Temporal Characteristics of Speech in Cortical and Subcortical Recordings

Diego Perez[1,2], Tyler Davis MD/PhD[2], Giuliana Rezende[1], Alan Dorval PhD[1], and Shervin Rahimpour MD[2]

Department of Biomedical Engineering, University of Utah[1], Department of Neurosurgery University of Utah[2]

Background

- Many speech-production impairments have been linked to damage in the basal ganglia[1], including aphasia, dysarthria, stuttering, and speech symptoms associated with Parkinson's Disease (PD)[2].
- There is still limited research on how basal ganglia dysfunction contributes to language production impairments[3].
- Understanding how the basal ganglia interacts with the cortex could illuminate the complex orchestration of the speech production mechanisms within the brain.

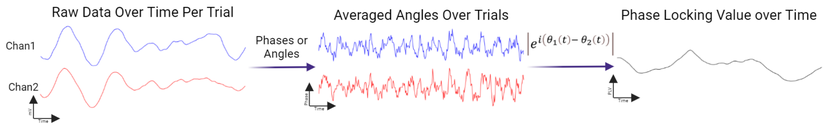
Methods

Data Collection:

Patients were recruited from deep brain stimulation implantation surgery for treatment-resistant PD and essential tremor (ET). The bilateral subthalamic nucleus (STN) or ventral intermediate nucleus (VIM) in the thalamus was simultaneously recorded with a cortical grid placed on the more severe hemisphere of the patients. The patients listened and repeated either a triplet syllable task of consonant-vowel (CV) patterns or a set of rhyming sentences.

Data Analysis – Functional:

Artifacts were removed from electrocorticography (ECoG) and Deep Brain Stimulation (DBS) channels by baseline normalization and bipolar re-referencing. Morlet Wavelet Transformation was used to extract frequencies over time. High-frequency activity (HFA) was extracted between 70-150 Hz and beta frequency from 12-32 Hz. The phase locking value (PLV) was calculated below to characterize behavior at HFA and beta frequencies. The time delay was measured by how much one signal had to shift to align with another.



Data Analysis – Structural:

Before surgery, the patients underwent an imaging protocol to collect structural and diffusion tensor imaging. Structural images were co-registered to diffusion images and then processed through MRtrix3[4] (open-source software) to create probabilistic tractography between brain regions. Structural connectivity measures were extracted and correlated with time delay measures between regions.

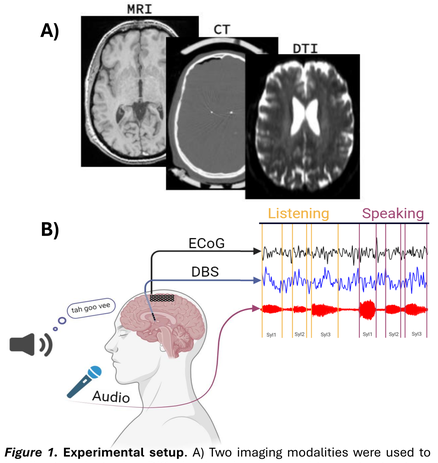


Figure 1. **Experimental setup**. A) Two imaging modalities were used to localize the electrodes. Diffusion imaging was used to create structural connectivity. B) Language task setup. MRI=Magnetic Resonance Imaging; CT=Computational Tomography; DTI=Diffusion Tensor Imaging.

Objective – To measure and model cortical and basal ganglia activity and connectivity during speech production

Results – Functional Connectivity

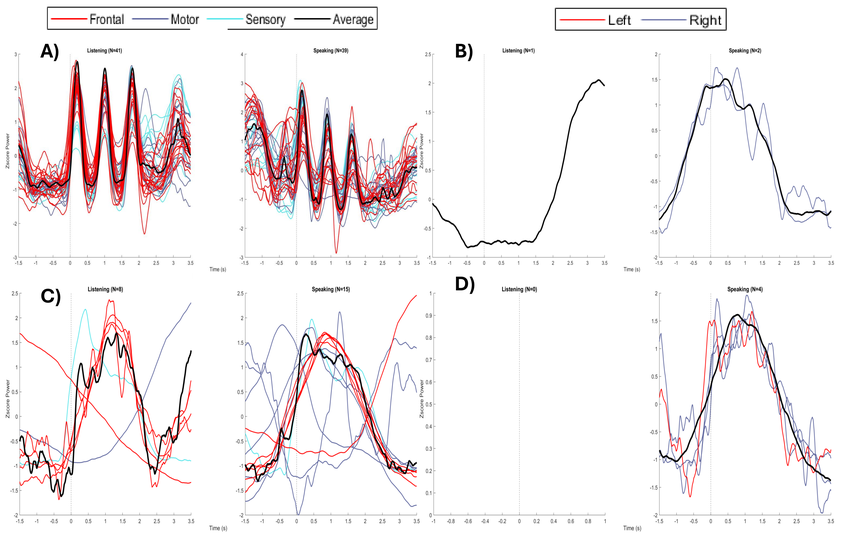


Figure 2. **High-frequency activity is found in different regions of the brain.** All graphs show the HFA averaged over trials during listening and speaking onsets. A) and B) are from a representative syllable patient and C) and D) are from a representative sentence patient. A) and C) are channels from the ECoG grid and B) and D) are from the DBS electrodes (STN and VIM respectively). Significant channels are traced at p-value < 0.05.

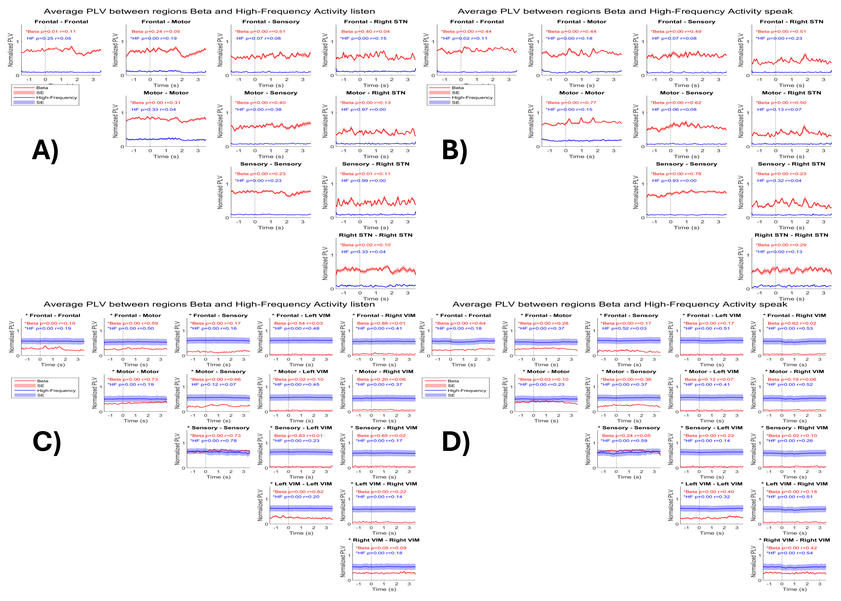


Figure 3. Phase locking value was found in HFA and beta frequencies. PLV was calculated from all possible pairs between regions. Mann-Whitney U test was performed on the non-parametric data. Effect size, p-values, and standard error shades were calculated for each combination of pairings. Blue represents HFA, and red represents beta frequency. A) and B) are from a representative syllable patient, and C) and D) are from a representative sentence patient.

Results – Structural Connectivity

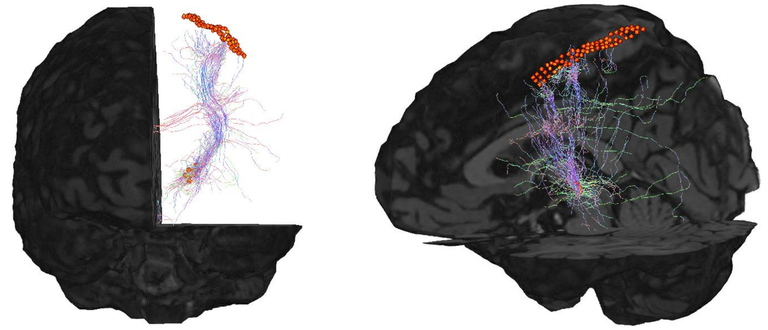


Figure 4. **Probabilistic fiber tracts created from patients' ECoG and DBS electrodes.** The two brain images are of a representative subject that shows fiber tracts going from the ECoG grid to the STN in 4mm region of interest (ROI) spheres for each contact. Tracts are color-coded as green from anterior to posterior, blue from superior to inferior, and red across hemispheres.

Discussion

- Based on the average z-scored power in HFA, we can see the increase and decrease in power caused by listening and speaking during each task. The significant DBS channels only show a spike in HFA at the onset of speaking and not listening.
- Regions show synchronization of beta and HFA bands between cortical basal ganglia regions. Some paired regions exhibit significant changes with speech onset.
- Probabilistic tracts were found between each subject's ECoG and DBS ROIs. In ongoing work, we are constructing structural connectivity matrices between regions for all subjects.
- Future, work will explore the relationship between structural connectivity and phase delay within and between cortical and basal ganglia regions.
- These efforts of modeling functional and structural connectivity during speech production will help provide more understanding of the speech production mechanism.

References

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