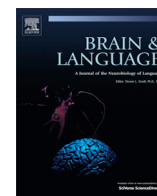Contents lists available at ScienceDirect

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Speech dysprosody but no music 'dysprosody' in Parkinson's disease

Robert Harris [a,b,]*, Klaus L. Leenders [a], Bauke M. de Jong [a]

[a] Department of Neurology, University Medical Center Groningen, University of Groningen, P.O. Box 30.001, 9700 RB Groningen, The Netherlands
[b] Prince Claus Conservatoire, Hanze University of Applied Sciences, Veemarktstraat 76, 9724 GA Groningen, The Netherlands

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ABSTRACT

Parkinson's disease is characterized not only by bradykinesia, rigidity, and tremor, but also by impairments of expressive and receptive linguistic prosody. The facilitating effect of music with a salient beat on patients' gait suggests that it might have a similar effect on vocal behavior, however it is currently unknown whether singing is affected by the disease. In the present study, fifteen Parkinson patients were compared with fifteen healthy controls during the singing of familiar melodies and improvised melodic continuations. While patients' speech could reliably be distinguished from that of healthy controls matched for age and gender, purely on the basis of aural perception, no significant differences in singing were observed, either in pitch, pitch range, pitch variability, and tempo, or in scale tone distribution, interval size or interval variability. The apparent dissociation of speech and singing in Parkinson's disease suggests that music could be used to facilitate expressive linguistic prosody.

1. Introduction

Impairment of singing would perhaps not be considered the most salient symptom of a movement disorder such as Parkinson's disease (PD). The expressive qualities of music, however, depend largely upon the same features which characterize expressive linguistic prosody: pitch, rhythm, and sound intensity, aspects of speech which can be severely impaired in PD (Sapir, 2014). Nevertheless, clinical assessment does not generally probe the singing abilities of these patients, and even more significant, scientific investigation of the issue is almost non-existent. One study, based solely on the singing of a scale, has suggested that Parkinson patients are no longer able to sing accurately (Rigaldie, Nespoulous, & Vigouroux, 2006).

It has previously been remarked that music is a useful tool for the study of the functional organization of the brain (Zatorre, 2005). That is particularly so in the case of Parkinson patients for whom the facilitating effects of music on gait have been well documented (Bernatzky, Bernatzky, Hesse, Staffen, & Ladurner, 2004; de Bruin et al., 2010; Hayashi, Nagaoka, & Mizuno, 2006; Ito et al., 2000; McIntosh, Brown, Rice, & Thaut, 1997; Rubinstein, Giladi, & Hausdorff, 2002; Thaut et al., 1996). Understanding how this takes place should be a main concern of current neuroscientific research. The immediate aim of the present study was to determine whether the previously demonstrated impairments of expressive linguistic prosody were paralleled by similar melodic impairments in patients' singing. Our hypothesis was that the well-documented effect of music on the gait of Parkinson patients is not specific to locomotion, but that it extends to vocal behavior as well. We therefore expected the singing of patients to be quite similar to that of healthy individuals, while their speech is not.

PD is a progressive movement disorder characterized by the loss of the dopaminergic neurons in the substantia nigra. Main motor symptoms of the disease are bradykinesia, rigidity, and tremor (Bartels & Leenders, 2009; Jankovic, 2008), symptoms that can be partly alleviated by dopamine repletion (Connolly & Lang, 2014). Remarkably, however, patients may exhibit improvement in walking speed and stride length while listening to music, particularly music with a salient beat (Dalla Bella, Benoit, Farrugia, Schwartze, & Kotz, 2015; Hove & Keller, 2015; Lim et al., 2005). While they may be severely impaired in their ability to walk, under the influence of 'groovy' music (Madison, 2006) some patients are even able to dance (Volpe, Signorini, Marchetto, Lynch, & Morris, 2013). The innate, largely human, capacity for musical beat induction (Fitch, 2012; Grahn & Brett, 2007; Honing, 2012; Large & Snyder, 2009; Schachner, Brady, Pepperberg, & Hauser, 2009) seems to play a role in the elicitation and synchronization of movement in patients with Parkinson's disease, apparently circumventing neural circuits devastated by the disease (Grahn & Brett, 2009).

Besides bradykinesia, rigidity, and tremor, PD is characterized by hypokinetic dysarthria, a term referring to a variety of speech

* Corresponding author at: Department of Neurology, University Medical Center Groningen, P.O. Box 30.001, 9700 RB Groningen, The Netherlands.
E-mail addresses: r.i.harris@pl.hanze.nl (R. Harris), b.m.de.jong@umcg.nl (B.M. de Jong).

abnormalities such as reduced volume, poor enunciation, and 'flat' prosody (Cheang & Pell, 2007; Fox & Ramig, 1997; Walsh & Smith, 2012). Prosody may be defined as the patterned distribution of stress, intonation and other phonatory features in speech (Scott, Caird, & Williams, 1984). Wennerstrom (2001) calls it 'the music of everyday speech'. Her reference to the term 'music' is an allusion to the word προσωδία (prosodia) whose original meaning connoted the ancient Greek practice of singing poetry instead of reciting it. Prosodic cues are used to convey emotion (Adolphs, 2002) as well as to resolve syntactic ambiguities (Steinhauer, Alter, & Friederici, 1999). The monotone character of patients' speech (Holmes, Oates, Phyland, & Hughes, 2000) suggests falsely that they are uninterested and emotionally detached (Benke, Bösch, & Andree, 1998; Mikos et al., 2009; Pitcairn, Clemie, Gray, & Pentland, 1990).

Impairment of expressive linguistic prosody, one of the most conspicuous features of Parkinsonian dysarthria (Skodda, Rinsche, & Schlegel, 2009), makes it difficult for patients to be understood (Blonder, Gur, & Gur, 1989; Pell, Cheang, & Leonard, 2006). They are frequently unable to make an audible distinction between compound nouns (a greenhouse) and noun phrases (a green HOUSE) or to emphasize salient words in a sentence (Where do you think YOU are going?). Patients do not succeed in producing the rising pitch that distinguishes a question from a statement (Darkins, Fromkin, & Benson, 1988; Pell et al., 2006). Sentences exhibit incongruent contour patterns, going up and down at the wrong places (MacPherson, Huber, & Snow, 2011), and breathing pauses do not always take place at syntactic boundaries (Huber, Darling, Francis, & Zhang, 2012).

That impairments of expressive linguistic prosody in PD are not only due to a general loss of motor abilities can be deduced from the accompanying impairments of receptive prosody (Monetta, Cheang, & Pell, 2008; Pell & Leonard, 2003; Pell & Monetta, 2008; Schröder et al., 2006). Patients fail to recognize prosodically communicated emotion (Ariatti, Benuzzi, & Nichelli, 2008; Dara, Monetta, & Pell, 2008; Gray & Tickle-Degnen, 2010; Schröder, Nikolova, & Dengler, 2010; Ventura et al., 2012; Yip, Lee, Ho, Tsang, & Li, 2003), and when meaning is being signaled by prosodic inflection, they may even fail to understand what is being said (Blonder et al., 1989; Lloyd, 1999; Pell, 1996; Scott et al., 1984).

A few studies have investigated patients' recognition of emotions in music (Lima, Garrett, & Castro, 2013; van Tricht, Smeding, Speelman, & Schmand, 2010). To our knowledge, however, no studies have investigated the role of auditory cues in Parkinson patients' comprehension of music. On the other hand, a recent study showed that patients' speech processing (as indicated by EEG) could be enhanced by first listening to music that exhibited a metric similarity to the spoken text. Semantic and syntactic processing of a trochaic text was significantly better when the spoken text was preceded by marching music than when it was preceded by a waltz (Kotz & Gunter, 2015). Moreover, in two different case studies, it has been observed that intelligibility could be enhanced by singing. Intelligibility was poorer when the text was spoken than when it was sung (Ferriero, Bettoni, Picco, Massazza, & Franchignoni, 2013; Kempler & van Lancker, 2002).

These results suggest that both expressive and receptive 'prosodic' aspects of music are spared in PD and that music might have a similar facilitating effect on vocal behavior as it has on gait, a hypothesis that was explored in the present study by comparing the singing of Parkinson patients with that of healthy controls matched for age and gender. The focus of the study was not on expert music performance, but rather on the general vocal ability of non-musicians to sing a familiar tune or to improvise a melodic continuation to an antecedent phrase.

Our main hypothesis was that during the vocal rendition of familiar melodies and the singing of improvised melodic continua-

tions to antecedent phrases, no differences between patients and healthy individuals would be observed. In order to confirm the presence of expressive linguistic prosodic impairments in the patient group, recordings were made of spontaneous oral autobiographical narratives and the rhythmic recitation of song lyrics. Dysprosody was assessed in two randomized aural discrimination tests in which ten neurologically skilled assessors (five senior neurologists and five residents in neurology) listened to soundbites of the autobiographical narratives of all participants and differentiated patients from healthy controls on the basis of aural perception. Dysprosody was further quantified by digital speech analysis of the recordings.

2. Material and methods

The present study was approved by the Medical Ethics Committee of the University Medical Center Groningen, Groningen, The Netherlands. All participants gave written informed consent in accordance with the Declaration of Helsinki (2008), prior to participation. In addition, patients gave written informed consent granting access to classified information concerning their medication.

2.1. Participants

Fifteen Parkinson patients, many of whom played a music instrument or sang in a choir, but none professionally, were recruited for this study: six males and nine females, mean age (±SD): 65 (±8) years. Fifteen healthy participants, mean age 65 (±8) years, with similar musical interests, matched for age and gender, were recruited as controls. Patients were recruited via the local patient society as well as by advertisement on the website of the Dutch Parkinson Society. Of the nineteen patients who responded, four patients were excluded on the basis of additional pathology (CerebroVascular Accident), treatment (Deep Brain Stimulation), career (semiprofessional musician), and in one case, general inability to sing. Eight patients had left-asymmetric symptom involvement, of whom one was affected bilaterally at the time of testing. Seven patients had right-asymmetric involvement, of whom one was affected bilaterally at testing. For ethical reasons, patients were not requested to refrain from taking their normal doses of (dopamine repletion) medicine.

As patients were recruited from all over The Netherlands, data were acquired in the homes of the participants by one of the researchers (RH) who holds a master's degree in Human Movement Science as well as two degrees in music performance. Acquisition in the homes of the patients made on-the-spot disease quantification on the Unified Parkinson's Disease Rating Scale (Movement Disorder Society Task Force on Rating Scales for Parkinson's Disease, 2003) impossible. The visiting researcher (RH) estimated the Hoehn & Yahr score during acquisition (Hoehn & Yahr, 1967) and obtained written consent from each patient permitting the participating neurologist (BMdJ) to acquire medical information from the patient's consulting neurologist which, however, did not consistently include UPDRS scores. Based on the available information, BMdJ established the Hoehn & Yahr scores and computed the LEDD (Levodopa Equivalent Daily Dose). Mean disease duration was 7.3 years (±3.5); mean Hoehn & Yahr score: 2 (±0.19); mean LEDD: 835 (±537). Individual Hoehn & Yahr scores, disease duration (years since diagnosis), and LEDD are reported in Table 1.

2.2. Experimental protocol

2.2.1. Speech tasks

While the assumption was that Parkinson patients would suffer from dysprosody, it was important to confirm its presence in the

Table 1
Patient LEDD and Hoehn & Yahr scores.

Patient	Gender	Age	Disease duration	H & Y	LEDD
1	F	73	11	2	307
2	F	69	4	1.5	500
3	F	50	7	2	1305
4	M	67	7	2.5	640
5	M	62	8	3	860
6	F	60	5	2	938
7	M	67	9	2	1160
8	F	61	12	2	1995
9	F	51	9	3	495[a]
10	M	64	3	1	0[b]
11	F	78	3	1	375
12	M	72	6	2	1660
13	F	61	12	2	575
14	F	68	2	1	463
15	M	74	12	3	1250

Disease duration: years since diagnosis. **H & Y**: Hoehn & Yahr scale of disease progression. **LEDD**: Levodopa Equivalent Daily Dose.
[a] Preference for minimal intake of standard medication with partial substitution by Mucuna Pruriens.
[b] Main symptom: tremor.

group of patients being studied. Therefore, several recordings were made of participants' speech, prior to performance of the singing tasks. For these recordings, participants were requested to execute two speech tasks: (1) a spontaneous oral autobiographical narrative with a duration of at least one minute; and (2) the recitation of several song lyrics of the participant's own choice, recited in the rhythm of the song. Examples of one patient's performance of the two speech tasks can be seen in Fig. 1.

Recordings of the autobiographical narratives were edited into short (20–30 s) anonymized soundbites and presented to ten neurologically skilled assessors (five senior neurologists and five residents in neurology from the neurology department of the UMCG (University Medical Center Groningen)) to determine whether the speech of the patients could be distinguished from that of healthy individuals, purely on the basis of aural perception. Soundbites were presented in two different protocols with a time-span of several weeks between presentations to avoid undesired influence of the first assessment on the second.

In the serial aural discrimination protocol, the ten assessors (five senior neurologists and five residents in neurology) listened to an anonymous soundbite from the improvised oral autobiographical narrative of each participant and rated the chance that he or she was a Parkinson patient on a five-point scale: (1) definitely healthy control; (2) probably healthy control; (3) maybe Parkinson patient; (4) probably Parkinson patient; (5) definitely Parkinson patient. The order of presentation of the recordings was randomized separately for each assessor.

After an interval of several weeks, the same ten assessors were again asked to discriminate all fifteen patients from their matched controls in a pairwise, forced-choice paradigm in which the sound-bite of the patient was either followed or preceded (randomly) by that of the healthy control, matched for age and gender. The soundbites were the same as those used in the serial assessment. Assessors were asked to indicate which of the two participants they considered to be the Parkinson patient. The order of presentation of the patient-control pairs was randomized separately for each assessor.

2.2.2. Music tasks

Participants were asked to perform two music tasks: (1) to sing several melodies of familiar songs (or themes from familiar pieces), singing on syllables such as la-la-la or pom-pom-pom, according to the participant's preference; and (2) to sing improvised melodic continuations to antecedent phrases sung by the researcher, singing on syllables such as la-la-la or pom-pom-pom, according to the participant's preference. Examples of one patient's performance of the two music tasks can be seen in Fig. 2.

As the rhythm, tempo, pitch range, and scale tone distribution of existing melodies is determined largely by the melody and not by the singer, vocal improvisation was used in the second music task to elicit pitch and rhythmic patterns produced primarily by the participant. Nine antecedent phrases in the major mode were composed, designed to elicit a melodic continuation (see Supporting Material: Antecedent Phrases). Each phrase was sung by the researcher without the aid of a tuning fork, metronome, or accompaniment, after which the participant continued the melody, singing as long as he or she wished. Depending on the length of the continuations, a larger or smaller number of recordings was made. Participants improvised on average 6 (±1.4) melodies.

Recordings were made in WAV (Waveform Audio File) format, using a Roland 05 hand recorder with a built-in microphone. A total of 390 recordings was made: 185 recordings of Parkinson patients and 205 recordings of healthy controls, an average of 393 (±93) seconds per patient and 402 (±71) seconds per control. Examples of familiar melodies and improvised continuations can be found in Supporting Material: Transcriptions of Recordings.

2.3. Analysis

Recordings of both the autobiographical narratives and the song lyrics were subjected to digital speech analysis to quantify tempo and pitch parameters using the speech processing tool PRAAT (Boersma & Weenink, 2013). The Inter-onset Interval (IOI: mean duration between successive syllable onsets) was taken as a measure of tempo. Fundamental frequency F_0 was expressed in MIDI nomenclature (Musical Instrument Digital Interface) and pitch range in semitones (1 semitone is 1/12 octave i.e. the distance from one MIDI tone to the next) to enable comparison between individuals. Mean Absolute Slope (semitones/s), which was taken as a measure of pitch variability, was computed in PRAAT 'minus octaves'. Differences of means were tested using a two-sample (two-tailed) T-test implemented in PAST (Hammer, Harper, & Ryan, 2001).

(A) "We see one another in the morning, and in the afternoon we drink a cup of tea. A few evenings a week we eat together, but sometimes not. I like to have other guests for dinner, etc..."

(B) ♩. = 100

Hoe be - staat 't - dat ik hou van een le - lij - ke vrouw? etc.

Fig. 1. Speech tasks. Excerpts from the transcriptions of recordings made of one Parkinson patient during the performance of: A. A spontaneous oral autobiographic narrative (translation from the Dutch, edited to prevent recognition); B. The rhythmic recitation of the lyrics of a familiar song. Music/lyrics: Jaap Fischer (translation: 'How can it be that I love an ugly woman?'). The metronome mark indicates the approximate tempo in which the second task was performed.

Fig. 2. Music tasks. Excerpts from transcriptions of recordings made of one (female) Parkinson patient during the performance of (A) the vocal rendition of a familiar song or theme; (B) the vocal improvisation of a melodic continuation to an antecedent phrase sung by the researcher. Clefs, key signatures, and metronome marks indicate the approximate pitch and tempo of the performance. Complete transcriptions can be found in Supporting Material: Transcriptions of Recordings.

Prior to the pitch analysis of patients' singing, fundamental frequency F_0 was extracted from the audio file, creating a digital pitch file with a resolution of 100 frequencies per second from which mean pitch was computed as well as pitch range and MAS (mean absolute slope in semitones/s). Music, unlike speech, is based on discrete scale tones. The distribution of scale tones is a function of tonal relationships (Krumhansl, 1990). On the basis of the actual pitch contour, a pitch density plot (Bíró & van Kranenburg, 2014) was created for each recording (for an example, see Fig. 3) from which the scale could be inferred. Each local peak corresponds to a scale tone. The highest peak is the most frequently occurring scale tone. In the present study, it was used as a measure of scale tone distribution.

The melodic interval was defined as the absolute distance in semitones between two successive tones of a melody. As pitch varies slightly in the course of a tone, particularly at the onset, determination of the pitch interval between two tones was based on the median pitch between onsets. The Inter-onset Interval (IOI: mean duration between successive onsets) was taken as a measure of tempo. Melodic interval variability was characterized not only by the coefficient of variation of the mean absolute melodic interval, but also by the nPVI (normalized Pairwise Index of Variability) of the melodic interval. The nPVI was originally developed as a measurement of rhythmic differences in "stressed-timed" and "syllabic-timed" languages (Ling, Grabe, & Nolan, 2000), measuring the degree of durational contrast between successive elements in a

sequence. While it has successfully been applied to the measurement of rhythmic variability in speech and music (Patel, Iversen, & Rosenberg, 2006), it was used here in a novel application to probe the degree of melodic interval (pitch distance) variability exhibited by successive tones within a melodic sequence.

3. Results

3.1. Aural assessment of dysprosody

Neurologically skilled assessors (five senior neurologists and five residents in neurology) listened to short (20–30 s) anonymized recordings of the speech of patients and healthy controls presented in two randomized aural assessment protocols designed to discriminate Parkinson patients from healthy controls on the basis of aural perception of dysprosody. On the basis of the scores given by all assessors, mean aural assessment scores were computed for each participant, one for each assessment protocol.

3.1.1. Serial assessment of dysprosody

On the basis of the serial assessment scores, eight out of fifteen Parkinson patients were identified as 'probably or definitely' Parkinson patient i.e. a mean score higher than or equal to 3.5 (mean: 4.01 ± 0.12), while two were misidentified as 'probably healthy' i.e. a mean score equal to or between 1.5 and 2.5 (mean: 1.9 ± 0.1). Of the fifteen healthy controls, eight were identified as 'probably or definitely' healthy i.e. a mean score lower than 2.5 (mean: 1.8 ± 0.12) and one was misidentified as 'probably patient' i.e. a mean score equal to or between 3.5 and 4.5 (mean: 3.67) (Table 2A). There was no significant ($p < 0.05$) difference of means between patients scored by senior neurologists and residents in neurology. Six of the eight patients identified by senior neurologists as 'definitely or probably Parkinson' were also identified by the residents. Seven of the ten controls identified by senior neurologists were also identified by residents.

3.1.2. Forced-choice assessment of dysprosody

In the forced-choice assessment, patients were identified correctly, on average, by 82% of the assessors (Table 2B), significantly higher than chance ($p < 0.001$). Five Parkinson patients were unanimously distinguished from their matched control by 100% of the assessors. Twelve of the fifteen patients were identified by at least 70% (interquartile range) of the assessors. Two Parkinson patients were distinguished from their matched control by only 40% of the assessors. Correlation between the results of the serial and force-choice assessments was high (Pearson's ρ: 0.73, p: 0.002). As can be seen in Fig. 4, the same two patients who were misidentified in the forced-choice protocol were also misidentified in the serial-order protocol (patients 9 and 13).
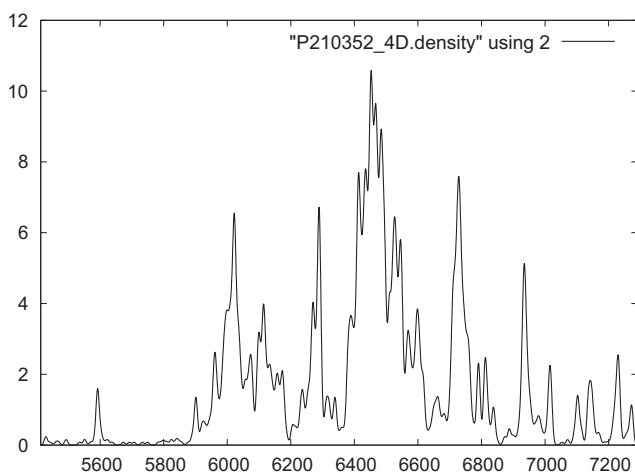

Fig. 3. Pitch density plot. Pitch density plot made of the recording of an improvised melodic continuation sung by one female Parkinson patient. The X-axis represents pitch in MIDI nomenclature (multiplied by 100). The Y-axis represents the frequency of occurrence of a given pitch. The highest peak i.e. the most frequently sung scale tone in this recording is slightly lower than MIDI 65 which corresponds to the piano key F4 (European notation: f¹).

Table 2
Identification of patients and controls on the basis of aural assessment.

A. Serial-order assessment									
Subjects	Definitely healthy		Probably healthy		Maybe parkinson		Probably parkinson		Definitely parkinson
Patients	0		2		5		7		1
Controls	1		7		6		1		0

B. Forced choice assessment														
Patient	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Identified by (%)	100	78	90	67	78	100	90	70	40	80	100	90	40	100	100

A. Serial-order assessment: number of subjects assigned to each of the five categories by neurologically skilled assessors on the basis of aural perception of dysprosody.
B. Forced-choice assessment: percentage of assessors that was able to distinguish the Parkinson patient from a healthy control, matched for age and gender, on the basis of aural perception of dysprosody.
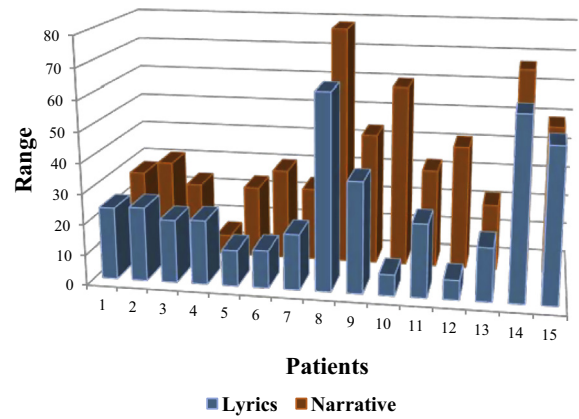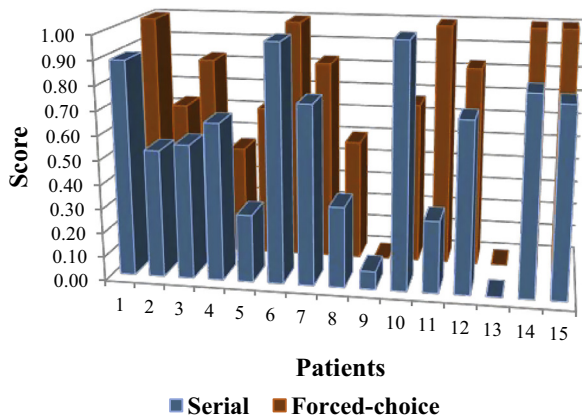

Fig. 4. Aural discrimination assessment scores. Normalized serial (blue) and forced-choice (red) aural assessment scores, per patient. Y-axis: normalized assessment scores; X-axis: patients. Patient numbers correspond with the numbers in Table 1.

Fig. 5. Pitch range: autobiographical narratives vs. rhythmic recitation of lyrics. Pitch range of all fifteen patients in semitones: spontaneous oral autobiographical narratives (red) and rhythmic recitation of song lyrics (blue). Y-axis: pitch range; X-axis: patients. Patient numbers correspond with the numbers in Table 1.

3.2. Quantitative speech analysis

Contrasting autobiographical narratives (of all participants) with the rhythmic recitation of the lyrics of familiar songs revealed no task-related differences in mean pitch or pitch variability (MAS minus octaves) and only a tendency towards a more limited pitch range during rhythmic lyric recitation. Mean IOI (Inter-onset Interval) was significantly longer during the rhythmic recitation of lyrics (Table 3A).

Contrasting tasks per group, however, revealed significantly lower pitch variability (MAS minus octaves) for patients during the rhythmic recitation of lyrics (Table 3B). Comparison of pitch range for the two tasks, per patient, indicated that for all but two of the patients (patients 4 and 15), pitch range tended to be more restricted during lyric recitation than during the autobiographical narrative (Fig. 5).

Table 3
Autobiographical narrative contrasted with the rhythmic recitation of lyrics.

A. Task contrast	Autobiographical narrative		Rhythmic lyric recitation
Pitch (MIDI nomenclature)	50.0 (8)		50.8 (10)
Pitch range (semitones)	35.9 (46)		28.1 (54)
Pitch variability (semitones/s)	5.4 (43)		5.6 (24)
IOI (seconds)	0.28 (14)		0.37 (27)[**]

B. Group contrast	Autobiographical narrative		Rhythmic lyric recitation	
	Controls	Patients	Controls	Patients
Pitch (MIDI nomenclature)	50.3 (7)	49.6 (9)	52.2 (12)	49.4 (7)
Pitch range (semitones)	34.5 (39)	37.3 (52)	29.8 (41)	26.5 (68)
Pitch variability (semitones/s)	5.2 (56)	5.7 (17)	6.1 (20)	5.1 (25)[*]
IOI (seconds)	0.27 (11)	0.29 (16)	0.39 (27)	0.35 (25)

Pitch: mean fundamental frequency F_0 (MIDI nomenclature: A440 = 69). **Pitch range**: mean difference between highest and lowest pitch in semitones. **Pitch variability**: Mean Absolute Slope (minus octaves) in semitones/s. **IOI**: mean Inter-onset Interval in seconds. Coefficient of variation in parentheses. Significant differences of means assessed using the T-test:

  [*] $p < 0.05$.
  [**] $p < 0.001$.

Table 4
Familiar melodies contrasted with improvised continuations.

A. Task contrast	Familiar melodies	Improvised continuations
Pitch (MIDI nomenclature)	56.8 (9)	57.5 (9)
Pitch range (semitones)	15.8 (15)	15.9 (15)
Pitch variability (semitones/s)	6.1 (29)	7.2 (25)[*]
IOI (seconds)	0.53 (26)	0.40 (14)[**]
Density peak (MIDI nomenclature)	57.4 (9)	57.9 (9)
Melodic interval (semitones)	2.2 (19)	2.2 (19)
Melodic interval variability (nPVI)	92 (13)	87 (18)

B. Group contrast	Familiar melodies		Improvised continuations	
	Controls	Patients	Controls	Patients
Pitch (MIDI nomenclature)	57.4 (9)	56.1 (9)	57.9 (9)	57.1 (9)
Pitch range (semitones)	16.2 (13)	15.4 (17)	15.9 (14)	15.8 (16)
Pitch variability (semitones/s)	6.1(18)	6.0 (37)	7.4 (18)	7.0 (32)
IOI (seconds)	0.54 (27)	0.53 (26)	0.40 (16)	0.39 (11)
Density peak (MIDI nomenclature)	58.3 (9)	56.5 (8)	58.2 (9)	57.5 (9)
Melodic interval (semitones)	2.2 (15)	2.1 (23)	2.3 (15)	2.1 (22)
Melodic interval variability (nPVI)	88 (15)	96 (11)	81 (19)	92 (16)

Pitch: mean fundamental frequency F_0 (MIDI nomenclature). **Pitch range**: mean difference between highest and lowest pitch in semitones. **Pitch variability**: Mean Absolute Slope in semitones/s. **IOI**: mean Inter-onset Interval in seconds. **Density peak**: mean maximum pitch density peak in MIDI nomenclature. **Melodic interval**: mean absolute distance in semitones between successive tones of the melody. **Melodic interval variability**: normalized Pairwise Variability Index of the melodic interval. Coefficient of variation in parentheses. Significant differences of means assessed using the T-test:

[*] $p < 0.05$.
[**] $p < 0.001$.

3.3. Melodic analysis

Comparing the two melodic tasks (all participants) revealed that mean pitch and pitch range were similar for improvised continuations and familiar melodies while pitch variability (Mean Absolute Slope) was significantly higher for improvised continuations but mean IOI significantly shorter. Mean maximum density peak and melodic interval were similar for both tasks, while the normalized Pairwise Variability Index of melodic interval tended to be slightly lower for improvised continuations, however the difference was not statistically significant. (Table 4A).

No significant differences were found between patients and controls for mean pitch, pitch range, pitch variability, or IOI during either the singing of familiar melodies or the generation of improvised continuations to antecedent phrases. No group differences were found for mean maximum density peak or melodic interval, although patients exhibited a higher coefficient of variation for melodic interval during both familiar melodies and improvised continuations as well as a tendency towards a higher nPVI (normalized Pairwise Variability Index) of melodic interval, particularly in improvised continuations (Table 4B).

A significant gender difference was found for mean pitch and maximum pitch density peak, the male voice being lower-pitched (consistent with Childers & Wu, 1991), however no other singing parameter revealed significant gender differences. No significant differences were found between the singing of male patients and controls, or between female patients and controls.

3.4. Correlations

No correlations were found between Hoehn & Yahr scores or LEDD and the data of individual patients, either for speech or singing. Neither did we find any correlation between age or disease duration and the data of individual patients for either speech or singing. A significant correlation was found between forced-choice assessment scores and Inter-onset Interval in the autobiographical narrative (Pearson's ρ: 0.518, p: 0.048). Serial assessment scores correlated positively with IOI as well, however this correlation was not significant (Pearson's ρ: 0.449, p: 0.09).

4. Discussion

The singing of Parkinson patients was investigated in an ecologically valid setting to determine whether previously demonstrated impairments of expressive linguistic prosody would be paralleled by similar deficits in the musical domain. No significant differences were found between Parkinson patients and healthy controls, matched for age and gender, in melodic tasks, although the two groups could be reliably distinguished on the basis of aural perception of their speech. The notion that the patients participating in this study suffered from significant impairments of expressive linguistic prosody was supported by the above-chance ability of neurologically skilled listeners to discriminate their speech from that of healthy controls in two different assessment protocols and further by the significantly different (opposite) effect of the rhythmic recitation of song lyrics on pitch variability that was observed in the two populations.

4.1. Dysprosody

The fact that the same two patients were misidentified in both aural assessment protocols argues in favor of their validity as instruments for the assessment of dysprosody in Parkinson's disease. As six of the fifteen patients were being treated in the UMCG (University Medical Center Groningen), their voices could theoretically have been recognized by one or more of the assessors. Due to the large size of the patient population and the large number of consulting physicians at the UMCG, however, we consider the chance that a neurologist or resident would recognize the voice of an individual patient from a recording to be negligible. In any case, patient recognition was not reported and no significant correlation was observed between either serial or forced-choice assessment scores and internal/external origin of the patient.

Perceptual assessment of dysprosody correlated positively with Inter-onset Interval, suggesting that listener perception of dysprosody might be associated with slower speech rates. Previous research on speech rate in Parkinson patients is inconsistent (Skodda & Schlegel, 2008), however one study suggests that it

may be task-specific (Goberman & Elmer, 2005). Although no significant difference in mean Inter-onset Interval was found between patients and healthy controls in the autobiographical narrative (Table 3), pairwise comparison of individual patients with their matched controls revealed a tendency towards a slower speech rate in seven cases and a significantly slower speech rate in another three cases. Only two Parkinson patients (patients 9 and 13) exhibited significantly faster speech rates than their matched controls in the autobiographic narrative. These were the same two patients whom assessors failed to identify in either assessment protocol (Fig. 4), indicating that slower speech rate might be an important factor contributing to listeners' perception of dysprosody in spontaneous speech.

A tendency towards higher pitch variability during lyric recitation was expected as an effect of participants associating the lyrics with the melody, but this difference was not significant. Comparing tasks per group, however, revealed an increase of pitch variability in the healthy control group during lyric recitation, but a decrease in the patient group, resulting in significantly lower pitch variability for patients in comparison with controls. The tendency towards a more limited pitch range, coupled with the significantly lower pitch variability patients exhibited during rhythmic lyric recitation, suggests that this task could be an even more potent tool for the aural discrimination of expressive prosodic impairment than the autobiographical narrative that was employed.

4.2. Singing

Contrasting groups during the singing of familiar melodies and the generation of improvised continuations to antecedent phrases revealed no hint of a difference between patients and healthy controls with respect to mean pitch, pitch range, pitch variability, or tempo (IOI). In addition, there was no significant difference between patients and healthy controls in scale tone distribution (mean maximum pitch density peak), size of the melodic interval, or normalized Pairwise Variability Index of the melodic interval in either task, suggesting that patients performed at least as well as controls in the musical domain.

The larger coefficient of variation for mean melodic interval and the tendency towards higher Pairwise Variability of melodic interval, particularly during improvised continuations, suggest that patients might even be outperforming controls. A supplementary post hoc group comparison of rhythmic variability during both improvised continuations and the vocal rendition of familiar melodies using the normalized Pairwise Variability Index of IOI revealed a slight tendency towards larger Pairwise Variability of IOI in patients' singing of familiar melodies, when contrasted with controls, but absolutely no difference between patients and controls during the generation of improvised melodic continuations.

In the between-group comparison of improvised melodic continuations to an antecedent phrase, mean maximum pitch density peak differed less than a semitone. Previous studies of pitch distribution, using the probe-tone paradigm, have demonstrated that, when the music style is familiar, individuals base their judgments on expectations arising from implicit knowledge of the tonal system (Eerola, 2004). The pitch distributions observed during the generation of improvised continuations to a melodic phrase suggest that vocal improvisation elicits similar musical expectations in both patients and controls and that, during motor control, these expectations are being used by both groups in an equally predictive manner (Adams, Shipp, & Friston, 2013).

No significant correlations were observed between age, disease severity (H & Y scores), medication (LEDD), or duration (number of years since diagnosis) and the observed mean F_0, F_0 range, MAS (mean absolute slope), IOI (Inter-onset Interval), or nPVI (normalized Pairwise Variability Index) of IOI in either speech or singing.

The failure to find a significant correlation between disease severity and acoustic assessment of linguistic dysprosody has been reported rather frequently (Gamboa et al., 1997; Metter & Hanson, 1986; Midi et al., 2008; Sapir, 2014; Tanaka, Nishio, & Niimi, 2011; Zwirner, Murry, & Woodson, 1991). In a longitudinal study of dysprosody, no correlation between the progression of prosodic impairment over time and either disease duration or UPDRS motor score was observed, suggesting that prosodic deterioration is independent from global motor function (Skodda et al., 2009). A similar dissociation has also been observed between disease duration and severity (UPDRS) and the recognition of emotion in music (van Tricht et al., 2010). The results of the present study support a dissociation between disease severity and musical expressivity as well.

5. Conclusions

The results of the present study support the hypothesis that, in PD, impairments of expressive linguistic prosody do not have a clear parallel in the musical domain. While Parkinson patients frequently end active participation in musical activities such as choirs due to poor health and loss of mobility, their singing does not seem to suffer from the 'prosodic' impairments they experience while speaking. It seems possible that musical behavior circumvents the malfunctioning basal ganglia-thalamocortical 'loops' (Alexander, DeLong, & Strick, 1986) and that the facilitating effect of music on locomotion, both during external cueing (Ford, Malone, Nyikos, Yelisetty, & Bickel, 2010) and mental singing (Satoh & Kuzuhara, 2008), holds true for expressive vocal behavior as well.

Both anatomically and functionally, the dissociation between prosody in speech and song in PD has very little to do with the dissociation of speech and song described in expressive aphasia (Yamadori, Osumi, Masuhara, & Okubo, 1977). Nevertheless, the idea of using music to improve the prosody of Parkinson patients (Ferriero et al., 2013) is worth considering. Just as infant-directed speech (Fernald & Simon, 1984) and even reading to children (Shute & Wheldall, 2001) can temporarily heighten prosodic variability in healthy individuals, it is quite possible that the speech of Parkinson patients might be susceptible to prosodic improvement based on the therapeutic use of singing, particularly of intermediate forms of speech and song such as infant-directed speech, *parlando*, *sprechstimme*, or rap. The fact that improvement of gait due to the aural perception of music has been shown to persist after a period of weeks (Benoit et al., 2014) suggests that possible prosodic improvement due to singing might do the same.

Acknowledgments

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.bandl.2016.08.008.

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