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Rhythmic Characteristics of Parkinsonian Speech: A Study on Mandarin and Polish

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Abstract

Previous studies on Italian speech showed that the percentage of vocalic portion in the utterance (%V) and the duration of the interval between two consecutive vowel onset points (VtoV) were larger for parkinsonian (PD) than for healthy controls (HC). Especially, the values of %V were distinctly separated between PD and HC. The present study aimed to further test the finding on Mandarin and Polish. Twenty-five Mandarin speakers (13 PD and 12 HC matched on age) and thirty-one Polish speakers (18 PD and 13 HC matched on age) read aloud a passage of story. The recorded speeches were segmented into vocalic and consonantal intervals, and then %V and VtoV were calculated. For both languages, VtoV overlapped between HC and PD. For Polish, %V was distinctly higher in PD than in HC, while for Mandarin there was no significant difference. It suggests that %V could be used for automatic diagnosis of PD for Italian and Polish, but not for Mandarin. The effectiveness of the rhythmic metric appears to be language-dependent, varying with the rhythmic typology of the language.

Index Terms: Parkinson's Disease, speech rhythm, early diagnosis, Mandarin, Polish.

1. Introduction

Parkinson's Disease (PD) dysarthria affects all aspects of speech, including respiration, phonation, articulation, and prosody. Impaired articulation in PD patients contributes to speech that is characterized by breathy or hoarse voice, reduced loudness, narrow pitch variability, abnormal speech rate, hesitancy and disfluency [1-3]. Hypokinesia and rigidity of the vocal tract cause a reduction in the range of motion of the lips, the tongue and the jaw, leading to imprecise articulation and a reduced amplitude and duration of the speech gestures, which has been defined as 'undershooting' of articulation. Such imprecise articulation and articulatory 'undershoot' contribute to reducing the speech intelligibility of PD patients [4].

At the segmental level, the production of vowels is impaired even in mildly affected patients [5-7]. A reduction of vowel space area was found by [7]. At the suprasegmental level, PD patients' reduced muscle activity has an effect on pitch variability, speech fluency and speech rate. However, studies diverge as to which prosodic characteristics of speech can be related unequivocally to PD. A study involving a sentence-repetition task conducted on Italian PD patients and controls [8] found no significant difference in noise level or F0 variability; the study also found that PD patients have longer pauses between each sentence repetition and an overall lower percentage of articulated time during a whole repetition period than the controls. According to [9], PD patients may speak at a rate that can be considered either too fast or too slow compared to that of unimpaired speakers.

As regards the search for the parameters that can serve as an index for the progression of the disease, [10] found that American English PD patients and controls could be classified on the basis of a number of rhythmic metrics (i.e. ΔV, ΔC, %V, VarcoV, VarcoC, nPVI-v, rPVI-c, Articulation rate). In a later study [11] found that the analysis of speech envelope modulation spectra (EMS) also allows distinguishing dysarthric patients from healthy controls (HC). Recently, studies have tried to monitor the progression of PD symptoms through speech tests. Elaborating on the evidence that healthy subjects could hold steady phonation while subjects with vocal impairment could not [12], Tsanas et al. showed that PD symptom severity could be monitored by checking the subject's ability to sustain the phonation of /a/ for a relatively long period [13]. Tsanas et al.'s finding and algorithm have been used for the development of a device for extracting clinically useful information about PD through non-invasive self-administered tests of manual dexterity and speech [14]. The system is known as the At-Home Testing Device (AHTD). For speech, the test measured the decay of normal and loud intensity phonation of maximally sustained /a/ phonation, and intensity decays for descriptions of pictures with and without a motor distraction of finger tapping. The results showed that only in the speech task involving picture description without distraction there was a trend of loud intensity phonation decline over time. Instead, in the task of sustained /a/ phonation no statistically significant decline was found during the 6-month test.

2. Speech and aging

2.1. Age-related rhythmic variations and the similarity with PD patients

Many traits of the phonation of PD patients present similarities with the modifications in phonation due to aging. Aging is generally associated with a number of changes in the speech production mechanism, including the vocal tract [15]. These changes, occurring from early childhood to old age, take place in the respiratory, phonatory, and supralaryngeal systems, and alter the way human beings speak, to the point that listeners are able to judge speaker's age fairly accurately from speech alone [16-18]. Age-related variations in speech production have been extensively investigated. They include stiffening of the thorax, decreasing of lung capacity, and weakening of respiratory muscles. The larynx undergoes anatomic changes, including

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ossification and calcification of laryngeal cartilages and atrophy of the vocal folds [19]. The supralaryngeal system is also affected: diminished accuracy in the lower lip and jaw when performing rapid movements, decreased lip strength and atrophy of facial, mastication and pharyngeal muscles have all been attested in relation to aging [20-22].

The physical changes coming with aging cause complex variations in speech signals. Yet, their relation with the voice changes occurring with age is not always straightforward. Assessing speakers' voice variations in relation to age is made complex by the number of variables involved. Scholtz grouped them as follows [23]:

- Speaker-related factors (such as gender, age, race, weight, health, and language, dialect, emotional state, attitude);

- The factors related to speech material (duration and speech mood);

- Methodological factors (recording equipment and technique).

There are, however, several acoustic features that are uncontroversially associated with aging [24-27]. One of these is F0, which appears to change differently in males and females: after middle age, F0 rises substantially in men (about 35 Hz), but decreases in women (about 10-15 Hz). Amplitude stability also declines with age, at least in men. Tremor and hoarseness, instead, increase regardless of gender, because of a decrease in F0 stability. Other voice qualities generally linked with an aging voice include: increased jitter and shimmer, increased breathiness, altered vowel formant frequencies, increased duration of vowels and consonants, and lowered speech rate.

Variations in speech rhythm in terms of vocalic and consonantal portions are generally not investigated in relation to aging, even if it is known that the vowel percentage in an utterance (%V) is a reliable parameter for the identification of linguistic rhythm [28]. In fact, %V together with the standard deviation of consonantal portions (ΔC) has been shown to contribute significantly to the perception of what have traditionally been defined as rhythmic types (i.e., syllable-, stress- and mora-timing) [29].

Preliminary evidence of age-related rhythmic variations have emerged in a case study on Italian [30-31]. In that study the speaker-related variables, the speech material-related factors and the methodological variables were controlled. A particular corpus of read speech was collected. In 2007, a 79-year old Italian anchorman, Piero Angela, was asked to read a script that he had already read before in a 1968 TV news, acting as if he were hosting a real TV news broadcast. The recording was taken at RAI TV studios in Rome, in order to maintain the same communicative situation. Acoustic-phonetic analyses were conducted on both corpora, the one uttered in 1967 at the age of 40, the other in 2007 at the age of 79. The results have shown that the old speech, besides the variations that consistently appear in the literature to change with chronological age (wider pitch range, longer and more frequent silences, decreased articulation and speech rates), presented higher percentage of vocalic portion (51%) than the young speech (46%). These results were confirmed by a study aimed at characterizing the rhythmic differences in the speech of young adult vs. older Italian speakers at 4 expected articulation rates [32]. To the purpose, eight Italian native speakers, equally distributed between the genders (4M, 4F) and two age groups (4 young adult and 4 old) were involved in the research. The four young adults ranged in age from 20 to 25, the four old were aged between 75 and 80. The results showed that the older speakers' speech had significantly higher %V than that of youngers', with the former ranging from 49.4% to 53% (mean = 50.8%) and the latter from 44.1% to 47.4% (mean = 46.0%).

Furthermore, experimental studies conducted on songs and verses performed with the beats of metronome have demonstrated that Vowel Onset Point (VOP) plays as an "attractor" for the task of speech-metronome synchronization [33-36]. In other words, VOPs represent those audible signal discontinuities that would guide listeners in the perception of rhythm. From this point of view, the interval between two consecutive Vowel Onset Points, henceforth called VtoV [36], can be considered as the perceptual counterpart of the Articulation Rate: the smaller VtoV is, the closer the vowels are to each other, and the more accelerated the speech is perceived to be. From this point of view, the parameter %V represents, on the perceptual level, a sort of linking between two consecutive VOPs: the greater the vowel percentage, the greater the continuity of the speech signal perceived by the listener. Conversely a greater consonant interruption will determine the perception of a less continuous speech: this is what, in musical terms, goes under the name of *legato* and *staccato*.

In conclusion, to diagram an utterance on the basis of %V and VtoV is a very effective tool to fully represent its rhythmic characteristics. Once it has been shown that %V is related to advancing age, the question is: what happens if aging is associated with a neurodegenerative disorder? In order to answer this question, we made a longitudinal study on Karol Wojtyła's speech.

2.2. Pilot study

Seven public speeches of Pope John Paul II St. Karol Wojtyła, five in Italian (from 1982 to 2002) and two in Polish (1979 and 1999), produced before and after he was diagnosed with PD in 1991 at the age of 71 [37], have been spectro-acoustically analyzed. The rhythmic characteristics of the collected speeches were analyzed using Praat [38]. The acoustic signal was segmented into three different tiers: CV segments, consonantal and vocalic portions, and VtoV intervals. Respiratory and syntactic pauses were labeled as silent pauses (SP). Different kinds of disfluencies (e.g., laryngealizations, nasalizations, and vocalizations) were treated as filled pauses (FP). The duration of all segments was extracted using a Praat script. The following two parameters were calculated:

- %V: the durational percentage of vocalic intervals in the articulated utterance (excluding silent/filled pauses) [28];
- VtoV: the mean value of VtoV intervals (ms) [36].

The results of acoustic analysis are shown in Fig. 1. %V increases rapidly from the early stages of PD (47% in 1982; 49% in 1994, 51% in 1995). In 2000, when KW is 80, %V is 59%; in 2002, at the age of 82, it reaches 60%. These values are definitely abnormal if compared to those of the 80-year-old healthy native Italian subjects (51%) analyzed in [32]. Also, VtoV is affected by the progression of PD, shifting from 212 ms in 1994 to 270 ms in 2000. The analysis of Wojtyła's speech produced in Polish confirms the above data, and shows that there is a relation between the progression of the disease and the increase in %V, ranging from 47% in 1979 to 56% in 1999.

These data were confirmed by an experiment conducted on Italian parkinsonian and healthy speech [39]. In that study a corpus of read speech produced by 11 parkinsonian and 15 healthy subjects was collected. The PD subjects were males and females, aged between 49 and 75, diagnosed with a mild degree of severity of PD, but differing in the year of insurgence of the

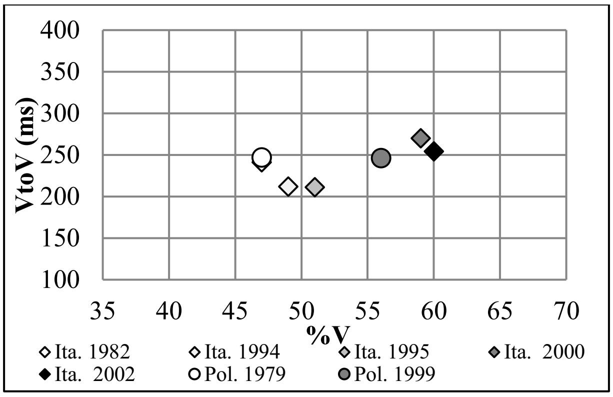

Figure 1: *Values of %V and VtoV of Karol Wojtyła speeches.*

disease, ranging from 3 to 20 years. Fifteen neurologically healthy controls had the same age range and regional area as the PD. All subjects were instructed to read aloud a text of about 500 syllables in their normal conversational voice. The results on Italian, as shown in Fig. 2, indicate that %V spans between 44% and 50% for HC (mean = 47%) and between 51% and 58% for PD (mean = 54.4%), with a percentage increase of 15.7%; VtoV spans between 153 and 212 ms for HC (mean = 176 ms), and between 144 and 244 ms for PD (mean = 186 ms), with a percentage increase of 5.7%. T-tests between HC and PD show a significant difference in %V ($p < 0.001$) and no significant difference in VtoV ($p = 0.328$).

These data show that Liss et al.'s finding on American English [10] also applies to Italian. The aim of this study is to test whether the rhythmic differences between parkinsonian and healthy speech in Italian also exist in Mandarin and Polish.

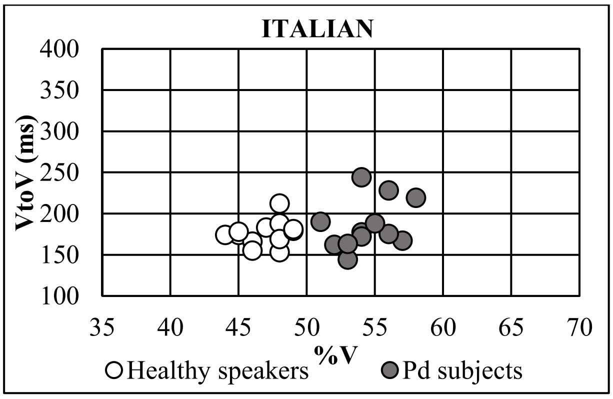

Figure 2: *Values of %V and VtoV for Italian PD and HC.*

3. Experiment on Mandarin

For Mandarin, thirteen people diagnosed with a mild degree of severity of PD (mean age 62.1, age range 52-72; 7M, 6F) and 12 healthy controls (mean age 62.0, age range 52-74; 7M, 5F) were asked to read aloud a short passage of about 185 syllables. The passage "The North Wind and the Sun" was chosen for its availability in many languages. Utterances were recorded in a quiet room. Using Praat, the speech was segmented into consecutive vocalic and consonantal portions, silent and filled pauses. Then, the values of %V and VtoV were calculated.

The results are shown in Fig. 3. The values of %V are between 54.4% and 63.1% for HC (mean = 59.2%), while they are between 53% and 64.3% for PD (mean = 58.2%). As regards

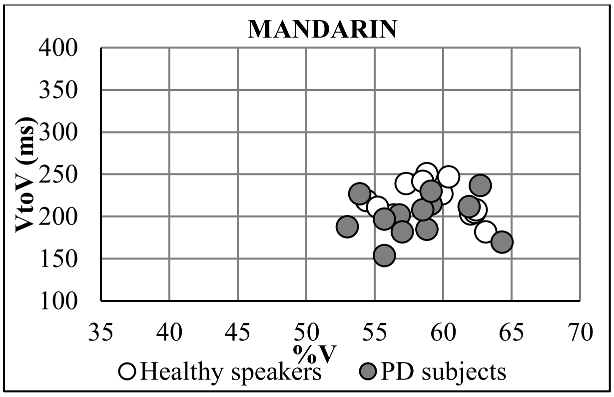

Figure 3: *Values of %V and VtoV for Mandarin PD and HC.*

VtoV, the values are between 182 and 251 ms for HC (mean = 220 ms), and between 154 and 237 ms for PD (mean = 201 ms), with a percentage *decrease* of 8.6%. T-tests between HC and PD show a significant difference ($p < 0.05$) in VtoV and no significant difference in %V ($p = 0.424$).

4. Experiment on Polish

For Polish, we conducted the same experiment as made for Mandarin. 18 people with Parkinson's Disease (mean age 67.7, age range 55-85, 7M+11F) and 13 healthy controls (mean age 65.7, age range 35-85, 7M+6F) were asked to read aloud the Polish version of "The North Wind and the Sun". Utterances were recorded in a quiet room. The acoustic analysis followed the same criteria for Mandarin. Results are shown in Fig. 4.

As can be seen, the values of %V are between 38% and 43% for HC (mean = 41%), while they are between 46% and 51% for PD (mean = 48%), with a percentage increase of 17.1%. As regards the VtoV, the values are between 158 and 279 ms for HC (mean = 221 ms), and between 188 and 346 ms for PD (mean = 266 ms), with a percentage increase of 20.4%. T-tests between HC and PD show significant differences both in %V ($p < 0.001$) and in VtoV ($p < 0.01$).

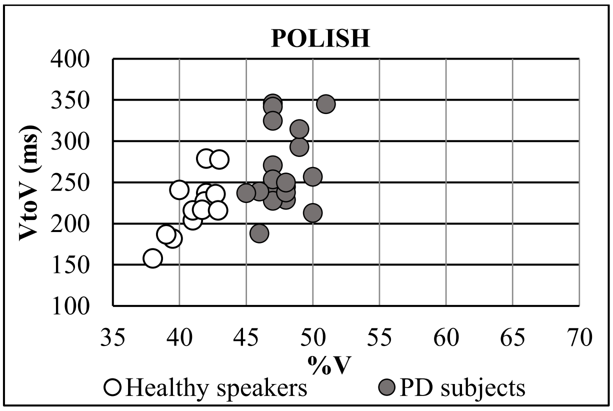

Figure 4: *Values of %V and VtoV for Polish PD and HC.*

5. Discussion and conclusions

Figure 5 shows the mean values of the two parameters plotted on the %V-VtoV chart for Italian, Mandarin and Polish speakers, including both HC and PD. Table 1 shows the percentage increase of %V and VtoV for the three languages, with the levels of significance indicated.

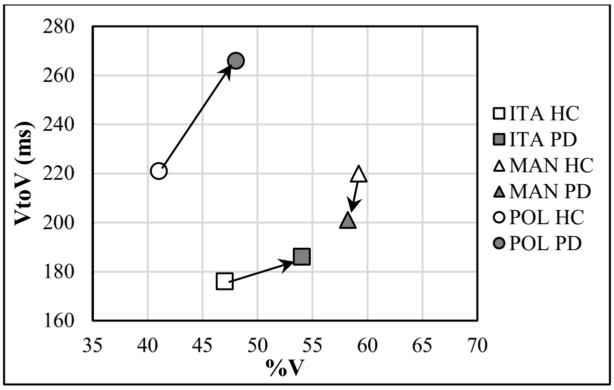

Figure 5: *Mean values of %V and VtoV of Italian, Mandarin and Polish for healthy and PD subjects.*

Table 1: *Percentage increase of %V and VtoV in Parkinsonian speech.*

	Italian	Mandarin	Polish
%V	+15.7%***	–1.7%	+17.1%***
VtoV	+5.7%	–8.6%*	+20.4%**

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

For VtoV, although different trends of PD compared to HC are found in the mean value among the three languages (i.e., slight increase in Italian, slight decrease in Mandarin, and big increase in Polish), the distributions of VtoV overlap heavily between HC and PD, as shown in Figs. 2–4. This coincides with the previous report that PD patients could speak at a too fast or too slow rate compared to healthy speakers [9]. So, VtoV or speech rate alone is not an effective indicator of PD's speech.

For %V, the three languages show different patterns: PD's speech is characterized by a conspicuous increase in %V compared to HC's for Italian and Polish, but little difference in %V is found for Mandarin. We can observe very clear separation in Figs. 2 and 4 but a serious overlap in Fig. 3.

Considering that an increase in %V distinguishes the speech of older from that of younger speakers in Italian [32], it is possible to hypothesize that PD causes an acceleration of aging. This also calls for future investigation on different degrees of severity (i.e., intermediate or advanced) of the disease. In fact, if in some languages %V shows significant difference between PD and HC in the initial stage of the disease, it will be useful for early diagnosis of PD.

On the one hand, the difference in %V in some languages can be explained by the motor impairments characterizing PD, such as the difficulty in initiating movements (acinesis), the slowing down of the velocity in execution of movements after they are initiated (bradicinesis), and muscular rigidity [41-43]. The motor impairments of PD patients have different effects on the production of vowels and consonants, for these sounds require different types of movements of the articulatory organs. While vowels are produced with a more static configuration (i.e., with no obstruction of the vocal tract), consonants require faster movements of the articulatory organs. Thus, because speech production requires a precise temporal coordination of articulatory movements, the motor impairments due to PD would make it difficult for the articulatory organs to pass rapidly from a static phase (for vowels) to a dynamic phase (for consonants). Vowel gestures, instead, can be sustained once they have been initiated. The prolonging of the static phase over the dynamic phase accounts for the greater percentage of vocalic portion in the PD's speech.

On the other hand, the little change in %V for Mandarin is quite possibly due to the rhythmic characteristics of the language. In fact, Mandarin already has a very high value of %V even in healthy speakers – higher than in Italian and Polish, which coincides with the results in previous studies on speech rhythm [28, 40]. Therefore, there might be very little room for further raising the vocalic percentage in Mandarin speech.

The rhythmic characteristics are closely related to syllable structure of the language. It should be noted that Mandarin does not have consonant clusters as in Italian and Polish. So, we may need to find more effective rhythmic metrics for Mandarin to distinguish PD's speech from that of healthy speakers.

A possible application of the results of the present study is a speech test based on automatic detection of %V, which could be used for detecting and monitoring the development of PD when one speaks a certain language. Unlike other speech tests which track PD progression based on the subject's ability to utter a vowel and maintain it at a fixed pitch but with varying loudness, this speech test would not pose any difficulty on the subject. Its execution would be based either on spontaneous speech or on a read short passage. However, it should be kept in mind that the effectiveness of this speech test appears to be language-dependent, varying with the rhythmic typology of the language. For Mandarin speakers, this test does not work well. Further investigation on Mandarin and other languages is needed to find out the language effects and the solution taking the language effects into consideration.

6. Acknowledgements

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7. References

[1] F. L. Darley, A. E. Aronson, & J. R. Brown, "Differential diagnostic patterns of dysarthria," *Journal of Speech and Hearing Research*, vol. 12, no. 2, pp. 246–269, 1969.

[2] F. L. Darley, A. E. Aronson, & J. R. Brown, *Motor Speech Disorders*. Philadelphia: W. B. Saunders Co., 1975.

[3] L. O. Ramig, C. Fox, & S. Sapir, "Speech treatment for Parkinson's Disease," *Expert Rev. Neurotherapeutics,* vol. 8, no. 2, pp. 299–311, 2008.

[4] K. G. Forrest, G. Weismer, & S. Turner, "Kinematic, acoustic, and perceptual analyses of connected speech produced by Parkinsonian and normal geriatric adults," *Journal of the Acoustical Society of America,* vol. 85, pp. 2608–2622, 1989.

[5] S. Sapir, L. Ramig, J. S. pielman, & C. Fox, "Formant Centralization Ratios (FCR): A proposal for a new acoustic measure of dysarthric speech," *Journal of Speech and Hearing Research*, vol. 53, pp. 114–125, 2010.

[6] S. Skodda, W. Visser, & U. Schlegel, "Vowel articulation in Parkinson's Disease," *Journal of Voice*, vol. 25, no. 4, pp. 467–72, 2011.

[7] S. Skodda, W. Gronheit, & U. Schlegel, "Impairment of vowel articulation as a possible marker of disease progression in Parkinson's Disease," *PLoS ONE*, vol. 7, no. 2, pp. 1–8, 2012.

[8] A. Bandini, F. Giovannelli, S. Orlandi, S. D. Barbagallo, M. Cincotta, P. Vanni, R. Chiaramonti, A. Borgheresi, G. Zaccara, & C. Manfredi, "Automatic identification of dysprosody in idiopathic Parkinson's disease," *Biomedical Signal Processing and Control*, vol. 17, pp. 47–54, 2015.

[9] P. G. Blanchet, & G. J. Snyder, "Speech rate deficit in individuals with Parkinson's disease: A reviews of the literature," *Journal of Medical Speech-Language Pathology*, vol. 17, pp. 1–7, 2009.

[10] J. M. Liss, L. White, S. L. Mattys, K. Lansford, A. J. Lotto, S. M. Spitzer, & J. N. Caviness, "Quantifying speech rhythm abnormalities in the dysarthrias," *Journal of Speech, Language, and Hearing Research*, vol. 52, pp. 1334–1352, 2009.
[11] J. M. Liss, S. LeGendre, & A. J. Lotto, "Discriminating dysarthria type from envelope modulation spectra," *Journal of Speech, Language, and Hearing Research*, vol. 53, pp. 1246–1255, 2010.
[12] I. R. Titze, *Principles of Voice Production*. Iowa City: National Center for Voice and Speech, 2000.
[13] A. Tsanas, M. A. Little, P. E. McSharry, & L. O. Ramig, "Nonlinear speech analysis algorithms mapped to a standard metric achieve clinically useful quantification of average Parkinson's disease symptom severity," *Journal of the Royal Society Interface*, vol. 8, no. 59, pp. 842–855, 2010.
[14] C. G. Goets, G. T. Stebbins, D. Wolff, W. DeLeeuw, H. Bronte-Stewart, R. Elble, M. Hallett, J. Nutt, L. Ramig, T. Sanger, A. D. Wu, P. H. Kraus, L. M. Blasucci, E. A. Shamim, K. D. Sethi, J. Spielman, K. Kubota, A. S. Grove, E. Dishman, & C. B. Taylor, "Testing objective measures of motor impairment in early Parkinson's Disease: Feasibility study of an at-home testing device," *Movement Disorders*, vol. 24, pp. 551–556, 2009.
[15] B. D. Eppley, & P. B. Mueller, "Chronological age judgments of elderly speakers: The effects of listeners' age," *Contemporary Issues in Communication Science and Disorders*, vol. 28, pp. 5–8, 2001.
[16] R. M. Krauss, R. Freyberg, & E. Morsella, "Inferring speakers' physical attributes from their voices," *Journal of Experimental Social Psychology*, vol. 38, pp. 618–625, 2002.
[17] P. H. Ptacek, & E. K. Sander, "Age recognition from voice," *Journal of Speech and Hearing Research*, vol. 9, pp. 273–277, 1966.
[18] T. Shipp, & H. Hollien, "Perception of the aging male voice," *Journal of Speech and Hearing Research*, vol. 12, pp. 703–710, 1969.
[19] S. N. Awan, "The aging female voice: acoustic and respiratory data," *Clinical Linguistics and Phonetics*, vol. 20, no. 2-3, pp. 171–180, 2006.
[20] S. E. Linville, "The aging voice," The American Speech Language-Hearing Association (ASHA) Leader, pp. 12–21, 2004.
[21] C. A. Tompkins, V. L. Scharp, & K. M. Meigh, "Communication disorders," in R. Schultz (ed.), *The Encyclopedia of Aging* (4th Edition), vol. I A-K, New York: Springer, 2006, pp. 234–242.
[22] A. Wohlert, & A. Smith, "Spatiotemporal stability of lip movement in older adult speaker," *Journal of Speech, Language and Hearing Research*, vol. 41, pp. 41–50, 1998.
[23] S. Scholtz, "Acoustic analysis of adult speaker age," in C. Müller (ed.), *Speaker Classification I*, LNAI 4343, New York: Springer, 2007, pp. 88–107.
[24] A. Dehqan, R. C. Scherer, G. Dashti, A. Ansari-Moghaddam, & S. Fanaie, "The effects of aging on acoustic parameters of voice," *Folia Phoniatrica et Logopaedica*, vol. 64, pp. 265–270, 2012.
[25] S. E. Linville, "Acoustic-perceptual studies of aging voice in women," *Journal of Voice*, vol. 1, pp. 44–48, 1987.
[26] L. A. Ramig, & R. L. Ringel, "Effects of physiological aging on selected acoustic characteristics of voice," *Journal of Speech and Hearing Research*, vol. 26, pp. 22–30, 1983.
[27] H. Traunmüller, & R. van Bezooijen, "The auditory perception of children's age and sex," in *Proceedings of ICSLP*, pp. 1171–1174, 1994.
[28] F. Ramus, M. Nespor, & J. Mehler, "Correlates of linguistic rhythm in the speech signal," *Cognition*, vol. 73, pp. 265–292, 1999.
[29] M. Nespor, M. Shukla, and J. Mehler, "Stress-timed vs. syllable timed languages," in M. van Oostendorp, C. J. Ewen, E. Hume & K. Rice (eds.), *The Blackwell Companion to Phonology*, Wiley-Blackwell, 2011.
[30] A. Giannini & M. Pettorino, "L'età della voce," in L. Romito, V. Galatà & R. Lio (eds.), *La Fonetica Sperimentale: Metodi e Applicazioni*, Torriana (RN): EDK, 2009, pp. 165–178.
[31] M. Pettorino, "Prosodia di ieri, prosodia di oggi. un esperimento di autotrapianto sul parlato televisivo," in A. Romano, M. Rivoira & I. Meandri (eds.), *Aspetti Prosodici e Testuali del Raccontare: Dalla Letteratura Orale al Parlato dei Media*, Alessandria: Dell'Orso, 2015, pp.3–15.
[32] M. Pettorino, and E. Pellegrino, "Age and rhythmic variations: A study on Italian", in *Proceedings of 15th INTERSPEECH*, Singapore, 2014, pp. 1234–1237.
[33] P. A. Barbosa, "Explaining Cross-Linguistic Rhythmic Variability via a Coupled-Oscillator Model of Rhythm Production", in *Proceedings of Speech Prosody 2002*, Aix-en-Provence, France, 2002, pp. 163–166.
[34] P.A. Barbosa, P. Arantes, A. R. Meireles, & J. M. Vieira, "Abstractness in speech-metronome synchronisation: P-centres as cyclic attractors," in *Proceedings of INTERSPEECH*, Lisbon, Portugal, 2005, pp. 1441–1444.
[35] P. Bravi, A Sa Moda Campidanesa: Pratiche, Poetiche e Voci Degli Improvvisatori Nella Sardegna Meridionale, Nuoro: ISRE, 2010.
[36] M. Pettorino, M. Maffia, E. Pellegrino, M. Vitale, & A. De Meo, "VtoV: A perceptual cue for rhythm identification," in P. Mertens & A. C. Simon (eds.), *Proceedings of the Prosody-Discourse Interface Conference (IDP-2013)*, Leuven, Belgium, 2013, pp. 101–106.
[37] http://w2.vatican.va/content/vatican/it.html
[38] P. Boersma, "Praat: A system for doing phonetics by computer," *Glot International*, vol. 5, pp. 341-345, 2001.
[39] M. Pettorino, M.G. Busà, & E. Pellegrino, "Speech rhythm in Parkinson's Disease: A study on Italian," in *Proceedings of INTERSPEECH*, San Francisco, CA, 2016, pp. 1958–1961.
[40] P. Mok, "On the syllable-timing of Cantonese and Beijing Mandarin," *Chinese Journal of Phonetics*, vol. 2, pp. 148–154, 2009.
[41] A. Berardelli and A. Currà, "Fisiopatologia della bradicinesia nella malattia di Parkinson," *LIMPE*, 2000.
[42] I. Donaldson, C. D. Marsden, S. Schneider, & K. Bhatia, *Marsden's Book of Movement Disorders*. Oxford: Oxford University Press, 2012.
[43] H. Sagar, The New Parkinson's Disease Handbook: The Essential Guide for Sufferers and Carers, London: Random House, 2002.