Assessing Differences in Articulatory-Acoustic Vowel Space in Parkinson's Disease by Sex and Phenotype

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Abstract

The goal of this study was to determine whether articulatory-acoustics differ between individuals in the tremor-dominant (TD) and postural instability/gait difficulty (PIGD) phenotypes of Parkinson's disease (PD). The study included 31 individuals with PD (21 TD, 10 PIGD) and 29 control speakers (CS) who were all Dutch native speakers. A read speech task and a semi-spontaneous speech task were completed, and the Articulatory-Acoustic Vowel Space (AAVS) was calculated for both tasks. Results showed no significant difference in AAVS between the overall control group and PD for either phenotype. Follow-up analyses, pooling speech data from our prior study (+27 PD, +23 CS), demonstrated a significantly lower AAVS in males with PD compared to controls and no group differences for females. Thus, articulatory-acoustic changes may be more pronounced for male compared to female speakers with PD, but may not differ by PD phenotype.

Keywords: Parkinson's Disease, Phenotype, Speech Acoustics, Articulatory-Acoustic Vowel Space

Introduction

Parkinson Disease (PD) is a neurodegenerative disorder that is associated with a degeneration of dopaminergic neurons (Tysnes & Storstein, 2017). PD is a multisystem disorder, characterized by both motor impairments, such as muscle rigidity, tremor, and slowness of movement, as well as non-motor impairments, such as cognitive impairments and fatigue (Jankovic, 2008). The symptoms and progression of the disease vary depending on the individual, with various factors, such as sex (Iwaki et al., 2021), age (Wickremaratchi et al., 2009), and cognition (Sollinger et al., 2010) playing a role.

Due to the differing symptomatologies, different distinct clinical phenotypes of PD have been identified, with a frequent distinction being made between Tremor Dominant (TD) versus Postural Instability/Gait Difficulty (PIGD) phenotypes of PD (Stebbins et al., 2013). The TD phenotype is primarily characterized by the presence of tremor in the limbs, while the PIGD phenotype is primarily characterized by gait disturbance, postural instability, and rigidity (ibid.).

A common problem faced by most individuals with PD (IwPD), regardless of phenotype, are speech impairments, including respiration, laryngeal impairments, and articulation (see also Pinto et al., 2004, Broadfoot et al., 2019). At the level of articulatory impairments, IwPD are often impaired in their vowel articulation, which has been shown to be potentially reduced when measured with acoustic measures such as the Vowel Space Area (VSA), Vowel Articulation Index (VAI; Sapir et al., 2011) and Articulatory-Acoustic Vowel Space (AAVS; Whitfield & Goberman, 2014). While many studies have found a smaller VSA in IwPD compared to control speakers (Tjaden et al., 2013; Skodda et al., 2011; Leung et al., 2018), some studies have shown no differences in VSA between the two groups (e.g., Douadi et al., 2022). However, as the VSA is sensitive to interspeaker variability (Sapir et al., 2011), other studies have used new vowel formant metrics that would be more likely to capture minute group differences in vowel production. One of these metrics, the VAI, is a measure for vowel centralization that is less sensitive to interspeaker differences and has been shown to be smaller in IwPD compared to control speakers (Sapir et al., 2011; Skodda et al., 2011).

However, both VSA and VAI rely on having clearly elicited and segmented vowels, even though IwPD potentially experience more issues in spontaneous speech tasks than in read speech (e.g., Rusz et al., 2013). It is therefore crucial to assess sentence-level speech metrics when investigating speech in IwPD. The Articulatory-Acoustic Vowel Space (AAVS), introduced as a measure of an individual's working formant space (Whitfield & Goberman, 2014) is a vowel space metric that is sensitive to differences between groups, calculated at a sentence-level and is not point-based (Whitfield, 2019). In prior work, IwPD showed significantly smaller AAVS compared to control speakers in one study (Whitfield & Goberman, 2014; based on a sample of 12 IwPD and 10 CS) but another study found no group differences in AAVS (Houle et al., 2023; based on a sample of 68 IwPD and 68 CS).

A potential explanatory variable for the conflicting results on AAVS findings in IwPD is the IwPD phenotype, which has not been previously considered in AAVS studies in IwPD. Prior work has suggested more severe speech impairments in PIGD than TD phenotypes of PD when compared to control speakers. Specifically, one study found slower speaking rates during a monologue in PIGD compared to TD speakers with PD (Tykalová et al., 2020), while other work found a faster DDK rate (in syllables/s) in PIGD compared to TD (Rusz et al., 2023). Another study, using VSA and VAI based on corner vowels extracted from a reading passage, suggested a negative correlation between VSA and VAI, and high bradykinesia and rigidity subscores, but no significant correlation between PIGD or tremor subscores and the VSA (Skrabal et al., 2022). However, no study to-date has assessed sentence-level vowel metrics in PD compared to controls while considering PD phenotypes. Assessing sentence-level articulatory differences allows us to analyze speech across a wider range of vowel productions and is more ecologically valid than using vowels in isolation.

The current study therefore assessed whether there is a difference in sentence-level vowel production between PD phenotypes, as well as compared to control speakers, as quantified via the AAVS (Whitfield & Goberman, 2014). In addition, we assessed whether other variables, including task (reading vs. semi-spontaneous speech task), speaker sex, age, cognitive abilities, and hearing status affect AAVS in these three groups. Based on prior studies, we expected IwPD of the PIGD phenotype to show a greater articulatory acoustic vowel impairment (i.e., a smaller AAVS) than control speakers (CS), but a comparable AAVS between the TD phenotype and control speakers. We additionally expected a larger AAVS in female than male speakers, regardless of group (Whitfield & Goberman, 2014; Houle et al., 2023).

Methods

The present study forms part of a larger study, approved by our institutional Medical Ethics Review Board (NL72589.042.21).

Participants

We report the data of 31 native Dutch IwPD (18 males, 13 females; mean age 69.5 ± 7.7 years) and 29 native Dutch CS (15 males, 14 females; mean age 68.1 ± 7.3 years). All participants completed the Montreal Cognitive Assessment (MoCA). To ensure the participants' ability to give consent, only individuals with a MoCA score of 22 or higher were included in the study (Karlawish et al., 2013).

Participants underwent an age-appropriate pure tone hearing screening at 25dB for tones at or below 1000 Hz, and 40 dB for tones at 2000 Hz and above (Schow, 1991). This screening was conducted without hearing aids. We subsequently classified the hearing impairment severity following the Global Burden of Disease Expert Group on Hearing Loss screening (Olusanya et al., 2019), resulting in 23 speakers with none-to-mild hearing impairment (9 CS, 9 TD, 4 PIGD) and 38 speakers with moderate-to-severe hearing impairment (20 CS, 12 TD, 6 PIGD). Where applicable, speech tasks were completed while the participants wore their hearing aids and therefore had corrected-to-normal hearing (hearing aids worn by 3 CS, 4 IwPD). Table 1 summarizes participant demographics.

Table 1: *Participant demographics, separated by group (PIGD: postural instability/gait difficulty, TD: tremor-dominant, CS: control speakers). Sex: M (male), F (female). Hearing: NtM (None to Mild), MtS (Moderate to Severe). MoCA scores: maximum 30 points (22–25 points: potential Mild Cognitive Impairment (MCI), 26—30 points: no Mild Cognitive Impairment (nMCI)).*

Variable	PIGD	TD	CS
Sex	7 M, 3 F	11 M, 10 F	15 M, 14 F
Age (years)	67.8 ± 8.3	73.1 ± 4.7	68.1 ± 7.3
Hearing	4 NtM 6 MtS	9 NtM 12 MtS	9 NtM 20 MtS
MoCA	4 MCI 6 nMCI	8 MCI 13 nMCI	7 MCI 22 nMCI
MDS-UPDRSIII	21-71 pt.	11-61 pt.	-

All IwPD completed Parts I-III of the Movement Disorder Society Sponsored Revision of the Unified Parkinson's Disease Rating Scale (MDS UPDRS; Goetz et al., 2008). This allowed us to assess the participants' motor symptom severity (part III of the scale) as well as classify the motor phenotype. Following Stebbins and colleagues (2013), our sample included 22 TD (11 male, 10 female; MDS-UPDRS part III range: 11-61 points) and 10 PIGD (7 male, 3 female; MDS-UPDRS part III: 21-71 points) IwPD. All IwPD completed the experimental tasks while ON levodopa.

Procedure

The study took place in two sessions; the data reported in this paper was collected at the beginning of the second session. The participants were seated in the sound-dampened booth of SPRAAKLAB, the mobile laboratory of the Faculty of Arts, University of Groningen (Wieling et al., 2023). After placing a Shure MX153 earset microphone seven centimetres away from the participant's mouth, they were asked to read the Dutch version of the North Wind and the Sun passage (Roach, 2004), to describe the Cookie Theft picture (Goodglass & Kaplan, 1983), and to answer four questions eliciting spontaneous speech (not reported in this paper). The acoustic data was recorded in Praat v6.2.18 (Boersma & Weenink, 2022). Data was collected with a sampling rate of 44.1 kHz and digitized via Focusrite Scarlett Solo (2nd gen).

Data pre-processing

The AAVS measures a speaker's vowel production based on continuously sampled formant trajectories in running speech. The recordings were first cut to remove any speech resulting from experimenter instructions, followed by a removal of all pauses and voiceless segments using a customized Praat script. We extracted formants automatically using a Praat script that determines speaker-specific and segment-specific optimal ceiling levels using the Burg algorithm, with five millisecond timesteps in a 25 ms time window (Carignan, 2022). AAVS was subsequently calculated in mels for two tasks, namely the North Wind and the Sun passage ('read speech') and the Cookie Theft picture description ('semi-spontaneous speech'), following the methods and formulas as specified in Whitfield and Goberman (2014) and Abur et al. (2022).

Statistical Analysis

We conducted a linear mixed-effects regression analysis in R version 4.3.1 (R Core Team), using the *lme4* package (Bates et al., 2015). Our hypothesis-testing models included AAVS as the dependent variable, group (TD PD, PIGD PD, CS) as the main fixed effect variable, and sex as an additional fixed effect variable. We included a by-participant random intercept. In our exploratory analysis, we further assessed the effect of age, task (read vs. semi-spontaneous speech), hearing impairment (none-to-mild vs. moderate-to-severe impairment) and cognition (MoCA score). We also evaluated whether a two-level group distinction (i.e., PD vs. CS) yielded a better model. Final models were determined via model comparison (using the `anova()` function). The alpha level for rejecting the null hypothesis was set at 0.05. Effect sizes were determined with Cohen's *d*, which classifies effects as small (d = 0.2), medium (d = 0.5) or large ($d \geq 0.8$).

Results

Figure 1 visualizes the difference in AAVS between the three groups, separated by sex. In our hypothesis-testing model, there was no significant difference in AAVS between control speakers and the PIGD (β = -3,858 mel^2, t = -1.9, p = 0.06, Cohen's d = -0.5) or TD (β = -1,036, t = -0.7, p = 0.5, Cohen's d = -0.2) phenotype groups.

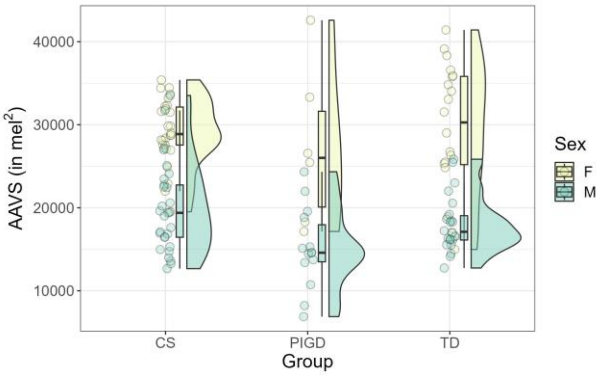

Figure 1: *Difference in AAVS (in mel²) depending on phenotype (CS, PIGD, TD) and sex (male (M), female (F)).*

There was a significant effect of sex on AAVS overall, with females having a significantly larger AAVS than males (β = 10,763 mel^2, t = 7.5, p < 0.001, Cohen's d = 2.0). The interaction between sex and group did not significantly improve the model, however (p = 0.7). The exploratory analysis did not result in a changed model, as including other variables (either separately or in interaction with group) did not yield an improved model. There was therefore no significant effect of age (p = 0.99), cognition (p = 0.4), task choice (p = 0.8), or hearing impairment (p = 0.4) on AAVS observed.

To test whether there was an overall difference between control speakers and IwPD, we ran an additional model with a binary distinction between the CS and (combined) PD groups. This model, likewise, did not show a significant effect of group on AAVS (β = -1,932 mel^2, t = -1.37, p = 0.17, Cohen's d = -0.36).

Exploratory analysis of sex

Our results conflicted with those of Tienkamp and colleagues (2024, current volume), as they found a significantly smaller AAVS in IwPD than CS. However, as the data used in the paper by Tienkamp and colleagues (2024) stems from the same lab, using the same reading task (i.e., The North Wind and the Sun) but different participant groups, we had the unique opportunity to conduct an additional analysis.

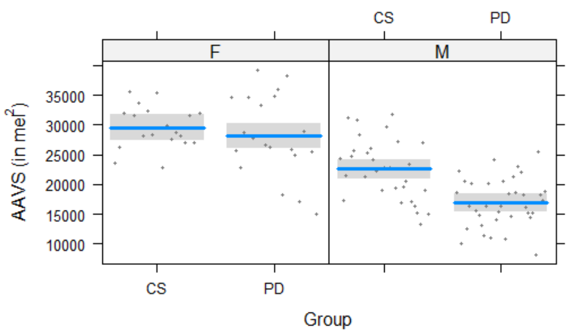

Figure 2: *Difference in AAVS (in mel²) depending on group (CS, PD) and sex (male (M), female (F)).*

We pooled the datasets in order to strengthen the power of the current investigation. The joint analysis therefore included 58 IwPD (21 female, 37 male) and 52 CS (19 female, 33 male). A linear model, assessing the effect of the interaction between group and sex on AAVS in mel^2, showed that male IwPD had a smaller AAVS compared to male CS (β = -4278 mel^2, t = -2.2, p = 0.03) while female IwPD and female CS had a comparable AAVS (β = -1345 mel^2, t = -0.9, p = 0.38). Figure 2 shows the effect of group and sex on AAVS. Unfortunately, we have no disease severity measurement or phenotype indication for the dataset used by Tienkamp and colleagues (2024); thus, it is not clear if there is an impact of PD phenotype on these results.

Discussion

The purpose of this study was to examine whether vowel articulation is differentially impacted in PD by an individual's clinical phenotype (TD or PIGD) compared to controls. Our study results indicate no significant impact of PD phenotype on the AAVS: while there was a trend towards the PIGD phenotype having lower AAVS than the TD phenotype or control speakers, the number of speakers in the PIGD group was too small and contained too many male speakers (7M, 3F) to draw reliable conclusions.

We likewise did not find any differences between CS and IwPD when the phenotypes were grouped. This finding aligns with the results of Houle and colleagues (2023), but conflicts with those of Whitfield and Goberman (2014) and Tienkamp and colleagues (2024, current proceedings), who report a smaller AAVS in IwPD compared to CS.

However, a linear model assessing the effect of the interaction between group and sex on AAVS, using pooled data from a study with the same methods and different speakers with PD (Tienkamp et al., 2024), revealed that male IwPD had a smaller AAVS compared to male CS, while female IwPD and female CS had a comparable AAVS. As we do not have motor severity scores for the entire dataset, it remains unclear whether our current finding indicates that more articulation impairments are actually present in male than female IwPD, or that our sample included more severely motor impaired male IwPD than female IwPD. This is not the first time a potential difference was shown in the articulation of male and female IwPD, however, as a study by Skodda and colleagues (2011) previously showed that only male IwPD showed a smaller VSA compared to CS, while both female and male IwPD showed smaller VAI values compared to CS.

Overall, following previous studies (Whitfield & Goberman, 2014; Houle et al., 2023), female speakers exhibited a significantly larger AAVS than male speakers. However, our current study did not find an effect of any other factors, such as cognition, hearing impairment, age or task choice on the AAVS. The latter finding, especially, is informative for future studies investigating articulation in IwPD. While prior studies used the Rainbow Passage reading task to assess the AAVS, our study also included a more ecologically valid semi-spontaneous speech task next to a read speech task. As the two tasks were comparable in terms of the AAVS, this indicates that choosing a semi-spontaneous speech task is a suitable choice for researchers who wish to evaluate differences in the articulatory-acoustic vowel space as part of a larger battery evaluating multiple subsystems. Alternatively, those wishing to conduct detailed acoustic analyses can use a reading task with a comparable text across participants.

A limitation of our study is the unbalanced participant sample, with a relatively small PIGD group (10 participants) compared to the TD group (21 participants) and the control group (29 participants), thereby limiting the generalizability of our findings.

Conclusion

The current study provided a look into the understudied sentence-level vowel production in PD phenotypes and control speakers, using the Articulatory Acoustic Vowel Space (AAVS) measure. While the results remain inconclusive and show no significant differences between PD phenotypes (TD or PIGD) and CS groups, they provide a first glimpse into sentence-level articulation of speakers of different IwPD phenotypes and underscore the importance of keeping sex and phenotype in mind when assessing speech motor control in IwPD.

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