duckworth, Kable, & Myers, 2013). Inspired by these observations, we asked whether the effort cost of cognitive stability is higher than that of cognitive flexibility. Specifically, we tested this prediction in the domain of working memory by using (i) a delayed response paradigm that allows us to quantify the stability (distractor resistance) and flexibility (flexible updating) of working memory representations (as in Fallon et al. 2017), as well as (ii) a subsequent cognitive effort discounting paradigm that allows us to quantify
the subjective effort assigned to performing the delayed response paradigm (as in Westbrook et al. 2013). We show strong evidence, in two different samples (28 and 62 participants respectively) that subjective value decreases as a function of demand. Moreover, we demonstrate that the subjective cost of performing a task requiring cognitive stability (distractor resistance) is higher than that requiring flexible updating. This finding informs recent theorizing that the cost of control might represent a solution to the stability-flexibility dilemma. In ongoing work with this paradigm we are assessing the role of brain dopamine in the tradeoff between stability and flexibility and associated effort costs (Musslick, Jang, Shvartsman, Shenhav, & Cohen, 2017). In future work we will adapt this paradigm to assess another key implication of this proposal, namely whether the cost of control varies with current task demands for stability versus flexibility, with higher costs in environment with greater demands for flexibility.


**[Poster # 74]**

**UNDERSTANDING SOCIAL DECISION-MAKING MECHANISMS USING MARKOV DECISION PROCESSES**

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Background. When decisions are made in a social context, the degree of uncertainty about the possible outcomes increases dramatically because the behavior of other human beings can be much more difficult to predict than the physics of the environment. The current proposal takes a general theoretical approach based on the hypothesis that the brain performs Bayesian inference based on observations using probabilistic representations of the world and utilizes the results of Bayesian inference to choose optimal actions (Rao 2010). Partially Observable Markov Decision Processes (POMDPs) provide a rigorous theoretical framework for solving tasks involving action selection and decision making under high uncertainty.

Methods. 30 volunteers (aged 19-29, M = 22, SD = 2.2 including 18 women) underwent a new social decision making task, consisting of a sequential repeated economic game in which participants played against an artificial agent who unpredictably changed its behavior between a cooperative (matching penny task) and a competitive game (Hide and seek task). Participants were led to believe that they were playing against other participants. The experimental task consisted of 125 trials. One red and one black king were displayed on a screen, from which the player would choose from. Displayed above the player’s cards were another two cards belonging to their opponent. To win, participants had to guess what color card their opponent (which unbeknownst to them was a computer algorithm) would choose and try to pick the same one. The computer algorithm exploited the bias of participants both in the competitive and cooperative games.

Results. Most participants succeeded to infer intention of their opponent with no more information than the behavior of their opponent and their own reward (lose or win). Our fitting methods were Q-learning for the model-free approach and Partially Observable Markov Decision Process models (POMDP) for the model-based method. POMDP explained the human behavior drastically better than Q-learning. It reproduces two third of participants’ decisions whereas Q-learning succeed only to guess a bit more than one decision on two. POMDP’s BIC (Bayesian Information Criterion) score is also significantly better than Q-learning one. Moreover, participants’ score on the task is positively correlated with the likelihood of the POMDP model.

Conclusions. POMDP is a framework based on probabilistic reasoning about the hidden state of the environment. Based on its observations from the environment, POMDP develops a belief (posterior probability distribution) over the current state and chooses an action that maximizes the expected reward. On the other hand, Q-learning selects the action with the highest average reward, obtained from the past.
Similar behavior between POMDP and humans, and failure of the model-free method based on previous rewards suggests a mechanism of action selection based on reasoning about others’ intention instead of solely looking at the resultant reward of each action in complex social decision making tasks among humans.

[Poster # 75]
ENCODING AND DECODING OBTAINED AND FORGONE OUTCOMES IN THE MEDIAL PREFRONTAL CORTEX

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In everyday life, we are constantly confronted with decisions. Usually, we can only experience the consequence of the decision we made and not of alternative decisions we could have made. However, knowing this additional information has a positive effect on learning. While the cognitive and neural mechanisms underlying actual outcomes processing when only information about the outcome of the selected option is available are well studied, the mechanisms subserving the encoding of foregone outcomes when the relative information is also provided, have been less investigated. In this study, we explored the neural substrates of both actual and foregone outcomes when either partial or complete information about the outcomes is provided.

Twenty-eight participants performed a probabilistic instrumental learning task while undergoing fMRI scanning. On each trial, they had to choose between two symbols probabilistically associated with a certain reward (or punishment). At the end of the trial, the outcome of the decision was shown. Importantly, on half of the trials participants received feedback only about the outcome of the decision they made, while in the other half they were informed about both the actual and the alternative outcome. We used univariate as well as multivariate methods to explore outcome value encoding for both actual and foregone outcomes, in trials with either complete or partial outcome information. Furthermore, we assessed the neural code by which value is represented in these different conditions.

Our results show that: 1) not only factual but also foregone outcomes could be decoded from neural patterns of brain activity, 2) both multivariate and univariate effects differ between regions along the dorsoventral axis of medial PFC, 3) univariate effects also differ between conditions, and 4) outcome value is represented with a fully-adaptive code in complete information trials, while in partial information trials it is represented with a partially-adaptive code. These findings suggest the presence of multiple adaptive-coding mechanisms flexibly activated in different choice settings.
[Poster # 76]
**INTER-INDIVIDUAL VARIABILITY IN DECISION-MAKING UNDER RISK REVEALS BEHAVIORAL PHENOTYPES NOT EXPLAINED BY STANDARD MODELS**

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Quantifying and predicting risk propensities is an important practical concern in many fields (insurance, policy-making, psychiatry, sales and marketing etc.). Some of these application areas benefit most from models that privilege generalizability and average predictive accuracy over explanatory depth. If, on the other hand, the goal is to develop a descriptive theory of human decision behavior, we would be better served by a model that is able to account for and articulate structural regularities in inter-individual behavioral variability. A first step toward this requires demonstrating the existence of clusters of decision-making strategies corresponding to different behavioral phenotypes within a well-defined space of quantifiable features. Once such behavioral phenotypes are established, it would be possible to explicitly parameterize them in a descriptive model aimed not only at generality or prediction, but also explanatory depth and sensitivity to meaningful inter-individual variability.

To assess the existence of different risk related phenotypes we analyzed data (N=450) from a choice prediction competition (Erev et al., 2017). Each participant was presented with 30 decision problems, and each decision problem was presented 25 times. The decision problems were binary choices between a safer option (A) and a riskier option (B) that varied in magnitude and probabilities. The first 5 trials were presented without feedback and the last 20 trials with complete feedback reflecting the true outcome probabilities, allowing us to assess the effect of recently received feedback on subsequent decisions. We fit individual-level linear models to quantify the influence of different predictors, such as the difference in prospect magnitudes, probabilities and recently obtained outcomes. These participant-level coefficients indicated that participants were overall risk-averse, and that their choices were determined by the described probabilities and magnitudes, as well as the obtained outcomes. We subsequently performed Gaussian mixture distribution clustering on the participant-level coefficients, revealing that the dataset was best explained assuming four clusters. One cluster can be said to represent ‘rational’ participants that take into account all declared features and neglect recently obtained and forgone outcomes. The other clusters are composed of apparently irrational participants that differ in the features that they take into account.

To summarize, our results demonstrate that strategies for decision making under risk significantly vary across participants. The results are consistent with a heuristic model of multi-attribute choice where some participants compare features individually to make their decisions.

[Poster # 77]
**CONTEXT-DEPENDENT VALUE COMPUTATION IN MORAL DILEMMA: AN fMRI INVESTIGATION**

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**Introduction:** A moral dilemma describes a conflict situation where people are confronted with two incompatible options which cause different moral consequences so that neither choice is perfect. Previous studies focused on dilemma involving a conflict either between one-self and others (e.g., earning money at the expense of other’s suffering; i.e., the self-other dilemma, S-O) or between two other-relevant consequences (e.g., sacrificing one person to save five lives; i.e., the other-other dilemma, O-O). Yet, it remains unclear how value computation is performed in these two contexts of moral dilemma and whether it engages similar brain systems regardless of the context. To investigate this question, we designed a novel, incentive-compatible paradigm by using fMRI in together with computational modeling.

**Methods:** Participants (N= 40) were provided with a series of offers involving two beneficiaries. Specifically, accepting the offer would always lead to an immoral consequence (i.e., bringing monetary profits for a pre-
selected morally-negative organization that endorse gun holding or hunting). In contrast, accepting the offer would either bring monetary profits to themselves (i.e., the S-O dilemma) in half of the trials, or to a preferred charity (i.e., the O-O dilemma) in the other half. If they rejected the offer, neither beneficiary would benefit. To better estimate people’s moral preference, we varied the payoffs orthogonally for each beneficiary involved in an offer across trials.

Results: Participants were more likely to accept offers in the S-O (vs. O-O) dilemma after controlling the payoff. Computational model-based analyses further demonstrated that participants weighted more negatively the payoff of the morally-negative organization in the O-O (vs. S-O) dilemma. The neuroimaging results revealed that value signals were observed in ventral medial prefrontal cortex (vmPFC) and the dorsal anterior cingulate cortex (dACC) during the decision-making period in both dilemma contexts. However, the ventral striatum (VS) displayed stronger sensitivity to the modulation by the gain for participants themselves relative to that for the charity. Moreover, individual difference in moral preference, characterized by the relative weights for the charity gain to the self-gain (both vs. morally-negative organization), modulated the context × decision interactive signals in bilateral inferior parietal lobule (IPL). An explorative general psycho-physiological interaction (gPPI) analysis further revealed the role of moral preference in affecting the functional coupling between left IPL and right lateral prefrontal cortex (LPFC) during accept (vs. reject) choice in different dilemma contexts.

Discussions: Our results showed that people’s decision can be modulated by the dilemma context, although it seems that costs and benefits are integrated in a similar fashion by the valuation system (i.e., vmPFC, dACC) across dilemma contexts. Moreover, the inter-individual behavior-brain correlation indicated that the moral flexibility across participants modulates behavioral responses to different dilemma contexts via the fronto-parietal control network. In summary, these findings extended our understanding of the neurocomputational mechanisms underlying how people weigh pros and cons in different moral dilemma.

[Poster # 78]
Gambling When Sleep Deprived: It Depends on You!

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Introduction: Total sleep deprivation (TSD) impairs various cognitive processes (Krause et al., 2017). Among them, decision-making in ambiguous/risky situations (IGT, Bechara et al., 2005 and BART, Lejuez et al., 2002) is also disturbed but with higher TSD protocol (at least 49 hours of continuous wakefulness for Iowa Gambling Task-IGT or 75 hours for BART; Killgore et al., 2006; McKenna et al., 2007; Killgore et al., 2011). The purpose of our study was thus to test risky decision-making deficits related to shorter TSD protocol (32 hours of wakefulness) but with taking into account individual responses (risky/secure profiles).

Methods: 16 healthy right-handed subjects (27.3±5.4 years) with a normalized body mass index (23.0±2.3 kg.m⁻²) and an intermediod chronotype participated in a TSD design (3 days). This TSD design included a baseline night (8h time in bed: 11pm-7am) and day (Day 1-BAS, 7am-12pm), a TSD period of 40 hours of wakefulness (TSD: from Day 2, 12pm to Day 3, 11pm) and a recovery night (8h TIB) and day (Day 3-REC: 7am-11pm). Risky/Ambiguous decision-making was evaluated using the IGT task (100 choices divided into 5 blocs of 20 choices). Test sessions (around 8 min.) were repeated 3 times at the same time of day (BAS at 3pm; TSD at 3pm; and REC at 3pm).

Results: Statistical analyses revealed bloc effect (F(4,60)=2.97; p<0.05), but no Day effect (F(2,30)=0.17; p>0.83) and no interaction (F(8,120)=0.69; p>0.69). When individual responses based on last choices during baseline (IGT-Bloc 5; p=0.001) were taking into account (Low Riskier-LR and High Riskier-HR subgroups), ANOVA analyses showed no bloc effect (F(4,56)=0.60; p>0.66) but a Day effect (F(2,28)=7.56; p<0.01) with an interaction (F(8,112)=2.45; p<0.05). Post-Hoc analyses revealed that for LR subjects, choices during bloc 4 and 5 (20 last choices) are significantly riskier during TSD and REC compared to BAS (respectively: p<0.05 and p<0.01 for bloc 4 and p<0.001 and p<0.001 for bloc 5) whereas for HR subjects choices during bloc 4 and 5 (20 last choices) are significantly more secure during TSD (p<0.05 for bloc 4 and 5) and to a lesser extent during REC (p<0.01 for bloc 4 and p>0.29 for bloc 5) compared to BAS.

Conclusions: These results would indicate that a TSD of 32 hours of continuous wakefulness differentially disturb decision-making processes in ambiguous situations related to individual profile at baseline (Low versus High riskier subjects) suggesting opposing processes. Our results are in accordance with previous observations (Killgore et al., 2006; Killgore et al., 2012) and revive the question of individual vulnerability of decision-making processes related to sleep loss.

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[Poster # 79]
**Drift diffusion modelling reveals decision-making mechanisms underlying inattentive behaviour in term and preterm children**

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Objective: Children born very preterm are at increased risk of ADHD symptoms, including inattention, but it remains unclear whether the mechanisms underlying inattention are the same as in their term-born peers. Slower and more variable processing speed, as measured using speeded reaction time (RT) tasks, is frequently reported in ADHD and may also be related to inattention in preterm children. Traditional RT measures are limited in the information they provide. This study used the drift diffusion model (DDM), which uses intra-individual variability in RT and accuracy across trials to better isolate underlying cognitive decision-making processes, to compare the mechanisms underlying inattention in very preterm and term-born children.

Method: 33 children born very preterm (≤32 weeks gestation) aged 8-11 years were recruited. A comparison group of 32 term-born peers (≥37 weeks gestation) matched to the very preterm group on inattention symptoms using the parent-rated Strengths and Weaknesses of ADHD and Normal behaviour (SWAN) questionnaire was selected. Performance on a cued continuous performance task was modelled using a DDM. A hierarchical multiple regression guided by correlational analyses was used to assess whether traditional or DDM parameters explained variance in parent-rated inattention (SWAN scores) and whether these relationships differed between preterm and term-born children.

Results: There were no group differences in performance on traditional or DDM parameters. SWAN scores correlated significantly with hit rate, response time variability (SD RT), and the DDM parameter drift rate in one or both groups. However, the regression analysis revealed that drift rate was the only significant predictor of inattention. This relationship did not differ between groups.

Conclusions: In both groups, higher levels of parent-rated inattention were best predicted by a slower drift rate, suggesting that slower evidence accumulation, or processing speed, may be a common mechanism underlying inattention in both term and preterm children. The importance of processing speed was not evident using the traditional metric, response time, thus this study demonstrates the benefits of using DDM to better characterise cognitive impairment in clinical samples.

[Poster # 80]
**Probing the dimensionality of value representation across the prefrontal cortex**

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Animals often act as if maximizing an objective reward function. Common theories assume that animals use a running average over past experiences to predict the value of an action. However, the use of such summary statistics comes at considerable cost: even when required, the animal cannot flexibly reweight the attributes to make optimal choices. Thus, memory of stimulus attributes ranges on a continuum from perfect knowledge of all values (multivariate code) to a summary statistic (univariate code). However, little is known about which part of this continuum different brain regions occupy. The ventromedial prefrontal cortex (vmPFC) has been implicated as a value comparison region and could thus support the univariate case, whereas the orbitofrontal cortex (OFC) is involved in the learning of attributes that were not currently relevant, thus potentially supporting the multivariate case.

Here, we present a task using human fMRI in which participants first learned the bids of two potential buyers (the value attributes) for a number of cars. Subsequently, participants progressed through a series of markets in which they chose one of two cars to sell. Importantly, the optimal weighting of bids changed such that in some “single” markets only one buyer was available, whereas in some “mixed” markets the buyer was unknown, thus requiring participants to average potential value attributes.

Participants performed well in all three markets, choosing the higher valued car most of the time, indicating a multivariate value code. Logistic regression analyses revealed that their choices in the single markets were biased by the currently irrelevant attribute. This deviation from optimality was best explained by a partial normalization model, whereby remembered car values scaled with the relative difference between the two
attributes. This led to a loss in choice precision that was greatest for cars at the high and low end of the value spectrum. In addition, vmPFC and ventrolateral PFC both scaled negatively with the irrelevant bid in a choice-independent fashion. The vmPFC also encoded the difference between the chosen and unchosen values in the relevant attribute. Taken together, these findings support a partial multivariate value code in the vmPFC.

Further analyses revealed that value representation in the lateral orbitofrontal cortex was invariant across markets, whereas vmPFC and dorsal anterior cingulate cortex employed a value code more closely related to the currently relevant attribute, albeit distorted by the irrelevant attribute.

[Poster # 81]
**STN DBS, not L-DOPA, restores the contextual regulation of perceptual decisions**

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Perceptual decision-making can be described as a process by which sensory evidence is accumulated until a decision threshold (DT) is reached. This DT is adaptively tuned to its context, such as the probabilistic regularities of the environment. Here, we consider two types of contextual information: (1) the predictive information, which is the log probability ratio of an event occurring given a previous event, relative to its frequency and (2) the contextual uncertainty which is the prior entropy over an events’ occurrence given a previous event. This study aims at specifying how patients suffering from Parkinson’s disorder (PD patients) adjust their DT to contextual information compared to healthy matched controls (HC) and how does levodopa (L-DOPA) treatment affect this adjustment compared to deep-brain stimulation of the subthalamic nucleus (STN-DBS).

14 PD patients performed a simple perceptual decision making task under 4 pseudo-randomly ordered conditions: ON or OFF L-DOPA treatment and ON or OFF STN-DBS. 31 HC subjects also performed the task once. In the task, the subjects pressed a button to match the shape presented on screen. Transitions between were controlled to systematically manipulate contextual information. The electroencephalography of patients was also recorded during each condition.

Performances were lower in PD patients compared to HC only when they were ON L-DOPA, irrespective of whether STN-DBS was ON (HC vs. PD patient L-DOPA ON+STN-DBS ON: t(35) = 3.57, p = .0021) or OFF (HC vs. PD patients L-DOPA ON+STN-DBS OFF: t (35) = 3.57, p = .001). Unsurprisingly, PD patients’ reaction times (RTs) were slower compared to HC regardless of treatment (HC vs. PD patients L-DOPA ON+STN-DBS ON: t(35) = 7.13, p < .0001). L-DOPA reduced both PD patient’s RTs (F (11) = 129.73, p < .0001) and performance (F (11) = 7574.2, p < .0001), suggesting a shift in the speed-accuracy trade-off. This deleterious effect was significantly limited with STN-DBS, both in performances (F (11) = 8201.5, p < .0001) and RTs (F (11) = 101.75, p < .0001).

As expected, RTs in HC decreased with predictive information (Z = 4.076, p < .0001) and increased with contextual uncertainty (Z = 129.73, p < .0001). There was no significant effect of predictive information nor of contextual uncertainty on RTs of untreated patients. When patients were ON L-DOPA + OFF STN-DBS there was no effect of predictive information on RTs but a significant increase of RTs with contextual uncertainty (Z = - 2.353, p = .018). However, the contextual uncertainty effect was significantly smaller than HCs (Z = 2.417, p = .016). The effects of both predictive information (Z = 2.746, p = .006) and contextual uncertainty (Z = - 2.275; p = .023) on RTs was restored when patients were OFF L-DOPA + ON STN-DBS and there was no more significant difference in the effects compared to HCs.

In conclusion, these preliminary behavioural results suggest that L-DOPA treatment has a deleterious effect on simple perceptual decisions causing a shift of the speed-accuracy trade-off toward impulsivity, which is somewhat rectified by STN-DBS. Moreover, the use of contextual information (both predictive information and contextual ambiguity) is deteriorated in untreated PD patients but this impairment is fully rectified through STN-DBS, but not L-DOPA.

[Poster # 82]
**Slow touch targeting C-tactile fibres does not increase prosocial behaviour in economic laboratory tasks**

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Field studies have demonstrated that humans become more generous, helpful and compliant after having been touched by another person (Gallace & Spence, 2010). Here, we explored whether these effects are larger for touch activating the C-tactile (CT) fibres, as it is ascribed a particular role in establishing and maintaining bonds and affiliative interactions (McGlone, Wessberg, & Olausson, 2014). The role of CT-
targeted and non-targeted touch on prosocial behaviour was investigated in three different experiments using a repeated trust game (Berg, Dickhaut, & McCabe, 1995) and a task measuring individual differences in social value orientations (the SVO task [Murphy, Ackermann, & Handgraaf, 2011]). Whereas participants in general acted prosocially, there was no influence of CT-targeted touch on prosocial behaviour, both in comparison to non-CT-targeted control touch and visual (non-tactile) stimulation. The null findings were further corroborated by Bayesian statistics. Thus, under the controlled laboratory conditions employed, CT-targeted touch did not play a particular role in prosocial behaviour. This indicates that touch does not increase prosocial behaviour in the absence of meaningful social and psychological connotations. Any touch related effects on prosocial behaviour likely depends on the ecological validity of the situation.

References

[Poster # 83]
CHILDREN’S TENDENCIES TO SUSTAIN COOPERATION DURING SOCIAL AND NON-SOCIAL EXCHANGE RELY ON DISTINCT COGNITIVE MECHANISMS

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Introduction: Establishing trust in repeated social interactions represents an integral part of prosocial development during childhood (e.g., developing close, dyadic friendships). Social exchange (i.e., cooperation with a real partner) may represent a unique process that not only depends on the partner’s level of adaptivity, but also on the very fact that the partner is perceived as a peer (i.e., a human with similar goals). Given that reinforcement learning (RL) models offer a robust framework for learning in social and non-social settings and have been successfully extended to describe developmental changes in learning, RL models may reveal differences between children’s tendencies to sustain cooperation with a peer vs. non-social computer partner. Using a developmentally appropriate version of the trust game, we tested whether RL models and simpler non-learning strategies could differentiate between children’s tendency to sustain cooperation in a repeated economic game (i.e., trust game).

Methods: Children (n=25; age=12 (SD=2.6)) were paired up with a peer (matched for age, sex and IQ). Children did not know each other before the visit. After a brief introduction, they participated in multiple rounds of the trust game. Participants were told that they would sometimes play with their human partner and sometimes with a computer algorithm. In fact, they only played with their human partner once. We ensured that all children understood that, as an investor, they could either keep five coins or share any amount (1 to 5 coins) with their partner on each trial. Investors shared more in the social compared to the non-social conditions and they shared similar amounts when playing with the real human vs. when thinking they played with the human, but in fact played with an adaptive computer algorithm. Children were also more forgiving, re-initiating cooperation more often, after the trustee defected in the social conditions compared to the computer conditions. Bayesian model comparison shows that the decision to trust and sustain cooperation in the social and non-social conditions (in conditions that only differ in the information given to the child) relies on different strategies. While an RL model outperformed fixed strategies in the non-social condition, a simpler tit-for-tat strategy described behavior of children more accurately than RL in the social condition.

Conclusions: Our results indicate that a computational modeling approach can detect selective social strategies for establishing trust and cooperation between children in multi-round economic games.

[Poster # 84]
LEARNING ABOUT SELF-PERFORMANCE IN THE ABSENCE OF FEEDBACK

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Accurately evaluating the outcome of our decisions is essential to adaptive behavior. Thus, learning from external feedback over time has been extensively studied. However, in real life, immediate feedback is often lacking, and much less is known about the computational mechanisms underlying learning in this case. Previous work on metacognition has focused on mechanisms supporting “instantaneous” metacognitive evaluations, elicited at or around the time of a particular decision, showing for instance that subjects can detect performance errors, and be appropriately confident in their decisions. In contrast, it remains poorly understood how people aggregate confidence over time to build “global” beliefs about performance. For instance, when estimating our skill level at a sport, we may reflect on our performance over multiple games, gradually forming a belief about our ability.

Here we developed a novel behavioral paradigm to investigate how subjects learn about self-performance over time, and specifically to assess whether internal confidence may serve as a learning signal in the absence of feedback. In short learning blocks, human subjects (N=29) performed two perceptual tasks (interleaved trials). Each pair of tasks was chosen according to a 2 by 2 factorial design crossing task difficulty (easy, difficult) and feedback (present, absent). At the end of a block, we measured subjects’ beliefs about their performance in each task (self-performance estimates, SPEs), either indirectly (by asking them to choose which task they think they are better at) or directly (via confidence ratings). We found that objective task performance and reaction times were similar in the presence and absence of feedback. Strikingly, however, participants showed substantially lower SPEs in the absence of feedback. We replicated these findings (N=29 new subjects), whilst also varying the length of each block to assess effects of learning duration on SPEs. Notably we found that performance on a given block (both in the presence and absence of feedback) influenced end-of-block SPE’s, indicating subjects were sensitive to local fluctuations in performance over and above objective difficulty level.

To explain the formation of subjects’ SPEs, we developed a hierarchical learning model which updates global beliefs about self-performance based on locally computed confidence estimates. Initial model simulations and model comparison suggest that local confidence may act as a learning signal in the absence of feedback, allowing subjects to develop insight into their abilities. In a final experiment (N=34), we sought to assess directly whether local confidence affects global SPEs over the course of learning. On trials in which feedback was not provided subjects were instead asked to provide a local confidence estimate. We found that the greater the difference in local confidence between a pair of tasks, the greater the difference in end-of-block SPEs, supporting this link. Our findings build a bridge between literatures on metacognition and learning, and support a functional role for confidence in higher-order behavioral control.

**[Poster # 85]**

**INFERRING THE BELIEFS OF OTHER AGENTS IN INTERACTIVE COOPERATIVE DECISIONS**

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Mentalizing refers to the human capability of explaining and predicting the behavior of others by ascribing mental states like desires, attitudes and beliefs. In classic tasks investigating mentalizing capacities, participants are presented with a social situation in form of a story and are asked to predict the behavior of the interacting agents in the story. Thereby, participants hold a purely observant position and their predictions are inconsequential to the social situation. However, cognition differs fundamentally during direct interactions when actions of interacting agents are relevant to each other: To successfully interact, humans need to continuously model other peoples’ mental states. Furthermore, when rewards of interacting agents depend on each other’s actions, these models can take a recursive form similar to: “Agent A thinks that agent B believes X”, and so forth.

To investigate these cognitive processes in an ecologically valid setting we designed an interactive cooperative decision task, which requires that participants continuously model mental states of their partners and incorporate these models into their decision making process. Two individuals engage in a simple choice task, in which probabilistic outcomes that also depend on the partner’s choice have to be learned. Cooperative choices are highly rewarded. After periods of successful cooperation one player’s (the Learner’s) outcome distribution is reversed, but only the other player (the Teacher) is informed about the reversal. The Learner thus has a false belief about the state of the world. To maximize the reward, the Teacher must track how the Learner’s false belief evolves over time and make choices to “communicate” the contingency switch to the Learner. During each trial, both players make explicit predictions of their partner’s choices before making their own.

The participants’ behavior shows that they continuously track their partner’s mental state and adapt their choices to it: In line with the Learners’ false belief, the Teachers initially predict unchanged behavior for the
Learners but switch their own choice. Furthermore, even though the Teachers’ predictions stay unchanged, their reaction times are strongly increased, suggesting more complex reasoning and decision processes. The resulting switches by the Teachers inform the Learners about their own contingency reversal. The Learners detect the Teachers’ signals and adapt their prediction about the Teachers’ choices accordingly. After accumulating enough evidence, the Learners react to the new reward distribution and adjust their choices. The Learners’ decision curves are accurately predicted by the Teachers. Moreover, Teacher-Learner prediction accuracy correlates with the player’s winnings in the task, indicating that accurate representations of a partner’s beliefs are beneficial in social interactions.

To investigate these processes in more detail, we model the participants’ behavior with an Interactive Partially Observable Decisions Process (I-POMDP). POMDPs map rational agents’ beliefs about uncertain environments to actions based on their preferences within an environment. Interactive-POMDPs allow agents not only to form a model about the non-social world, but also to build intentional models of other agents to predict their behavior. As in POMDPs, agents maintain beliefs about the non-social environment. However, additionally they retain “interactive beliefs” about other agents, including their preferences, actions, capabilities and beliefs. The other agents within the environment might also hold intentional models on their own, allowing for recursive mental models. By applying I-POMDPs to this data we can accurately predict the participants’ behavior and trace their representation about their partner’s mental state over time, providing us with a more detailed understanding of cooperative decisions during human interactions.

[Poster # 86]

**Timing of attribute recognition and influence on multi-attribute value-based decisions**

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Background: Neuroeconomics has provided evidence that the overall subjective value of options is represented in specific frontal and striatal regions, and that those signals can predict choice. Typical real-life decisions involve options made up of multiple attributes. The brain mechanisms by which individual attributes come to influence global subjective value are unknown. Recent work has suggested that individual attribute representations (e.g. in perceptual brain regions) influence global value-related signals in the frontal lobes, and may do so with different timings, depending on the perceptual circuits involved. Here, we present two studies that aim to further define the timing of attribute processing and attribute influence on value-based choice.

Methods and results: Experiment 1 tested the effects of exposure time on recognition of three different attributes of foods (still photos): taste, healthiness and aesthetic beauty. Healthy young participants were reliably better than chance at picking the option they had previously rated higher for a given attribute with 51ms exposure time. Recognition performance improved somewhat with longer exposures, plateauing for times > 85 ms, with the pattern the same for all 3 attributes. In Experiment 2, we asked whether the influence of these attributes on value-based choice varied with exposure time, and with decision context. Both context and exposure time influenced the weighting of attributes.

Conclusions: We find that attributes as diverse as taste, health and beauty are recognized equally well based on brief stimulus exposures. However, the degree to which these attributes influence value comparison varies with exposure time. Attribute influence on choice seems to be determined mainly by decision goals rather than differences in the relative availability of attribute information during stimulus processing. These results have implications for brain-based models of how evidence is accumulated to support value assessment and choice.

[Poster # 87]

**Gut-brain interaction: exploring the link between bodily states and decision making**

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The prevalence of obesity is increasing at alarming rate, yet very little is known about how behavioral factors might be implicated in weight gain. Recent animal studies demonstrated that the neurobiological control of food intake implicates adaptations in the brains dopamine (DA) system. In fact, at a cellular level, motivational drive is dependent on the concentration of DA that is tightly regulated by metabolic signals relating to body states both in short term (nutritional status, hunger) as well as in the long run (fat reserves). This raises the question of how decision making might be influenced by bodily state.
In a series of experiments, we study the relationship between parameters of body composition, energy state, and cognitive traits in a group of healthy participants (N=120). In addition to a battery of questionnaires, all individuals carried out behavioral tasks to assess their impulsivity (stop signal task), incentive motivation (force task), and risk taking (fortune wheel), respectively, for monetary and food rewards. Furthermore, individuals were asked to come to the lab fasted overnight, and underwent a series of anthropomorphometric measurements to assess their body weight and composition. Our results show that both body composition and fasting duration have differential effects on motivation and impulsivity scores. More precisely, we find that higher body fat percentage is associated with lower motivation, irrespectively of the outcome (p<.001). Also, fasting increased the impulsivity for food relative to monetary outcomes (p<.001), an effect especially pronounced in leaner individuals (p<.05). Collectively, our results indicate that decision making and energy balance are more intricately coupled than previously thought and provide further impetus for studying the bidirectional relationship between body state and decision parameters.

**[Poster # 88]**

**TRADING OFF THE COST OF CONFLICT AGAINST EXPECTED REWARDS**

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Adaptive behaviour requires the continued monitoring of action and its outcomes, to detect conflicts and correct behaviour accordingly. Conflict is considered aversive, and is typically avoided: people may choose easier tasks, or be biased by external suggestions. Conflict has also been shown to reduce the perceived control over action outcomes, and alter the perceived valence of subsequent events. Yet, it remains unclear whether external information could influence goal-directed decision-making, and whether response conflict could impact instrumental learning. The present study investigated these questions by embedding irrelevant flankers within a reversal learning task, with intermixed free and instructed trials. Results showed that participants learned to adapt their choices to maximize rewards. Nevertheless, participants were still biased by flanker stimuli, and were more likely to choose to follow, than to go against, the flankers’ suggestions. The perceived cost of being in conflict with an irrelevant suggestion can sometimes trump the evaluation of internal value representations. Adapting computational models of reinforcement learning allowed us to assess the influence of response conflict on the decision and on learning. Modelling results showed that the cost of conflict was traded-off against expected rewards, such that conflict was avoided when evidence for the conflicting option was weak. Turning to the learning phase, we found that free choices were associated with higher learning rates than instructed choices. However, there was no robust evidence for an influence of response conflict on learning. Our results show that external information can interfere with value-based decision-making, but may not affect instrumental learning.

**[Poster # 89]**

**IT’S NEW, BUT IS IT GOOD? HOW GENERALIZATION AND UNCERTAINTY GUIDE THE EXPLORATION OF NOVEL OPTIONS**

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How do people decide whether to try out novel options? We argue that they utilize contextual information to efficiently generalize from learned functional relations in order to decide between known or novel options. In a contextual multi-armed bandit task, in which rewards are a noisy function of observable features, we assess participants’ preferences for newly introduced options. We show that participants preferably choose a novel option if its features indicate high rewards, but shun the option if its features indicate low rewards, a behavior that can only be explained by functional generalization. Moreover, we assess people’s preferences for novel options that have medium rewards to test whether they prefer options less similar to experienced options, consistent with choices guided by uncertainty. Given that novel options normally come with observable features, we argue that contextual learning is a parsimonious yet powerful explanation of behavior in the face of novelty.

**[Poster # 90]**

**INTERACTION BETWEEN THE LIMBIC AND SENSORI-MOTOR CORTICO-BASAL LOOPS: A SYSTEMIC FRAMEWORK TO EXPLAIN ANIMAL BEHAVIOR**
We propose an integrated framework of interaction between cortico-basal loops, described as the projection of specific regions of sensory and frontal cortex, experimentally observed to be involved in the generic functioning of decision making and action selection of a primate [Alexander et al., 1986]. These loops, acquiring stimulus information and possible actions, project towards respective regions of the striatum and connect back to the initial frontal areas to trigger the selected action. We implement a framework of such cortico-basal loops, adapting a well established neuronal model proposed in [Hazy et al., 2006], as a set of two limbic loops and two sensori-motor loops. Two limbic loops include (i) a preferential loop through the Orbito Frontal Cortex (OFC, widely understood to represent states of the environment and their learned preference value) and (ii) a motivation-guided loop through the Anterior Cingulate Cortex (ACC), influencing the decision with the agent's internal needs and motivation. Two sensori-motor loops consist of (i) an orientation loop through the Parietal Cortex to orient towards the chosen stimulus and (ii) a motor loop through the supplementary motor area to evoke an action to reach the stimulus that is oriented towards.

We study the dynamics of hierarchy and competition among these cortico-basal loops, with stronger emphasis on the role of internal emotional characteristics (goal-driven behavior) and the external stimuli characteristics (stimulus driven behavior) in the decision. We take into account the distributed consensus among the loops depending on the dynamic situation [Pezzulo and Cisek, 2016], role of neuromodulation and learning across these loops and the role of external world. For experimentation, we demonstrate how a virtual agent, considering a survival task, can interact with an unknown and dynamic external environment. We use Malmo (Johnson et al., 2016), a platform on the top of Minecraft (the well-known immersive world game) to evaluate the framework and explore realistic scenarios that mimic survival tasks.

References

[Poster # 91]
Depression affects reinforcement learning in a context-dependent manner
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The core clinical symptoms of depression include anhedonia, defined as reduced motivation to engage in daily life activities (motivational anhedonia) and reduced enjoyment of usually enjoyable activities (consummatory anhedonia). This feature could be explained by reduced reward processing in these patients12. A direct prediction of this hypothesis is that depressive subjects should display reduced reward sensitivity at both the behavioral and the neural level in the reward-learning context. However, while some studies did find evidence of blunted reward learning and reward-related signals in the brain, others indicate no effect, empirical evidence failed to provide strong and robust evidence of this hypothesis. Here we hypothesized that such inconsistencies may at least be explained by the fact that reinforcement learning impairment in depression is dependent on the context value of the decision problem.

To test this hypothesis, we designed a new variant of a classical two-armed bandit task that include two different contexts, while keeping their difficulty constant. The task included a ‘rich’ environment where both options where associated with an overall positive expected value (90% and 60% of gain rate) and a ‘poor’ environment where both options were associated with overall negative expected value (60% and 90% of loss rate). We tested N=31 patients undergoing a major depressive episode and N=26 age, gender and socio-economically matched controls.

At the individual level, the correct response rate in the learning session was analyzed with a general linear model approach with trial number, context value (rich vs. poor), and their interaction as predictors. Between-group comparison indicated that baseline correct response rate was the same in the two groups (t(55)=-
0.1592 p=0.8741), while the effect of the context value was significantly different between patients and controls (f(55)=-2.4962, p=0.0156). More precisely, the effect of valence was significantly different from zero only in the patients group (f(30)=3.4201, p=0.0018), translating the fact that patients performed better in the ‘rich’ compared to the ‘poor’ environment.

To assess whether this context-induced reinforcement deficit in patients was due to a decision or a value-update process, we analyzed performance in a transfer test, performed immediately after the learning test, where we asked to indicate the most rewarding option in all possible combinations. Crucially, in order to not modify the option value during the transfer test, we did not present the trial-by-trial feedback at this stage. Analysis of the transfer test confirmed a context-value induced deficit in patients that generalized when the options were extrapolated from their original context.

To conclude, our results illustrate the reinforcement learning deficits in depression are complex and depend on the context-value of the decision problem. In particular we show that depressive patients have a specific trouble in environment with an overall negative state value.


[Poster # 92]

LEARNING BY OBSERVATION OR THROUGH ACTION? BEHAVIORAL AND NEURAL CHARACTERIZATION OF COGNITIVE PROCESSES UNDERLYING CUE-BASED AND OUTCOME-BASED INFERENCES

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Beside obvious differences in input, perceptual and outcome-guided decisions diverge in the degree of control conferred to the decision-maker in the sampling of external cues. We thus asked whether humans learn differently from the same uncertain cues when the cues in question are sampled either as external cues as in perceptual decisions, or as the outcome of an action as in outcome-guided decisions. We designed a probabilistic reversal learning paradigm with two conditions, in which the same oriented stimuli can correspond either to samples of a generative category (A or B) which subjects have to infer (‘cue-based condition), or to outcomes of an action-to-category mapping rule (e.g., A if left and B if right) which subjects have to infer (‘outcome-based condition). Importantly, the two conditions are matched in terms of all task parameters and all latent variables predicted by an optimal decision-maker modeled using Bayesian inference that seeks to identify the most probable cause of observed events, whether sensory cues or action outcomes (Wyart and Koechlin, 2016). (Drugowitsch, Wyart et al., 2016). Non-invasive electromagnetic neural signals were collected in magneto- and electro-encephalography (MEEG) while 24 healthy subjects performed the task.

Behavioural analysis showed slower learning curves (p < 0.001), a stronger need for disconfirming evidence (p < 0.001) for subjects to change their mind along with a greater reliance on previous decision in outcome-based condition, but with no differences in sensitivity to evidence provided by cues (p > 0.2). Computational modeling of behavior indicated that subjects perceived the cues as more predictable and the environment as more stable in outcome-based condition. Multivariate analyses of magnetoencephalographic (MEG) brain signals revealed shared neural representations of stimulus and latent variables predicted by the inference process in the two conditions with a different representation of individual cues in relation to their inferred cause - a dynamic coding relative to the strength of internal belief about the ongoing state of the environment which accounted for the behavioral and computational results. We link this binding of evidence relative to it inferred cause with a specific right parahippocampal and left precuneal activity (p < 0.001), representative of the strength of the internal belief. Furthermore, changes of mind were associated with a stronger recruitment of the dorsal attention network during outcome-based inference.

Together these findings are strong support for the use of a single neural algorithm in both conditions with a different instantiation of forward causal predictions, due to parahippocampal and precuneal activity, resulting in a stronger influence of prior belief and higher perceived environmental stability when humans learn about its structure through action rather than by observation.
Planning, in behavioral and neural sciences, is viewed as a mental simulation of the environment that foresees the potential consequences of different courses of actions. Previous research has demonstrated indirect signatures of forward planning where, starting from the animal's current state, a decision-tree is expanded in a forward fashion. Other behavioral evidence suggests backward planning where, starting from a goal state, a tree is expanded in a backward fashion until it reaches the animal's current state. Artificial intelligence literature, however, proposes bidirectional planning as a powerful solution to the curse of dimensionality. We propose a novel behavioral paradigm that measures whether humans, within a single decision problem, expand both a forward and a backward tree and by finding where the two trees meet, discover a path (i.e., a sequence of actions) for reaching the goal state from their current state. Our preliminary results show that humans indeed use a bidirectional planning strategy in a complex decision environment where using forward-only or backward-only strategies is more cognitively demanding than using bidirectional planning.

Methods: During an initial training phase, participants learned the friendships in a social network of 20 celebrities, where every person has exactly three friends (the left panel). On each trial of the training phase, one person (randomly selected) was shown in the middle of the screen, and then his/her three friends were shown around him/her, in randomized positions. Participant continued this training phase until they reached a 95% accuracy in reporting the three neighbors of each person.

On each trial of the test phase (right panel), participants were asked to go from one person to another, passing through the social network (e.g. from s1 to g2). They were told the shortest path always has exactly three people in the middle, and that the solution is unique. They were also instructed that they could, if they wanted, choose (by mouse click) any of the 7 color bars on the right, and mark whoever person they wanted, just as a helping tool to ease their thinking process.

Results: 14, out of the total 18 participants, in more than half of their test trials, started each trial by first marking the three neighbors of the starting point with one color, and then the three neighbors of the goal point with a different color, or vice versa. We interpret this marking pattern as a very strong evidence for bidirectional planning. Further statistical analysis is being done. We also developed a theory (drift-diffusion model) which shows that bidirectional planning is the optimal strategy in this specific map, in terms of both speed and accuracy.

The prospect of reward enhances cognitive control, suggesting that control is regulated by cost-benefit decision-making [1,2]. While the nature of cognitive effort costs remains unresolved, one account holds that costliness reflects opportunity costs incurred by allocating precious control resources [3]. In turn, costliness discourages intensive control so that resources remain free to pursue alternative opportunities. This hypothesis motivated the seemingly paradoxical proposal that high average reward rates implying high opportunity costs should reduce cognitive control [4] via the same mechanisms by which high average reward (encoded in striatal dopamine tone) promotes physical vigor [5]. While recent data supports this prediction in the context of a Simon task, where high average reward drives faster and less accurate responding [6], it is also possible that such results reflect strategic adjustments rather than reduced control per se. That is, perhaps control is recruited strategically to maximize opportunities, when opportunity costs are high, rather than reduced reflexively. Moreover, it is also unclear whether high dopamine tone tracking high average reward can influence which actions are selected, or simply increase action invigoration generally [7]. To address these questions, we describe on-going work to investigate whether average reward rate manipulations over trials alter proactive control in the context of the AX-CPT, where participants have time to recruit control strategically. Preliminary results confirm prior findings that high average reward induces response vigor, and yet also find evidence that high average reward may also increase proactive control strategically. That is, rather than reducing control globally, participants may use information about opportunity costs to optimize allocation of resources, depending on local reward statistics.

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The ability to overcome time and effort costs is an important predictor of higher education and professional success. This ability has been related to the intervention of the executive control network, including lateral prefrontal and parietal regions. Recently, it has been shown that fatigue of the executive control system leads to an increased preference for immediate rewards, over larger but delayed rewards (Blain, Hollard, & Pessiglione, 2016). However, the executive control system may also involved in the choice process itself, ensuring precise selection of the best option. We thus tested whether executive fatigue would specifically change the preference about options (i.e., exert a bias on which option is selected) or change the amount of control exerted on the choice process itself (i.e., altering the accuracy of decision-making).

To better dissociate these two possibilities, we compared the effects of executive fatigue and time pressure, in two separate experiments. In both experiments, participants made choices between no-cost options (immediate, sure and free rewards) and costly options (delayed rewards, probabilistic rewards and rewards in exchange for performing an effort, either cognitive or physical). In the first experiment (n=24), we induced executive fatigue in participants by 6 hours of difficult executive control tasks (working memory and task-switching). In the second experiment (n=27), participants had to make the same choices with and without time pressure (timeout set at 70% of self-paced response time). Choice behavior was fitted with standard discounting models including 3 parameters (bias toward no-cost option, weight on cost level and choice stochasticity).

Comparison of fitted parameters revealed distinct effects of executive fatigue and time pressure. Executive fatigue increased the bias towards no-cost options (without affecting choice accuracy), when opposed to delayed and effortful options. By contrast, time pressure increased the choice stochasticity (without affecting choice preference), for all types of options. Thus, we conclude that executive fatigue changes preferences about time and effort, but does not disrupt the choice process itself.

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From foraging for food to learning complex games, many aspects of human behaviour can be understood as a search problem with a vast space of possible actions. Under finite search horizons, optimal solutions are
generally unobtainable. Yet how do humans navigate the vastness of real-world state-spaces, where the key question is not only “when” but also “where” to explore? One key ingredient of human intelligence is the ability to generalize from observed to unobserved outcomes, in order to form intuitions about where exploration seems promising. Using a variety of bandit tasks with up to 121 arms, we study how humans search for rewards under limited search horizons, where the spatial correlation of rewards (in both artificial and natural environments) provides traction for generalization. Across a variety of different probabilistic and heuristic models, we find evidence that Gaussian Process function learning—combined with an optimistic Upper Confidence Bound sampling strategy—provides a robust account of how humans use generalization to guide search. Our modelling results and parameter estimates are highly recoverable, and can be used to simulate human-like performance, while also suggesting a systematic—yet sometimes beneficial—tendency towards undergeneralization. These results have been replicated in a number of follow-up studies, where we use this paradigm to model generalization across both conceptual and spatial features, and to enrich our understanding of developmental differences, where we find that children display more directed but not more random exploration than adult

[Poster # 97] Engineering Brain Activity Patterns for Therapeutics of Disorders

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Brain networks are disrupted in numerous disorders. Existing treatment options often cannot address such complex dysfunctions. We first show that the aberrant brain-wide activity patterns can be completely corrected by targeting distinct network motifs with multiple neuromodulators using a zebrafish model of human epilepsy and autism. Our systematic approach rescues behaviour unlike any other treatment. With methods promising future therapeutic use, we next show how specific molecular targets in different brain circuits can be non-invasively and spatially targeted in mammals, and discuss how cortex-wide activity patterns can be captured chronically at single neuron resolution with minimal invasiveness using neuromorphic microchips.

[Poster # 98] Neural Mechanisms of Motivational Incentive Integration and Cognitive Control

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Motivational incentives play a central role in influencing goal-directed behavior. However, few studies have examined whether and how different categories of incentives are integrated in terms of their motivational influence on cognitive control. We conducted an fMRI study to examine whether the combined diverse motivational incentives (e.g., money, liquids) are in represented as a neural common currency in valuesensitive brain regions, and whether and how this putative motivational signal modulates cognitive control regions in prefrontal cortex (PFC).

To test this hypothesis, we developed an innovative task paradigm that quantifies dissociable and integrative effects of liquid valence (e.g., appetitive, neutral, aversive) and monetary rewards (e.g., low, medium, high) on cognitive control. In the study, participants (N=51, 25 females, 18-38 years) performed a cued task-switching paradigm to earn varying monetary reward amount (e.g., low, medium, high) across trials. Critically, post-trial performance feedback - in the form of oral liquid delivery - signaled successful task performance (i.e., accurate and fast responses) and attainment of monetary reward. Thus, the symbolic meaning of the liquid was held constant, and the liquid valence was blocked.

A general linear model was performed to extract a time course of beta coefficients for the nine motivation experimental conditions (3 levels of monetary reward, 3 liquid types). Preliminary results revealed distinct temporal profiles of BOLD activation for monetary rewards and liquid incentives in the striatum, anterior cingulate, and frontoparietal network, with highest monetary rewards eliciting earlier BOLD activation compared to medium and lower monetary reward trials. Dorsal striatum activation was associated with liquid salience (i.e., intensity), whereas left medial frontal gyrus activation was associated with liquid valence. Taken together, these results provide evidence of putative dissociable neural mechanisms for motivational incentive integration in a cognitive control context. Future directions involve utilizing multivariate approaches (e.g., MVPA) to elucidate motivation-control interactions in PFC, and examining brain-behavior relationships between subjective preferences for different incentives and motivated cognitive task performance.
**[Poster # 99]**

**Certainty Effect: How Reward Probability Affects Choice on Behavioural, Cognitive and Neural Levels**

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Recent studies suggest that perceptual decisions are influenced not only by the relative difference in evidence between options, as is predicted by many classical accounts, but also by the absolute magnitudes of the stimuli. In this work we aimed to (a) test whether absolute reward certainty could also affect choices (b) describe the cognitive and neural underpinnings of this effect.

23 healthy volunteers participated in a value-based decision task, where 6 abstract symbols were associated with three levels of reward certainty: 20%, 80% and 100%. Participants chose between 2 symbols representing matching reward probabilities (equal condition) or picked only 1 available option (control condition). Simultaneously with the behavioural task, 32-channels EEG recordings from each participant were collected.

Reaction time analysis revealed a strong effect of breaking decision deadlock faster for more certain alternatives. Factorial repeated-measures ANOVA showed significant main effects of Condition (Equal; Control): F(1, 22) = 32.99, p<0.001 and Certainty (100%; 80%; 20%): F(2,44) = 44.49, p < 0.001 as well as their interaction: F(2, 44) = 14.85, p < 0.001 (Fig. 1.B). Post-hoc analysis reported significant (p < 0.01) differences between all comparisons in both conditions.

We fitted a Bayesian hierarchical drift-diffusion model to the equal condition data. Best model predicted that 100% reward certainty is characterized by higher drift rate and lower decision threshold. Pairwise comparisons of posterior parameter distributions indicate significant differences in parameter values between certain (100%) and partial (80%; 20%) reward levels, but no effect between the two uncertain conditions.

There was no significant difference between equal certainty levels in the univariate Evoked Response Potential activity Multivariate Pattern Analysis (MVP) was used to decode pattern information across EEG electrodes. Linear Supper Vector Machines (L-SVM) classification revealed significant differences between certain and partial reward levels starting from 100 ms. after stimulus onset. No differences were identified between the two uncertain levels.

Our results provide strong evidence for the presence of certainty sensitivity in value-based choices. Modelling analysis indicates that absolute reward certainty: 1) drives the accumulation process, biasing choice towards one of the options, and 2) is associated with dynamic threshold adjustment, where less evidence is needed to support a more certain choice. The classifier activation patterns expanding over pre-motor and motor cortices are in agreement with previous findings suggesting the role of pre-Supplementary Motor Area cortex in dynamic intra-trial threshold adjustments. Together, our study provides first evidence of certainty effect in value-based decisions and describes its potential neuro-cognitive signatures.

**[Poster # 100]**

**Terror-induced Stress Causes Selective Affect Bluntness and Disrupts Integration of Incidental Affect on Subsequent Evaluation**

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Objective: Much research across disciplines has provided accumulating evidence that judgments and evaluations are shaped by the affective state of the decision maker (Loewenstein et al 2001; Phelps, Lempert and Sokol-Hessner 2014). One powerful modulator of affective states that is omnipresent in everyday life in modern societies is stress. In a natural experiment, a subset of our participants experienced an exogenous, non-acute stressor due to terror-related events in Paris and Brussels while we collected data for a study on affect integration on evaluation. This setting allowed us to investigate the following three questions on behavioral, psycho-physiological, and -motor levels: (1) how did an exogenous, terror-related stressor influence participants’ baseline affective responses? (2) how did such a stressor influence participants’ affective responses toward primary and secondary affective stimuli? (3) how did such a stressor alter the integration of incidental affect induced by the monetary gains on subsequent evaluations?

Methods: Participant’s affective responses were sampled using automated facial expression recordings to capture affective valence, and skin conductance recording to capture arousal at a baseline phase followed by sampling the same affective reactions during an value-based evaluation task. At baseline phase, participants viewed different pictures of objects and scenes one at a time after a resting black screen. In the evaluation task, participants received random monetary rewards (15 EUR or 0 EUR) and subsequently, in a seemingly unrelated task, evaluated their enjoyment of looking at different pictures on a nine-point scale.
(1=not at all, 9=very much). These pictures depicted neutral objects and scenes as well as happiness, fear, and disgust inducing motives. We also collected self-reported measures of participants’ mood (Positive and Negative Affect Schedule, or PANAS). 51 participants (Mage = 23.27; SDage = 3.04) participated in the study up to 7 days after either the Paris terror attacks or the Brussels’ attacks and 35 participants (Mage = 22.28; SDage = 3.13) in the absence of a terror attack. The terror and control groups of participants were recruited from the same subject pool and shared a similar demographics background.

Results: (1) At baseline phase, we found that participants’ psycho-motor reactions (i.e., facial affect valence, or FAV) were not different between those in the terror-induced stress group (SG) and control group (CG), but participants in SG had significantly lower psycho-physiological reaction magnitudes (i.e., skin conductance amplitude, or SCA) than those in CG ($\beta_{SG} = 0.026$ vs. $\beta_{CG} = 0.127$, $p < 0.001$). Terror-induced stress had no impact on self-reported mood measured by PANAS.

(2) Primary affective stimuli: Our design allowed us to examine the question of how people reacted to different primary affective pictures in two ways. First, during the passive viewing phase, we found a significant main effect of picture type on FAV such that FAV was highest when viewing positive pictures, followed by viewing neutral pictures and negative pictures in both groups ($\beta = 0.027$, $p < 0.001$).

In contrast, for SCA, we found a significant interaction between stress and picture type ($\beta = 0.049$, $p < 0.001$). Skin conductance responses to picture presentations only found in the CG, but were absent in the SG. In the CG, SCAs were highest when viewing negative pictures, followed by viewing positive pictures and neutral pictures. The main effects of stress ($\beta = 0.049$, $p < 0.001$) and picture type ($\beta = -0.211$, $p < 0.001$) were also significant.

Second, we replicated the stress-dependency of FAR and SCA responses to similar pictures during the evaluation task.

Secondary affective stimuli: We found a significant main effect of FAV when participants won money vs. did not win in both SG and CG ($\beta = 0.025$, $p < 0.001$). As for SCA, we found a trend for an interaction between monetary gains and stress ($\beta = -0.018$, $p = 0.056$) and a significant main effect of monetary gains ($\beta = 0.028$, $p < 0.0001$). These results suggest that SCAs in responding to winning money vs. not winning money was significantly increased for participants in CG ($15\text{ EUR} = 0.084$ vs. $10\text{ EUR} = 0.055$, $P < 0.001$) but not in SG.

(3) In terms of affect integration, we examined reported aesthetic evaluation of pictures conditional on winning money as a seemingly unrelated task. We found a significant interaction of stress by monetary gains ($\beta = -0.223$, $p = 0.029$) and a significant main effect of monetary gains ($\beta = 0.371$, $p < 0.001$). These results suggested that while receiving money increased aesthetic evaluation of pictures among participants in CG (which replicated previous findings), the magnitude of the effect was significantly attenuated in the SG.

We previously found that the arousal state of a decision maker is crucial for affect integration to take place (i.e., the arousal transport hypothesis, Ling et al. 2017). Specifically, we found that while the valence of affect would mediate subsequent, unrelated evaluations, a higher arousal state of this decision maker would amplify the mediating effect (i.e., a moderated mediation effect). In the current study, we showed in above analyses that terror-induced stress dampened the psycho-physiological response of arousal. As a consequence, we found in a moderated mediation analysis that the attenuation of affect integration was caused by reduction of arousal that suppressed the integration of affect on picture evaluations among participants in SG ($\beta_{low\ arousal} = 0.01$, 95% BCI = [-0.0103 0.0447]; $\beta_{high\ arousal} = 0.009$, 95% BCI = [-0.0205 0.0566]). The moderated mediation effect was maintained among participants in CG ($\beta_{low\ arousal} = 0.056$, 95% BCI = [0.0268 0.0988]; $\beta_{high\ arousal} = 0.076$, 95% BCI = [0.0356 0.1333]).

Discussion: Relying on a natural experiment, we extended the understanding of stress on judgment and evaluation from the lab to the field. By sampling participants’ psycho-physiological (i.e., SCA) and -motor responses (i.e., FAV), we found that terror-induced stress selectively dampened the reactivity of SCAs while the reactivity of FAV remained intact. Such selective impairment was consistently observed in our data when participants were at a baseline phase and responded to primary affective pictures (i.e., primary rewards) and monetary gains (i.e., secondary rewards). We also found that terror-induced stress attenuated integration of affect on subsequent evaluation as a seemingly unrelated task. Such attenuation was caused solely by the suppression of participants’ psycho-physiological responses of arousal, which in turn diminished the mediation of valence that underlay affect integration processes. Our data also suggest real-life evidence for a recently hypothesized lasting effect of stress hormones on affect regulation and decision-making: immediately after acute stress, the brain is influenced by a first wave of arousal-inducing catecholamines whose action is fast, but also short-lived. Briefly afterwards, cortisol joins the neuromodulator cocktail via non-genomic corticosteroid effects. In the aftermath of stress, genomic cortisol effects on brain function outlast the acute stress effects by days or even weeks. It has been hypothesized that these slow, genomic long-term effects of cortisol contribute to counteracting the stress-related arousal, as well as the immediate emotional and motivational response to stress, by means of upregulation of a prefrontal cognitive control network conjoint with the downregulation of limbic affective brain regions; this large-scale, long-term neural reconfiguration results in the promotion of cognitive control capacities at the cost of emotional responsiveness. Our results of dampened arousal and diminished secondary reward carry-over effects on picture evaluation in the stress group are consistent with this hypothesis, and reveal a unique pattern by which exogenous stress induced outside the lab influences judgment and evaluation.