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Vocalic transitions as markers of speech acoustic changes with STN-DBS in Parkinson's Disease

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ABSTRACT

Purpose: Deep Brain Stimulation of the subthalamic nucleus (STN-DBS) effectively treats cardinal symptoms of idiopathic Parkinson's disease (PD) that cannot be satisfactorily managed with medication. Research is equivocal regarding speech changes associated with STN-DBS. This study investigated the impact of STN-DBS on vocalic transitions and the relationship to intelligibility.
Methods: Eight Quebec-French speakers with PD and eight healthy controls participated. The slope of the second formant frequency (F2 slope) for glides was obtained. Locus equations (LEs) were calculated to capture vocalic transitions in consonant-vowel sequences. A visual analog scale was used to obtain judgments of intelligibility. Measures for the PD group were obtained both On and Off stimulation.
Results: F2 slopes and LEs differed among groups, but there were no systematic differences for On versus Off STN-DBS. On an individual level, participants with PD exhibited heterogeneous changes with DBS stimulation. Intelligibility was significantly correlated with F2 slope.
Conclusion: F2 slope appears to be sensitive to articulatory impairment in PD and could be used in clinical settings to distinguish these speakers from healthy controls. However, acoustic metrics failed to identify systematic change with STN-DBS. The heterogeneity of results, as well as the clinical relevance of acoustic metrics are discussed.

1. Introduction

Deep brain stimulation of the subthalamic nucleus (STN-DBS) is a surgical intervention that has been proven effective in treating the cardinal symptoms of PD (i.e. tremor, rigidity and bradykinesia). Studies have shown a marked improvement in quality of life for the vast majority of patients that undergo this surgical intervention (Volkmann, 2004). Over the past decade, research has begun investigating the impact of STN-DBS on non-cardinal symptoms of PD. This interest from the scientific community, sparked from clinical observations, demonstrated that these other facets of PD could be modified by STN-DBS. For example, STN-DBS may reduce sleeping disorders (Chahine, Ahmed, & Sun, 2011), pain (Kim et al., 2008) or olfaction impairment (Guo et al., 2008) for individuals with PD. Various explanations have been offered to account for the association between STN-DBS and the non-cardinal symptoms of PD. For example, it has been suggested that strong connectivity between neural sub-systems responsible for motor and non-motor functions explains the association between STN-DBS and the non-cardinal symptoms of PD. Another explanation is that electrical stimulation, particularly at higher voltages, spreads to neighboring regions around the STN (Tommasi et al., 2008).

Dysarthria is common in PD. More than 90% of people with PD develop dysarthria over the course of the disease (Sapir, Ramig, & Fox, 2013). Widely studied, hypokinetic dysarthria is characterised by altered prosody (i.e., reduced loudness and pitch

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variation, rate control anomalies), phonation (i.e., breathy and/or harsh voice) and articulation (i.e., imprecise consonants, centralized vowels) (Duffy, 2012). The neurology community is divided as to whether dysarthria should be considered a motor or non-motor symptoms of PD. For some movement disorders specialists, dysarthria is considered a non-motor symptom of PD (Seppi et al., 2011). This view is contested by those who consider speech production to be a fine motor skill that shares all of the characteristics of other fine motor skills, such as improvement with practice, automatization and being goal oriented in nature (Netsell, 1982).

While still relatively rare, research conducted over the past decade has begun to investigate speech outcomes following STN-DBS. These studies include those investigating the short and/or long-term effects of the intervention (i.e., “Pre-Post studies”) as well as studies investigating the direct effect of the electrical stimulation (i.e., “On-Off studies). Collectively, Pre-Post as well as On-Off studies report high inter-subject variability. The high inter-subject variability, in turn, contributes to equivocal outcomes across studies (Aldridge, Theodoros, Angwin, & Vogel, 2016; Schulz & Grant, 2000; Skodda, 2012) (Skodda, 2012). In addition, most Pre-Post studies indicate that speech is not improved by the intervention, and recent research suggests intelligibility is reduced, on average, in the years following surgery (Tripoliti et al., 2014). On the other hand, for some patients, the post-surgical reduction in required daily dosage of L-dopa is associated with improvement in some aspects of articulation (Martel-Sauvageau, Roy, Cantin et al., 2015).

Multiple hypotheses have been suggested to explain the lack of consistency regarding the outcomes of studies investigating the impact of STN-DBS on speech production in PD. One of these hypotheses concerns electrode placement during surgery or post-surgery electrode migration. The exact location of the implanted electrodes within the STN varies from participant to participant because this information requires an imaging procedure that is not routinely employed in clinical practice. However, in a rare study reporting detailed information regarding electrode placement, Tripoliti et al. (2011) reported that electrodes located more medially in the left STN were associated with higher risk of speech impairment.

Another explanation for the mixed results in studies investigating the impact of STN-DBS on speech production could be related to the choice of speech measures. While many studies have used perceptual measures to characterize the effects of STN-DBS on speech production (Aldridge et al., 2016; Skodda, 2012), acoustic measures of phonation, prosody and articulation have also been employed (Choi, 2012; D’Alatri et al., 2008; Hoffman-Ruddy, Schulz, Vitek, & Evatt, 2001). In a recent essay, Weismer and colleagues questioned the choice of measures used in many extant studies investigating the impact of STN-DBS on speech production (Weismer, Yunusova, & Bunton, 2012). It was further suggested that the ideal measure(s) for evaluating the effects of DBS on speech production should 1) have known sensitivity to dysarthria; 2) have relevance to functional communication or intelligibility; 3) be interpretable with respect to speech movement, and 4) be straightforward to obtain and interpret. The slope of the second formant (F2) frequency, an acoustic measure reflecting rate of vocal tract shape change was endorsed as a candidate measure for evaluating the effects of DBS on speech production. Bearing in mind the evaluative criteria suggested by Weismer et al. (2012), F2 slope is reduced for speakers with a variety of dysarthrias and neurological diagnoses relative to age and sex matched healthy controls (e.g. Kim, Kent & Weismer, 2011; Kim, Weismer, Kent & Duffy, 2009; Yunusova et al., 2012). F2 slope also is correlated with intelligibility as well as lingual movement speed, such that shallower slopes are associated with poorer intelligibility and slower speeds (e.g., Yunusova et al., 2012; Weismer et al., 2012). Acoustic measures like F2 slope also meet the criteria for ease and simplicity of application. However, despite a recent review concluding that STN-DBS prominently impacts articulation (Aldridge et al., 2016), F2 slope has thus far been reported in a single study STN-DBS study employing an On-Off paradigm (Dromey & Bjarnason, 2011).

Formant transition characteristics (i.e., F2 slope) of diphthongs, obstruent-vowel sequences, and semivowels have been studied a fair amount in dysarthria, albeit not in the context of STN-DBS (see review in Weismer et al., 2012). Collectively, these studies suggest that phonetic events requiring relatively rapid and large-scale changes in vocal tract shape are particularly sensitive to dysarthria. Locus equations (LE) are an alternative acoustic metric for characterizing segmental transition characteristics. By observing the transition of the second formant (F2) of different vowels in consonant-vowel (C-V) syllables, where the consonants consist of voiced plosives, it has been broadly demonstrated that for a single place of articulation, the relationship between F2 at the onset ($F2_{onset}$) and F2 at the midpoint ($F2_{mid}$) of all vowels follows a linear pattern (Lindblom & Sussman, 2012). In other words, for a given voiced plosive followed by a set of different vowels (e.g./ba/,/bi/,/be/, etc.), the F2 value at midpoint for each vowel can be linearly predicted by its F2 value at onset. One of the strengths of using LE measures to investigate vocalic transitions in C-V sequences is that the measure takes into account both anticipatory and carry-over coarticulation effects (Lindblom & Sussman, 2012). In fact, the F2 transition patterns of the vowel depend directly on the place of articulation of the preceding consonant. A variety of studies suggest that LEs are sensitive to pathological speech, including studies of childhood and acquired apraxia of speech (Sussman, Marquardt, & Doyle, 2000; Whiteside, Grobler, Windsor, & Varley, 2010), stuttering (Sussman, Byrd, & Guitar, 2011), hearing impairment (McCaffrey Morrison, 2008) and dysarthria (Kim & Hasegawa-Johnson, 2012; Martel-Sauvageau, Roy, Langlois, & Macoir, 2015). LEs have not been used to study the effects of STN-DBS. However, LEs meet many of the evaluative criteria suggested by Weismer et al. (2012) and capture transitional characteristics of phonetic events in a manner different from F2 slope.

Given questions regarding the relevance of metrics used in previous studies investigating the impact of STN-DBS on speech production in PD, and the suggestion that acoustic transitions could provide an adequate means to evaluate the effects of the intervention, the present study was undertaken. Using an On-Off paradigm, the current study had three main objectives: 1) to document the impact of STN-DBS in PD on two different metrics of vocalic transitions (F2 slopes in glides and Locus Equations in C-V sequences), 2) to document the link between these metrics and speech intelligibility, and 3) to compare these two metrics in terms of capacity to adequately evaluate the effects of STN-DBS on speech production.

Two previous studies have been published on the effects of STN-DBS on speech production in PD in a Quebec-French setting, with the speakers with PD in the current study being the same participants as those one of these. While these previously published studies also investigated vowel acoustics Pre- vs Post- DBS (Martel-Sauvageau, Roy, Cantin et al., 2015) and On- vs Off-DBS (Martel-