Short-time Prediction of Motor Performance Using Local Field Potential in Parkinson's Disease

Minkyu Ahn PhD; Shane Lee PhD; Julie Guerin; David J Segar BS; Tina Sankhla; Wael Asaad MD, PhD
Brown University, Providence, Rhode Island
(Brown Institute for Brain Science; Department of Neuroscience; Warren Alpert Medical School)
Department of Neurosurgery, Rhode Island Hospital, Providence, Rhode Island.

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Introduction

Motor deficits in Parkinson's disease (PD) are typically evaluated over relatively long time scales [Apa and Goetz 2013], but in reality, movement states may vary on the timescale of seconds. Deciphering the neural states associated with real-time movement is critical for designing better neuromodulation systems, such as closed-loop deep brain stimulation (DBS). In this study, we quantified motor deficits on a rapid time scale in PD patients using a continuous motion task and demonstrated that these deficits can be predicted with ~1 sec. precision using local field potentials (LFP) recorded from subthalamic nucleus (STN).

Methods

Behavioral task and recordings

In this task (Fig. 1), an open green target circle moves along one of three invisible paths on screen. The subject's objective is to use a joystick to control a cursor to follow the target as closely as possible. Each session consists of up to 36 trials, each lasting 10 to 20 seconds. LFP recordings were obtained from STN in 7 PD patients during awake DBS electrode implant surgery. Additional behavioral data was collected from PD patients preoperatively and the age-matched controls. The task was run using MonkeyLogic [Asaad et al. 2013].

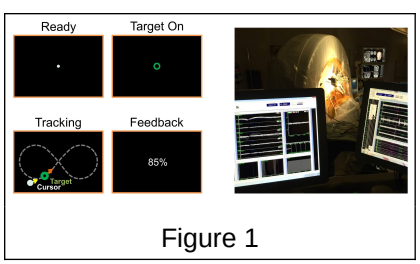

Figure 1

Motor error quantification.

To assess performance, we measured the tremor severity and the ability to track the moving target. Tremor Magnitude (TM) was calculated as the absolute value of bandpass filtered (4–12 Hz) joystick data to capture physiological tremor. The vector error (VE) was calculated as the difference vector between the cursor and target (Fig. 2). For each epoch (2 sec. window with 1 sec. step), single TM and VE values were calculated by averaging over samples within the window. This process yielded several hundred epochs and their corresponding TM and VE values.

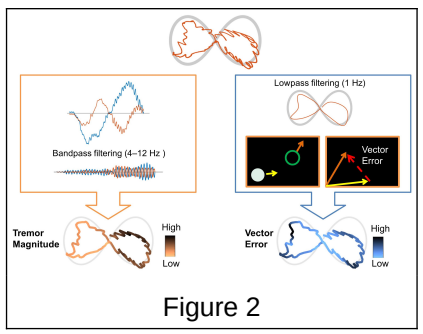

Figure 2

Epoch categorization and classification.

For each session of each subject, we sorted all epochs in ascending value according to TM and compared the lowest and highest quartiles. We did the same for VE but also eliminated the epochs with concurrently high TM (top 10% of TM values) to better dissociate independent neural correlates of VE and TM (Fig. 3).

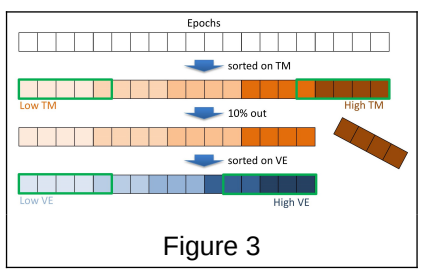

Figure 3

Feature identification and classification.

A Support Vector Machine (SVM) (Fig. 4) was applied to classify epochs based on neural features (2 Hz bandpass spectral powers from 1–400 Hz) corresponding to low or high motor performance states (TM and VE), and final accuracy was obtained through 10-fold cross-validation techniques.

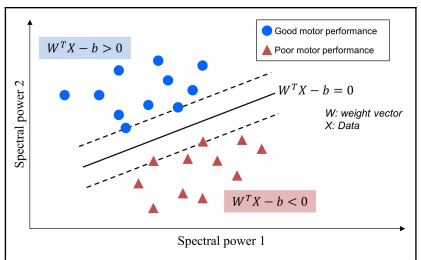

Figure 4

Results: Behavioral data

TM and VE differentiate movement states.

Motor errors attributable to different symptoms (tremor vs. bradykinesia and rigidity) may be differentiable by TM and VE (Fig. 5A). As expected, motor performance was worse intraoperatively compared to clinic (Fig. 5B). Each pair was significantly different ($p < 0.05$, MWU), except for PreOp vs. IntraOp in tremor magnitude.

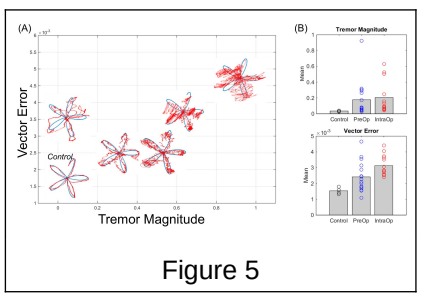

Figure 5

Results: Neural activity

Motor and neural activity changes on 1-sec. timescales (Fig. 6).

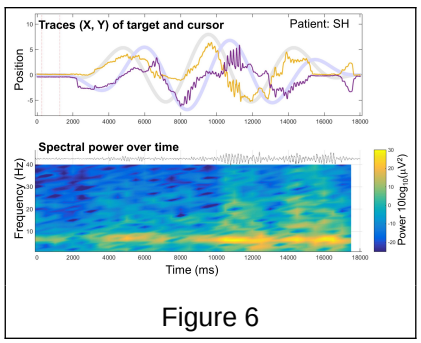

Figure 6

1–40 Hz power accounted for ability to predict error.

The squared SVM weight of each frequency band revealed that of the 400 Hz analyzed, ~1–40 Hz was the primary contributor in differentiating low and high error epochs for both TM and VE (Fig. 7).

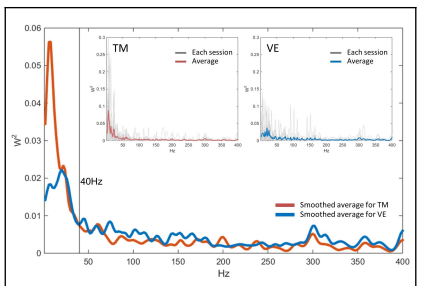

Figure 7

Predicting movement states.

Classification analysis (Fig. 8) revealed that neural activity (1–40 Hz) predicts behavioral motor performance (TM: 83%, VE: 69%).

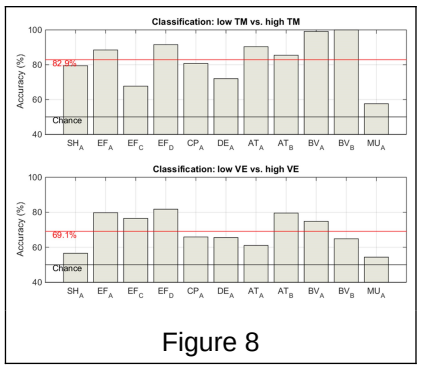

Figure 8

Increased spectral power correlates with high motor errors.

Spectral power of individual epochs shows positive correlation (mean r = 0.28) with TM and relatively weak positive correlation (mean of r = 0.11) with VE (Fig. 9).

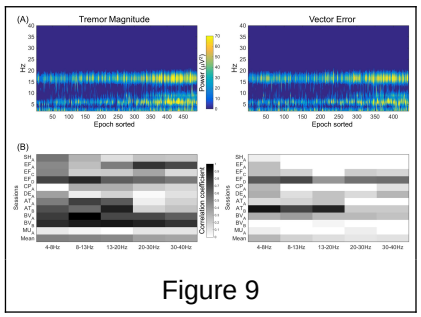

Figure 9

Conclusion

These results demonstrate that severity of tremor and difficulty to smoothly follow the target can be predicted on a short time scale using the spectral power of STN LFP (1–40 Hz). States reflecting poor motor performance may be useful as biomarkers for controlling closed-loop DBS.

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