Hosted by
Berlin School of Mind and Brain, Humboldt-Universität zu Berlin

In collaboration with
Wellcome Trust Centre for Neuroimaging, University College London

4th joint meeting London & Berlin

31 July and 1 August 2014 in Berlin

Decision-making

Venue
Humboldt Graduate School, Berlin School of Mind and Brain
Luisenstraße 56
Haus 1, Festsaal
10117 Berlin

Programme

Organized by
Raymond J Dolan
Einstein Visiting Fellow of the Berlin School of Mind and Brain

Invited presentations
by doctoral and post-doctoral fellows from Berlin and London

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Invited guests only

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Posters

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Age-dependent interaction of novelty-driven exploration and reinforcement learning

Ousdal Olga T., Milde Anne Marita, Craven Alex, Ersland Lars, Johansen Venke A., Grønli Janne, Melinder Annika, Endestad Tor, Hugdahl Kenneth (UCL, University of Bergen, Haukeland University Hospital)
Emotional conflict processing in survivors of the 2011 Oslo terror attack: behavioural and fMRI data

Pooresmaeili Arezoo, Wannig Aurel, Dolan Raymond J. (The Einstein Visiting Fellow's Group, Berlin School of Mind and Brain)
Impact of reward on retrospective evaluation of effort

Schad Daniel J. (Charité – Universitätsmedizin Berlin)
Trading goals and habits: the role of dorsolateral PFC structure supporting working memory

Wright Nicholas (Carnegie Endowment for International Peace)
Knowing how the other thinks: the brain and influence in international confrontations

Abstracts

Bach Dominik R. TALK

Modelling behavioural inhibition in a human approach-avoidance task

Approach avoidance conflict tasks are common rodent models of anxiety, in which an animal is motivated both to approach a spatial location or perform an action, and to avoid it. These tasks have recently been extended to encompass human behaviour. Behavioural inhibition – delaying a decision to approach or to avoid – is observed in these ethological models and has been proposed to reflect risk assessment, or to be due to decision difficulty. This implies that inhibition should not delay a motor action once all information has been gathered and a decision has been taken. Here, use a cost minimisation model to analyse a situation in which decision and motor action are decoupled. In this task, human players leave a "safe place" to obtain monetary tokens which appear randomly and decay exponentially. A looming "predator" might wake up and catch the player and all previously collected tokens at any point in time with a flat hazard function. In this situation, all information required for the decision is known before a token appears. Minimising cost in this task mandates minimising motor response latency. Yet, if the player mistakenly assumes a biologically plausible temporal correlation of threat and reward, it can be cost-minimising to delay a motor action. If this is the case, we show that the optimal delay increases both with increasing threat probability and with increasing stakes. Predictions from this model are tested in two behavioural experiments with different graphical set ups. In both tasks, response latency increases with both increasing threat probability and increasing potential loss. This supports a model in which a temporal coupling of reward and threat is subjectively assumed. To conclude, our model and data suggest that behavioural inhibition might be a biologically adaptive behaviour under prior assumptions about temporal coupling of threat and reward.

Bernal-Casas David POSTER

Brain structural and functional changes in healthy adolescents

Adolescence is a period of significant development at the level of cognition, behaviour, and the brain. Neural development during human adolescence involves highly coordinated and sequenced events, characterized by both progressive and regressive processes. In the last years, brain imaging studies have showed specific

changes in neural architecture during adolescence, outlining trajectories of grey and white matter development, and differences in brain network function. Therefore, changes at the level of the brain may map onto cognition and behaviours commonly associated with adolescence.

Under the auspices of the Wellcome Trust, a large cohort of 300 healthy male and female participants aged 14-24 years have been measured using multimodal magnetic resonance imaging (MRI) techniques. Notably, there have been no prior MRI studies of normal youth brain development that have combined measures of brain structure, such as conventional MRI or diffusion tensor imaging (DTI), with measures of brain function, such as resting-state functional MRI (rs-fMRI), in the same subjects. Moreover, all MRI cohort members have completed cognitive testing and a clinical examination with additional behavioural questionnaires.

In this talk, preliminary results of age-dependent changes in structural and resting-state functional brain networks in this large cohort of adolescents using voxel based morphometry (VBM) and spectral dynamic causal modelling (spDCM) will be presented. Furthermore, relations among these brain developmental changes, cognitive parameters, and behavioural scores will be discussed. The final goal of this work is to provide a validated reference curve for structural and functional brain maturation during adolescence in relation to cognition and behaviour, which would be clinically very useful.

Bobrowski-Khoury Natasha, Hunt Laurence, Dolan Raymond J. **POSTER**

Estimating and tracking novel features of a decision

Humans have the unique ability to categorize information based on its relevance and internalize that information for future reference. Learned information is known to influence the time spent making the categorization by biasing our attention towards features needed to distinguish an underlying rule. However, in previous studies such features have typically consisted of known properties of stimuli. By contrast, when learning real-world objects, *novel* features may have to be extracted from the stimuli through learning. How novel features are integrated and utilized in choice-based decision making is the focus of this study. First, subjects were trained to make use of a novel feature of a stimulus to classify it as possessing more

or less of that feature. Second, feature formation was behaviourally tested with the presentation of objects with components that are either *relevant* or *irrelevant* to the participant's assignment of an object to a category. In this phase, subjects were slower to learn these assignments when the relevant components of the novel feature were made orthogonal to those the original training session, rather than along the same 'novel' axis – even though there was an equal amount of variability in the underlying constituents of this feature in both conditions. The results support the idea that learning is delayed when the novel feature is different from previous experience, suggesting subjects had learnt the novel feature and used it in subsequent discrimination. These findings offer insight to how prior information learned can influence the distinction of stimuli in other future contexts.

Chien Samson POSTER

Influence of inherent prior values in decision-making

Reinforcement learning (RL) has become the predominant model for predicting a subject's decision based on the expected reward value (EV) of each cue, which is adjusted during learning in proportion to a reward prediction error (PE). Common experimental setup utilizes value-neutral cues to study EVs in isolation. However, most environmental cues representing decision options are not neutral but exhibit values intrinsically (e.g. attractive faces), which may interfere with the acquisition of new EVs. This project investigates how such inherent cue value affect the learning of new EV. One possibility is that congruent cue-outcome association with similar inherent value and EV yields faster learning rate (LR) than incongruent pairing.

We tested the hypothesis in a 2×2 factorial design, using facial attractiveness (high/low) as a proxy for inherent value and reward probability (0.7/0.3) as a target for learned EV. Subjects were shown attractive and unattractive face pictures of the opposite gender. Each picture was paired with monetary reward or penalty either congruently or incongruently. Subjects were instructed to select the pictures with the goal of maximizing the overall monetary reward. RL models were fitted to behavioral data using hierarchical Bayesian analysis to derive cue-specific LRs. Concurrent fMRI data were correlated with these LRs, EVs, and PEs.

Behavioral results indicated both faster response time and faster LR for the congruent cue-outcome pairing. Model-based fMRI analyses revealed that several signals derived from the RL model (LRs, PEs, outcomes) populate the ventral striatum (vStr) in distinct locations. An additional connectivity analysis revealed a functional link between the vStr (encoding LR and PE) and the ventromedial prefrontal cortex (encoding EV). These findings suggest that value congruency leads to a distinct advantage in learning new reward associations and uncover the functional neural architecture supporting this learning process.

Crockett Molly J., Kurth-Nelson Zeb, Siegel Jenifer Z., Dayan Peter, Dolan Raymond J. **TALK**

Selfless valuation of pain in moral decision-making

How we evaluate the suffering of others is a central concern in moral decision-making, but is relatively underexplored. To investigate this question, we observed people trading off profits for themselves against pain for themselves or an anonymous other person, and used computational models and fMRI to quantify how they valued others' pain relative to their own pain. In three independent studies we show that most people selflessly sacrifice more money to prevent others' pain than their own pain. This selflessness is linked to slower responding when making decisions that affect others, suggesting a role for deliberative processes in moral decisions. Preliminary neuroimaging results revealed robust activation in the mentalizing network when deciding for others relative to oneself and specifically when computing the cost of pain to others. Sub-clinical psychopathic traits correlated negatively with aversion to harming both self and others, consistent with past reports of aversive processing deficits in psychopathy. Our results provide evidence for a surprisingly conscientious valuation of others' suffering, a prosocial disposition with implications for understanding antisocial behavior.

De Berker Archy **POSTER**

Computations of uncertainty predict acute stress responses in humans

Much as fever is the body's response to an infectious agent, acute stress is the response to something; this project aims to identify that something. Specifically, there is indirect evidence that uncertainty is an important contributor to stress responses, leading to the idea that stress might represent an adaptive reaction to uncertainty about threat. We have testing this hypothesis in human subjects, assessing subjective and physiological stress in response to electric shocks of varying predictability. By using computational models of learning to infer individuals' levels of uncertainty, we have found that surprising events, including the surprising omission of a shock, are strong contributors to emotional and physiological stress responses. I will present data from subjective assessment, skin conductance, and pupillometry that suggest that uncertainty is a key modulator of acute stress responses in humans, bringing us closer to a computational characterisation of stress processes.

Deserno Lorenz **TALK**

Ventral striatal presynaptic dopamine modulates behavioral and neural signatures of model-based choices

Dual system theories of behavioral control suggest the parallel existence of a deliberative 'model-based' and a more reflexive 'model-free' system. The balance of control exerted by these systems is thought to be influenced by dopamine.

However, in the absence of direct measures of human dopamine, it remains unknown whether this influence reflects a quantitative influence of dopamine either in the striatum or other brain areas. Using a sequential decision task during fMRI, combined with striatal measures of dopamine using [^{18}F]DOPA PET, we report that higher presynaptic dopamine levels in ventral striatum predict a behavioral bias towards more model-based choices. Furthermore, higher presynaptic dopamine in ventral striatum is linked to a greater coding of model-based information in lateral prefrontal cortex and a diminished coding of model-free prediction errors in ventral striatum. Thus, we provide the first direct human evidence for a pivotal role of ventral striatal presynaptic dopamine in mediating a balance in both the behavioral expression and neural signatures of model-free and model-based control. This conciliates findings of altered presynaptic dopamine levels in aging or neuropsychiatric diseases, such as schizophrenia and addiction, associated with a disrupted balance of behavioral control.

Diaconescu Andreea TALK

Connectivity among "Theory of Mind" regions reflects social inference computations

Adequate inference of another's intentitons is the cornerstone of social interactions. This is particularly important when we have to make decisions based on someone else's advice. Using an ecologically valid, socially interactive paradigm and a hierarchical Bayesian computational model, we have previously shown that participants infer on the volatility of other agents' intentions to inform their current estimates of advice accuracy. Fitting computational trajectories from this model to participants' fMRI data, we demonstrated that trial-wise predictions about the advice accuracy were represented in regions previously linked to intentionality processing, including the dorsomedial prefrontal cortex (dmPFC), anterior temporal-parietal junction (TPJ), and posterior superior temporal sulcus (pSTS). By combining computational models of learning with dynamical causal models, we highlight a specific neural mechanism for inferring on the intentions of other agents: predictions about advice accuracy are conveyed via top-down projections from the dmPFC to the TPJ, while social prediction errors (PEs) modulate bottom-up connections from anterior TPJ to pSTS and dmPFC. This study provides a first demonstration how computational and physiological models can be combined to obtain a deeper understanding of mechanisms of social inference, a domain where many psychiatric disorders are characterized by particularly salient deficiencies.

Economides Marcos TALK

Practice makes perfect: task training recovers model-based reasoning under load

The brain has been suggested to employ parallel architectures for solving problems using habitual (model-free) or goal-directed (model-based) algorithms. Over-reliance on habits may underlie a number of disorders including addiction. In a task that

engages both model-based and model-free systems, increasing cognitive load with a challenging concurrent task reduces the expression of model-based behavior, suggesting that a shared pool of cognitive resources is used for model-based calculations and the concurrent task. Here, we show that this impairment in model-based reasoning under load is diminished when subjects receive prior primary task training, whether the training is under load or not under load. Thus, task familiarity permits utilization of model-based reasoning even under heavy cognitive load. These data suggest a shift in the mechanism by which model-based calculations are implemented with increasing task exposure, and may have implications for therapies to enhance model-based reasoning in psychiatric disorders.

Fiore Vincenzo G. POSTER

The effects of striatal dopamine on flexibility and discrimination among competing stimuli

Two major families of models have described the neural dynamics and mechanisms characterising the striato-thalamo-cortical loops and the associated selection performed within the basal ganglia (Gurney et al. 2001a,b, Frank et al. 2004, and subsequent). We assess key features of these models under different conditions of dopamine (DA) showing the main role played by tonic DA within the striatum is to alter the gain of channels present in the basal ganglia: increased DA release enhances the gain of the most salient stimuli (via D1) clearing the signal from noise. If further increased, high DA release causes maintenance of a selection despite changes in the environment, resembling compulsive behaviour or addiction (distractors are ignored and selection of weakened/vanished stimuli can be preserved). Decreased DA enhances the gain of the least salient stimuli (via D2) favouring a switch to competing options and flexible behaviour among competing options (in healthy agents it favours exploration, in pathological agents it causes ambitendency). Finally the activity of hyperdirect pathway (via the subthalamic nucleus), which is directly correlated with the average salience of the stimuli processed in the cortex, is responsible for delaying decisions and blocking all actions.

Thus selection – of actions, attention or goals – is determined by a balance among direct, indirect and hyperdirect pathways, having in the DA release the dynamic modulator of this competition. Two key predictions currently tested in a behavioural study involving DA manipulation (via L-Dopa and Risperidone) ascribe to DA release the role of altering: 1) the shape of the psychophysics curve, with higher DA release required to discriminate among strong and closely related stimuli; 2) the overall flexibility of the system, with an inverted U effect regulating responses in a changing environment.

FitzGerald Thomas TALK

Model averaging, inference and habit formation

Postulating that the brain performs approximate Bayesian inference generates principled and empirically testable models of neuronal function – the subject of much current interest in neuroscience and related disciplines. Current formulations address inference and learning under some assumed and particular model. In reality, organisms are often faced with an additional challenge – that of determining which model or models of their environment are the best for guiding behaviour. Bayesian model averaging – which says that an agent should weight the predictions of different models according to their evidence – provides a principled way to solve this problem. Importantly, because model evidence is determined by both the accuracy and complexity of the model, optimal inference requires that these be traded off against one another. This means an agent's behaviour should show an equivalent balance. We hypothesise that Bayesian model averaging plays an important role in cognition, given that it is both optimal and realisable within a plausible neuronal architecture. We outline model averaging and how it might be implemented, and then explore a number of implications for brain and behaviour. In particular, we propose that model averaging can explain a number of apparently suboptimal phenomena within the framework of approximate (bounded) Bayesian inference, focussing particularly upon the relationship between goal-directed and habitual behaviour.

Fleming Stephen TALK

A computational approach to insight

The human brain has the ability to reflect on and analyze its own cognitive processes. This ability varies in healthy individuals, and is often impaired in psychiatric and neurological disorders. Such lack of "insight" may lead to deleterious consequences such as an inability to seek help or adhere to treatment programs. However the computational and neural basis of insight is poorly understood, largely due to the absence of a quantitative framework within which to study insight in the lab. In this talk I will describe how extensions of signal detection theory can quantify insight across different cognitive domains such as perception and memory. I will provide examples of how this method can be applied to understand changes in insight that occur following brain damage and in healthy aging. Together this work converges to support a specific neural basis for insight centered on the prefrontal cortex and indicates that mechanisms supporting insight may dissociate across different domains.

Garvert Mona, Motoussis Michael, Kurth-Nelson Zeb, Behrens Tim, Dolan Ramond J. **TALK**

Learning-induced plasticity in medial prefrontal cortex predicts preference malleability

Learning induces plasticity in neuronal networks. Yet, plasticity has been studied primarily at the level of synapses or in well-defined neuronal circuits. As populations of neurons often contribute to multiple computations, plasticity induced by learning a novel representation may influence overlapping computations. Here, we used human fMRI repetition suppression to show that plasticity induced by learning a precise model of another individual's values exerts an impact on an existing value-based neuronal representation for oneself. Furthermore, we show this dynamic interaction between neuronal populations is driven by a striatal "prediction error", signalling the discrepancy between the other's choice and a subject's own preferences. This dynamic interaction between overlapping neuronal populations is strongly predictive of inter-individual differences in the malleability of subjective preferences and can thus explain the powerful influence of social interaction on beliefs and preferences. Our findings show that when computations are coded within overlapping neuronal populations a learning-induced plasticity in one population can induce change in overlapping populations supporting other computations.

Guo Rong **POSTER**

Dissociable saliency and reward signals in ventral striatum

Although the co-existence of both reward and saliency related signals in human ventral striatum has been confirmed, the precise interaction between these two signals has not been fully resolved. Here, we approach this question computationally using a conditioning task that requires subject to make probabilistic choices for salient visual stimuli. 27 participants were instructed to predict the occurrence of a visual stimulus by choosing between left and right button presses in the fMRI scanner to maximize their reward. If correct, subjects received a monetary reward randomly drawn from a distribution whose mean was location-dependent under two experimental conditions. We compared a condition in which the stimulus appeared randomly on either side (Equal-condition), against a condition in which the higher stimulus probability was assigned to the lower reward probability side (Biased-condition), thus creating a conflicting situation in which the salient visual stimulus was misleading for the reward distribution. We found out that subjects tend to trade off the reward against the predictability of where the stimulus is more likely to appear. Behavioral results were analyzed on a single trial basis using two independent Rescorla-Wagner models for stimulus and reward occurrences, which were negotiated by a tradeoff parameter. We extracted model-derived signals for both the stimulus and the reward prediction errors. These signals are used in

a model-based fMRI analysis. At the neural level we found a co-existence of stimulus and reward prediction errors in the ventral striatum suggesting that this region responses for general surprising perceptual events as well as unexpected reward delivery or omission. Furthermore, the activation patterns of the stimulus and the reward prediction errors are different under the experimental manipulations: The stimulus prediction error is stronger in the Biased-condition whereas the reward prediction error is stronger in the Equal-condition. This neural activation pattern was related to the behavior that subjects went for the stimulus in the Biased-condition but tend to optimize the performance in the Equal-condition. These data raise a possibility that the striatum encodes the reward signal in the same fashion as a value-nonspecific saliency signal for guiding behavior.

Hauser Tobias U., Hunt L.T., Iannaccone R., Brandeis D., Walitza S., Dolan R.J., Brem S. **POSTER**

The timecourse of brain regions involved in decision making: insights from simultaneous EEG-fMRI

Adaptive learning and decision making is essential for survival, and several frontal areas are strongly implicated in these skills. Ventromedial prefrontal cortex (vmPFC) is crucially involved in the valuation and evaluation of decision options. Dorsal regions of the medial frontal cortex (MFC – incorporating dorsal anterior cingulate and pre-supplementary motor areas), by contrast, are implicated in action selection and adaptive response behaviour. Additionally, the anterior insula has been implicated to be involved in outcome evaluation as well. There is extensive knowledge about the functions of these regions in humans based on functional magnetic resonance imaging (fMRI) studies. By contrast, little is known about the differential temporal dynamics of these regions' activity, and the interaction between them. Notably, conditions which elicit the feedback-related negativity (FRN) component in electroencephalogram (EEG) – which is frequently modelled as a single dipole in MFC – can elicit widespread activation in many other nodes of the medial wall in fMRI. It is unclear whether the temporal dynamics of these nodes can be disentangled from that of MFC activity.

Here, we use simultaneous EEG-fMRI to dissociate the contributions of areas involved in decision making to the electroencephalogram. First, we show that our novel approach to combine EEG and fMRI is sensitive to motor and visually evoked responses. Second, our preliminary analysis of decision making regions reveals that these areas process outcomes with different temporal dynamics. These findings crucially advance the understanding of regions involved in decision making, and our new approach to fMRI-EEG analysis reveals the temporal dynamics of regions whose activity might be hidden via traditional EEG methodology.

Houillon Audrey, Lorenz Robert, Gleich Tobias, Heinz Andreas, Gallinat Jürgen, Obermayer Klaus **POSTER**

Age-dependent interaction of novelty-driven exploration and reinforcement learning

Stimulus novelty enhances exploratory choices through engagment of neural reward systems. SN/VTA activation by novelty in a rewarding context has raised the possibility that novelty per se might have intrinsic rewarding properties. SN/VTA activations to novelty alone also suggest a second, reward-independent mechanism that favors directed exploration toward the novel cue. Therefore we proposed that novelty per se – a form of unexpected uncertainty – can act as a directed explorative bias, but can also act as a bonus for rewards when these are explicitly attended. Interestingly, the noradrenergic system mediates learning from unexpected uncertainty and has also been shown to be linked to explorative behavior. It has further been proposed that the exploration–exploitation tradeoff is mediated by the interaction of dopamine and noradrenaline systems, where dopamine is believed to be stronger associated with exploitative and noradrenaline with explorative behaviors. Dopamine levels and novelty-seeking scores tend to decrease with increasing age. Therefore, we hypothesized that undirected explorative behavior should increase, but novelty-driven explorative behavior should decrease across the lifespan. We applied a reward-dependent learning task to different age groups. Computational models were used to quantify differences in behavioral performance and fMRI activation. Novel stimuli presented from pre-familiarized categories could accelerate or decelerate learning of the most rewarding category, depending on the individual sensitivity to novelty. Choices were quantified in computational models, including parameters to characterize individual variation in novelty-driven exploration and undirected exploration. As expected, simulations showed that older subjects had lower novelty-driven explorative behavior, but increased undirected exploration. In addition, undirected exploration anticorrelated with working memory performance. Preliminary fMRI analysis show that striatum and midbrain are activated by the novelty conditions contrast in explorative trials, suggesting that novelty activates the reward system during the explorative learning phase. Cingulate cortex is activated by the mere novelty contrast, suggesting that novelty also activates reward-independent exploration mechanism.

Hunt Laurence, Malalaskera Nishantha, Grigat Daniel, Dolan Raymond J., Kennerley Steve **TALK**

Information search strategies during multi-attribute choice

A central feature of many real-world decisions is that each alternative consists of several attributes. Such multi-attribute decisions may be realised in many different ways – ranging from attribute-based strategies (such as elimination-by-aspects) to alternative-based strategies (such as weighted adding of attributes). These strategies

make opposing predictions as to how information will be acquired during decision formation, and, importantly, to how neural circuits can implement the decision as it is being made. Information acquisition may also frequently involve costs to the decision-maker.

In this study, we consider what normative principles might govern information search strategies in a multi-attribute choice task, and whether these match with empirical observations in primates. Two choice alternatives, consisting of two attributes, were presented. Subjects sequentially selected which feature of each alternative they wished to reveal; they were also able to terminate information sampling early in order to make a choice. Potential information that might be uncovered at each turn was drawn from a flat probability distribution, with which the subjects were familiarised with before commencing the task. This meant that a normative dynamic programming approach could be adopted, to derive the optimal strategy for calculating the value of gathering information at each turn. The dynamic programming model provides normative predictions of both *when* information sampling should be terminated, and also *which* information is most valuable to sample next, if reward is to be maximised.

We probed information gathering behaviour of both human and macaque subjects on analogous versions of the decision task. Human data was collected from a large subject pool (>8,000 participants) via a smartphone app, and compared to laboratory data from a smaller subject pool (21 participants, collected whilst undergoing magnetoencephalography). Choice data from two macaque monkeys was collected whilst undergoing neurophysiological recording from prefrontal cortex. Whereas human subjects paid explicit costs for sampling information, macaque subjects underwent the opportunity cost of time.

Some key aspects of human and macaque behaviour matched well with predictions from the normative model. For example, subjects would terminate information sampling early if informative cues had been received that made one alternative much more likely to be rewarding. However, there were also intriguing and unambiguous violations of the normative model. For example, human subjects were found to be particularly biased toward reducing uncertainty about the value of the currently preferred alternative, even if other information searches would prove more valuable. Macaque subjects showed a similar bias, in that they would often be unwilling to terminate a decision when confronted with one very poor alternative, without first ascertaining information about the other alternative. I will present potential considerations for the origins of these non-normative behaviours, and what they may imply for the implementation of such decisions in neural circuits.

Oganian Yulia, Korn Christoph W., Heekeren Hauke R. **TALK**

Foreign language effects on decision biases: is the framing effect abolished by second language use?

Recent evidence suggests that well-established biases in decision-making such as the framing effect (FE) may be abolished when decisions are made in a foreign language (L2). Here we investigate whether this observation depends on L2 proficiency and on linguistic context in the example of the Asian Disease task. In Experiment 1 (n=760) we found the same magnitude of the framing effect when participants were presented with the Asian Disease problem in their first and second languages, independently of second language proficiency. In Experiments 2 (online, n=320) and 3 (lab, n=233) we investigated the effects of language switching on the FE. We found that the framing effect was unaffected by language if task instructions were given in the same language. However the framing effect was significantly reduced if participants had to switch into the foreign language directly before the task.

Our results indicate that performing in L2 does not abolish framing effects. Instead they suggest that switching into a foreign language leads to a transient change in cognitive processing, reducing decision biases.

Ousdal Olga T., Milde Anne Marita, Craven Alex, Ersland Lars, Johansen Venke A., Grønli Janne, Melinder Annika, Endestad Tor, Hugdahl Kenneth **POSTER**

Emotional conflict processing in survivors of the 2011 Oslo terror attack: behavioural and fMRI data

The 2011 terror attack in Oslo and Utøya marks the most violent act in Norway since World War II, claiming a total of 77 lives, and causing physical and mental injuries to an additional hundreds of people. A hallmark of this event was the young age of the victims, and thus the majority of the survivors were in their adolescence, a time of continued brain maturation. Importantly, significant psychological traumas during this time period may especially affect the trajectory of neural development within late maturing limbic and prefrontal brain areas, and contribute to the increase in psychological morbidities, like anxiety and depression.

In the present study, we compared affect categorization for emotional conflicting information (i.e. Emotional Stroop task) between a group of Utøya survivors (N=25) and a socio-demographic matched control group (N=23). We measured response accuracy from the subjects' performance on the task, and corresponding brain correlates with fMRI. The results showed a significant emotional conflict x group interaction in behavioural performance. Preliminary analyses indicate that this effect was due to significantly worse performance in the Utøya group for the emotional conflict trials, and a failure to engage pregenual anterior cingulate cortex when faced with incongruent emotional information. We are currently investigating the neuro-chemical underpinning of these findings from MR spectroscopy data obtained in the

same scanning session as the fMRI data. The results support that significant psychological traumas during adolescence may have long-term effects on ventro-medial prefrontal cortical regions that is essential for emotional conflict detection and resolution. Furthermore, the results may help bridge the gap between traumatic experiences in adolescence and the increased vulnerability to various stress-related disorders during adulthood.

Pooresmaeili Arezoo, Wannig Aurel, Dolan Raymond J. **POSTER**

Impact of reward on retrospective evaluation of effort

Recent studies have shown that effortful options are devaluated, suggesting that effort is incorporated as a cost when a choice is to be made. It is also shown that prior effort affects the processing of a subsequent reward. Whether obtained reward impacts on retrospectively evaluated effort, a common situation faced by humans when assessing their performance/pay balance, is unknown. This is an important question because perceived effort/reward imbalance could lead to serious professional and health-related consequences. In a behavioral experiment, we investigated how humans integrate reward and effort when effort is judged retrospectively, after receiving reward feedbacks. Our results show that the impact of reward on estimated effort depends on the reliability of reward signals: highly variable rewards do not affect effort estimation while less variable reward cues result in under/over-estimation of effort when reward is low or high respectively, a pattern akin to sensory cue integration. These findings suggest that humans employ an adaptive strategy to cope with inconsistencies between exerted effort and obtained reward very much similar to the way that they use conflicting sensory signals to derive a unified perceptual judgment.

Rigoli Francesco, Rutledge Robb, Dayan Peter, Dolan Ramond J. **TALK**

The influence of contextual reward statistics on risk preference

I will present a study investigating the influence of contextual reward statistics on decision-making under risk. Adaptive decision-making requires appropriate adjustment to reward statistics of the environment (Rangel & Clithero, 2012; Stewart et al., 2006). It is surprising that we know little regarding how contextual reward statistics influence important decision-making dimensions such as risk preference (Kolling et al., 2014, Louie et al., 2011; Ludvig et al., 2013; Stewart et al, 2003). I will address this question describing an experiment where participants repeatedly chose between a certain monetary gain and a gamble associated with an equal probability of double the monetary gain or zero. Crucially subjects performed the task across two distinct contexts involving different but overlapping reward distributions. We show that choice behaviour was explained by three independent components comprising a baseline gambling propensity, a gambling preference dependent on reward

amount/variance, and a contextual reward normalization factor. We used this generative model of behaviour to analyse simultaneously acquired functional magnetic resonance imaging (fMRI) data and show that activity in ventral striatum correlated with subjective value of options, while ventromedial prefrontal cortex encoded the subjective value difference between chosen and unchosen option. Ventral tegmental area/substantia nigra alone was involved in a context effect suggesting this dopaminergic midbrain region supports a reward normalization process that influences a propensity to choose risky options. I will finally discuss how these findings clarify the process by which decision-making under risk adapts to contextual reward statistics and highlight a key role for ventral tegmental area/substantia nigra in such adaptation.

Rutledge Robb, Smittenaar Peter, Brown Harriet, Zeidman Peter, Adams Rick, Dayan Peter, Dolan Ramond J. **TALK**

A computational model of economic decision making across the lifespan

The number of dopamine neurons gradually declines across the lifespan and the consequences of this decline for economic decision making are poorly understood. We characterized economic preferences in a smartphone-based experiment (n=25,189) in which subjects collected points by making choices between safe and risky options. In gain trials, subjects chose between certain gains and lotteries with equal probabilities of larger potential gains or zero. In loss trials, subjects chose between certain losses and lotteries with larger potential losses or zero. In mixed trials, subjects chose between certain options of zero and lotteries with potential gains and losses. The number of gambles chosen in gain trials declined over the lifespan in both men and women, while the number of gambles chosen in mixed and loss trials did not. We recently developed a computational model that incorporated approach-avoidance mechanisms into the standard Prospect Theory economic model and found that the dopamine precursor L-DOPA selectively increased approach behavior in the gain domain but did not affect value-dependent risk or loss aversion. Using this model, we show that changes in risk taking across the lifespan are explained not by changes in risk or loss aversion but by decreased approach behavior in the gain domain, consistent with the possibility that this behavioral change is explained by the loss of dopamine neurons that occurs during normal aging.

Schad Daniel J. **POSTER**

Trading goals and habits: the role of dorsolateral PFC structure supporting working memory

Distinct neural systems for habitual (model-free) versus goal-directed (model-based) choices are key to complex human decision-making. Imaging, electrophysiological interference and pharmacological results point to the lateral PFC as an important

mediator of the balance between the two systems. The lateral PFC is also known to be involved in working memory and other neural processes that relate to individual variation in this trade-off. We therefore asked whether structural aspects of the lateral PFC might relate to the individual variation in the trade-off between model-based and model-free decision-making.

130 subjects underwent structural and 91 subjects functional MRI while performing a Markov-decision task. We performed voxel-based morphometry and model-based computational fMRI analysis.

Subjects with stronger model-based (goal-directed) components in their behavior had higher grey matter density in the dorsolateral prefrontal cortex (dlPFC; p_FWE whole brain = .05, t = 4.71). At this site, grey matter density was also associated with a larger working memory capacity (p_FWE ROI = .04, t = 2.52), and fMRI BOLD showed a model-based reward prediction error signal (p_FWE ROI = .03, t = 2.73).

These results suggest that structural variation in the human brain may contribute to individual variation in decision-making. Higher grey matter density in the dlPFC may support working memory processes facilitating model-based control of choice behavior.

Schwartenbeck Philipp, FitzGerald Thomas H. B., Dolan Raymond J. TALK

Changes in behaviourally relevant beliefs are encoded in the dopaminergic midbrain

The neuronal mechanisms underlying belief updates about hidden variables of the environment are largely unknown albeit central for understanding how we navigate through an uncertain and dynamic environment. We devised a novel multi-sensory learning paradigm in an fMRI experiment to investigate how beliefs about true states of the world are updated in the brain. Subjects had to infer which of a simultaneously presented visual and auditory cue was relevant for predicting a monetary outcome. The relevance of the cues changed dynamically in time, thus creating the need to update current beliefs about the relevant cue according to their predictive value of a subsequent reward. We found that updates in behaviourally relevant beliefs were signalled in dopaminergic midbrain areas whilst controlling for possible effects of reward prediction errors, whereas surprise about outcomes was signalled in the cingulate cortex and bilateral insula. These results shed new light on the role of dopaminergic discharges in the brain, suggesting that they encode belief-updates relevant for action selection and inferring the true states of the environment. This is consistent with recent proposals of a general, modulatory role of dopaminergic firing in brain activation as opposed to restricting its function to the signalling of reward prediction errors, novelty or salience.

Smittenaar Peter TALK

Self-control across age, gender, depression and education assessed through a smartphone game

Here we report findings from a population study examining how self-control, measured through a selective stop-signal task, relates to age, gender, education and depression. The data were acquired through a smartphone application ("The Great Brain Experiment") over the course of 14 months, and we will discuss results from 12,496 individuals. Results from this cross-sectional study suggest that smartphone apps can be used to study cognition across the population.

Stenner Max-Philipp, Rutledge Robb, Zähle Tino, Voges Jürgen, Heinze Hans-Jochen, Dolan Raymond J. TALK

Local field potentials in human Nucleus accumbens show no sign of reward prediction error coding

fMRI has shown that the human Ncl. accumbens (Nacc) is involved in the evaluation of outcomes relative to expectations. We recorded local field potentials (LFP) from the Nacc of six epilepsy patients during a monetary gambling task to study electrophysiological signals underlying these BOLD signal changes. Patients could accept or reject a gamble offer, which, if accepted, led to a monetary gain or loss with a 50% probability. Four of the six patients adjusted their choices to the expected value of the gamble offer. Despite this effect on behaviour, neither evoked responses nor oscillatory power in the Nacc were modulated by expected value in any of the six patients. Instead, we observed a consistent enhancement of the power of beta-oscillations (15–30 Hz) ~300 to 1000 ms after the onset of the gamble outcome, which was modulated by outcome valence, but not by outcome magnitude. A similar modulation of outcome-evoked responses was observed. In summary, while decisions were influenced by expected value, LFPs reflected outcome valence but showed no sign of reward prediction error coding. We discuss the relative information content of BOLD signal changes vs. local field potentials in the Nacc in relation to its role in value-based decision making and outcome evaluation.

Stoppel Christian TALK

Representations of motivated behavior – shared neural resources for attention and reward

Central to the organization of behavior is the ability to deploy cognitive resources to certain – supposedly beneficial – external events or in accordance with one's own internal goals. In this respect, numerous studies have shown that externally driven resource allocation (i.e. to rewarding, novel or salient stimuli) relies on dopaminergic mechanisms (Bunzeck & Düzel 2006; Daw et al. 2006; Wittmann et al. 2005; Zink et al. 2003). Until recently, however, only few studies have shown that similar neural

substrates also govern the deployment of cognitive resources by intrinsic motivational processes (i.e. for example during attentional or cognitive control; Stoppel et al. 2013). In a series of recent experiments, we were able to show that intrinsically-driven resource recruitment in fact relies on/targets largely overlapping neural systems. Therein, we (i) observed enhanced hemodynamic activity within the dopaminergic midbrain for high task demands in the absence of rewards or other extrinsic motivating factors (Boehler et al. 2011). (ii) We demonstrated that increased reward magnitude and attentional load are processed in largely overlapping (Stoppel et al. 2011) but partly distinct (Krebs et al. 2012) neural systems. (iii) Beyond such effects on dopaminergic areas (e.g. SN//VTA or NAcc) and their (mainly frontal) target regions, attentional and reward-related processes also exert a highly similar impact on the processing of low-level features within extrastriate visual cortex (Stoppel et al. in preparation). And finally, (iv) recent evidence indicates that neural activity as a result of endogenous resource recruitment could either be beneficial (self-rewarding) or detrimental (in the sense of effort discounting) based on the perceived controllability of the task at hand (Schouppe et al. 2014). Taken together, these data indicate that recruitment of cognitive resources by extrinsic as well as intrinsic motivating factors relies on overlapping neural networks. This allows to adjust the amount of available cognitive resources to meet changing situational demands and opportunities without wasting energy when such resources are not required or their recruitment might be detrimental under certain task conditions.

Story Giles W., Vlaev Ivo, Metcalfe Robert D., Crockett Molly, Kurth-Nelson Zeb, Darzi Ara, Dolan Raymond J. **TALK**

Human preferences for fairness in the allocation of pain

Cooperative human relationships entail sharing both rewards and hardships. While much economic research has examined how people share rewards, how humans share hardships, such as physical pain, has been little studied. We hypothesized that pain inequality would motivate the transfer of *pain* between individuals, and influence pain perception. Firstly, we implemented a modified Dictator Game, in which the 'Dictator', was given the opportunity to alter (by fixed amounts) initial allocations of moderately painful electrical stimuli between themselves and an anonymous other, the 'Responder'. We found that Dictators adjusted allocations towards equality, and were increasingly likely to do so as the initial allocations became more unequal. In a follow-up study we observed the same tendency, and overall level of regard for others, for monetary outcomes. We conclude that people transfer both pain and money as if inequality carries an increasing marginal cost. A *status quo* bias was also evident for both modalities. Secondly, selected allocations of pain were realized, framed as being chosen either by the Dictator or at random. Unexpectedly, inequality *per se* did not influence pain perception. However we found that, compared with the

random condition, Responders perceived the same number of painful shocks as less intense when the Dictator had chosen to receive a larger number of shocks. The latter effect might arise from a mismatch between predicted and realized pain, where the former is shaped by social inferences.

Toelch Ulf, Pooresmaeili Arezoo, Dolan Raymond J. TALK

Normative and informational influences on conformity re-evaluated in a computational framework

Two major components feature in the literature why individuals conform to a majority. Firstly, the actions of others carry information on currently adaptive responses to environmental demands (informational influences). In addition, individuals conform out of the need to reduce social tension and signal in-group membership (normative influences). Most prominently, this has been investigated in the line judgement task conducted by Salomon Asch. Classically, participants' behaviour in the Asch experiment has been attributed mainly to social norms inducing conformity. Based on Bayesian decision-making in perceptual contexts, we present a computational model and an experiment questioning this interpretation. By exposing participants to different normative contexts and varying information accuracy, we identify interactions between informational and normative components. Our results suggest that informational influences compose an important and overlooked mediator for conformist behaviour. We review the findings from the Asch experiment and recent MRI studies in the light of these findings.

Wright Nicholas POSTER

Knowing how the other thinks: the brain and influence in international confrontations

To manage crises and escalation, or to conduct deterrence operations, it is necessary to forecast how an adversary will decide to respond to our actions. Effective deterrence and escalation management thus crucially depend on understanding human decision-making. I apply two core new insights from the modern brain sciences. First, the neural phenomenon of "prediction error" that provides a tool to *increase* or *decrease* the impact of our actions. Second, specific social motivations that can limit deterrence and cause escalation and de-escalation. I discuss historical and contemporary cases, doctrine, a China–U.S. escalation scenario and policy recommendations.

Imprint

Copies
120

Copyediting
Valerie Keller, Annette Winkelmann

Design, Typesetting, Production
Sebastian Lehnert, Munich ☞ www.deskism.com

Printed by
Eder Druck, Dachau