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Vocal Emotional Expression in Parkinson's Disease: Roles of Sex and Emotions

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Abstract: Introduction: Parkinson's disease (PD) commonly causes speech impairments, including difficulties in expressing emotions through voice. Method: The objective of this study was to investigate gendered vocal expressions of fear, anger, sadness, and happiness for mild to moderate PD. Prosodic features (related to fundamental frequency (F0), intensity (I), speech rate, articulation rate, and number and duration of pauses) and acoustic correlates of voice quality (CPPS, jitter, shimmer, and HNR) were collected from 14 patients with PD (mean age = 69.93; SD = 7.12; 8 males, 6 females) and 13 healthy controls (HC) (mean age = 68.13; SD = 8.27; 5 males, 8 females) matched for age, sex, and years of education. The utterances were extracted from four emotional and one neutral text. The neutral utterance and the emotional utterances were compared. Intra-sex comparison (female with PD vs. female HC and male with PD vs. male HC) and inter-sex comparison (female vs. male both for patients with PD and for HC), were performed with the Mann–Whitney test. A Mann–Whitney test was also used to compare the different emotional conditions, considering sex and PD diagnosis as well. Results: No significant intra-sex differences were found for the neutral speech, but inter-sex differences emerged. Regarding emotional speech, females with PD featured lower MaxF0 than female HCs for happiness and higher intensity variability (SD I) for sadness. Utterances by females with PD had lower CPPS than utterances by HCs for anger and fear. Utterances by males with PD had lower minimum intensity (MinI) than utterances by male HCs when expressing fear. Conclusions: Emotional vocal expression in individuals with PD was found to be impaired and showed sex differences. These findings have the potential to significantly impact the quality of life of PD patients.

Keywords: Parkinson's disease; prosody; vocal emotion expression; sex; vocal expression

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1. Introduction

1.1. Functional Communication Impairment in Parkinson's Disease

Parkinson's disease (PD) affects 0.3% of the population worldwide and is the second most common neurodegenerative disorder after Alzheimer's disease [1,2]. Some studies report that up to 80–90% of patients with PD present profound speech and voice impairments, which may occur at an early stage or may develop later [3].These speech difficulties, known as hypokinetic dysarthria, can manifest in the earlier stages of the disease or develop over time and have a significant impact on patients' quality of life [4,5]. Hypokinetic dysarthria in PD is characterized by various impairments in prosody and articulation [6]. Prosodic attributes such as inappropriate silences, rapid or irregular speech rate, and overall increased speech rate are commonly reported as affected in individuals with PD, leading to reduced intelligibility [6,7].

Particularly, the domains most affected by Parkinsonian hypokinetic dysarthria are articulation and prosody [8,9]. Mastering prosody entails the ability to use suprasegmental

signals as markers of the pragmatic function, such as to differentiate the declarative from the interrogative speaking mode, to disambiguate utterances characterized by the same verbal form but different meanings, to express illocutionary force signaling intentions and to convey emotions [10]. These abilities are categorized into the management of two types of prosody: linguistic prosody and emotional prosody [11]. Linguistic prosody supports the clarification and identification of the internal structure of sentence components, as well as conveying the intonation contour of a phrase. Emotional prosody, on the other hand, is essential for expressing emotions. Despite their differences, both types of prosody rely on the same acoustic features. In PD, prosody impairments, known as dysprosody, often involve combined alterations such as flat pitch, reduced volume, and diminished stress, which affect both linguistic and emotional prosody [8,12–14].

Moreover, PD-specific pathological language patterns jeopardize the ability to provide the listener with the cues required to decode the speaker's mental states [15] since such cues are typically conveyed through the conversation structure [16] or the prosody contour [17]. Patients affected by PD experience a lack of skill in conveying their communicative intention, and consequently, may feel inadequate and alienated [18,19].

The decreased ability of patients with PD to modulate prosody may lead listeners to perceive them as bored, introverted, unhappy, or withdrawn based on the limited impressions from their voices [8,20]. Moreover, the impaired communication of patients with PD may cause comprehension difficulties and a sense of unease in the discourse partners, eventually resulting in stigmatization [18].

Naive listeners consistently report that they experience greater difficulty in identifying which words within the utterance are meant to be emphasized by the speaker with PD and in distinguishing the expressed emotions [5,21].

In summary, Parkinsonian hypokinetic dysarthria can have a significant impact on various aspects of patients' lives, highlighting the need for further investigation into the underlying mechanisms and potential interventions. In particular, the detrimental impact of hypokinetic dysarthria on the quality of life raises a profoundly important issue: a better understanding of how prosodic skills are impaired in patients with PD is necessary to promote their personal and interpersonal well-being. Therefore, a comprehensive understanding of the nature and extent of these deficits is crucial to developing personalized treatment plans and improving the overall quality of life for these individuals.

1.2. A Focus on Vocal Impairment in PD

In PD, the basal ganglia are affected by the degeneration of dopaminergic neurons [22]. Although it is true that the basal ganglia play a critical role in speech and language difficulties in PD, they work closely with the cortex, cerebellum, thalamus, and the white matter connections to form a fundamental network involved in both motor and cognitive tasks [23–25]. For example, disruptions in the loop between the basal ganglia, its projections to the ventral anterior and ventral lateral thalamic nuclei, the mediodorsal thalamic nuclei, and projections to premotor, dorsal prefrontal cortices, and the anterior cingulate cortex are often the reason why PD patients struggle to initiate speech [26]. Moreover, recent studies have shed light on the complex interplay of various bilateral brain regions and networks involved in emotional speech processing, encompassing subcortical regions such as the amygdala and basal ganglia, as well as cortical regions like the superior temporal gyrus, insula, and prefrontal cortex [27,28].

The characterization of dysprosody in PD has sparked debate among researchers, with varying perspectives on its underlying nature. Some researchers argue that dysprosody in PD primarily manifests as a motor and articulatory disorder [6], while others propose an emotional deficit as its underlying cause [29]. Despite progress in understanding the perception of emotional prosody, the neural basis for its generation in PD remains unclear [30]. However, there is evidence indicating that the subcortical structures responsible for emotional prosody production, notably the basal ganglia, are heavily impacted by PD [31–34].

Within this context, simple vocalization/phonation tasks have emerged as valuable tools for investigating the voice characteristics of individuals with PD [35]. These tasks involve basic vocal activities such as sustaining vowel sounds or producing short phrases. Findings from recent studies utilizing these tasks have demonstrated significant differences in various acoustic measures and parameters between PD patients and HC [35]. These measures include fundamental frequency (F0) variations such as mean F0, max F0, and min F0 as well as measures like jitter, duration of speech, and median intensity of speaking [36,37]. The utilization of these simple vocalization/phonation tasks allows for the assessment of diverse acoustic measures and parameters, providing valuable insights into the underlying mechanisms of voice dysfunction in this neurodegenerative disorder. Furthermore, recent research suggests that voice dysfunction may serve as an early indicator of motor impairment in PD and holds the potential for remote monitoring of patients [25]. By further exploring the voice characteristics and acoustic profiles through simple vocalization/phonation tasks, we can deepen our understanding of dysprosody in PD, contribute to early diagnosis, and develop innovative approaches for the monitoring and management of this complex disorder.

1.3. Expression of Emotional Prosody in PD

More than one hundred studies have consistently reported that patients with PD have difficulties in recognizing vocal expressions of emotion [27,38]. Interestingly, the research examining the recognition of vocal emotions consistently indicates that individuals with PD are predominantly impaired in recognizing negative emotions such as anger, disgust, fear, and sadness [39]. However, studies investigating the production process of emotional expression in PD patients yield inconsistent results, with the exception of consistently highlighted difficulties in expressing anger. Various factors could contribute to this inconsistency, including the specific tonal characteristics of different languages (such as tonal or non-tonal languages) and the severity of PD in the sampled individuals, both of which can influence emotional prosody. To the best of our knowledge, only ten studies have examined the process of producing emotional vocal expression (see Table 1). In the production of emotional prosody, some studies have shown that patients with PD have difficulty when uttering emotional content within semantically neutral sentences [40], when uttering spontaneous emotional speech [41], and when imitating a speaker's model of emotional expression [41]. All ten studies that analyzed the link between the acoustic features of the utterances and the effectiveness of emotional expression in patients with PD consistently highlighted a deficit in both conveying emotional meaning and reacting to the emotional cues as a recipient [4,8,29,42]. Pell et al. (2006) reported that expressions of anger, disgust, and happiness produced by individuals with PD were poorly representative of those emotions and were often misinterpreted. Anger, disgust, and happiness were mistaken for neutral speech or for the expression of sadness because the vocal characteristics of PD speaker's utterances did not match the correct prosody, mainly due to the lack of appropriate vocal inflections and intonation cues [4,8]. Hsu [42], as far as we are aware, is the only study that has investigated emotional prosody in PD in a tonal language, specifically Mandarin Chinese. She found that the expression of anger by patients with PD featured a lower mean fundamental frequency (F0) and a narrower fundamental frequency range than the expression of happiness, while the opposite was found for the control group. In the same study, participants with PD were able to control voice intensity and syllabic duration to convey different emotions. However, such results are inconsistent with the general clinical description of PD speech as invariant in loudness modulation and slow speech rate [6]. These discrepant findings may be partly attributable to the differences in the methodology of the two considered studies, including task-related differences. For example, although these two studies included participants with the same levels of disease severity (mild to moderate), Hsu [42] administered a reading task in Mandarin Chinese while Duffy [6] administered different tasks (namely vowel prolongation, syllable repetition, isolated sentences, and conversation) in English. Möbes et al. [29] found that

although the PD and control groups did not differ in the linguistic prosodic condition, patients with PD exhibited a reduction in the production of emotional prosody. Indeed, individuals with PD showed significantly lower fundamental frequency (F0) and intensity ranges than the control group for happiness, sadness, and neutral speech. However, the few studies investigating the existence of vocal emotion expression impairment in patients with PD (see Table 1) show highly variable results. Such variability may be explained by different research questions, different task types, different views adopted by the researchers, different emotion labels, and different emotion conceptualizations (for instance, the differences between hot and cold anger, see Biassoni et al. [43]). A closer examination of research methods revealed that most of the studies investigating prosodic abilities in patients with PD did not have any specific theory of emotion as a research framework; such an atheoretical research approach often compromises the interpretation of results [42,44]. Indeed, many studies often fail to provide explanations for their choice of specific emotions and instead utilize cognitive and affective states, rather than strictly adhering to distinct emotions as defined in traditional emotion theory (e.g., Borod et al. [40], who examined 'interest' and 'indifference'). However, in line with the theory of basic emotions, our study focused on fundamental emotions such as fear, anger, sadness, and happiness, excluding disgust due to its limited representation through vocal cues [34,45]. These selected emotions are featured by distinct physiological and psychological patterns, including unique vocal expressions that are recognized across different cultures.

Moreover, some studies lack information about the stage of the disease and the severity of cognitive impairment, which are fundamental elements in explaining some differences in prosody expression. In conclusion, despite the consensus that emotional prosody impairment is a persistent symptom and negative feature that impairs communication in those with PD, the ability of these patients to modulate prosodic cues to express specific emotional meanings in their speech remains a largely unexplored domain [8,41,46–49]. The impaired expression of emotional prosody deeply impacts the quality of life of patients with PD and of their caregivers as well; nonetheless, studies on emotional expression in patients with PD have produced inconsistent outcomes [4].

Further research is therefore needed to investigate this area, with a particular focus needed in the identification of specialized and personalized treatment to help patients with PD recover communication skills.

Table 1. The studies that have investigated emotional prosody production in PD.

Studies	N. Subjects	Years of Disease	Emotions	Main Result	Causes of Prosodic Impairment
Scott et al., 1984 [49]	28 PD; 28 HC	8 (average)	Only anger	Patients with PD were unable to express anger effectively	Emotional or cognitive processing
Borod et al., 1990 [40]	20 PD; 21 HC	NS	Happiness, pleasant surprise, interest/excitement, sadness, anger, fear, and disgust	Patients with PD expressed positive emotions more intensely than negative emotions	Emotional processing
Blonder et al., 1989 [41]	21 PD; 17 HC	NS	NS	Monotone speech reported in PD	Emotional and linguistic processing
Buck & Duffy, 1980 [50]	9 PD; 10 HC	NS	NS	Patients with PD were less expressive	NS
Caekebeke et al., 1991 [46]	21 PD; 14 HC	5.5 (average)	Anger, neutral, and hesitating emotion	Patients with PD were unable to express anger	Motor symptoms
Benke et al., 1998 [51]	22 cognitive intact PD; 26 cognitive impaired PD/18 HC	NS	NS	Patients with PD who are cognitively intact perform better in emotional prosody compared to those who are cognitively impaired.	Mental processing

Table 1. *Cont.*

Studies	N. Subjects	Years of Disease	Emotions	Main Result	Causes of Prosodic Impairment
Pell et al., 2006 [8]	21 PD; 12 HC	3.9 (average)	Anger, disgust, happiness, neutral, sadness, and surprise	Expressions of anger, disgust, and happiness produced by speakers with PD were poorly representative of those emotions	Motor symptoms
Möbes et al., 2008 [29]	16 PD; 16 HC	4.8 (average)	Happiness, neutral, and sadness	Patients with PD showed a significantly lower pitch and intensity range than HC for all emotions	Emotional processing
Hsu et al., 2016 [42]	11 PD; 11 HC	NS	Happiness, neutral, and anger	Patients with PD expressed anger with lower mean pitch and narrower pitch range than happiness	Emotional processing
Alhinti et al., 2021 [52]	3 PD; 21 HC	9.66 (average)	Anger, sadness, happiness, and neutral.	The results show that patients are able to control some aspects of the prosodic features of their emotional speech.	Motor symptoms

Notes: The table shows for each paper: the first author of the study, the publication year, the number of subjects, the years of the disease, the emotions analyzed, the main result, and the hypothesized causes of prosodic impairment. NS stands for not specified, HC stands for healthy control, and PD for Parkinson's disease.

1.4. The Dynamic Architecture of Emotional Space

The present study combines categorical and dimensional approaches to emotions within a theoretical framework. The categorical approach, influenced by the works of Ekman and Friesen [53], Johnson-Laird and Oatley [54], and Tomkins and McCarter [55], classifies emotions into distinct categories. In contrast, the dimensional approach, inspired by Russell [56] and Bradley [57], maps emotions onto a dimensional space. For this study, we have chosen to consider three dimensions: arousal, potency, and valence. Valence represents the spectrum of pleasantness to unpleasantness, while potency captures feelings of power and control, and the inclination to act or refrain from action. Arousal reflects the overall sense of energy or inertia associated with mental and physical preparedness. Within this integrated model, discrete affective labels are incorporated into a multidimensional framework.

The adoption of this integrated model aims to address the limitations of both categorical and dimensional accounts of emotions. The categorical approach provides familiar discrete categories but lacks direct acoustic cues that correspond to specific basic emotions. On the other hand, the dimensional approach suggests that variations in dimensions, particularly arousal, manifest as variations in acoustic parameters, enabling listeners to interpret vocal expressions of emotion in relation to the emotional experience. However, previous research suggests that the dimensional approach alone is insufficient for fully capturing the distinctions between emotions. While emotions can be described in terms of dimensions, incorporating a description in terms of discrete entities contributes to a better understanding of their structure and functions. For instance, even though guilt and shame may share similar evaluations along certain dimensions (such as high arousal, negative valence, and low potency), they are not qualitatively, conceptually, or phenomenologically identical.

Regarding voice quality measures the results are inconclusive. However, it seems that these parameters may contribute to discriminating between valence and potency (see [58,59]). Specifically, shimmer, jitter, and HNR appear to be discriminative parameters for the potency dimension, while cepstrum peak prominence seems to be related to valence [60], even though a breathy voice (or lax voice), characterized by a lower CPPS, has been associated with low arousal emotions, such as sadness and boredom [44,61]. By integrating the categorical approach (using emotional labels to describe recognized emotions in vocal expressions) and the dimensional paradigm (utilizing valence, arousal,

and potency to describe variations in emotional experience), we can gain insights into the relationship between these properties in nonverbal vocal expressions of emotions (refer to Table 2). In summary, our goal is to utilize emotional dimensions in order to differentiate discrete emotions.

Table 2. Pattern of vocal cues associated to the three emotional dimensions (readapted from [59,62,63]).

Emotion Dimension	Vocal Cues
Arousal (high)	High F0 mean, large F0 variability, high maximum F0, high mean intensity, precise articulation, high frequency energy, slow speech rate, and few pauses. The cepstrum peak prominence is low as well.
Valence (positive)	Low F0 mean, large F0 variability, low mean intensity, slackened articulation, fast speech rate, and high cepstrum peak prominence.
Potency (high)	Large F0 variability, large intensity variability, precise articulation, slow speech rate, high shimmer, jitter, and high HNR.

1.5. Sex Differences in Prosody Production

Significant sex differences were observed in all main vocal parameters for healthy participants (speech rate, F0 mean, F0 variability, F0 range, etc.) due to the physiological differences in anatomical structures, such as the size of the vocal folds and the length of the vocal tract [64,65]. Moreover, sex differences have also been reported among those with PD in pausing and articulatory precision [66]. Generally, motor symptoms causing speech problems are more common in males with PD [67]. Some authors have described a specific male articulatory slurring demonstrated by a reduction in pauses [66]. However, Azevedo et al. [68] found that females with PD produced slower speech characterized by a narrow range of F0 variation (which likely accounts for the poor vocal tessiture typical of Parkinsonian speech) and higher vocal intensity in the repetition of five standard utterances. In contrast, in Bowen et al.'s study [69], females had significantly greater F0 variation values than males during running speech. Hertrich and Ackermann [65] examined sustained vowel production using electroglottography and found that females with PD presented an increased number of subharmonic segments (low-frequency segments) and more abrupt F0 shifts. On the other hand, Tykalova et al. [14] showed that males with PD have a lower ability to convey contrastive emphasis with F0, although they could still significantly increase fundamental frequency, intensity, and duration to emphasize a sentence. Skodda et al. [66] described no difference in overall articulatory parameters or speech rate between PD and control groups matched for the sex variable. However, they found that all intonation parameters were notably higher in female patients with PD (but with an increased mean F0 and a relatively stronger reduction in F0 variability in male patients). Moreover, in a previous study, they found that F0 variability in female patients decreased over time, while F0 variability in male patients remained relatively stable [12]. Therefore, participants' speech performance may depend on the stage of the disease and illustrates the necessity of comparing participants at the same stage of the disease [70]. Furthermore, research in the field of emotional prosody has demonstrated that males and females may have distinct emotional responses and display different vocal expressions when conveying emotions [71]. These differences could potentially extend to individuals with PD in a different way. Indeed, when analyzing the role of sex in the vocal emotional production of patients with PD recent research has begun to include cepstral measures since they are sensitive to sex [72]. Cepstrum peak prominence smoothed (CPPS) is defined as the peak prominence obtained from two smoothing processes before calculating the cepstrum, a measure (in dB) of the amplitude of the cepstral peak [73]. To date, there is evidence of the advantages of CPPS over cepstral peak prominence (CPP) in the evaluation of dysphonia [74] and sex identification [72]. Most studies suggested that (both in the normal and dysphonic samples) CPPS values are higher in males than in females [75];

however, evidence in continuous emotional speech is lacking. In conclusion, the causes of emotional prosodic sex-related differences in PD are still not fully understood.

1.6. The Present Study

Whereas it seems to be largely proven that flat pitch is a typical feature of dysprosody in individuals with PD, few studies have examined this speech pattern considering sex-related differences [66,69,76,77] and only one study has explored the effects of sex in the production of emotional prosody [78].

Studies investigating speech impairment in PD, particularly in patients whose native language is not English, are scant; to the best of our knowledge, only two Italian studies have explored the dysprosody in PD using acoustic analysis [79,80]. Moreover, the exploration of sex differences in a task of emotional prosody production has never been investigated with native Italian patients. The present study adds to the previous literature by investigating the vocal emotional expression of patients with PD focusing on:

- The impact of speech impairment on the expression of specific emotions;
- The relationship between emotional dysprosody and sex (investigating both intra-sex differences (female with PD vs. female in HC and male with PD vs. male in HC) and inter-sex differences (female vs. male both for patients with PD and for HC);
- An innovative focus on CPPS, that is considered a good indicator of the vocal tract health status and, particularly, a promising measure of dysphonia severity.

We aimed at verifying two hypotheses:

1. In accordance with Möbes et al. [29] that the impairment in emotional prosody may be explained considering alterations of emotional processing and not only by a motor disease, it is expected that speakers with PD and HCs produce emotional utterances with different acoustic patterns, whereas no differences in the acoustic patterns of utterances produced by patients with PD and HCs are reported for the neutral utterance. Moreover, based on prior evidence [5,7,40–42,81–84], it is expected that the emotional speech of patients with PD is different from the emotional speech of healthy subjects for all the investigated emotions;
2. The second hypothesis posits that sex may be another variable that affects vocal emotional speech. In this regard, the pattern of impairment in the production of emotional speech in patients with PD is different not only as a function of the expressed emotion but also as a function of the sex of the speaker.

2. Materials and Methods

2.1. Participants

Fourteen patients with PD (mean age = 69.93; SD = 7.12; 8 males, 6 females) and 13 HC matched for age, sex, and years of education (mean age = 68.13; SD = 8.27; 5 males, 8 females) participated in the study (Table 3). The inclusion criteria for the present study were: (1) diagnosis of PD according to the United Kingdom Parkinson's Disease Society Brain Bank [85]; (2) positive dopamine transporter scan; (3) at least 8 years of education; (4) no decline in cognitive ability reported by either the patient or the clinician; (5) Italian native language; (6) Mini-Mental State Examination (MMSE) [86] with a score higher than or equal to 24; (7) stable drug therapy with L-Dopa (alone or in association with dopamine agonists, catechol-O-methyltransferase inhibitors, monoamine oxidase inhibitors, and anticholinergic drugs); and (8) right-handedness according to the Edinburgh Handedness Inventory [87].

Table 3. Demographic and clinical characteristics.

Variable	PD (*N* = 15)	HC (*N* = 15)
Age (years)	69.93 ± 7.12	68.13 ± 8.27
Sex (Males + Females)	8 + 7	6 + 9
Education (years)	12.20 ± 3.99	13.20 ± 3.69
UPDRS motor score	27.80 ± 10.60	
H & Y	1.7 ± 0.41	
Disease duration (years)	41.80 ± 21.37	
LEDD	174.31 ± 159.18	
MMSE	27.64 ± 1.79	27.85 ± 1.32

Notes: Demographic and clinical characteristics of participants with PD and HC participants (mean ± standard deviation). H & Y: Hoehn and Yahr scale. UPDRS: Unified Parkinson Disease Rating Scale (UPDRS). LEDD: L-dopa equivalent daily dose. MMSE: Mini Mental State Examination.

Exclusion criteria were: (1) clinical signs satisfying the criteria for other neurological disorders, including possible atypical, secondary, or iatrogenic parkinsonism, (2) major psychiatric illnesses excluding the presence of mild to moderate depression, and claustrophobia, and (3) a structural magnetic resonance imaging (sMRI) (1.5 T Siemens Magnetom Avanto) with conventional anatomical scans (proton density—T2, FLAIR) was used to exclude patients with brain changes and/or white matter hyperintensities outside the normal range.

The participants with PD underwent evaluation while in the "ON" medication condition. Participants in the control group were recruited from healthy family members or caretakers of patients from the neurology outpatient clinic 'Fondazione Don Gnocchi'. None of the control group members had any previous neurological or psychiatric disorders. The MMSE was also administrated to the HC group (cut-off score 24).

The present study was approved by the Ethical and Scientific Committee of 'Fondazione Don Gnocchi' in accordance with the articles of the Helsinki Declaration. Informed written consent was provided by the participants according to the local ethical requirements.

2.2. Vocal Production Task

The aim of the task was to record four vocal emotional expressions and one neutral utterance. To elicit the target emotions, all participants (PD and HC) read five narrative texts [88–90]. The texts met the following criteria: (1) no emotional labels were included in the narration; (2) information about the context and occurring events (antecedents) were included in the text; (3) information about the significance of stimuli and responses considered were included to represent a prototypical picture of the applicable emotions, based on theoretical information available in the literature; (4) the description of prototypical responses to the situation, such as physiological responses, behavior, and emotional expression, were provided by the text; and (5) the language used was common and of daily use. Each text contained the same standard phrase "non è possible non ora" ("it is not possible, not now"), which conveys no emotional sense by itself. The phrase was inlaid in four different emotional contexts: fear (F), anger (A), happiness (H), and sadness (S), as well as in one neutral context (N) to gain a specific emotional connotation (pragmatic function of the context), consistently with previous studies in the literature (see Anolli and Ciceri [88] and Anolli et al. [89]).

The decision to use a single standard phrase intended to control any possible influence or interference of segmental phonemic differences that would occur in the case of spontaneous speech collection, which is more sensitive to prosodic abnormalities. In Italian, the sentence is composed of nine syllables, and the multiple vowel sounds convey considerable prosodic information; the semantic structure includes two parts ("non è possible" and "non ora"), allowing the speaker to choose to pause or not pause in the middle. All the utterances were audio recorded using a low-noise AKG C 520 head-worn condenser microphone, with a 10 cm fixed mouth-to-microphone distance used for all subjects. A standard calibration procedure was used. The audio recordings were calibrated for each participant prior to

the recording of vocal production tasks. All subjects were asked to generate a sustained phonation for a minimum of 2 s at 70 dB sound pressure level on a sound level meter placed at 10 cm from the lips. The data were digitized at a sampling rate of 44.1 kHz. The recordings of three participants (one with PD and two HCs) were excluded since the target utterances were disturbed due to background noise. The emotional texts and the neutral text were presented in a randomized order.

2.3. Measures

The recorded audio tracks of the utterances were edited and analyzed using Praat software [90] (see Figure 1 for an example). All considered measures are acoustic parameters: fundamental frequency-related, intensity-related, duration-related, and voice quality-related; the 13 most representative prosodic features were extracted (see Table 4 for the description of the measures, along with their related perceptual correlates). Praat provides automated algorithms and functions specifically designed to calculate these measures from voice recordings. The onset point T1 and the offset point T2 of each utterance were segmented manually. Specifically, the audio waveform was visually inspected to identify the start and end points of each utterance based on perceptual cues such as the presence of sound and silence. In relation to the fundamental frequency (F0), pitch floor and pitch ceiling were set; for males, the floor was set at 75 Hz, and the pitch ceiling was set at 300 Hz; for females, the floor was set at 100 Hz, and the ceiling was set at 500 Hz. The pause duration ($\geq$200 ms) was excluded to calculate the articulation rate.

Table 4. The acoustic measures used in the study.

Parameter (Unit of Measure)	Description	Perceptual Correlate	Main Reference
Mean fundamental frequency (F0) (Hz), standard deviation, and max and min (Hz)	F0 represents the estimated frequency of the (almost) regular pattern found in voiced speech signals. The SD captures the variation of F0 values, while the max and min reflect the highest and lowest F0 values observed. The fundamental frequency (F0) parameters are extracted by analyzing the pitch contour of a voice signal.	Tone perception (from low to high). Two pitches generally have the same tone if they share the same F0. The standard deviation corresponds to variability of the tone. Frequency-related features are commonly considered the most salient in the detection of monotone speech or highly accented syllables.	Pierrehumbert (1979) [91]
Mean intensity (dB), standard deviation intensity, and max and min (dB)	This group of features is commonly used to capture the voice power in speech. It is the perceived amplitude of a sound. The intensity's parameters are determined by analyzing the amplitude of the voice waveform.	Loudness of the sound. The standard deviation corresponds to variability of the volume.	Lane et al. (1961) [92]
Speech rate (syll/s)	Speech rate refers to the measurement of how quickly an individual speaks. To calculate the speech rate, the number of words pronounced within a specific time period is counted and divided by the duration of that period.	The speed or slowness of speech. This perception may vary depending on the listeners' own speech habits. Speech that is perceived as fast by slow speakers may be interpreted differently by fast speakers and conversely.	Dellwo (2008) [93]
Articulation rate (sill/s)	Articulation rate (sill/s) refers to the measurement of how quickly an individual articulates or produces speech sounds within a given time frame. To calculate the articulation rate, the number of syllables pronounced is counted and divided by the duration of the speech, resulting in the number of syllables pronounced per second.	Speech rhythm and the style of speaking. The perceived articulatory effort can often be judged as a characteristic of faster speech.	Koreman (2006) [94]
Number and duration of pauses (s)	The duration of breaks in the speech that are over 200 ms can be extracted. The pauses are identified by identifying segments in the waveform where the amplitude falls below a certain threshold for a specified duration, indicating the presence of a pause. By measuring the onset time, end time, and duration of silent segments, the number and duration of pauses can be calculated.	Interpreted as silence.	Ephratt (2008) [95]

Table 4. *Cont.*

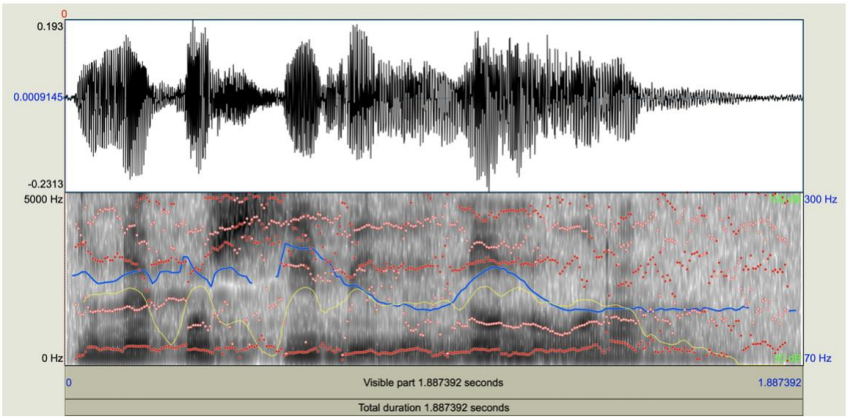
Parameter (Unit of Measure)	Description	Perceptual Correlate	Main Reference
Cepstral peak prominence smoothed (CPPS) (dB)	The outcome of taking the inverse Fourier transform (IFT) of the logarithm of the estimated signal spectrum that informs the rate of change in the different spectrum bands. A smoothing process is applied to the cepstral coefficients prior to calculating the peak prominence.	Measurement of perturbation in voice harmonics and perceived breathiness, i.e., the noise caused by the air passing between the vocal folds even in their occlusion phase. It correlates with the perception of dysphonia: the lower it is, the more the voice is compromised and described from listeners as hoarse and breathless (Theodoros and Ramig, 2011).	Heman-Ackah et al. (2003) [74] Fernandes et al. (2018) [96]
Harmonic to Noise Ratio (HNR) (dB)	This measure estimates the level of noise in speech signals measuring the ratio between periodic and non-periodic components. HNR is calculated by analyzing the spectral properties of the voice signal and estimating the ratio of harmonics to noise.	It is perceived as breathiness or hoarseness. A voice characterized by a low HNR is a dysphonic or an asthenic voice.	Shama et al., (2006) [97]
Jitter (μs) and Shimmer (dB)	Jitter measures the perturbations of the period durations of the glottal wave while shimmer measures the perturbations of the amplitude of the glottal pulses. Jitter is calculated based on the differences between consecutive F0 values. Shimmer is computed based on the differences between consecutive intensity values.	These measures are perceived as breathiness and roughness. Jitter is related with the lack of control of the vocal folds, while shimmer is related with noise emission and breathiness.	Teixiera et al., 2014 [98]

Notes. Prosodic features (related to the fundamental frequency (F0), intensity (I) and speech rate, articulation rate, and number and duration of pauses) and acoustic correlates of voice quality (CPPS, jitter, shimmer, and HNR)" considered in the present study and their related perceptual correlates.

2.4. Design

A comparative cross-sectional study was conducted. Three independent variables were considered: sex (two levels: male vs. female), diagnosis (two levels: PD vs. HC), and emotional tone (neutral condition vs. emotional condition with four levels referring to four emotions: anger, fear, happiness, and sadness). The acoustic parameters, including all prosodic features and acoustic correlates of voice quality, were compared between patients with PD and HC using the Mann–Whitney U test in SPSS (version 25.0). The significance level was set at $p < 0.05$.

Speech signal of the utterance "Non è possibile non ora" expressed by a health female



Speech signal of the utterance "Non è possibile non ora" expressed by a female subject with PD

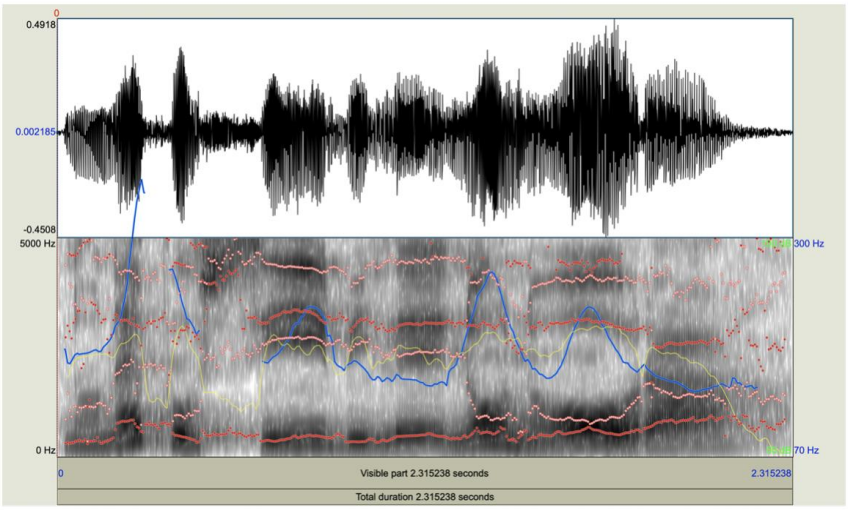


Figure 1. Oscillograms and spectrograms of utterances expressing happiness. Notes: extraction of F0 (in blue), intensity (in yellow), and formants (in red).

3. Results

3.1. Neutral Speech

For neutral speech, no statistically significant differences emerged between the PD and HC subsamples for all parameters, nor intra-sex differences were reported. However, differences were found regarding inter-sex variable. Females with PD showed greater MF0 (Hz) (U = 48; p = 0.001), MinF0 (Hz) (U = 33; p = 0.02) and MaxF0 (Hz) (U = 46; p = 0.02) than males with PD. In the HC group, females showed greater MF0 (Hz) (U = 36; p = 0.05), MaxF0 (Hz) (U = 33; p = 0.02) and HNR (dB) (U = 25; p = 0.03) compared to males. Jitter (µs) and shimmer (dB) were higher in the male group (U = 2; p = 0.021) and (U = 4; p = 0.031).

3.2. Emotional Speech

The four emotional conditions were analyzed individually, considering the effect of the two independent variables, "sex" and "diagnosis". Regarding inter-sex comparison (female vs. male both for patients with PD and for HC), MF0 (Hz) was significantly higher in females than in males with PD in all emotional conditions: anger (U = 42; p = 0.026) happiness (U = 45; p = 0.005), fear (U = 47; p = 0.002), and sadness (U = 47; p= 0.002). MaxF0 (Hz) was also higher in females than in males for happiness (U = 44; p = 0.01) and for sadness (U = 47; p = 0.002). In the HC sample, MF0 (Hz) was significantly higher in females than in males with PD in anger (U = 36; p = 0.005), in fear (U = 36; p = 0.005), and in

sadness (U = 36; $p = 0.005$). MaxF0 (Hz) was also greater in females than in males for anger (U = 31; $p = 0.03$) and for fear (U = 35; $p = 0.006$). HNR (dB) was significantly different as a function of the speaker's sex for anger (U = 0.34; $p = 0.11$), for happiness (U = 0.32; $p = 0.02$), for fear (U = 0.32; $p = 0.007$), and for sadness (U = 32; $p = 0.034$), with females having higher HNR (dB) than males. The jitter (µs) was significantly different as a function of the speaker's sex for happiness (U = 3.5; $p = 0.02$) and for sadness (U = 3.00; $p = 0.02$), with men showing higher jitter than female. The MinF0 (Hz) was higher in fear for female (U = 34; $p = 0.013$). Regarding intra-sex comparison (female with PD vs. female HC and male with PD vs. male HC), considering all the emotional conditions one by one, several acoustic parameters showed significant differences. Namely, in anger condition, PD and HC female subsamples showed a statistically significant difference for CPPS (dB) mean values (U = 6; $p = 0.013$); the HC subsample recorded a CPPS (dB) mean value of 28.0 ± 1.08, and the corresponding value for the PD subsample was 22.7 (±3.91). There were no statistically significant differences between the PD and HC male subsamples. In happiness condition, PD and HC female subsamples showed a statistically significant difference for MaxF0 (Hz) (U = 7.5; $p = 0.021$); the mean value for MaxF0 (Hz) for the HC subsample was 301 (±31.7), while for the PD subsample it was 240.94 (±52.1). There were no statistically significant differences for the male subsample. In fear condition, PD and HC female subsamples showed a statistically significant difference for CPPS (dB) mean values (U = 5; $p = 0.009$); 29.3 (±3.47) and 22.1 (±4.78) in the HC and PD subsample, respectively. Conversely, the PD and HC male subsamples showed a statistically significant difference for the MinI (dB) (U = 12; $p = 0.02$); the HC subsample recorded a mean value of 59.83 ± 34.08, and the PD subsample had a mean value of 34.18 ± 9.96. In sadness condition, PD and HC female subsamples showed a statistically significant difference for the SD of intensity (dB) (U = 4; $p = 0.007$); the mean value recorded for the HC subsample was 5.48 (±0.75), whereas for PD subsample was 6.78 (±0.61). There were no statistically significant differences for male subsamples.

4. Discussion

This study aimed to better understand the proven dysfunctional vocal communication in patients with PD, investigating the possible effect of the "sex" variable with different expressed emotions in continuous speech. The emotional speech was investigated both intra-sex (females with PD vs. females HC and males with PD vs. males HC) and inter-sex (female vs. male both for patients with PD and for HC). The acoustical analysis examined two aspects: prosodic features and acoustic correlates of voice quality.

Considering the neural utterance, there were no significant differences between PD and HC, as well as between females and males. A possible interpretation suggests that the absence of noticeable differences between patients with PD and HC in the neutral condition could be associated with the stage of PD the patients are in [99]. Indeed, a global impairment in speech is frequently observed in the most advanced stages of the disease, but not in mild to moderate PD. The lack of differences even taking into account the sex variable is instead consistent with Sapir et al. [100], who found that speech impairment in PD did not correlate with sex. However, both within PD group and HC group, participants displayed different voice characteristics as a function of the sex. In both neutral and emotional speech, females in both groups exhibited higher parameters related to F0 compared to males. This finding aligns with our understanding of the inherent and distinct characteristics of female speech, which have been extensively studied and attributed to anatomical differences in the larynx and variations in the length of vocal folds [101,102]. A notable decline was observed for the jitter only in healthy female voices, as corroborated by other studies [85,98,101,103]. Female speakers in the HC group reported also reduced shimmer and more breathy speech. All these results are consistent with a recent study on healthy Italian subjects of age comparable to our sample's [104]. Moreover, in line with Deliyski et al. [105], our results suggest that the sex variable is among the characteristics that have the strongest impact on mean F0, jitter and shimmer. Conversely, no statistically significant difference was found

between male and female voices in the pathological group for jitter, shimmer, and HNR. Our interpretation is that the disease flattens sex differences in voice production, resulting in more similarity between the two sexes regarding voice physiology. Therefore, the role of sex in the modification of emotional speech caused by PD needs further clarification.

Furthermore, the variable "emotional tone" and the interaction with the variables "diagnosis" and "sex" showed significant effects. With regard to the variable "sex", when comparing these results with those of neutral speech, we hypothesized that the increase of f0 parameters in all females was relatively independent of the effects of diagnosis and emotion but is distinctive of female speech. For the healthy females, also the HNR is independent of the emotion variable. Conversely, the high SD of the CPPS in the males with PD in happiness condition (but not in the neutral condition) might be a pattern of expression of the specific emotion or may disclose a loss of control of voice intensity. Indeed, although there are some sources in the literature suggesting that CPPS may be somewhat of a marker for the emotional valence dimension [60] and depression [106] it is possible to believe that the pronounced SD of this measure could indicate a loss of control, which relates to the 'potency' emotional dimension. Therefore, this result must be interpreted very carefully, also considering that no data in the literature emerged in this direction.

When considering the intra-sex comparison (females with PD vs. females HC and males with PD vs. males HC), the utterances produced by female speakers with PD were characterized by lower maximum F0 (MaxF0) values than HC female speakers when expressing happiness and higher intensity variability (SDI) when expressing sadness. PD female speakers' utterances were also characterized by lower CPPS than healthy female speakers when expressing anger and fear. These findings suggest deviations from typical prosodic patterns associated with happiness and sadness expressions in healthy subjects [59,107]. In contrast, PD males exhibited lower minimum vocal intensity (MinI) when expressing fear, which is contrary to what is typically observed in healthy vocal expressions. The observed differences in vocal characteristics suggest a potential difference in the emotional valence dimension between PD and healthy individuals. For instance, the lower MaxF0 values in PD females when expressing happiness may indicate an altered production of hedonic valence compared to healthy females. Additionally, the lower values in CPPS during anger and fear expressions in PD females may suggest a reduced sensitivity to high arousal negative emotions (in line with Dara et al. [108]). Indeed, a breathy voice (or lax voice), the most important perceptual correlate of a low CPP and CPPS, has been associated with low arousal emotions, such as sadness and boredom [44,61,109], and the association of breathy voice with anger and fear is less supported [61]. However, it is important to note that this is just a tentative explanation and should be interpreted with caution, as further research is needed to fully understand the underlying mechanisms and potential confounding factors.

To the best of our knowledge, no study on the variations of CPPS in emotional speech has been conducted with Italian speakers; however, some studies in different languages have proved that CPP (very similar to CPPS; both are considered to be measures of breathiness and roughness) may correlate with the emotional state [110]. This specific result may indicate a typical pattern of female speakers with PD. Since emotional expression in speech normally results in variations of the spectral energy and vocal quality parameters [111], it should also be considered that the alteration of the regularity or periodicity in the voice signal, which is typical in participants with PD due to the dysfunction in the physiology of vocal fold vibration, may impair the vocal expression of emotions. The low MinI shown in the male sample with PD is not coherent with the expression of fear, which is characterized by the high minimum of intensity, that reflects the urgency and novelty of the stimuli [63].

In conclusion, the collected data show that individuals with PD exhibit significant deficits in vocal emotional expression, which may reduce their ability to communicate effectively. Moreover, our results suggest the possibility that the differences in prosodic and CPPS patterns found when comparing PD and HC speakers also bring into play a sex specificity, underlying emotional processing and speech disorders in patients with PD.

This, in turn, may be determined by biological sex differences in brain organization and structure related to emotional expression in PD. Based on the collected data, we argue that the observed sex-related patterns of dysprosody are beyond sex differences in healthy adults. Namely, we assume that PD effects on vocal emotional expression and normal physiologic sex differences are interrelated with each other. Furthermore, the presented results are consistent with the current state of research on the role of sex on the effects of PD, suggesting a possible different pattern of neurodegeneration on the dopaminergic neuronal system in the basal ganglia that have repeatedly been linked to impairment in motor coordination and emotional processing.

The analysis of the impact of the sex variable (both intra and inter group) on the vocal emotion productions with Italian patients and the use of CPPS to analyze emotional speech are the distinctive elements of the present study. At the best of our knowledge, previous research investigated sex differences in non-emotional speech e.g., [66] or the effects of PD on emotional speech without taking into account sex differences (e.g., Borod et al., 1990, [40]). Our work aims at providing an integrated overview of the effect of the variables "diagnosis" and "sex" and of their interrelation.

Since intra-sex differences (female with PD vs. female HC and male with PD vs. male HC) did not emerge in the neutral condition, we postulate that these differences are due to a failure in emotional prosody processing in addition to (or beyond) the impairment of motor abilities, in accordance with Möbes and colleagues [29]. In the process to understand the aprosodic speech in PD, we strongly assume that future research should consider the variable "sex" when investigating emotional speech impairment. In addition, it is important to encourage research on this topic considering other languages. Actually, though there are universal emotional cues for vocal expression of emotions, culture and language influence how emotions are expressed [112]. Our data show a specific pattern of deterioration in dysarthric symptoms among Italian patients with PD and the heterogeneity across studies demonstrates that PD is associated with some voice changes that cannot always be extended to all languages (e.g., for different F0 contours language-specific) [78]. Thus, the interplay of several factors highlighting the variability among speakers (e.g., subjective cognitive/emotional differences, factors related to the patient history) may explain the differences in these results associated with the emotional performance. Regardless of the language and of the variability among speakers, however, the impairment in emotional expression can have important implications for a patient's quality of life. The present study has some limitations. First, the sample was small, given the pilot nature of this study. The small sample size limits statistical approaches (we used a nonparametric test). Second, emotional speech has been investigated by analyzing short utterances (to control any possible influence or interference of segmental phonemic differences). Nonetheless, observing the possible effects of vocal emotional expression impairment related to PD in spontaneous conversation would provide a more complete overview of the problem. In addition to considering larger samples of speakers, future research should include patients with PD at different stages of the disease to control for the effect of disease severity on the impairment of vocal emotional expression in both female and male speakers. Furthermore, it would be intriguing to establish a correlation between the initial findings of this study and data concerning other disease-related impairments that manifest differently in female and male patients [42,113]. Additionally, examining the relationship between neuropsychological measures and speech performance could provide insights into identifying a vocal marker indicative of motor, cognitive, or emotional impairment [114].

5. Conclusions

The results of the present study showed that patients with PD exhibited deficits in vocal emotional expression, as evidenced by variations in prosodic features (related to fundamental frequency (F0), intensity (I), speech rate, articulation rate, and number and duration of pauses) and acoustic correlates of voice quality (CPPS, jitter, shimmer, and HNR). Our hypothesis is that such differences are related to both emotional processing

and speech disorders associated with motor symptoms. In addition, our results also highlighted a sex specificity in the impairment of vocal emotional expression in patients with PD, therefore suggesting that future research should consider the variable "sex" when investigating emotional speech impairment in PD.

In conclusion, impairment in the expression of emotions in PD may have a significant impact on the patients' and caregivers' quality of life; as such, speech disorder deeply affects and jeopardize the emotional attunement process. Moreover, the present study pinpointed a possible specificity of the impairment in relation to sex differences. Further research is required to explore the underlying factors contributing to such differences and to develop interventions that can effectively enhance the vocal emotional communication abilities of male and female patients with PD. This would improve social interactions and foster a stronger sense of connection among individuals affected by this condition.

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