A Multimodal Framework for Joint Kinematic and EEG Data Analysis during a Haptic Reaching Task in Parkinson's Disease

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INTRODUCTION: Haptic reaching tasks can be explored to study unknown underlying mechanisms of motor control in Parkinson's disease (PD). Particularly, when concurrent multimodal data (e.g. EEG, EMG and kinematic data) are available, one can assess functional interactions in human motor control systems. In this study, we aim to analyze the kinematic and EEG data from a joint blind source separation perspective by assuming that there exist common sources between the two modalities. For the methodology perspective, this joint analysis problem for haptic reaching tasks can be formulated similarly to the problem of corticomuscular coupling analysis. There were several popular methods proposed in the literature, such as magnitude-squared coherence (MSC) and partial least squares (PLS) [1]. However, they suffer from certain limitations: It is hard for MSC to be extended to a group level analysis, which is important in real-world medical applications. It is also hard for PLS to be extended to a multimodal method to handle multiple datasets. In this work, we investigate a joint multimodal group analysis framework to jointly analyze kinematic and EEG data and study the underlying sources.

METHODS: Twelve normal and nine PD subjects sat at a table with two phantom haptic robots affixed to their thumb and index finger of the right hand. The robots allow the subjects to reach to and grasp a virtual object presented on the monitor by generating a force on the digits when the object was touched, feeling as if a real object was present. Experimental recordings include 64-channel EEG (BioSemi), eye tracking (EyeLink) and digit trajectories and kinetics (Phantom Robots).
The framework has a two-step modeling strategy. In the first step, a multidirectional latent variable (LV) extraction solution is established for preliminary LV preparation. It is formulated by solving a simple optimization problem. In the second step, a joint post-processing, multiset canonical correlation analysis (M-CCA), is performed on the extracted LVs to acquire common information in each dataset [2]. The EEG features consist of pair-wise correlations within overlapped 1-second windows [3]. The kinematic features include hand position, aperture, velocity, acceleration and eye-finger distance.
Using this joint analysis framework, we can extract completely uncorrelated components within each dataset and keep the corresponding components across different datasets highly correlated.

RESULTS: We find two underlying components that demonstrate significant correlation ($p < 0.05$) between kinematic variables and EEG features. By regressing the EEG components back to the original EEG time-varying features, we find that the connections with occipital regions are prominent in PD subjects. Compared to normal subjects, the PD subjects heavily rely on visual cues for the initiation and ongoing control of movement [4], consistent with previous studies suggesting that PD subjects rely excessively on visual information to counteract the deficiency in being able to generate internal commands from their affected basal ganglia.

CONCLUSION: We apply a joint multimodal group analysis framework to concurrent kinematic and EEG signals collected from twelve normal subjects and ten PD patients when performing a motor task. The results demonstrate the presence of highly correlated temporal patterns among the two data modalities and meaningful spatial activation patterns between the control and PD groups. The framework can also be applied to other types of multi-subject and multi-modal concurrent signals including but not limited to fMRI, PPG, ECG and EMG signals.

References

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