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Research Note

Kinematic Features of Laryngeal Motor Control in Parkinson's Disease

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ABSTRACT

Purpose: Laryngeal kinematics were examined under high-speed videoendoscopy to examine laryngeal motor control of persons with Parkinson's disease (PD).
Method: A retrospective analysis was performed on 24 people with idiopathic PD and 24 age- and sex-matched controls as they produced repetitions of the utterance /ifi/ at self-induced levels of vocal effort (typical, mild, moderate, and maximum effort). Two kinematic measures of laryngeal motor control were measured during vocal fold adduction: spatiotemporal index (STI; adductory variability across repeated utterances) and asymmetry index (AI; ratio of deceleration to acceleration of adduction). Mixed-effects analysis of variance models were constructed to determine the main effects of group (PD, control), self-induced level of vocal effort, and their interaction.
Results: Statistically significant main effects of group were found for STI, but not AI. No statistically significant effects of vocal effort level or its interaction with group were observed for either measure.
Conclusions: Larger STIs in people with PD are consistent with the increased production variability observed in other speech articulators. Neither laryngeal kinematic measure was modulated by vocal effort level. These findings indicate that the STI was sensitive to differences in laryngeal motor control impairment between people with and without PD.

Parkinson's disease (PD) is the fastest growing neurological disease worldwide (Dorsey et al., 2018). Approximately 90% of people with PD develop hypokinetic dysarthria (Chaudhuri et al., 2024; Ho et al., 1999), a motor speech disorder characterized by reduced vocal intensity, monotonous pitch, and imprecise articulation. These speech characteristics stem from fundamental changes in muscle function and neural control (Mu et al., 2012; Rossi et al., 1996; Watts et al., 1986). Within the laryngeal system, these changes manifest as atypical biomechanics and altered neuromuscular control, including disrupted agonist–antagonist muscle coordination (Hirose, 1986) and increased rigidity or hypercontractility (Gallena et al., 2001; Zarzur et al., 2007, 2013). These physiological changes are reflected acoustically in elevated fundamental frequency, reduced vocal intensity and frequency range, and decreased intensity variability (Duffy, 2019; Rosen et al., 2006).

Speech motor control models such as the Directions Into Velocities of Articulators model (Tourville & Guenther, 2011) posit that speech production relies on feedforward control for efficient movement execution and feedback control for monitoring and correcting errors. Altered auditory feedback studies indicate that people with PD exhibit relatively intact auditory feedback mechanisms on dopaminergic medication (Abur et al., 2021; Kiran & Larson, 2001) but demonstrate hyperactive auditory responses and reduced feedforward efficiency off medication (Abur et al., 2018; Chen et al., 2013; Liu et al., 2012; Mollaei et al., 2016). These findings suggest impaired generation and maintenance of stable feedforward motor representations, which may contribute to the reduced precision and increased variability characteristic of Parkinsonian speech (Anderson et al., 2008;

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Kleinow et al., 2001). The laryngeal subsystem is particularly sensitive to motor control disruptions because phonation requires rapid alternation of adductory and abductory gestures. However, most prior studies have relied on acoustic measures or altered auditory feedback paradigms, which cannot capture underlying biomechanical mechanisms. High-speed videoendoscopy (HSV) provides direct visual assessment, offering the temporal resolution (≥ 1,000 frames/s) necessary to quantify laryngeal kinematic movements that typically span 104–227 ms (Dailey et al., 2005). HSV enables quantification of laryngeal articulator properties, providing insight into how feedforward and feedback processes shape movement patterns in typical and disordered speech.

Two laryngeal kinematic indices—spatiotemporal index (STI) and asymmetry index (AI)—were recently applied to HSV data to evaluate laryngeal motor control (Weerathunge et al., 2025). STI quantifies movement variability across repeated gestures by summing standard deviations of normalized displacement traces over time (Smith et al., 1995; Wohlert & Smith, 1998). Higher STI values indicate greater inconsistency in movement execution, which has been interpreted as a heavier reliance on feedback-based corrections rather than stable feedforward commands, although other factors such as execution noise or attentional fluctuation may also contribute (Kim & Max, 2014). AI measures deviation of a velocity profile from an ideal symmetric, bell-shaped curve representing maximally efficient movement (Suzuki et al., 1997). Typical laryngeal (Munhall et al., 1985) and articulatory (Ostry et al., 1987) movements follow relatively symmetric profiles, reflecting smooth and well-timed feedforward plans. When feedback-based corrections are incorporated during movement, profiles may become distorted or asymmetric, resulting in higher AI values, which has been proposed as one contributor to higher AI values, although other sources of asymmetry cannot be excluded. For laryngeal motor control, AI captures asymmetry of laryngeal movements during adduction, measured as the temporal ratio of acceleration to deceleration duration from maximum vocal fold abduction to gesture end. Applying these measures to PD may clarify how efficiency and consistency of laryngeal motion are affected by disrupted motor regulation.

Vocal effort, defined as the perceived exertion used to produce a desired vocal output (Hunter et al., 2020), may modulate STI and AI. Increased vocal effort has been associated with greater engagement of laryngeal musculature (McKenna et al., 2017), but its effects on laryngeal kinematics in PD remain unknown. Increased effort could reduce STI and AI by constraining degrees of freedom and stabilizing motor output, consistent with findings that increased vocal intensity reduces articulatory STI (Kleinow et al., 2001). Alternatively, increased effort could increase STI and AI if heightened muscle activation introduces rigidity or interferes with smooth motor execution, particularly in people with PD where muscle hypercontractility is common (Gallena et al., 2001).

Thus, the present study used STI and AI to assess stability and efficiency of laryngeal adductory movement across different levels of self-modulated vocal effort in people with PD and age- and sex-matched controls. We hypothesized that people with PD would exhibit higher STI and AI values than controls during typical speech, consistent with greater movement variability and asymmetry due to impaired feedforward control. We further hypothesized that increased self-modulated vocal effort would reduce STI and AI in both groups by increasing attentional resources allocated to movement execution, resulting in more stable and consistent laryngeal movements with more symmetric velocity profiles. By characterizing how vocal effort influences laryngeal kinematics, this work aimed to advance understanding of mechanisms underlying disordered voice production in PD and inform targeted approaches for improving vocal control.

Method

Participants

Forty-eight adults participated: 24 people with PD (six females, 18 male; M_{age} = 62.8 years, SD = 9.6, range: 43–75) and 24 age- and sex-matched controls (six females, 18 male; M_{age} = 63.9 years, SD = 10.2, range: 41–81). All data were collected with informed consent in compliance with the Boston University Institutional Review Board (Protocol #2625). All participants with PD were fluent in English, diagnosed with idiopathic PD by a neurologist, and had no other ongoing conditions affecting vocal function. Participants with PD were recorded in their typical on-medication state; those with deep brain stimulation devices (n = 4) turned them off during data collection. Controls had no history of speech, language, hearing, neurological, or voice disorders.

The Montreal Cognitive Assessment was administered to all participants with PD and to control participants over the age of 50 years; an a priori cutoff of ≥ 23 was set to ensure all enrolled participants had the capacity to consent to study tasks (Landsheer, 2020). The Movement Disorder Society–Sponsored Revision of the Unified Parkinson' Disease Rating Scale (MDS-UPDRS; Goetz et al., 2008) was administered to each participant with PD by a trained administrator. The average extent of motor complications (Part III) was moderate, at 47.7 (SD = 20.1, range: 13–91).

Procedure

Prior to data collection, participants received training on producing repetitions of the vowel–voiceless consonant–vowel

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token /ifi/. This target was selected because /f/ minimizes intraspeaker acoustic variability (Lien et al., 2014) while /i/ keeps the pharynx open for optimal nasoendoscopic visualization. Each set consisted of four consecutive tokens followed by a breath and then four additional tokens. Participants used their typical pitch, volume, and speaking rate while maintaining consistent intonation. After baseline familiarization, participants were trained to produce /ifi/ sequences under three levels of self-modulated vocal effort beyond their typical voice. Instructions emphasized increasing vocal effort as if pushing air out while maintaining typical pitch, volume, and rate, since vocal sound pressure level shows diverging relationships with subglottal pressure and listener-perceived effort (Rosenthal et al., 2014). Effort levels were elicited using the following instructions: "mildly more effort than your regular speaking voice" (mild), "more effort than mild" (moderate), and "as much effort as you can while still having a voice" (maximum).[1]

Following task training, participants underwent nasoendoscopy. A nasal decongestant was offered to minimize discomfort; topical anesthetics were not administered to avoid confounding effects on laryngeal function. Participants were fitted with a directional headset microphone positioned 7 cm from the corner of the mouth at a 45° angle. A flexible endoscope (Pentax, Model FNL-10RP3, 3.5 mm) was then advanced through the inferior nasal turbinate into the hypopharynx for vocal fold visualization. In cases of participant discomfort or anatomical constraints, a smaller pediatric endoscope (Pentax FNL-7RP3, 2.4-mm diameter) was substituted.[2] The endoscope was coupled to a high-speed camera (FASTCAM Mini AX100; 256 × 256 pixels) with laryngeal images captured at 1,000 frames/s. The microphone signal was preamplified and digitized at 30 kHz and then time aligned with videoendoscopic recordings using a custom MATLAB script.

During nasoendoscopy, participants were seated in a sound-attenuated booth and recorded producing /ifi/ repetitions under all four effort conditions (typical, mild, moderate, and maximum). Additional recordings were obtained if vocal fold movement was unclear, resulting in a minimum of 16 utterances per condition per participant. Due to camera memory constraints, recording duration was limited to approximately 8 s. Of the 3,072 anticipated /ifi/ utterances (48 participants × 4 conditions × 16 utterances), 2,890 were captured (average 15.1 per participant per condition, range: 7–32). Token counts were comparable across groups (PD: $M = 14.2$, $SD = 3.1$, range: 7–18; control: $M = 15.9$, $SD = 3.3$, range: 11–32).

Data and Statistical Analysis

Glottic angle waveforms were extracted from each /ifi/ production using semi-automated software (Diaz-Cadiz et al., 2018). Videoendoscopic recordings were first inspected in the software for image quality, unobstructed glottal views, and complete productions. Of 2,890 captured /ifi/ productions, 478 were excluded for poor usability. The remaining 2,412 were processed using semi-automated tracking; if automated tracking failed, technicians manually marked glottic angles at 50 frames/s. Manual guidance successfully resolved 759 of 824 cases requiring intervention, yielding 2,347 productions with usable glottic angle waveforms. Technicians passed reliability training and then used custom MATLAB software to identify landmarks of the laryngeal adduction gesture (see Weerathunge et al., 2025, for detailed methodology). Analysis focused on the adduction period from the maximum glottic angle (during the /f/) to first complete vocal fold approximation during voicing onset of the second /i/. Productions with extreme anterior commissure movement (e.g., due to unstable camera movement) or incomplete gestures (e.g., due to recording limitations) were then excluded ($n = 95$), resulting in 2,252 final productions.[3] Three time points were manually extracted from each glottic angle waveform: maximum glottic angle (start of adduction), vocal fold approximation (end of adduction), and maximum adductory velocity (peak negative velocity). Readers are referred to Weerathunge et al. (2025) for detailed illustrations of glottal angle waveforms and comprehensive description of these kinematic measures.

STI was calculated per participant per condition from all glottal angle waveforms. Waveforms were amplitude-normalized (z score) and time-normalized (cubic spline interpolation to 1,000 points, resampled at 2% intervals = 50 points). Standard deviations across waveforms at each of 50 time points were summed to produce raw STI (Smith et al., 1995, p. 200), with gamma correction applied to account for bias introduced by variable production numbers across participants and conditions (Wisler et al., 2022). AI was calculated as the ratio of deceleration to acceleration duration, measured from maximum glottic angle to

[1]Although participants were instructed to maintain typical pitch, post hoc analyses revealed that fundamental frequency increased monotonically across effort conditions, with moderate and maximum effort levels differing significantly from typical ($p < .05$), consistent with the known physiological coupling between subglottal pressure and fundamental frequency (Rosenthal et al., 2014). Sound pressure level did not significantly change across effort levels ($p > .05$).

[2]A pediatric endoscope was used in 15 of 48 participants (11 controls, four PDs). Both endoscopes provided adequate image quality for identifying vocal fold landmarks and extracting laryngeal kinematic measures at 1,000 frames/s.

[3]Exclusion rates were comparable across groups for maximum effort (PD: 28.8%, CT: 27.2%), moderate effort (PD: 16.2%, CT: 18.6%), mild effort (PD: 17.5%, CT: 20.6%), and typical effort (PD: 16.1%, CT: 22.4%).

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maximum velocity (acceleration) and maximum velocity to vocal fold approximation (deceleration), and then averaged across productions per participant and condition.

Linear mixed-effects models were fit in R (v.4.5.1; R Core Team, 2025) for each kinematic measure (STI, AI) with self-modulated effort level (typical, mild, moderate, maximum), group (PD, control), and their interaction as fixed factors, and participant as a random factor. For the STI model, glottic amplitude was additionally included as a covariate to account for the potential influence of between-group amplitude differences on amplitude-normalized STI values, as hypokinesia in PD may result in systematically reduced glottic movement range relative to controls. Levene's test indicated significant heterogeneity of residual variance by group for both STI and AI ($p < .05$). Models were therefore fit when allowing residual variances to differ by group using the nlme package (v3.1.168; Pinheiro et al., 2025). Prior to model fitting, AI values were transformed using a log transformation to satisfy the assumption of normality of residuals. Fixed effects were evaluated using Type III analysis of variance tests, and post hoc Tukey tests were computed using the emmeans package (v1.11.2.8; Lenth et al., 2025). Significance was set a priori at $\alpha = .05$, and partial omega-squared (ω_p^2) values were calculated to determine the effect sizes of significant main effects. Finally, to examine the relationship between disease severity and laryngeal kinematics within the PD group, exploratory Spearman rank correlations were computed between MDS-UPDRS Part III scores and STI and AI values obtained at the typical effort condition.

Results

The results of the mixed-effects models are shown for STI and AI in Table 1, and the measures as a function of group and self-modulated vocal effort level are shown in Figure 1. Group membership demonstrated a significant, medium effect, $F(1, 46) = 4.887$, $p = .032$, in the model for STI, but was not significant in the model for AI ($p = .333$). Effort level and the interaction of Group × Effort level were not significant in either model ($p > .05$). Glottic amplitude demonstrated a significant, small effect, $F(1,130) = 5.693$, $p = .019$, in the model for STI; no interactions involving glottic amplitude were significant ($p > .05$). Overall, the PD group showed higher mean values than controls for both STI (12.5 vs. 9.6) and AI (2.4 vs. 1.9) with greater variability ($SD = 5.8$ vs. 3.5 for STI; $SD = 2.0$ vs. 0.9 for AI). Mean STI and AI values remained relatively stable across effort conditions for both groups. MDS-UPDRS Part III scores were not significantly correlated with STI ($\rho = .003$, $p = .989$) or AI ($\rho = -.023$, $p = .916$) at the typical effort condition.

Discussion

The present study examined whether self-modulated vocal effort differentially affects laryngeal kinematic measures in people with PD compared to age- and sex-matched controls using high HSV. We found that the PD group demonstrated significantly higher STI values than the control group, indicating greater variability in laryngeal movement patterns. This group effect remained significant after accounting for glottic amplitude, suggesting that the observed difference in laryngeal movement variability between groups is not attributable to hypokinesia-related reductions in movement range. However, no significant group differences were observed for AI, and vocal effort level did not significantly affect either measure in either group.

Although prior research has primarily examined auditory feedback mechanisms in PD using altered feedback paradigms (e.g., Abur et al., 2021; Kiran & Larson, 2001; Liu et al., 2012), the kinematic measures used here reflect different aspects of motor control. STI captures trial-to-trial variability, which may reflect aspects of feedforward motor planning, while AI reflects within-movement execution patterns that may be influenced by somatosensory and proprioceptive feedback, among other factors.

Impaired feedforward control in PD is thought to result in compensatory hyperactive auditory feedback (Yu et al., 2007, p. 200), consistent with movement variability. Considering similar increases in variability noted for articulatory movement (Kleinow et al., 2001) and acoustic signals (Anderson et al., 2008) in PD, we anticipated higher variability relative to controls would likewise be observed with laryngeal motor control. Our results provide support for this hypothesis, as people with PD demonstrated significantly higher STI values than controls. However, we also expected to see decreases in STI as the level of self-modulated vocal effort increased. This expectation was supported by prior articulatory kinematic research showing reduced STI with increased vocal intensity (Kleinow et al., 2001). However, effort level did not significantly affect STI in either group. For controls, robust feedforward systems may already optimize laryngeal movement across varying effort levels. For people with PD, elevated baseline variability may have created a ceiling effect, obscuring potential effort-related changes.

We hypothesized that people with PD would exhibit higher AI values, consistent with increased reliance on feedback control (Kiran & Larson, 2001; Liu et al., 2012). Although the PD group showed numerically higher AI values across all conditions, this difference did not reach statistical significance. This null finding should be interpreted with consideration of what AI measures: the physiological movements of the laryngeal mechanism prior to voice onset, before auditory feedback becomes available.

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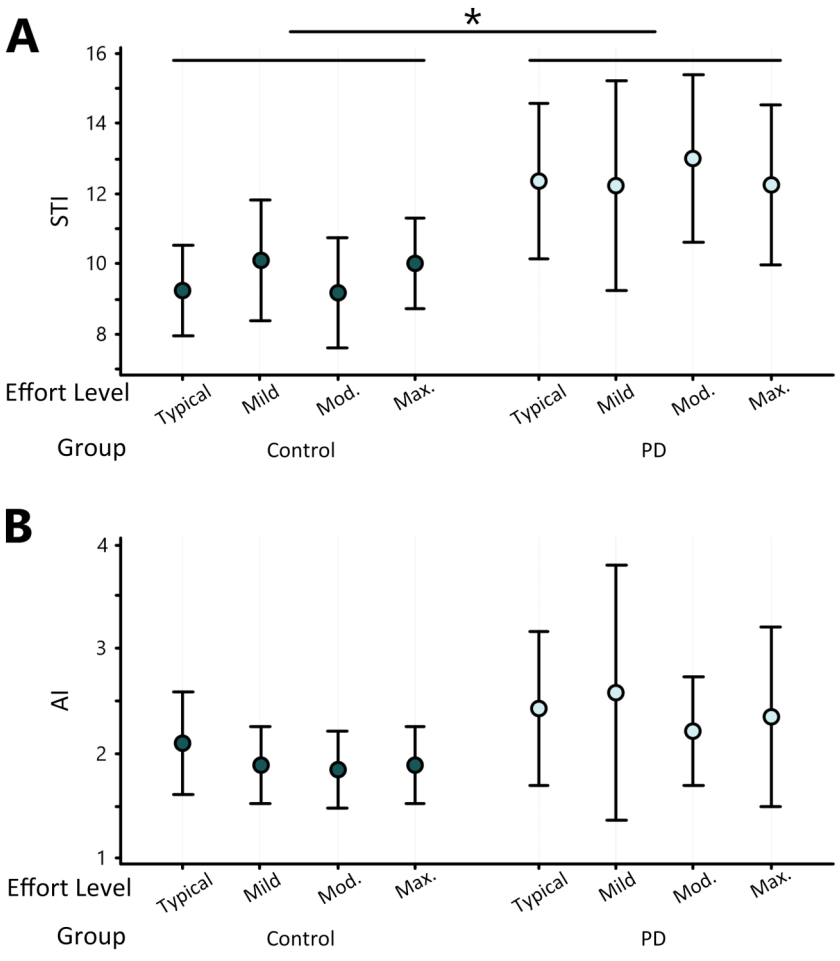
Table 1. Linear mixed-effects model results for the spatiotemporal index (STI) and the asymmetry index (AI).

Model	Effect	*df*	*F*	*p*	ω^2_p
STI	Group	1, 46	4.887	.032	.10
	Effort Level	3, 130	0.070	.976	.00
	Glottic Amplitude	1, 130	5.693	.019	.03
	Group × Effort Level	3, 130	0.984	.403	.00
	Group × Glottic Amplitude	1, 130	0.634	.428	.00
	Effort Level × Glottic Amplitude	3, 130	0.170	.917	.00
	Group × Effort Level × Glottic Amplitude	3, 130	0.093	.964	.00
AI	Group	1, 46	0.333	.567	.00
	Effort Level	3, 138	0.301	.824	.00
	Group × Effort Level	3, 138	0.182	.908	.00

Note. *df* = degrees of freedom.

Although the participants in the PD group were recorded on dopaminergic medication—which may reduce hyperactive auditory feedback reliance during phonation—this is unlikely to affect the prephonatory laryngeal adjustments captured by AI. Whether dopaminergic medication similarly modulates feedforward motor planning for these prephonatory movements remains unexplored and warrants investigation in future on/off medication studies.

Figure 1. Group descriptives examining control speakers (dark green) versus speakers with Parkinson's disease (PD; light green) across self-modulated vocal effort level for (A) spatiotemporal index (STI) and (B) asymmetry index (AI). Error bars represent 95% confidence intervals. *$p < .05$. Mod. = moderate; Max = maximum.



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Vocal effort level also did not significantly affect AI in either group, contrary to our hypothesis that increased effort would reduce degrees of freedom and yield more symmetric movement profiles. This may reflect that PD primarily affects movement-to-movement consistency (captured by STI) rather than within-movement symmetry (captured by AI).

It is important to consider the limitations of the current study. The interpretation of effort conditions is limited by the multidimensional and subjective nature of "vocal effort" (Hunter et al., 2020). Participants' interpretation of instructions to vary effort was likely individualized, which may have contributed to minimal variability across conditions. Although topical anesthetic was withheld to avoid confounding laryngeal function, the presence of the endoscope may have introduced discomfort that influenced vocal effort perception, particularly at baseline. This is a recognized methodological tradeoff in nasoendoscopic studies of vocal effort. Additionally, the decontextualized /ifi/ utterances limit generalizability to conversational speech. Future studies should consider the use of spontaneous speech samples to simulate naturalistic conversation, as well as data collection in participants with PD in the off-medication state to clarify the role of dopaminergic medication in laryngeal kinematic patterns.

Conclusions

STI was significantly higher in people with PD than controls, suggesting greater laryngeal movement variability, which may reflect impaired feedforward control among other contributing factors. The absence of significant group differences in AI and the lack of effort-related effects suggest that AI may be less sensitive to PD-related motor control impairments than STI. The lack of effort-related effects on either measure suggests that self-modulated vocal effort, as elicited in this study, may not substantially alter laryngeal kinematic strategies in either people with PD or controls. These findings support continued investigation of laryngeal kinematics as markers of motor control impairment in PD.

Data Availability Statement

The data sets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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