Examining the effect of Parkinson disease on Clear Speech using Utterance-level Vowel Space Metrics

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Introduction

Though several authors have examined clear speech production in speakers with Parkinson disease (PD), most have measured vowel space using formant frequencies of corner vowels. More recent investigations suggest that sentence-level metrics that do not rely on corner vowels may be more sensitive to articulatory changes in speakers with and without PD (Whitfield et al., under review; Whitfield & Goberman, 2014, 2017). The purpose of this study was to examine clear speech in speakers with PD by comparing multiple utterance-length vowel space metrics and to examine changes in vowel articulation across the speaking task.

Method

Participants and Protocol: Fifteen individuals with PD and fifteen older adult controls (OA) participated as speakers in the current study. Participants read the Caterpillar passage using habitual and clear speaking styles. Audio samples were recorded using a table-top microphone (15 cm mouth-to-microphone distance) onto a solid-state recorder (Marantz PMD661; Sampling Rate: 44.1 kHz) in a quiet room.

Speech Rate Metrics: Articulation Rate, Pause-to-Speech Ratio, and Mean Pause Duration was measured for each sample using PRAAT. A pause was defined as a silent interval lasting at least 150 ms bounded by sounded speech. Articulation rate was calculated by averaging the rate of each speech run in syllables per second.

Acoustic analysis: Formant frequencies were extracted every 10 ms in MATLAB using a Kalman-based autoregressive model (Mehta et al., 2012). Voiced intervals were identified using PRAAT-based voice activity detection. Using a custom MATLAB script, local outliers in the formant traces of each voiced interval were identified and removed using a median absolute deviation moving average, and the traces were low-pass filtered (10 Hz). Bivariate outliers in F1-F2 space were identified by calculating the Mahalanobis distance, and data that were greater than 2 standard deviations from the centroid were excluded.

Vowel Space Metrics: Several utterance-length vowel space measures were calculated. The Articulatory-Acoustic Vowel Space (AAVS) was calculated as the square root of the generalized variance of F1 and F2 data (Figure 1, left; Whitfield & Goberman, 2014). The Vowel Space Hull Area (VSAhull) was calculated using the MATLAB convex hull function (Figure 1, center; Sandoval et al., 2013). Vowel Space Density (VSD) was also examined by creating a density distribution of the formant data for each passage by generating a mesh bounded by a median-normalized F1-F2 range. The sum of the F1-F2 data in each grid was calculated, and contours of the normalized density distribution were smoothed (Figure 1, right). VSD was calculated as the area of the 0.1 and 0.9 density level contour (VSD-10 & VSD-90) to examine changes in the peripheral and central regions of formant space.

Because the AAVS is a variance-based measure, it reaches asymptote upon accumulating enough data. To determine this asymptote, plots were examined showing the absolute percent difference between AAVS of the passage (actual) and cumulative AAVS estimates iteratively calculated by adding formant data. Calculating the AAVS using one-third of the formant data from the passage minimized the difference between the estimate and actual AAVS across all samples (see Figure 4). To examine changes in vowel space, the AAVS was calculated for sliding windows that were one-third of the passage duration (50% overlap), yielding 5 AAVSs across the passage.

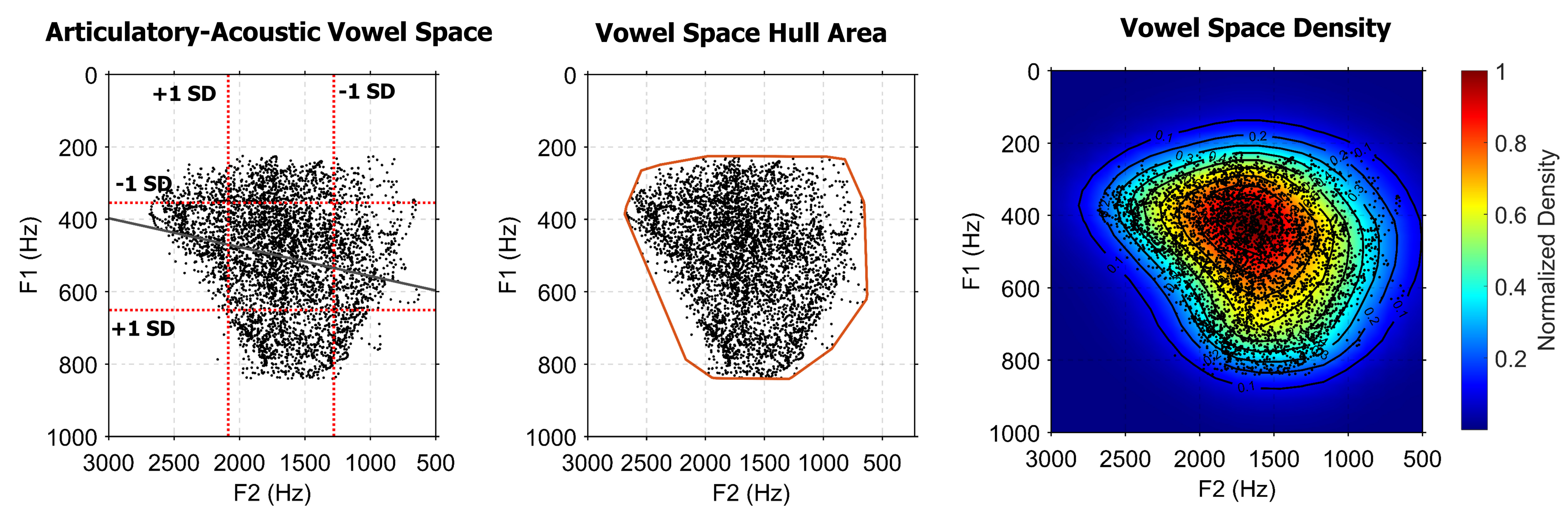


Figure 1. Visual representations of the vowel space metrics including the Articulatory-Acoustic Vowel Space (AAVS; left pane), Vowel space hull area (VSAhull; center pane), and Vowel Space Density (VSD) metrics (right pane).

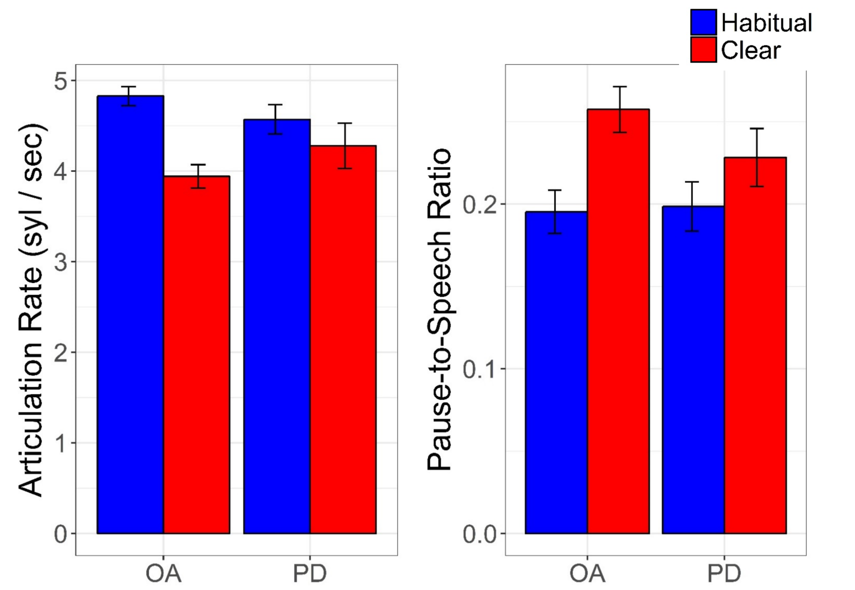
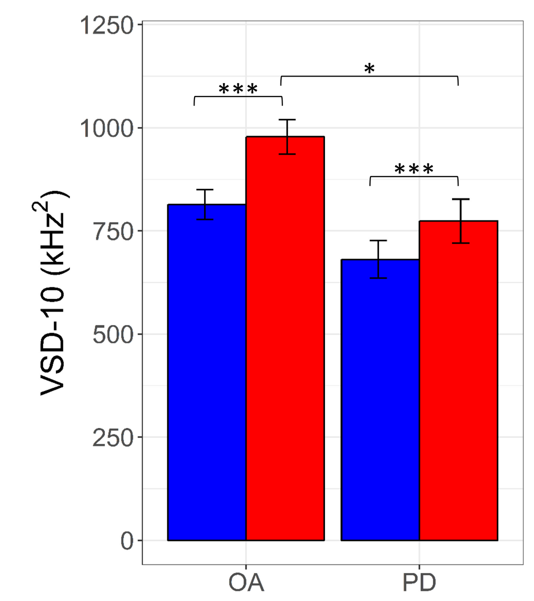


Figure 2. Means and standard error of Articulation Rate and Pause-to-Speech Ratio for the habitual (blue) and clear (red) speaking styles for the Parkinson disease (PD) and control (OA) groups.



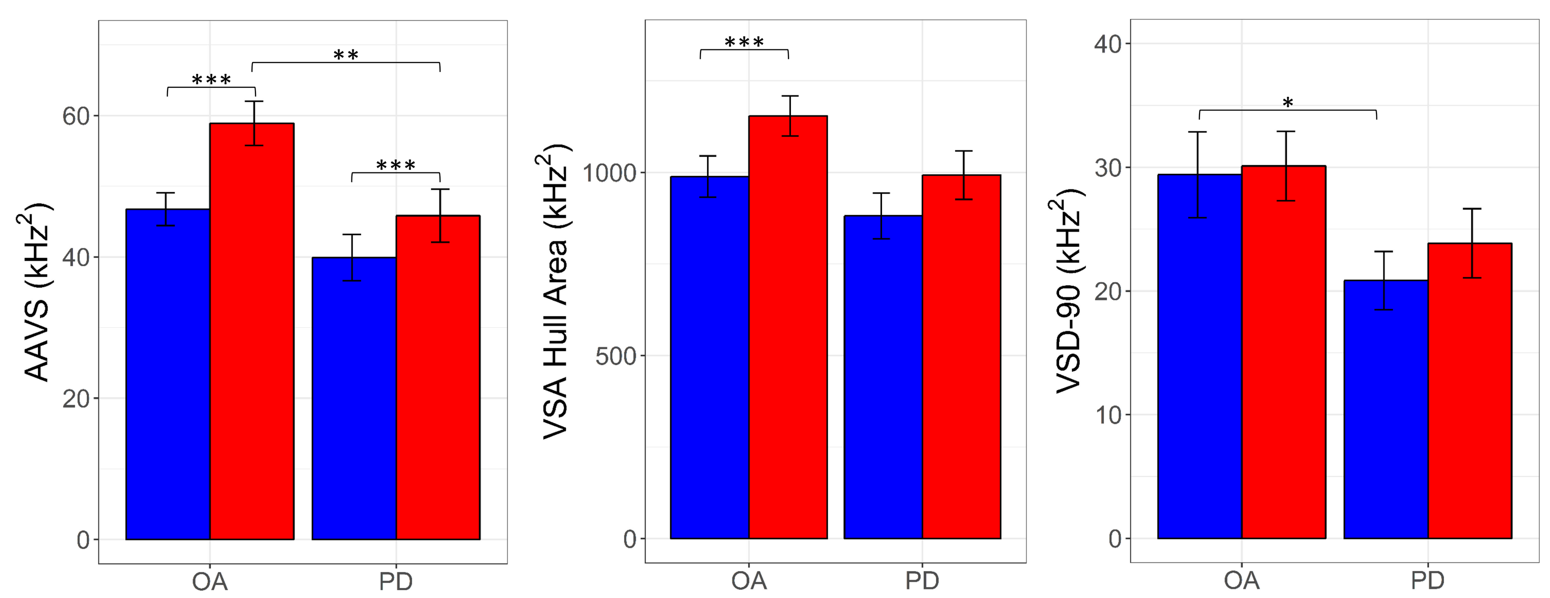


Figure 3. Means and standard error of the Articulatory-Acoustic Vowel Space (left pane), Vowel space hull area (center pane), and Vowel Space Density (VSD) metrics VSD-10 (right upper pane) and VSD-90 (right lower pane) for the older adult control group (OA and Parkinson Disease (PD) group for the habitual (blue) and clear (red) speaking styles. Note: *p<0.05, **p<0.01; *p<0.001

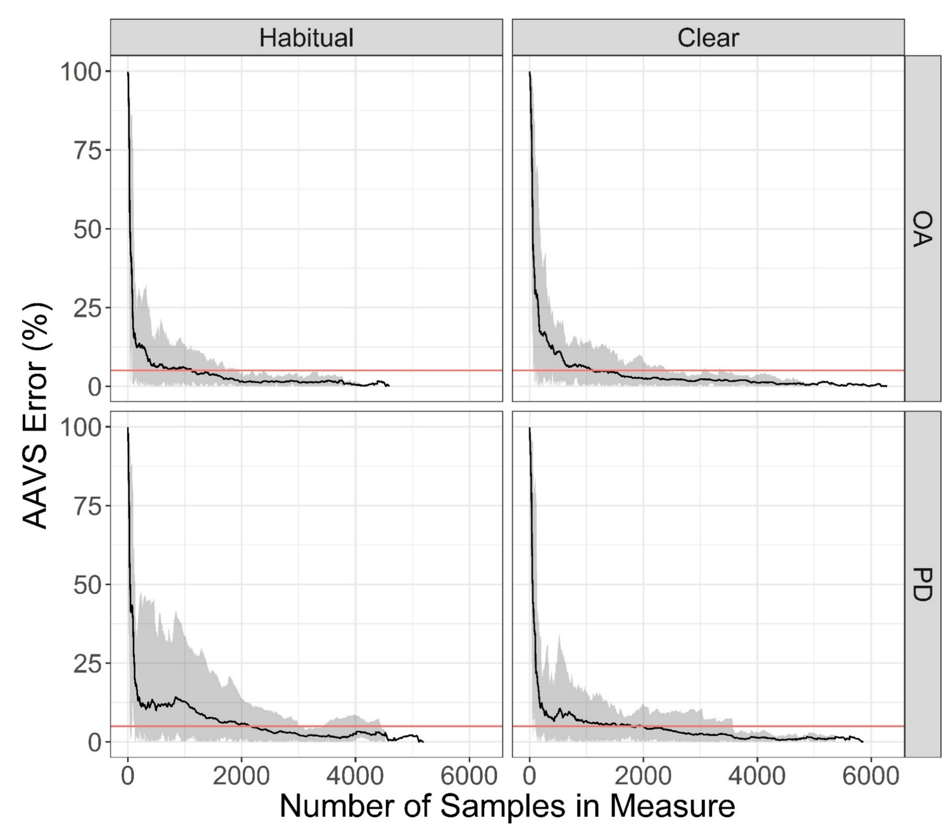


Figure 4. Error curves showing the relationship between iteratively calculated AAVS estimates and the true AAVS (whole passage value). Each estimate was calculated by adding one successive F1-F2 pair to the AAVS calculation. The figure shows that the AAVS estimate converges at a value that is within 5% of the passage value (red line) within the first one-third of the passage on average.

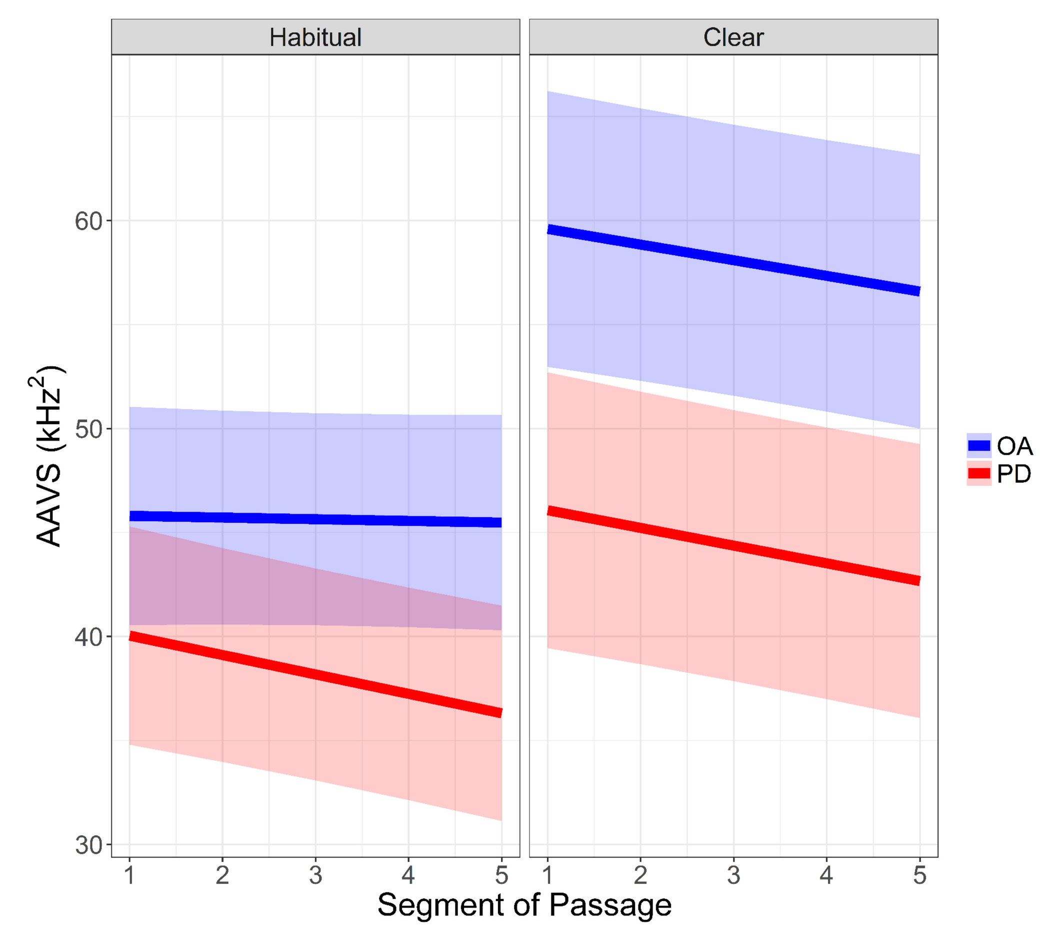


Figure 5. Parameter estimates showing the trend in the AAVS estimates calculated for the 5 segments of the passage. The Parkinson disease (PD) group is shown in red and the control (OA) group in blue. The figure shows that the PD group exhibits a decrease in vowel space over the course of the habitual reading task.

Results and Discussion

Clear Speech Effects:

Table 1. Fixed effects for LMM of the AAVS

Parameter	Est.	Std. Error	*df*	*p*-value
Intercept	46.45	4.55	2.94	0.0022**
Style (Clear)	12.15	1.33	30.00	<0.0001***
Group (PD)	-4.47	4.06	32.12	0.2792
Style (Clear) X Group (PD)	-6.22	1.88	30.00	0.0025**

Table 2. Fixed effects for LMM of the VSA_{hull}

Parameter	Est.	Std. Error	*df*	*p*-value
Intercept	715.89	54.09	3.28	<0.0001***
Style (Clear)	145.94	16.89	29.99	<0.0001***
Group (PD)	-93.98	54.10	23.07	0.1990
Style (Clear) X Group (PD)	-59.17	23.89	29.99	0.2380

Table 3. Fixed effects for LMM of the VSD-10

Parameter	Est.	Std. Error	*df*	*p*-value
Intercept	810.34	61.63	3.28	0.0008***
Style (Clear)	163.85	18.34	29.99	<0.0001***
Group (PD)	-102.78	57.87	23.07	0.0852
Style (Clear) X Group (PD)	-70.83	25.93	29.99	0.0105*

Table 3. Fixed effects for LMM of the VSD-90

Parameter	Est.	Std. Error	*df*	*p*-value
Intercept	29.40	2.79	56.05	<0.0001***
Style (Clear)	0.70	3.38	30.00	0.837
Group (PD)	-8.56	3.94	56.05	0.034*
Style (Clear) X Group (PD)	2.32	4.77	30.00	0.631

Note: *p<0.05; **p<0.01; ***p<0.001

Changes in Vowel Space Across the Passage: A final LMM was conducted using the AAVS time-series data to determine whether either group exhibited changes in vowel space across the passage. Participants with PD exhibited a decrease in the AAVS across the passage in the habitual style (Est=-8.52 kHz^2/sec, SE=2.52, p=0.034), whereas control participants did not (Figure 5). Group trends in the AAVS across the passage were similar for the clear speech condition.

Conclusions

- All vowel space metrics were sensitive to style-related changes
- Only the AAVS and VSD metrics reflected group differences in vowel acoustics.
- Speakers with PD exhibited a significantly smaller VSD-90 in the habitual condition, potentially indicating centralization of the working formant space.
- Additionally, participants with PD exhibited a decrease in vowel space across the reading passage, which may indicate worsening hypokinesia across the speaking task.

References

Mehta, D. D., Rudoy, D., & Wolfe, P. J. (2012). Kalman-based autoregressive moving average modeling and inference for formant and antiformant tracking a. *The Journal of the Acoustical Society of America, 132(3),* 1732-1746.
Sandoval, S., Berisha, V., Utianski, R. L., Liss, J. M., & Spanias, A. (2013). Automatic assessment of vowel space area. *The Journal of the Acoustical Society of America, 134(5)*, EL477-EL483.
Whitfield, J. A., Dromey, C., & Palmer, P. (under review). Examining acoustic and kinematic measures of articulatory working space: Effects of speech intensity. *Journal of Speech, Language, and Hearing Research.*
Whitfield, J. A., & Goberman, A. M. (2014). Articulatory-Acoustic Vowel Space: Application to Clear Speech in Individuals with Parkinson disease. *Journal of Communication Disorders, 51,* 19-28.
Whitfield, J. A., & Goberman, A. M. (2017). Articulatory-acoustic vowel space: Associations between acoustic and perceptual measures of clear speech. *International Journal of Speech-Language Pathology, 19(2),* 184-194.

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