Effects of STN deep brain stimulation on voice motor control in Parkinson's disease

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Introduction

Background

Parkinson's disease (PD) is a neurodegenerative neurological disorder resulting from progressive cell death of dopaminergic neurons in the basal ganglia. Damages to neurons in the basal ganglia can negatively affect voluntary movements in different parts of the human body. When these movement disorders affect the voice control system, the patients start to develop voice disorders.

The effect of PD on voice has primarily been associated with reduced loudness (hypophonia) and reduced vocal pitch range, which appear to have a sensory contribution. Recent studies have suggested that PD can impair voice motor control and adaptation mechanisms [1-3].

Deep brain stimulation (DBS) is a common treatment of general motor impairment in PD, although its effect on voice has been reported to be highly variable [4-9].

Objective

The present study was a systematic investigation toward understanding the effect of DBS on vocal poduction and motor control mechanisms. Our goal was to use objective measures of voice production and motor control to address the following questions:

1 – How does DBS affect mechanisms of voice motor control?
2 – What are the neurophysiological correlates of DBS effect on voice?

Deep Brain Stimulation (DBS)

DBS is a neurosurgical procedure involving the implantation of a neurostimulator (brain pacemaker) through electrodes, to specific brain areas for the treatment of movement and affective disorders.

DBS has been used for treatment of Parkinson's disease, essential tremor, dystonia, chronic pain, major depression and obsessive-compulsive disorder (OCD).

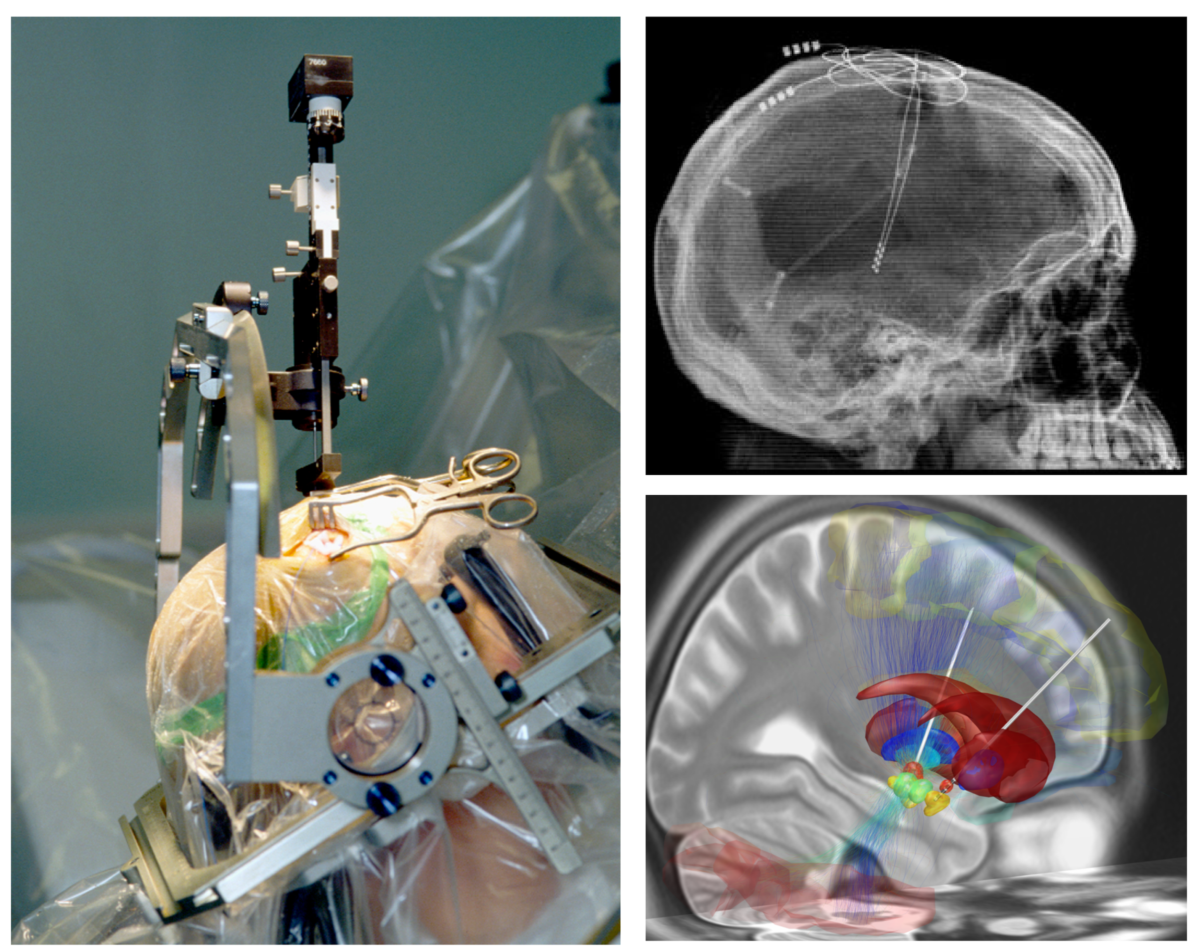

Figure 1. a) Surgical procedure using streotactic system to impant DBS electrodes. **b)** CT scan of the implanted DBS electrodes in STN for a patient with Parkinson's disease. **c)** 3D reconstruction of DBS electrode implantation in STN.
(photo source: https://en.wikipedia.org/wiki/Deep_brain_stimulation)

Experimental Task and Results

Experimental task:

10 patients with Parkinson's disease with STN-DBS implantation repeated steady vocalizations of the vowel sound /a/. During vocalizations, a randomized (up or down) pitch-shift stimulus perturbed voice auditory feedback at 100 cents. Patients were tested in two blocks of DBS ON and DBS OFF.

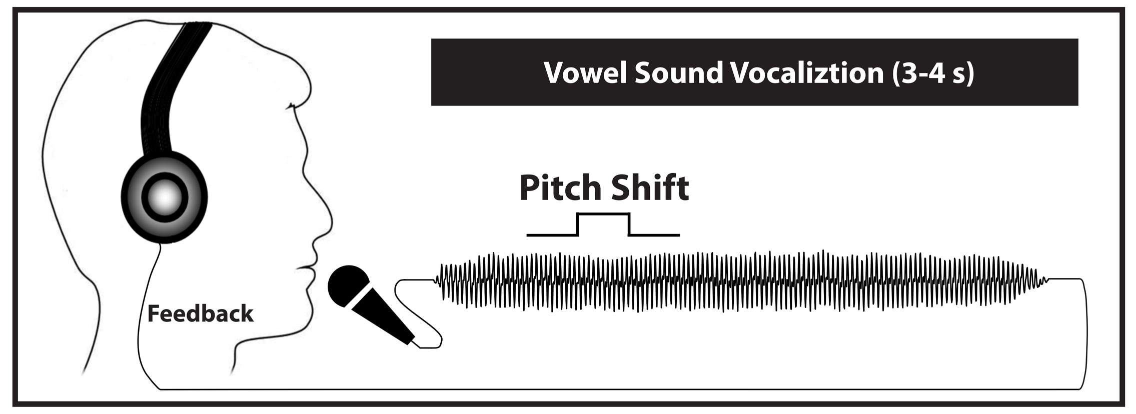

Figure 2. Auditory feedback perturbation paradigm.

Effects of DBS on Voice Motor Control:

All subjects controlled their voice by producing compensatory responses that changed their vocal pitch in the opposite direction to auditory feedback perturbation.

DBS ON did not modulate the magnitude of vocal compensation in response upward pitch-shift stimuli compared with DBS OFF condition (Figure 3a).

DBS ON resulted in significantly larger *($p<0.05$)* vocal compensations in response downward pitch-shift stimuli compared with DBS OFF condition (Figure 3b).

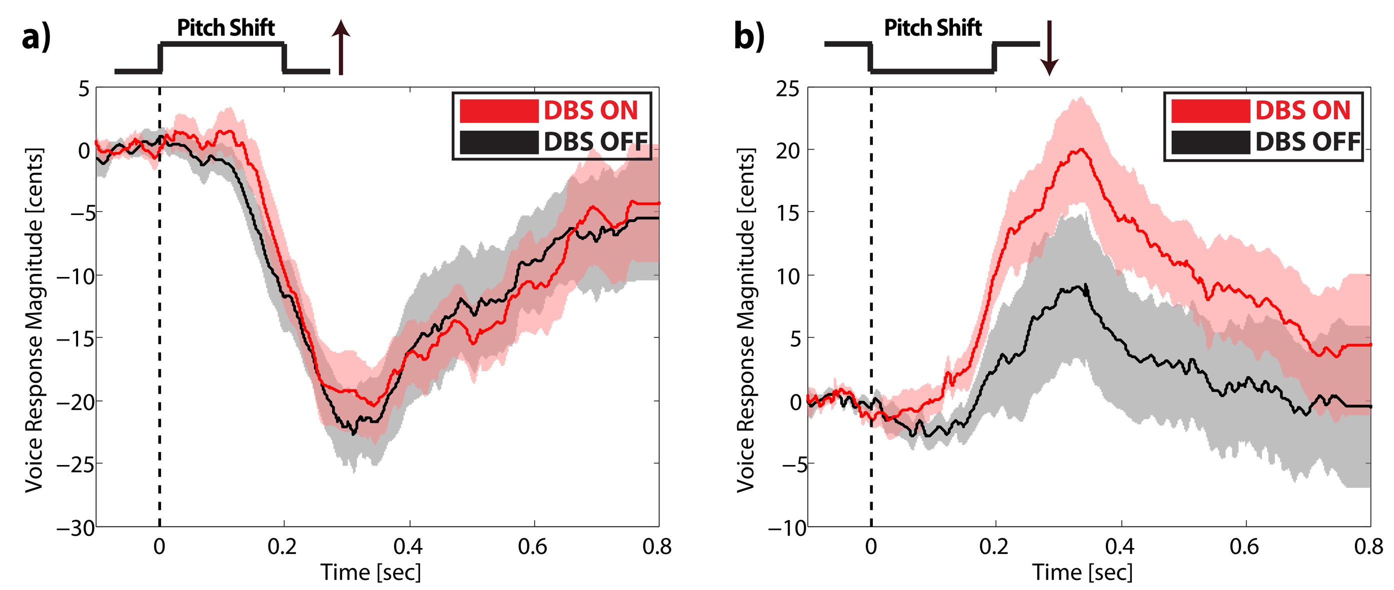

Figure 3. Behavioral compensatory vocal responses to auditory feedback perturbation for **a)** upward and **b)** downward pitch-shift stimuli overlaid across DBS ON and OFF conditions.

Effect sof DBS on Voice Parameters:

DBS significantly reduced variability in voice pitch frequency *($p<0.05$)*, as indexed by lower jitter during DBS ON compared with DBS OFF condition (Figure 4).

DBS did not have an effect on voice pitch, intensity, harmonic-to-noise ratio (HNR) and shimmer (intensity variability).

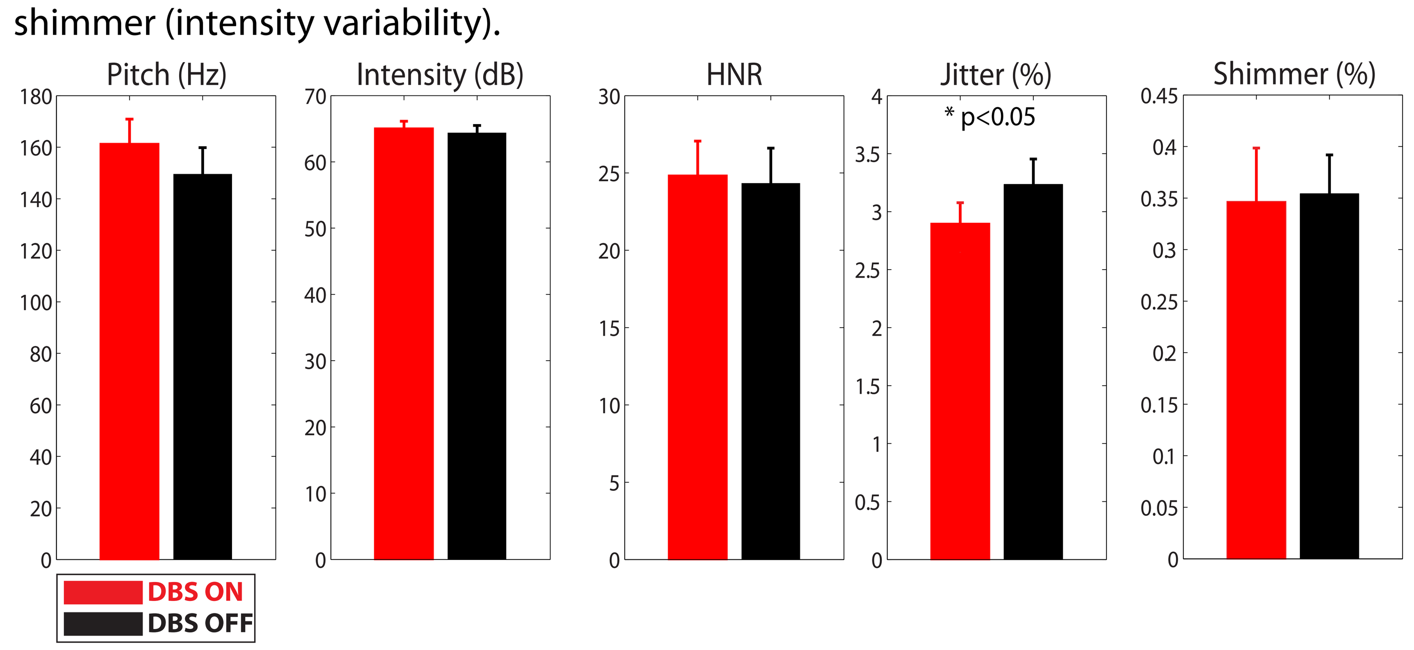

Figure 4. Bar plot representation of voice pitch, loudness, harmonic-to-noise ration (HNR), jitter and shimmer for DBS ON and OFF conditions.

EEG Data Analysis:

EEG data was recorded from 64 channels. Results of the analysis indicated a significant suppression of Beta (13-30 Hz) and Gamma band power (30-50 Hz) for DBS ON vs. OFF. The suppression of Beta band power was significantly correlated with enhanced magnitude of voice motor control response to auditory feedback perturbation.

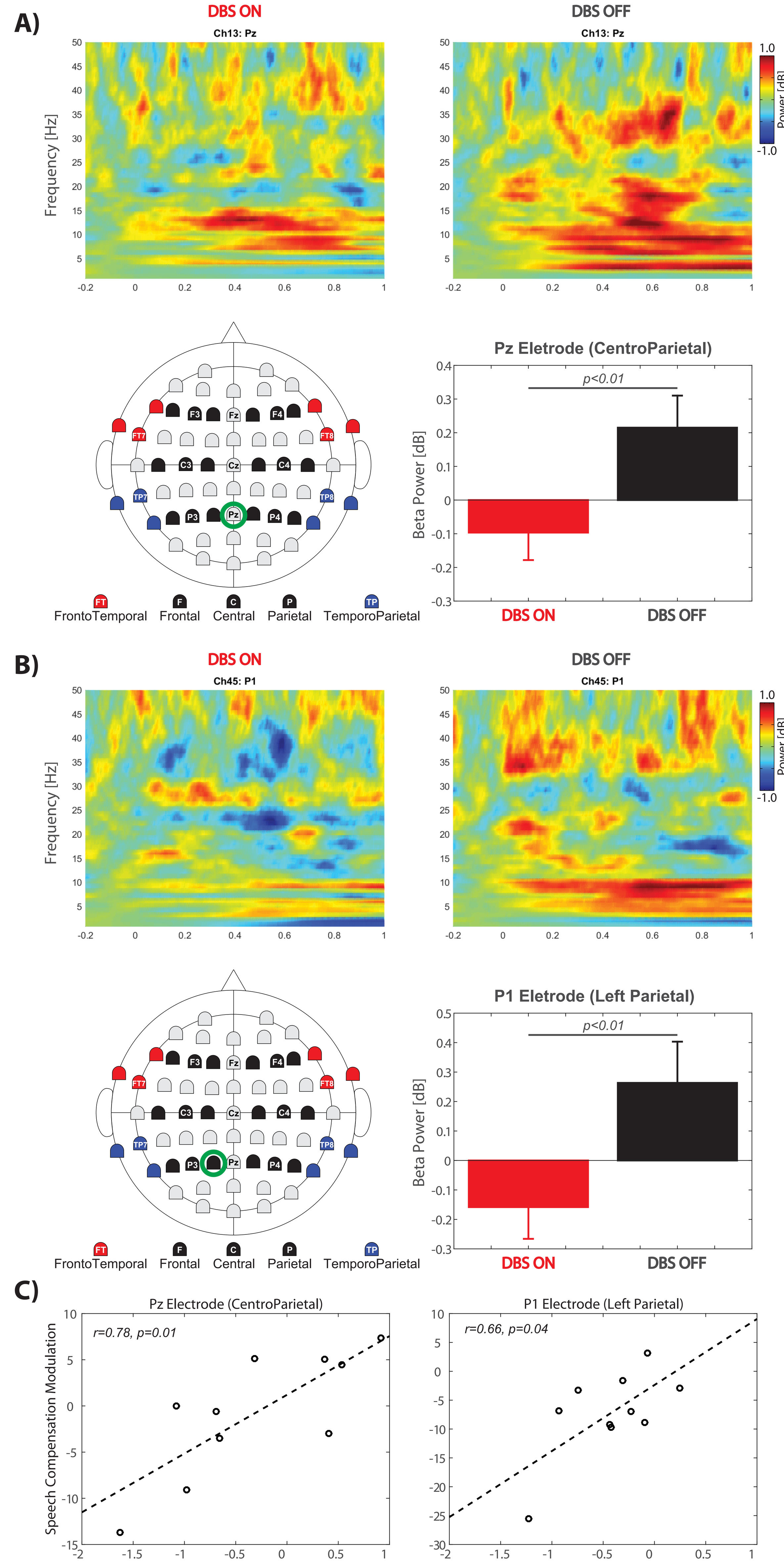

Figure 5. Time-frequency plots of neural activity along with error bars indicating Beta band power suppression in responses to **A)** upward and **B)** downward pitch-shift stimuli in voice auditory feedback. **C)** Shows the correlation between modulation of Beta band power and magnitude of vocal responses to pitch perturbation in the auditory feedback.

Discussion

We propose that our findings support the following notions:

STN-DBS has a positive impact on the mechanisms of voice motor control by helping individuals better control their voice pitch during self-vocalization and in response to auditory feedback perturbation.

This notion is corroborated by our findings indicating that PD patients exhibited a significatly larger compensatory vocal pitch response to auditory feedback perturbaion, and their general vocal pitch variability (jitter) was reduced for DBS ON vs. OFF condition.

DBS effect on voice control was significant only when patients increased laryngeal motor activity to raise pitch in response to downward pitch-shift stimuli.

We found a differential effects of DBS on vocal responses to upward and downward pitch perturbations in the auditory feedback, suggesting that the mechanisms that drive vocal folds muscle contraction (raising pitch) and relaxation (lowering pitch) are not equally facilitated by DBS.

The DBS-induced suppression of Beta band neural activity is a neurophysiological biomarker of improved voice motor control ability in patients with Parkinson's disease.

These findings are consistent with previous studies [10,11] and provide new insights into the neural mechanisms that incorporate auditory feedback for voice motor control.

Acknowledgement

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