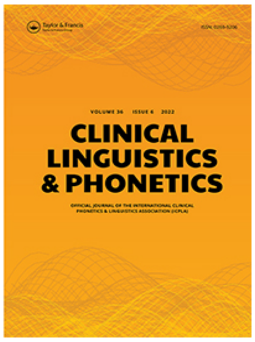

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Prosodic features in Finnish-speaking adults with Parkinson´s disease

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ABSTRACT

The aim of this study was to assess prosodic features in Finnish speakers with (n = 16) and without (n = 20) Parkinson's disease (PD), as there are no published studies to date of prosodic features in Finnish speakers with PD. Chosen metrics were articulation rate (syllables/second), pitch (mean F_0) and pitch variability (standard deviation F_0), energy proportion below 1 kHz (epb1kHz), normalised pairwise variability index (nPVI), and a novel syllabic prosody index (SPI). Four statistically significant results were found: (1) energy was distributed more to lower frequencies in speakers with PD compared to control speakers, (2) male PD speakers had higher pitch and (3) higher syllabic prosody index compared to control males, and (4) female PD speakers had narrower pitch variability than controls. In this study, PD was manifested as less emphatic and breathier voice. Interestingly, male PD speakers' dysprosody was manifested as an effortful speaking style, whereas female PD speakers exhibited dysprosody with a monotonous speaking style. A novel syllable-based prosody index could be a potentially useful tool in analysing prosody in disordered speech.

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Introduction

Parkinson's disease (PD) is a neurodegenerative movement disorder characterised by tremor, bradykinesia, and rigidity (Gelb et al., 1999). It affects the central nervous system and causes a progressive loss of dopaminergic neurons in the substantia nigra. Besides producing motor symptoms, it also leads to cognitive and social symptoms (Prenger et al., 2020). Speech motor symptoms in PD are generally referred to as hypokinetic dysarthria (Duffy, 2005). Darley, Aronson, and Brown (as cited in Duffy, 2005, p. 196) have listed the most deviant speech dimensions associated with hypokinetic dysarthria in order of severity: (1) monopitch (most severe), (2) reduced stress, and 3) monoloudness.

Hypokinetic dysarthria impacts spoken communication (Miller, 2017; Moreau & Pinto, 2019), especially the production of prosody (Thies et al., 2020). Prosody is acoustically manifested as differences in fundamental frequency (intonation, melody), duration (rhythm, tempo), and intensity (emphasis, prominence, stress; Hawthorne & Fischer, 2020). Speech prosody impairment, that is, dysprosody (Harris et al., 2016), refers to a deficit in transmitting intonational and affective information to the listener (Ma et al.,

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2015). Most commonly, dysprosody in people with Parkinson's disease (PWPD) is perceived as altered intonation and stress patterns (Miller, 2017). In fact, Jaywant and Pell's study (Jaywant & Pell, 2010) revealed that listeners perceived the speech of the PWPD as sounding "unhappy" and "less friendly" compared to the speech of control speakers. These communication changes reduce the quality of life and cause a burden on social communication (Miller et al., 2007; Schrag et al., 2000).

Changes in intonation, stress, and rhythm have been reported in several studies as common speech symptoms in PD (Cheang & Pell, 2007; Skodda et al., 2009; Tykalova et al., 2014). Different languages have different stress and intonation patterns, and Finnish as Uralic language has its own specialities (Suomi et al., 2008). For example, Finnish is a full-fledged quantity language and has three stress levels, where the main stress is always on the first syllable with secondary stress (if the word includes four syllables) on the third syllable: "**kah**vi**tau**ko" (Engl. *Coffee break*; stressed syllables bolded). Usually, the second and the last syllable are non-prominent. We lack information on prosodic features in Finnish Parkinsonian speakers, as the only published papers in this population so far, have been master's theses (Hyppönen, 2020; Paronen & Vuomajoki, 2019).

Intonation changes can be assessed by analysing pitch (F_0) and pitch variability (F_0 SD). Reduced F_0 variation in PWPD leads eventually to monotonous speech (Rusz et al., 2011; Skodda et al., 2009) manifesting acoustically as flat (Tykalova et al., 2014) or syntactically inappropriate F_0 contours (MacPherson et al., 2011). Descending intonation (Suomi et al., 2008) and low pitch (Järvinen, 2017) are typical for the Finnish language, in which F_0 in males is around 100–110 Hz and for females around 180–190 Hz. The first syllable in Finnish is commonly uttered at the middle of the speaker's voice range and the last syllable on a very low pitch, often accompanied by a creak (Suomi et al., 2008). Therefore, many authors (e.g. Brazil et al., 1980; Iivonen, 1998) have generally claimed Finnish as a "flat" and "monotonous" language, which obviously challenges assessment and differential diagnoses of speech disorders.

Rhythmic disturbances in Parkinsonian speech, such as slow speech rate or short rushes of speech, disturb stress production (Bunton & Keintz, 2008; Lowit et al., 2018). Among short rushes of speech, studies have found that PWPD produce fewer pauses and the pauses can occur in syntactically inappropriate places (Lowit et al., 2018; Skodda et al., 2009). Normalised pairwise variability index (nPVI) has been used as an acoustic measure in the assessment of speech prosody and to describe distinguishing rhythm patterns between different types of dysarthric speech (Kim et al., 2011; Liss et al., 2007, 2009). The nPVI attempt is to capture the sequential nature of rhythmic contrasts by investigating durational differences between successive syllables (Low et al., 2000). In earlier studies, it has been observed that control speakers have higher nPVI values than PWPD (Y. Kim & Choi, 2017; Liss et al., 2009). It is known that rhythmic patterns are language dependent and, for example, the length of the word influences the rhythm (Y. Kim & Choi, 2017). Because of the morphosyntactical structure of Finnish, words are long and often equivalent to phrases in English, as the base forms of words are built upon with affixes (Helasvuo, 2008; Moore & Korpijaakko-Huuhka, 1996). This is seen in the following example: the English clause "I wonder if I could throw myself into an adventure" (10 words) translates into Finnish as "Heittäytyisinköhän seikkailuun" (2 words). Differences in the rhythmic structure of speech across languages may determine the degree to which listeners gain access to spoken words

(Y. Kim & Choi, 2017; Liss et al., 2009). Therefore, it becomes crucial to observe different metrics in different languages for the assessment of speech prosody and treatment of speech disorders (Hawthorne & Fischer, 2020).

Voice symptoms in PWPD has perceived as harsh and breathy qualities (Rusz et al., 2011; Tykalova et al., 2014). Acoustically harsh and breathy qualities can be detected as a steeper slope of a long-term average spectrum, that is, relatively more energy in lower than higher frequency levels (Leino, 2009; Maryn & Weenink, 2015; Stemple et al., 2018). Also, energy in less-emphasised linguistic units is usually distributed to lower frequencies. Voice quality together with prosodic emphasis can be assessed, for example, by analysing the percentages of frequencies below 1 kHz (epb1kHz; Tavi & Werner, 2020). The higher the value, the weaker the voice, and the less emphasised the speech. Indeed, PWPD have found to have greater spectral tilt compared to control speakers (Tjaden et al., 2010).

Phonetically, prominence, or linguistic emphasis, is characterised as changes in pitch, duration, and energy (Streefkerk, 1997) and can be assessed by measuring sound- and syllable durations, spectral changes, and intensity (Czap & Pintér, 2015). The syllabic prosody index (SPI) is a measure for prosodic emphasis that combines these metrics into a single index (Tavi & Werner, 2020). The SPI increases when F_0 and duration increase and energy proportion below 1 kHz decreases; that is, the relative acoustic energy in a spectrum shifts towards higher speech frequencies. Similar changes have been reported, for example, in the prominent positions in the speech of PWPD (Thies et al., 2020) and in the improved speech of dysarthric individuals (Schlenck et al., 1993; Watson & Hughes, 2006). In dysarthric speech, however, prominence can be related to an excessive amount of effort in the glottal and subglottal system (Thies et al., 2019) rather than linguistic emphasis. As F_0 is higher in females than in males, typically female speakers tend to also have higher SPI values than males (Tavi & Werner, 2020). All the metrics presented in this literature review and their mathematical formulas are summarised in Table 1.

Table 1. Prosodic variables (see, Bunton et al., 2001; Daniele & Patel, 2013; Grabe & Low, 2002; Y. Kim & Choi, 2017; Tavi & Werner, 2020; Tsao et al., 2006).

Variable	Definition
Pitch	• average fundamental frequency (F_0) shows the typical pitch • standard deviation of F_0 indicates pitch variability • can be used as a measure of intonation
Articulation rate	• number of syllables a person can produce in a unit of time excluding pauses • usually expressed as syllables per second (syl/sec) • can be used as a measure of rhythm
Energy proportion below 1 kHz (epb1kHz)	• percentage of frequencies in the voice frequency spectrum below 1 kHz $epb1kHz = \frac{\text{band of energy between } 0-1\,kHz}{\text{band of energy between } 0-4kHz}$ • can be used as a measure of prosodic emphasis and voice quality
Normalised pairwise variability index (nPVI)	• equation that measures how much durational contrast exists between successive events in an utterance $nPVI = \frac{100}{m-1} \times \sum_{k=1}^{m-1} \left\| \frac{d_k - d_{k+1}}{\frac{d_k + d_{k+1}}{2}} \right\|$ • can be used as a measure of rhythm
Syllabic prosody index (SPI)	• combines median pitch, energy balance, and duration in syllables $SPI = \frac{Pitch_{median} \times \sqrt{Duration}}{\sqrt{Energy_{below1kHz}}} / 10.$ • can be used as a measure of prosodic prominence

Acoustic speech analyses can possibly identify markers of disease, its progression, and the severity of speech disorder (Bocklet et al., 2011; Kato et al., 2018; Khodabakhsh et al., 2015; Miller, 2017). Potentially, identifying altered speech prosody can improve early detection and reveal new biomarkers for the development of PD. In Hawthorne and Fischer's (Hawthorne & Fischer, 2020) study, speech-language pathologists (N = 245) reported that dysprosody is a highly common symptom in several speech disorders. However, they rarely assess prosody with acoustic-phonetic analysis due to lack of training, resources, and clinically feasible assessment methods. Although prosodic analyses have already been applied to detect neurodegenerative diseases in academic research (Bocklet et al., 2011; Kato et al., 2018; Khodabakhsh et al., 2015), there is a need to gain knowledge of dysprosody in different diseases and languages as well as to develop impactful clinical tools for assessment to support clinical practice. The aim of this study was to increase our knowledge of prosodic changes in Finnish Parkinsonian speakers. Based on the literature, our assumptions were that speakers with PD have (1) a slower articulation rate (syllables/second) and (2) less-rhythmic (nPVI) speech than control speakers, as well as (3) reduced intonation (F_0 SD), (4) weaker voice quality (epb1kHz) and (5) effortful stress patterns (SPI). Therefore, our research question was:

What prosodic features are characteristic in Finnish speakers with PD, and how do these features differ from those of control speakers?

Methods

Participants

In this study, we used two speech corpora collected by the Kuuluva Ääni – To be heard project: Parkinson's Disease Speech corpus of Tampere (PDSTU) and Healthy Adults Speech corpus of Tampere (HASTU; "To be heard," 2018; Liu et al., 2021). The first corpus, PDSTU, includes speech data from both Finnish-speaking (n = 35; 21 females/14 males; M = 66.7 years; 48–82 years) and Finland Swedish-speaking (n = 7; 2 females/5 males; M = 67.9 years; 57–70 years) adults with PD from different speaking tasks: word and sentence repetitions, regular and emotional reading tasks, a spontaneous speech task, and a diadochokinesia test (/pa/ta/ka) before and after group speech therapy. The second corpus, HASTU, contains speech data from healthy Finnish-speaking adults (n = 47; 29 females/17 males/1 other; M = 49.9 years; 21–93 years) without any acquired or developmental disorders affecting speech, language, or cognitive skills (e.g. dementia, developmental language disorder, stuttering). HASTU includes the same speech tasks used in PDSTU.

From PDSTU, we chose sixteen right-handed Finnish speakers with PD (Table 2), whose Hoehn and Yahr severity rating (scale 1–5; see, Rabey & Korczyn, 1995) indicated mild severity (1–2.5). Voice Handicap Index-9 (VHI-9; Nawka et al., 2009) is a 9-item questionnaire where scores 0 ≤ 7 indicates healthy voice, and scores 8 ≤ 16 mild-, 17 ≤ 26 moderate-, and 27 ≤ 36 severe voice-related handicap (Caffier et al., 2021). Speakers with PD self-rated their voice-related handicap severity level as mild. PD speakers' (n = 16) speech impairment was rated auditory-perceptually on a 10 cm long VAS-scale by three speech therapists based on sustained phonation /a/ and reading sample. Participants' speech impairment was rated as mild (0 ≤ 2 very mild; 2.1 ≤ 4.0 mild, 4.1 ≤ 6.0 moderate, 6.1 ≤ 8.0 severe, 8.1 ≤_10.0 very severe).

Table 2. Participant groups.

		Speakers with Parkinson's disease			Control speakers		
		All (n = 16)	Female (n = 8)	Male (n = 8)	All (n = 20)	Female (n = 10)	Male (n = 10)
Age (years)	*M*	69.6	65.7	73.6	62.8	60.7	65.0
	SD	7.25	7.22	5.01	7.47	3.40	9.79
Voice Handicap Index-9	*M*	13.9	11.3	16.5	2.9	3.0	2.7
	SD	5.6	6.4	3.2	3.4	3.7	3.3
Speech impairment (VAS 0–10)	*M*	2.1	1.5	2.7			
	SD	1.5	0.7	1.9			
Time from the diagnosis (years)	*M*	6.3	6.5	6.1			
	SD	3.70	4.56	2.90			
Hoehn and Yahr severity rating*	*M*	1.5	1.43	1.56			
	SD	0.54	0.63	0.67			

**Hoehn and Yahr scale: 1 = unilateral involvement only, 1.5 = unilateral and axial involvement, 2 = bilateral involvement without impairment of balance, 2.5 = mild bilateral disease, 3 = mild to moderate bilateral disease, 4 = severe disability, 5 = patient confined to bed or wheelchair unless aided*

From HASTU, then, we chose ten right-handed female and ten right-handed male speakers over 55 years old to comprise the control group for PD speakers (Table 2). Control speakers (n = 20) and speakers with PD (n = 16) did not differ statistically from each other based on the age [$U(34) = 102.500$, $Z = -1.835$, $p = 0.067$]. Control speakers' self-ratings from VHI-9 indicated healthy voice. HASTU-corpus did not include auditory assessments of speech impairment. Permission to conduct the present study on PDSTU and HASTU was obtained from the Ethics Committee of Tampere University. All subjects provided written informed consent according to the Declaration of Helsinki.

From both corpora, we chose a speech sample from the regular reading task 'The Northwind and the Sun', whose Finnish version has been commonly used in clinical and research settings in Finland (Kankare et al., 2020). All the recordings in the corpora were collected with a headset microphone, where the microphone was kept 4 cm from the corner of the speaker's mouth at a 45-degree angle. Recordings in the corpora were made at a sampling rate of 44.1 kHz in WAV format, through Praat software (Boersma & Weenink, 2018) and Focusrite audio interface.

Data analysis

A segment from the middle of the reading sample was analysed in this study from each speaker (Appendix 1). The selected segment (23 words/51 syllables) was annotated with Praat (Boersma & Weenink, 2018) in syllable level. The annotated segment was then analysed with Praat script (Tavi, 2019), which measures articulation rate, energy proportion below 1 kHz, normalised pairwise variability index, typical pitch (mean F_0), pitch variability (SD), and syllabic prosody index from annotated syllables (see, Table 1). Because of the relatively small number of participants, we observed data normality with descriptive analyses, such as analysing kurtosis and skewness values and their standard deviations, comparing mean values to 5% trimmed mean values, and observing the curve in a histogram. As the data were not normally distributed, we tested group differences with the nonparametric Mann–Whitney U test. Statistical significance was set at $p < 0.05$, and significance p-values were adjusted by the Bonferroni correction for multiple comparisons.

Results

In speakers with PD, articulation rate was slightly slower and nPVI value lower than in control speakers (Table 3). Also, pitch variation (SD F_0) was narrower in the PD group compared to controls. SPI values in PD speakers were instead higher than in control speakers. These findings, however, were not statistically significant. However, we found a statistical difference between control speakers and speakers with PD in epb1kHz (Figure 1); the value in PD speakers was higher than in controls. This means that the energy in PD speakers speech was distributed in lower frequencies [$U(34) = 236.000$, $Z = 2.420$, $p = 0.016$].

Table 3. Prosody features in two speaker groups.

		Articulation rate	nPVI	epb1kHz	F_0	F_0 SD	SPI
Control group	Mean	5.580	41.257	0.959	142.294	27.390	6.031
(n = 20)	Std. Deviation	0.566	3.523	0.033	44.037	13.998	1.762
	Median	5.575	41.430	0.966	143.625	23.080	5.771
	Minimum	4.610	33.590	0.890	65.140	10.800	3.456
	Maximum	7.020	47.070	0.996	206.260	51.650	8.708
PD group	Mean	5.349	39.841	0.984	146.327	22.133	6.222
(n = 16)	Std. Deviation	0.508	3.835	0.011	25.726	6.457	1.092
	Median	5.415	40.480	0.985	139.285	21.430	6.197
	Minimum	4.170	33.990	0.950	111.950	14.580	4.902
	Maximum	6.200	47.140	0.998	185.370	38.130	8.473
Statistical significance	Level $p < 0.05$	*ns*	*ns*	$p = 0.016$	*ns*	*ns*	*ns*

* *ns = not statistically significant*

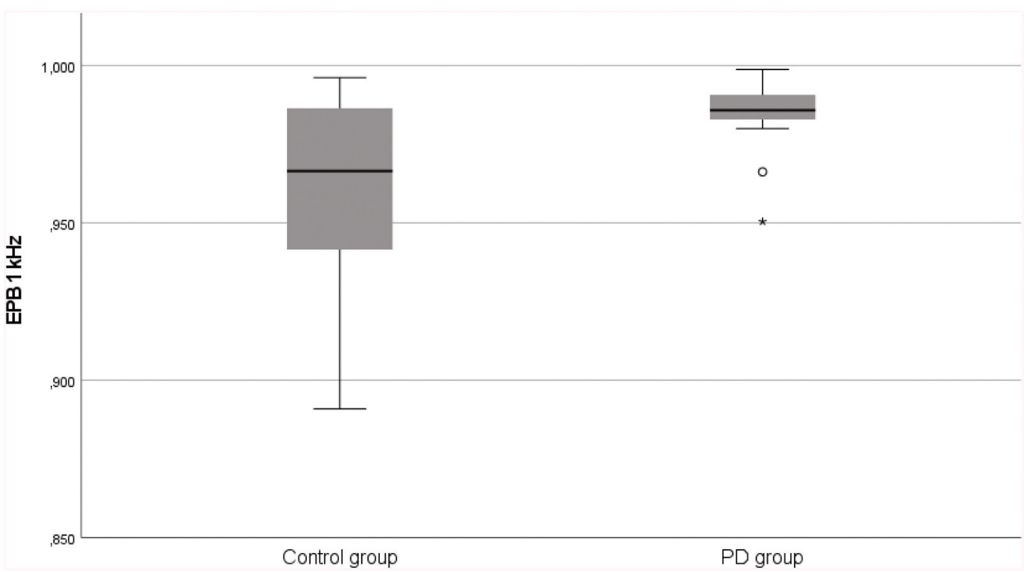

Figure 1. Energy distributions (energy proportion below 1 kHz) in two speaker groups.

Table 4. Prosody features in subgroups.

		Articulation rate	nPVI	epb1kHz	F_0	F_0 SD	SPI
PD males (n = 8)	Mean	5.266	39.048	0.990	123.491	18.692	5.277
	Std. Deviation	0.569	5.155	0.005	7.830	4.827	0.344
	Median	5.205	37.005	0.990	122.340	16.785	5.233
	Minimum	4.170	33.990	0.983	111.950	14.580	4.902
	Maximum	6.140	47.140	0.998	134.450	29.130	6.002
Control males (n = 10)	Mean	5.781	40.829	0.959	103.990	16.913	4.502
	Std. Deviation	0.665	3.910	0.036	21.137	4.628	0.783
	Median	5.650	40.680	0.964	104.545	15.965	4.390
	Minimum	4.980	33.590	0.890	65.140	10.800	3.456
	Maximum	7.020	47.070	0.996	143.590	23.620	5.826
Statistical significance	Level $p < 0.05$	*ns*	*ns*	*ns*	$p = 0.013$	*ns*	$p = 0.026$
PD females (n = 8)	Mean	5.432	40.633	0.978	169.163	25.573	7.168
	Std. Deviation	0.465	1.872	0.013	12.844	6.245	0.628
	Median	5.495	40.625	0.983	169.510	23.980	7.115
	Minimum	4.630	37.420	0.950	144.120	18.750	6.392
	Maximum	6.200	43.660	0.988	185.370	38.130	8.473
Control females (n = 10)	Mean	5.380	41.685	0.959	180.598	37.867	7.560
	Std. Deviation	0.381	3.241	0.031	19.669	12.178	0.867
	Median	5.550	41.840	0.969	181.625	39.300	7.572
	Minimum	4.610	34.560	0.902	143.660	20.020	5.716
	Maximum	5.850	46.800	0.991	206.260	51.650	8.708
Statistical significance	Level $p < 0.05$	*ns*	*ns*	*ns*	*ns*	$p = 0.033$	*ns*

* *ns = not statistically significant*

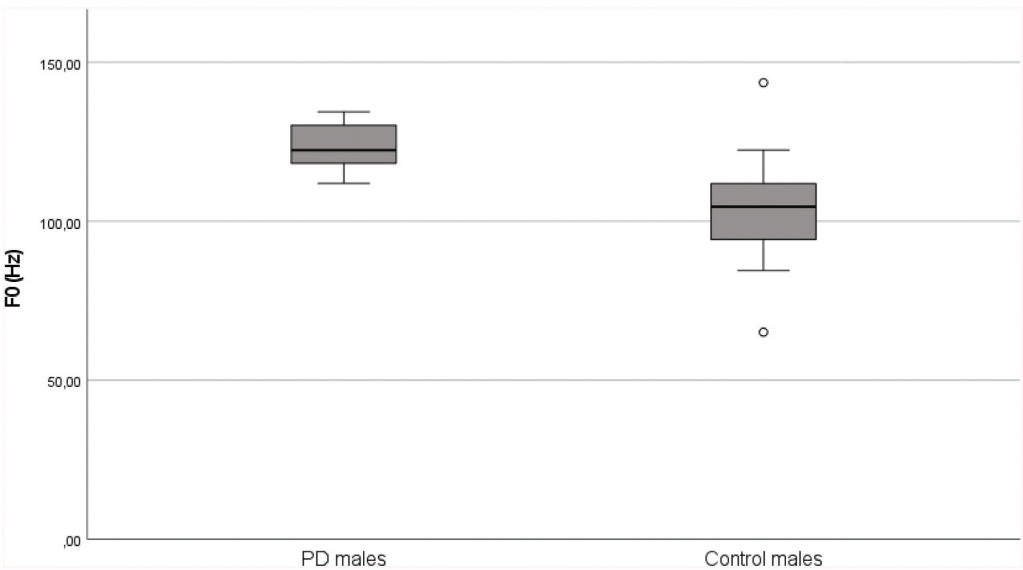

Figure 2. Typical pitch (F_0) in male speakers.

When observing possible differences in smaller subgroups based on participants' sex (Table 4), we found that, although articulation rate was slower in PD males, the difference with control males was not statistically significant. Also, males with PD had a lower nPVI value than control males and a higher epb1kHz value than controls without statistical significance. Statistical difference was not found either in the pitch variability (F_0 SD)

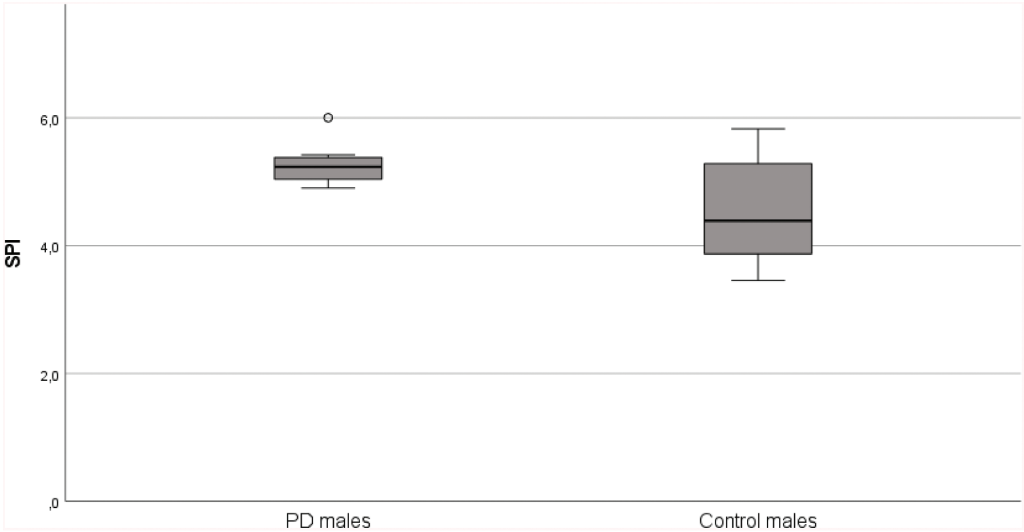

Figure 3. Syllabic prosody index (SPI) in male speakers.

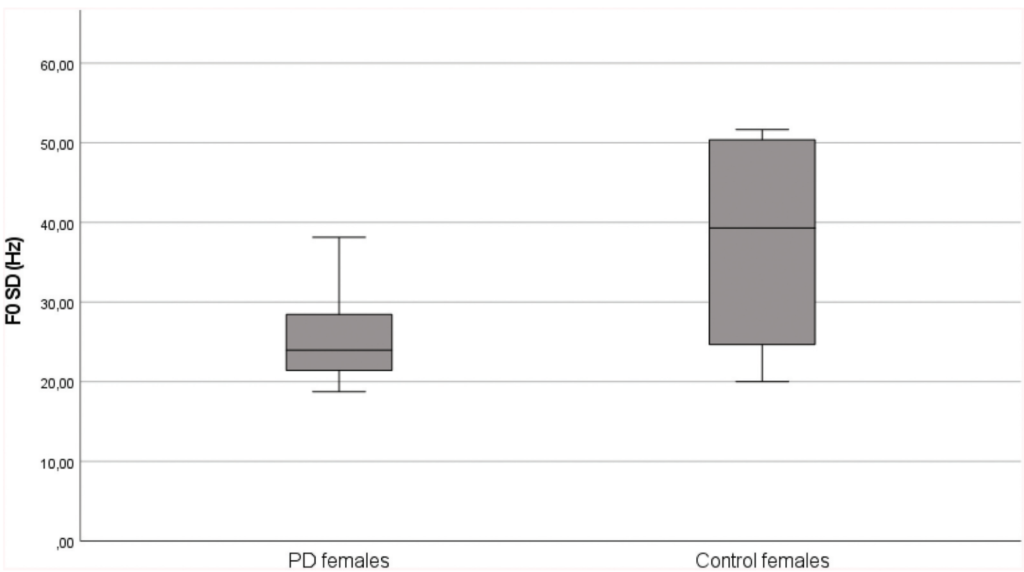

Figure 4. Pitch variability (F_0SD) in female speakers.

between PD and control males. Instead, males with PD had statistically higher typical pitch (Figure 2) compared to control males ($U(16) = 68.000$, $Z = 2.488$, $p = 0.013$). Statistical difference was also found between SPI values ($U(16) = 65.000$, $Z = 2.221$, $p = 0.026$), where PD males' SPI was higher (Figure 3) than in control males.

Articulation rates between PD and control females were almost equal, as well as the nPVI values (Table 4). Like PD males, PD females also had a higher epb1kHz value compared to control females, but the difference was not significant. SPI values between control and PD females didn't differ between speaker groups either. Although typical pitch (F_0) was noticeably lower in PD females than in control females, the difference was not statistical. The only prosodic feature that differentiated the PD female group from the control female speakers was narrower pitch variability (F_0 SD) ($U(16) = 16.000$, $Z = -2.134$. $p = 0.033$; Figure 4).

Discussion

The present study aimed to examine prosodic features in Finnish speakers with PD. Four statistically significant results were found: (1) energy was distributed more to lower frequencies in speakers with PD compared to control speakers, (2) male PD speakers had higher pitch, and (3) higher syllabic prosody index compared to control males, and (4) female PD speakers had narrower pitch variability than controls. Articulation rate or normalised pairwise variability index did not differentiate PD speakers from control speakers. The discussion section is ordered according to these findings.

Effortful, monotonous, and less emphasised speech

The first statistical finding was related to energy proportion below 1 kHz (epb1kHz), which has been previously utilised as a measure for prosodic emphasis and voice quality (Tavi & Werner, 2020). More energy is distributed in the low-frequency regions in a weak and breathy voice compared to a normal voice (Stemple et al., 2018). In this study, PWPD had statistically higher epb1hKz values than control speakers, meaning that in the PD group, the energy was mostly located in the lower-frequency regions. This is understandable, as hypokinetic dysarthria leads to a harsh and breathy voice quality, as well as reduced intensity, which can cause challenges to expressing syllable stress and prosodic emphasis (Miller, 2017).

Acoustically, the way speakers use their voices is reflected by the typical pitch (F_0) and pitch variability (SD; Baken & Orlikoff, 2000, p. 185). Pitch and pitch variability not only describe the intonational patterns but also word and sentence stress, statement form, and affective content (Baken & Orlikoff, 2000, p. 170). In this study, male PD speakers had statistically higher pitch and female PD speakers narrower pitch variability, compared to sex controls. Although the difference between PD and control females' mean pitch (F_0) wasn't significant, it was lower in PD females. Our findings are in line with previous studies, where PD females tend to have decreased $F_{0,}$ and on the contrary, in PD males, F_0 tends to increase (Skodda et al., 2011). Also, the lowest possible F_0 of PD speakers has been found to be higher than in control speakers (Baken & Orlikoff, 2000, pp. 187–189), which was the case in our study as well. Pitch variability, on the other hand, differentiated PD females from controls statistically, as in a study by Skodda et al. (2009), where the difference was noted to grow over time in their longitudinal study.

Finnish has been stated to be a monotonous and "creaky" language, and the creak in Finnish females' voices has even increased during last decade (Uusitalo et al., 2022). Gaining normative data of different speech disorders is important both for clinical and academic use. For example, in this study Finnish PD males F_0 was 123.5 Hz and in females 169.2 Hz, whereas in German-speaking PD males (137.1 Hz) and females (191.7), pitches were much higher (Skodda et al., 2009). F_0 serves as an important acoustic cue to word boundaries in spoken Finnish, where words are exceptionally long (Tuomainen et al., 1999). Therefore, stress marking in the "wrong" place, that is, the second syllable, leads to misunderstandings. In a classic study of Finnish stress by Vroomen et al. (1998), word stress on the correct (first) syllable led to faster and more accurate reactions in listeners in a word-spotting task compared to stress on the second syllable. Stress, or prosodic marking, requires dynamic changes in the glottal, subglottal, and supraglottal system (Thies et al., 2020).

Dysregulation in prosodic production due to PD, especially problems producing prosodic prominence, decreases the naturalness and intelligibility of speech (Thies et al., 2020). By adjusting prosodic prominence, a speaker can highlight information within an utterance and, for example, distinguish statements from questions (Thies et al., 2020, 2019). However, PWPD may use an excessive amount of effort in the glottal and subglottal system and less effort in the supraglottal system, leading to inappropriate prominence marking (Thies et al., 2019). In addition, PWPD overuse F_0 and intensity in prominent positions (Thies et al., 2020), which may also reflect abnormalities in the regulatory mechanism for expressing prosodic prominence. In this study, male PD speakers had a higher syllabic prosody index (SPI) than control males. Although the SPI values were slightly higher in the PD group versus the control group, the difference was not significant on this group level or between females (PD females vs control females). As SPI combines F_0, duration, and energy balance in syllables (Tavi & Werner, 2020), male PD speakers' increased F_0 have impacted the results. Also, the articulation rate in male PD speakers was slower compared to other speakers. As the energy of speech was still distributed in the lower frequencies (higher epb1kHz value), indicating a weaker and less emphasising voice, these findings can be interpreted as effortful speaking style. In addition, gender-related differences have been found in PD (Georgiev et al., 2017): in comparison to men, female patients have more tremor-dominant PD but are, for instance, less rigid. This rigidity in speech muscles can decrease the contrasts between stressed and unstressed syllables, possibly seen as differences in the SPIs between PD males and controls (Ma et al., 2015).

Interestingly, nPVI as a rhythmic measure didn't differentiate groups in this study, although speakers in the control group had higher variation in the durations between successive syllables. In English-speaking PD speakers (Liss et al., 2009), the nPVI value ($M = 37.98$, $SD = 1.35$) has been lower and standard deviation narrower compared to both Finnish control ($M = 41.3$, $SD = 3.5$) and PD speakers ($M = 39.8$, $SD = 3.8$). Language differences, especially as regards long Finnish words, can explain the difference. In the future, it would be interesting to pilot variations on the nPVI metrics by using different contrast pairs of syllables. In addition, the articulation rate didn't differentiate speakers in this study. Possibly, the reading passage as a speaking task unified the speaking and rhythmic patterns between PD and control speakers. In fact, S. Kim and Jang (2009) noted that nPVI values were higher (greater variability) in spontaneous speech than in read speech. It is also possible that as the PD speakers in this study represented a mild disease level (Hoehn & Yahr < 2.5) as well as mild speech impairment level based on VAS-ratings (M = 2.1, SD = 1.5), rhythmical changes that separate speakers with PD from control speakers occur later due to disease progression.

Methodological considerations and future directions

This study reported findings from relatively small study sizes and varying methodologies to gain understanding of the prosodic features in Finnish PD speakers as well as differences related to control speakers. Although the study size was small, we tried to control speakers' age, sex, handedness, and disease stages to be as homogenous as possible. In addition, speakers' speech impairment (VAS 0–10) was rated to be mild (M = 2.1, SD = 1.5) as well as their subjective rating of voice impairment (VHI-9; M = 13.9, SD = 5.6). In the future, it would of course be beneficial to study these prosodic features with larger groups of speakers, and with speakers with different disease and severity stages.

In this study, we used a reading sample as a speech task, instead of spontaneous speech. Even though spontaneous speech might represent a more natural speaking style, a reading passage is more reliable because it enables both intrapersonal and interpersonal comparisons, even though reading style and reading abilities can still affect the outcome (Baken & Orlikoff, 2000, p. 172). In the future, studying prosodic changes in different speaking tasks, such as in spontaneous speech or between regular and emotional reading, would be interesting.

Different prosodic features were analysed from the short-speaking sample. For analysing possible monopitch, we chose fundamental frequency (F_0 mean and standard deviation) as a traditional measure (Frota et al., 2021). In addition, nPVI and articulation rate as rhythmic measures were also reliable and traditional, as they have been used previously in speech prosody assessments in dysarthria (Y. Kim & Choi, 2017; Kim et al., 2011; Liss et al., 2007, 2009). Spectral energies, as well, such as energy proportions (Sluijter & Van Heuven, 1996) and centre of gravity (Nirgianaki, 2014) has been studied before. In this study, epb1kHz separated PD speakers from control speakers statistically. We also used SPI as a novel method to study prosodic prominence and emphasis, and SPI separated male PD speakers from control males statistically. As far as we know, there is only one upcoming publication of SPI in a PD population (Tavi & Penttilä, 0000), but based on the findings by Tavi and Werner (2020), SPI has been evaluated as a potential tool in analysing prosody (Tavi, 2020), at least in control speech, and based on this study, it also has potential in disordered speech. In the future, it would be beneficial to analyse SPI in different dysarthria profiles, such as in spastic or mixed dysarthrias. Finally, in recent years many researchers have noted that prosodic characteristics of speech, such as intonation and duration, can be sensitive detection of early-stage Alzheimer's disease (Petti et al., 2020). Since SPI combines well-known prosodic features into a single phonetic index (Tavi & Werner, 2020), analysing prominence marking with SPI in this population would be interesting and worthy of exploring.

Conclusion

Different acoustic metrics can increase our knowledge of the possible prosodic profiles of different speech disorders and diseases, but the data need to be language-specific. The findings of this study add to information on prosodic features of Finnish Parkinsonian speakers for researchers, but they can also help speech-language pathologists in assessing speech impairment and disease progression in PD, as well as possible rehabilitation outcomes. A novel SPI was used in this study, and it clearly has potential as a new tool for analysing prosody for both clinicians and researchers. In this study, PD in general was manifested as a breathy and less emphatic voice. Interestingly, male PD speakers' dysprosody was manifested as an effortful speaking style, while female PD speakers' dysprosody presented as a monotonous speaking style.

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Appendix 1. Reading sample

Pohjantuuli ja aurinko (The Northwind and the Sun)

Pohjantuuli ja aurinko väittelivät kummalla olisi enemmän voimaa, kun he samalla näkivät kulkijan, jolla oli yllään lämmin takki. Silloin he sopivat, että se on voimakkaampi, joka nopeammin saa kulkijan riisumaan takkinsa. **Pohjantuuli alkoi puhaltaa niin että viuhui, mutta mitä kovempaa se puhalsi, sitä tarkemmin kääri mies takin ympärilleen, ja viimein tuuli luopui koko hommasta**. Silloin alkoi aurinko loistaa lämpimästi, eikä aikaakaan, niin kulkija riisui manttelinsa. Niin oli tuulen pakko myöntää, että aurinko oli kuin olikin heistä vahvempi.