A framework for investigating decision-making in the brain with high spatio-temporal resolution using simultaneous EEG/fMRI and joint ICA

Sreenath Pruthviraj Kyathanahally[1], Nurhan Erbil[1], Ana Maria Franco-Watkins[2], Xiaoxia Zhang[1], Vince D Calhoun[3,4], and Gopikrishna Deshpande[1,2]

[1]*AU MRI Research Center, Department of Electrical and Computer Engineering, Auburn University, Auburn, Alabama, United States,* [2]*Department of Psychology, Auburn University, Auburn, Alabama, United States,* [3]*The Mind Research Network and Lovelace Biomedical and Environmental Research Institute, Albuquerque, NM, United States,* [4]*Department of Electrical and Computer Engineering, University of New Mexico, Albuquerque, NM, United States*

Introduction: Many decisions involve making intertemporal choices between immediate and future prospects. Such comparisons are ubiquitous across many decision domains ranging from health [1] social [2], financial [3], and environmental [4] contexts. Despite the plethora of evidence that future prospects are discounted, the basic mechanisms underlying intertemporal choice remain poorly understood and under-examined [5-7]. The basic temporal decision making paradigm has been associated with real-world problematic behaviors, but it does not adequately model real-world situations wherein there are immediate and delayed costs (as well as rewards); and the rewards and costs of future outcomes are probabilistic rather than certain. Extensive electroencephalography (EEG) literature exists on event-related potentials (ERPs) associated with reward and decision making [8-10]. However, due to poor spatial localization, existing results can mostly capture only cortical sources. In contrast, the functional magnetic resonance imaging (fMRI) studies of intertemporal choice [11] are silent on the important aspect of fast temporal dynamics of decision making, but they can spatially localize deeper structures. As such, combining EEG and fMRI data provides complementary measures of neural electrical activity at high temporal resolution and hemodynamics at high spatial resolution. In this study, we investigate the spatio-temporal dynamics of neural substrates of intertemporal decision making by acquiring simultaneous EEG/fMRI along with a novel decision making paradigm that relies on rewards and costs with varying probabilities.

Method: Six participants (1 female, 5 male, 23±2.4 years of age) completed different decision tasks including *1) Standard Task-Reward* (delayed reward) *2) Standard Task-Cost* (delayed cost) *3) Temporal-Mixed Reward and Cost* (delayed, but certain, reward and cost) *4) Temporal-Uncertainty Mixed Reward and Costs* (delayed reward and cost with varying probabilities) *and 5) Control Task* as in [11]. Decision tasks were completed in a mixed block and event-related design. MRI data were collected on a 3T Siemens Verio scanner using a 12-channel matrix head coil. Functional images were acquired using a multiband gradient echo-planar imaging sequence [12] with 30ms TE, 600ms TR, 55° flip angle and 64 x 64 x 16 acquisition matrix. MR-compatible 64 channel EEG amplifiers (Brain Products, Germany) and a MR-compatible EEG cap with 63, 10-20 system distributed scalp electrodes and an ECG electrode were used. For simultaneous EEG/fMRI recordings, the EEG data acquisition clock was synchronized with the MRI scanner clock using Brain Product's SyncBox, resulting in exactly 10,000 data points per TR interval. EEG data were digitized with a sampling frequency of 5kHz and 0.5 µV resolution, within a DC-250Hz frequency range and with reference to FCz. Impedance at all recording electrodes was less than 20 kΩ. The recorded EEG data were preprocessed to remove gradient and cardioballistic artifact using Brain Vision Analyzer 2.0 software. For deriving response-related ERPs, 800 ms epochs were obtained, extending 200 ms prior to and 600 ms following the choice event. For baseline correction, the mean voltage associated with each electrode during the 200-ms interval preceding the event was subtracted from each sample of that electrode. After standard pre-processing of fMRI, activation t-maps at the individual subject level were obtained using SPM8 software. The resulting t-maps, along with the epochs obtained from all electrodes, were input into the Fusion ICA toolbox [13] to obtain joint ICA (jICA) components for each task. jICA components from each task were compared with the control task to obtain the components that were spatio-temporal different from control.

Results and Discussion: The results for *Temporal-Uncertainty Mixed Reward and Costs* decision task are presented in Figure 1. The proposed task activated the reward and decision making circuits, most notably ventral striatum, insula, medial/lateral parietal cortex and medial/lateral frontal cortex. Also, the temporal dynamics revealed multiple activations of this circuit, showing reward-related positivity and negativity, both prior to and after the decision making point. The dynamics of the control task was notably anti-correlated with that of the present task. The fMRI activation maps (task-control) at the group and individual level (not shown here) activated more areas in the proposed task as compared to standard tasks reported before [11,14]. Additionally, the fMRI activation maps had some spatial similarities with the jICA fMRI component that was most significantly different from the control task (shown in Fig.1), though the former does not provide the fast temporal dynamics information that the latter does. Also, the jICA component of the proposed task was most significantly different from the control task, though other standard tasks also had components different from control at a lower significance. This study provides a framework for investigating decision-making in the brain with high spatio-temporal resolution. Specifically, it validates the superiority of the proposed temporal decision task, allowing us to more accurately model real world decision-making.

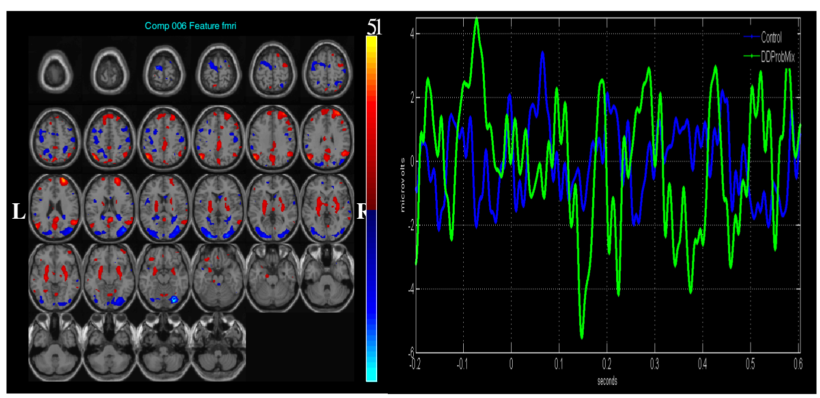

Fig.1 *Joint ICA component most significantly (p=0.011) different in the proposed Temporal-Uncertainty Mixed Rewards and Costs task (DDProbMix), as compared to the control task. Left: fMRI component with red indicating activation and blue deactivation; right: corresponding EEG component with the response time-locked to t=0 s on the x-axis.*

References: 1. Chapman, Russell Sage Foundation, 395-418, 2003 **2.** Jones B et al, *Psychological Science*, 17, 283-6, 2006 **3.** Loewenstein et al, *Journal of Economic Perspectives*, 3, 181-193, 1989. **4.** Carson et al , *J Neuroscience, Psychology, and Economics*, 2, 112-130, 2009 **5.** Carter et al, *Journal of Neuroscience*, *Psychology, and Economics*, 1, 27-45, 2010. **6.** Figner et al, *Nature Neuroscience*, 13(55), 538-539, 2010 **7.** Loewenstein et al, *Annual Review of Psychology*, 59, 647-672, 2008 **8.** Cherniawsky et al, *Cogn Affect Behav Neurosci*. In press, 2012 **9.** Blackburn et al, *Cogn Emot.* 26(8):1459-74, 2012 **10.** Walsh et al, *Neuroscience and Biobehavioral Reviews*, 36, 1870–1884, 2012 **11.** Weber et al, *Brain Research*, 1234, 104-115, 2008 **12.** Feinberg et al, *PLoS One*, 5(12), 2010 **13.** http://mialab.mrn.org/software/fit/ **14.** Wittman et al, *Journal of Neuroscience, Psychology, and Economics*, 3, 15-26,2010