Evidence for past and present subjective value signals in the human orbitofrontal cortex

Wan-Yu Shih[1], Chien-Chen Chou[2], Jeng-Ren Duann[3], Cheng-Chia Lee[2], Shih-Chieh Lin[1], Hsiang-Yu Yu[2], Paul Glimcher[4], Shih-Wei Wu[1]

[1]National Yang-Ming University, [2]Taipei Veterans General Hospital, [3]National Central University, [4]New York University

There is accumulating evidence suggesting that the orbitofrontal cortex (OFC) represents the subjective value (SV) of options essential for value-based decision-making. A growing body of research further indicates that value representations in OFC are sensitive to both past and present rewards and that OFC encodes relative SV that depends on temporal context of experience. However, these findings are predominantly based on single-unit electrophysiology in non-human primates and have not been widely reported in humans. In this study, we investigated value representations in the human OFC using intracranial electrophysiology (stereo-electroencephalography, SEEG). Four subjects implanted with multi-contact depth electrodes performed a Becker-DeGroot-Marschack (BDM) auction task on snack food items to elicit and estimate the subjective value (SV) of rewards. Two 2500-ms time windows were extracted from the SEEG data: one time-locked to the stimulus onset, the other time-locked to the response onset. The high gamma power (80-150 Hz) - previously shown to positively correlate with the firing rate of single neurons - was extracted. For each SEEG contact on each subject, we regressed 50-ms time-binned high-gamma power against the SV of the present reward and of the reward in the previous trial. A contact was considered value-related if the regression coefficient is significant ($p < 0.05$) for three consecutive 50-ms time bins. All four subjects showed value-related representations in the OFC: three subjects showed significant representation of current SV and three showed significant representation of previous SV. Two out of four subjects showed both current and previous SV representations in the same time windows (stimulus-locked and response-locked). Interestingly, both subjects had contacts that showed opposite signs of correlation with previous and current SV, suggesting subtraction-based relative SV computations. In summary, using human SEEG, we found evidence that high-gamma activity in the human OFC encodes current as well as previous SV for food rewards. Furthermore, our results provide support to the hypothesis that OFC computes relative value that is sensitive to the temporal context of experience.

Session III Learning and Memory

The effect of counterfactual information on outcome value signal encoding: Evidence for fully-adaptive coding along the rostrocaudal axis of the medial prefrontal cortex

Doris Pischedda[1], Stefano Palminteri[2], Giorgio Coricelli[3]

[1]University of Trento, [2]Institut National de la Santé et de la Recherche Médicale, [3]University of Southern California

OBJECTIVE When we make a decision, usually we experience its consequences but we have no information about potential outcomes of alternative decisions we could have made. Yet, this additional information is useful to improve learning (e.g., Palminteri et al., 2015). In this study, we analyzed brain activity related to outcome processing in loss and gain contexts to explore the neural coding of value for both factual and counterfactual outcomes, when either partial or complete feedback about the outcomes is provided. The aim of the experiment is two-fold: 1) to investigate where factual and counterfactual information is represented and 2) to unravel how outcome value is encoded in different feedback conditions. We hypothesize that counterfactual information will produce rescaling of value

signal depending on the context, such that the value of a neutral outcome becomes positive in a loss context (as absence of punishment) and negative in a gain context (as absence of reward), thus reflecting fully-adaptive coding of value signals. METHODS Twenty-eight participants performed a probabilistic instrumental learning task while undergoing functional magnetic resonance imaging scanning. On each trial, they had to choose between two symbols probabilistically associated with a certain reward (or punishment). Then, the outcome of the decision was revealed. Importantly, on half of the trials participants received feedback only about the outcome of their decision (partial feedback condition), while in the other half they were informed about both the factual and the counterfactual outcome (complete feedback condition). We used univariate analysis as well as multivariate pattern classification (Haynes, 2015) to explore outcome value processing and encoding of factual and counterfactual outcomes, in trials with either complete or partial feedback. Furthermore, we assessed neural coding of outcome value in these two conditions. RESULTS Our results show that: 1) not only factual but also counterfactual information can be decoded from local patterns of brain activity, 2) brain activation in regions along the rostrocaudal axis of the medial prefrontal cortex (mPFC) increases for processing of factual outcomes but decreases for counterfactual information processing, 3) outcome decoding is significant in less rostral regions of mPFC, and 4) outcome value is represented with a fully-adaptive code when complete feedback is provided, while it is encoded in an absolute way when feedback is partial. CONCLUSION These findings suggest that outcome value processing is implemented through multiple coding mechanisms flexibly activated depending on the specific choice setting at hand.

Modeling structure in learning to self-regulate motivation via veridical real-time fMRI neurofeedback from the ventral tegmental area

Shabnam Hakimi[1], Jeffrey MacInnes[2], Kathryn Dickerson[1], R Adcock[1]
[1]Duke University, [2]University of Washington

INTRODUCTION: The ventral tegmental area (VTA) and its dopaminergic projections are central to volitional behavior. Previous work from our group demonstrated that individuals can learn to self-activate the VTA using self-generated motivational imagery during real-time neurofeedback training, but only with veridical VTA feedback. Here, we investigate how the temporal structure of neurofeedback training predicts transfer. METHODS: Using a previously detailed task (MacInnes et al., 2016), participants learned to volitionally upregulate VTA response. Briefly, participants completed a pre-test, 3 training runs, and a post-test. During training, they received real-time fMRI neurofeedback from the VTA (N=19) via a graphical thermometer every 1 s over a total of 15 20-s trials (3 per run). Another group (N=14) received Gaussian noise instead of veridical VTA feedback. All participants received minimal instruction about how to self-activate and their strategies were not reported until after the scan. Thus, our analyses were blind to the strategies used, instead focusing on the effect of context. To examine the structure of neurofeedback learning, we used MATLAB (v2016b), first extracting mean VTA response during training (ie, the feedback signal) at the single-participant level; we then resampled the signal to 2 Hz and rescaled it to [-1,1]. Next, we computed the slope of the feedback time series in three temporal contexts: single trial, scanner run, and full training session. This produced parameters reflecting learning during each context (trial: 15, run: 3, session: 1). We then used linear regression to examine how well these parameters predicted transfer, indicated by the change in average VTA response from pre- to post-test, fitting one model per temporal context on the group-level. Finally, we estimated and compared model evidence. RESULTS: The slope of VTA activation change over the entire course of training predicted the magnitude of transfer (adj. R2=0.335, F2,17=8.56, p<0.01). An initial comparison of model evidence suggested that the full session was the best model for the data (AICc: -2.58, BIC: -1.44) relative to other contexts (AICc, BIC; trial: 243, -13.9 and run: 10.8, 11.7). Further, only the full session explained