A graph-based approach to study motor coordination in Parkinson’s Disease gait: a longitudinal study to assess the effectiveness of Deep Brain Stimulation neurosurgery

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ABSTRACT

Introduction

Graph theory is emerging as a promising technique in different contexts [1], and it can be used to extract a network of muscles based on their coordinated activity during gait. This work aims to investigate the motor control strategies of Parkinson’s Disease (PD) patients through graph theory and Louvain clustering and to evaluate the successfulness of Deep Brain Stimulation (DBS) in alleviating PD motor symptoms.

Methods

Gait analysis, inclusive of surface electromyography (EMG) of the main muscles involved in locomotion, was carried out on 30 PD patients and 30 controls. A detailed description of the acquisition protocol is provided in Ref. [2]. PD patients were longitudinally followed-up, with assessments at 3 time points: pre-DBS implant (T_0), 3-month post-DBS implant (T_1), and 12 months post-DBS implant (T_2). Intermuscular adjacency matrices computed from EMG data of 12 lower-limb and trunk muscles were used to extract graph networks. Each graph network consists of nodes (i.e., muscles) and edges (i.e., weighted connections between muscles). The graph “modularity” was extracted from each graph, as defined in Ref. [3]. A *1-way* ANOVA with Bonferroni correction for multiple comparisons was performed to discriminate statistically significant differences in graph modularity among PD patients (at the 3 time points) and controls.

Results

Muscle-network graph of a representative PD patient is shown before (Fig. 1A) and 12 months after DBS (Fig. 1B). The graph modularity increased from 0.28 to 0.49 during the follow-up of this specific patient. The modularity of the PD population at T_0, T_1, and T_2 vs. controls are shown in Fig. 1C. The PD modularity at T_0 was significantly smaller than that of controls (PD at T_0: 0.35±0.01 (mean±SE); controls: 0.40±0.01; p=0.019), becoming not different from that of controls at T_1 (0.36±0.01; p=0.18) and T_2 (0.38±0.01; p=1.00).

Discussion

Modularity is a metric that reflects the separability of muscle groups that activate synergistically. Lower graph modularity may indicate reduced independence among the muscle groups and decreased motor

control complexity. Graph modularity proved a sensitive measure to assess short- and long-term motor improvements in PD patients following DBS.

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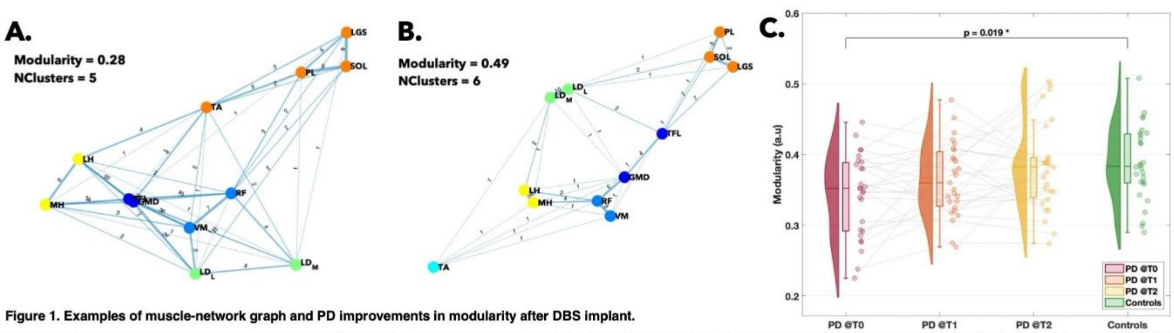

Figure 1. Examples of muscle-network graph and PD improvements in modularity after DBS implant.

Muscle-network graph of a PD patient before (**Fig. 1A**) and after DBS implant (**Fig. 1B**). Muscle considered: Tibialis Anterior (TA), Lateral Gastrocnemius (LGS), Peroneus Longus (PL), Soleus (SOL), Vastus Medialis (VM), Rectus Femoris (RF), Lateral Hamstring (LH), Medial Hamstring (MH), Gluteus Medius (GMD), Tensor Fasciae Latae (TFL), Longissimus Dorsii of the more- and less-affected side (LD_M and LD_L). **Fig. 1C** shows graph modularity of the PD population (T_0: baseline; T_1: 3 months after DBS; T_2: 12 months after DBS) vs. controls. For each group, the raincloud plot shows, sequentially, the data distribution (split-half violin plot), a standard visualization of central tendency with a boxplot (representing minimum, 25th percentile, median, 75th percentile, and maximum), and raw jittered data points of each specific individual (scatter plot).

References

[1] F. Hug, S. Avrillon, A. Sarcher, A. Del Vecchio, D. Farina, “Correlation networks of spinal motor neurons that innervate lower limb muscles during a multi-joint isometric task”, J Physiol 601.15 (2023) pp. 3201–3219, Doi: 10.1101/2021.10.13.460524.

[2] M. Ghislieri, M. Lanotte, M. Knaflitz, L. Rizzi, and V. Agostini, “Muscle synergies in Parkinson’s disease before and after the deep brain stimulation of the bilateral subthalamic nucleus,” *Scientific Reports 2023 13:1*, vol. 13, no. 1, pp. 1–13, Apr. 2023, Doi: 10.1038/s41598-023-34151-6.

[3] V.D. Blondel, J.L. Guillaume, R. Lambiotte and E. Lefebvre, “Fast unfolding of communities in large networks”, *Journal of Statistical Mechanics: Theory and Experiment 2008*, vol. 10, Oct. 2008, Doi: 10.1088/1742-5468/2008/10/P10008.