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Articulatory–acoustic vowel space: Application to clear speech in individuals with Parkinson's disease

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ABSTRACT

Background/purpose: Individuals with Parkinson disease (PD) often exhibit decreased range of movement secondary to the disease process, which has been shown to affect articulatory movements. A number of investigations have failed to find statistically significant differences between control and disordered groups, and between speaking conditions, using traditional vowel space area measures. The purpose of the current investigation was to evaluate both between-group (PD versus control) and within-group (habitual versus clear) differences in articulatory function using a novel vowel space measure, the articulatory–acoustic vowel space (AAVS).

Methods: The novel AAVS is calculated from continuously sampled formant trajectories of connected speech. In the current study, habitual and clear speech samples from twelve individuals with PD along with habitual control speech samples from ten neurologically healthy adults were collected and acoustically analyzed. In addition, a group of listeners completed perceptual rating of speech clarity for all samples.

Results: Individuals with PD were perceived to exhibit decreased speech clarity compared to controls. Similarly, the novel AAVS measure was significantly lower in individuals with PD. In addition, the AAVS measure significantly tracked changes between the habitual and clear conditions that were confirmed by perceptual ratings.

Conclusions: In the current study, the novel AAVS measure is shown to be sensitive to disease-related group differences and within-person changes in articulatory function of individuals with PD. Additionally, these data confirm that individuals with PD can modulate the speech motor system to increase articulatory range of motion and speech clarity when given a simple prompt.

Learning outcomes: The reader will be able to (i) describe articulatory behavior observed in the speech of individuals with Parkinson disease; (ii) describe traditional measures of vowel space area and how they relate to articulation; (iii) describe a novel measure of vowel space, the articulatory–acoustic vowel space and its relationship to articulation and the perception of speech clarity.

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1. Introduction

Parkinson disease (PD) is a progressive neurological disorder that results from degeneration of dopamine-producing cells (Damier, Hirsch, Agid, & Graybiel, 1999; Lang & Lozano, 1998). Movement deficits observed in PD are often attributed to basal ganglia dysfunction resulting from loss of dopaminergic input to the sensorimotor region of the striatum (Damier et al., 1999; Lang & Lozano, 1998; Redgrave et al., 2010). This results in decreased facilitation of cortical motor regions such as the supplemental motor cortex (Alexander, DeLong, & Strick, 1986; Mink, 1996; Redgrave et al., 2010). Hypokinesia is often marked in individuals with PD, and is suggested to result from increased difficulties initiating and properly executing automatic components of sequential behavior (Redgrave et al., 2010).

The hypokinesia in PD is associated with a decrement in the velocity and amplitude of habitual movements, and has been shown to affect reaching (e.g., Torres, Heilman, & Poizner, 2011), walking (e.g., Morris, Iansek, McGinley, Matyas, & Huxham, 2005), and writing (e.g., Tucha et al., 2006). For example, individuals with PD exhibit abnormal handwriting kinematics characterized by reduced movement excursions, decreased maximum velocities, and longer movement durations compared to healthy control participants (Broderick, Van Gemmert, Shill, & Stelmach, 2009; Tucha et al., 2006). Similarly, the self-initiated reaching movements of individuals with PD are characterized by decreased peak velocities and longer movement durations (Torres et al., 2011). Kinematic data collected from speech movements suggest articulatory movements are similarly affected, as individuals with PD exhibit decreased articulatory excursions and lower velocities of labial (e.g., Forrest, Weismer, & Turner, 1989) and lingual movements (e.g., Walsh & Smith, 2012) than control speakers. Because kinematic measurement of articulatory movements can be cumbersome, less feasible for patient populations, and costly to implement (e.g., Stone, 1997; Weismer, Yunusova, & Bunton, 2012), a number of studies have used acoustic measurements to infer articulatory function.

Acoustic investigations of articulation often include measures derived from the first two formant frequencies of the vocal tract (*F*1 and *F*2, respectively), as relative changes in the formant pattern reflect changes in the degree and location of maximum vocal tract constriction, thereby relating acoustic events to the underlying physiology (Dromey, Jang, & Hollis, 2013; Huber & Chandrasekaran, 2006; Mefferd & Green, 2010; Tasko & Greilick, 2010; Weismer, Yunusova, & Westbury, 2003). A number of static and dynamic formant-derived measures have been used to examine differences in articulatory–acoustic behavior between individuals with and without PD.

1.1. Vowel space area

Vowel space area (VSA) is an acoustic metric widely used to quantify articulatory function (e.g., Bradlow, Kraus, & Hayes, 2003; Ferguson & Kewley-Port, 2007; Lam, Tjaden, & Wilding, 2012). Traditional VSA is the two dimensional *F*1–*F*2 space formed by the first two formants of the corner vowels. For VSA, *F*1 and *F*2 are typically measured at the quasi-steady-state locations of corner vowel productions. The VSA measures have both triangular (e.g., Liu, Tsao, & Kuhl, 2005; Skodda, Visser, & Schlegel, 2011) and quadrilateral (e.g., Goberman & Elmer, 2005; Lam et al., 2012) forms that are reported in the literature. For both variants, the VSA is calculated as the area formed by connecting the corner vowels using the Euclidean distance between each coordinate in *F*1–*F*2 space.

1.1.1. VSA in PD and other motor speech disorders

A number of investigations have used VSA to examine articulatory function in individuals with neurological motor speech disorders. Specifically, VSA has been used as a measure of vowel production in individuals with PD (e.g., Goberman & Elmer, 2005; McRae, Tjaden, & Schoonings, 2002; Tjaden, Lam, & Wilding, 2013; Tjaden & Wilding, 2004), amyotrophic lateral sclerosis (ALS; Turner, Tjaden, & Weismer, 1995; Weismer, Jeng, Laures, Kent, & Kent, 2001), multiple sclerosis (MS; Tjaden et al., 2013; Tjaden & Wilding, 2004), and cerebral palsy (CP; Liu et al., 2005). Some of these studies have found statistically significant differences between healthy controls and individuals with neurological disorders, while others have found no statistically significant differences.

Relative to ALS, a number of studies suggest the speech of individuals with this disorder exhibited a restricted VSA (e.g., Lansford & Liss, 2014; Turner et al., 1995; Weismer et al., 2001). Specifically, a common finding reported in the literature is that the speech of individuals with ALS is characterized by smaller VSA relative to control speakers (e.g., Turner et al., 1995; Weismer et al., 2001). Turner and Tjaden (2000), however, failed to find a significant difference in VSA between neurologically healthy adults and individuals with ALS, although there was a trend for VSA to be reduced in speakers with ALS.

Relative to PD, some studies have reported a significantly smaller VSA for individuals with PD when compared to control speakers (Tjaden et al., 2013; Tjaden & Wilding, 2004). Conversely, a number of other studies have reported no statistically significant differences in VSA between Parkinsonian and control speakers (Sapir, Ramig, Spielman, & Fox, 2010; Skodda et al., 2011; Skodda, Grönheit, & Schlegel, 2012; Weismer et al., 2001). For example, Sapir et al. (2010) failed to observe pretreatment differences in vowel articulation as measured by traditional VSA between neurologically healthy controls and individuals with PD, though other acoustic measures differentiated the groups. Another study by Weismer et al. (2001) reported a non-significant trend for decreased VSA in the PD group as compared to the control group, though the PD group was perceived to be significantly less intelligible than control speakers.

One possible explanation for the lack of consistent VSA findings is that traditional VSA may not be adequately sensitive to changes in the articulatory behavior, especially in individuals with motor speech disorders. This hypothesis is supported by