# CORRELATION ANALYSIS OF FREEZING OF GAIT AND SPEECH DISORDERS IN PARKINSON'S DISEASE

**Zoltán Galáž**
Doctoral Degree Programme (3), FEEC BUT
E-mail: z.galaz@phd.feec.vutbr.cz

Supervised by: Jiří Mekyska
E-mail: mekyska@feec.vutbr.cz

**Abstract**: This paper deals with the analysis of a relationship between freezing of gait (FOG) and hypokinetic dysarthria (HD) in Parkinson's disease (PD). Experimental dataset consisted of 74 PD patients. We used freezing of gait questionnaire (FOG-Q) to characterize FOG in PD. The speech features that quantifies phonation, articulation and prosody was computed from the reading task composed of interrogative, imperative and indicative sentences. Using Spearman's and Pearson's correlation coefficients, we showed that reduced mobility of the articulatory organs in HD is significantly correlated with FOG in PD.

**Keywords**: Parkinson's disease, hypokinetic dysarthria, freezing of gait, correlation analysis

## 1 INTRODUCTION

Parkinson's disease (PD) is a frequent neurodegenerative disorder [1]. It is characterized by the substantial reduction of dopaminergic neurons especially in *substancia nigra pars compacta* [2] but also in other regions of the brain [3]. PD affects approximately 1.5 % of people aged over 65 years [4]. It is associated with a variety of motor and non-motor symptoms [2] including speech disorders [5] and freezing of gait [6].

Speech disorders in PD are referred to as hypokinetic dysarthria (HD) [5]. HD is manifested in the area of phonation, articulation, prosody, speech fluency and faciokinesis [7, 8]. Increased acoustic noise, reduced voice intensity, harsh breathy voice quality, increased voice nasality, reduced variability of pitch and loudness combined with speech rate abnormalities, imprecise consonant articulation, unintentional introduction of pauses, rapid repetition of words or syllables, sudden deceleration/acceleration in speech has been observed in HD.

Freezing of gait (FOG) in PD is characterized by the inability to initiate or continue normal gait [6, 9]. Although, FOG is common in PD [10] affecting daily functioning and quality of life of the patients, the exact pathophysiological mechanism underlying FOG in PD is still not fully understood [11]. To assess FOG in PD, clinicians use a specialized six-item Likert-scale (5-point scale where a score of 0 indicates absence of the symptom, while a score of 4 indicates the most severe stage) questionnaire: Freezing Of Gait questionnaire (FOG-Q) [12].

The aim of this work is to investigate the relationship between HD and FOG in PD. For this purpose, wide range of speech features quantifying HD are computed. Correlation analysis between the speech features and FOG-Q is employed. The rest of this paper is organized as follows. Section 2 presents the dataset and the methodology. Experimental results are presented in section 3, and section 4 provides discussion and some conclusions.

**Table 1:** Freezing Of Gait Questionnaire template [12]

| points | description |
|---|---|
| | Q1: *During your worst state – do you walk:* |
| 0 | Normally |
| 1 | Almost normally – somewhat slow |
| 2 | Slow but fully independent |
| 3 | Need assistance or walking aid |
| 4 | Unable to walk |
| | Q2: *Are your gait difficulties affecting your daily activities and independence?* |
| 0 | Not at all |
| 1 | Mildly |
| 2 | Moderately |
| 3 | Severely |
| 4 | Unable to walk |
| | Q3: *Do you feel that your feet get glued to the floor while walking, making a turn or when trying to initiate walking?* |
| 0 | Never |
| 1 | Very rarely – about once a month |
| 2 | Rarely – about once a week |
| 3 | Often – about once a day |
| 4 | Always – whenever walking |
| | Q4: *How long is your longest freezing episode?* |
| 0 | Never happened |
| 1 | 1 – 2 s |
| 2 | 3 – 10 s |
| 3 | 11 – 30 s |
| 4 | Unable to walk for more than 30 s |
| | Q5: *How long is your typical start hesitation episode (freezing when initiating the first step)?* |
| 0 | None |
| 1 | Takes longer than 1 s to start walking |
| 2 | Takes longer than 3 s to start walking |
| 3 | Takes longer than 10 s to start walking |
| 4 | Takes longer than 30 s to start walking |
| | Q6: *How long is your typical turning hesitation episode (freezing when turning)?* |
| 0 | None |
| 1 | Resume turning in 1 – 2 s |
| 2 | Resume turning in 3 – 10 s |
| 3 | Resume turning in 11 – 30 s |
| 4 | Unable to resume turning for more than 30 s |

## 2 MATERIALS AND METHODS

We examined 74 Czech native speakers with idiopathic PD (mean ± std): age = 66.95 ± 8.68, disease duration = 7.86 ± 4.84 years, FOG-Q = 6.88 ± 5.78. All patients were enrolled at the First Department of Neurology, St. Anne's University Hospital in Brno, Czech Republic. The patients were examined approximately 1 hour after their regular dopaminergic medication. The assessment of FOG-Q [12] was conducted by a movement disorders specialist. Template of the questionnaire can be seen in Table 1. The speech data acquisition consisted of the following reading tasks (interrogative, imperative and indicative sentences): in Czech – *Prostřete k obědu? Prostřete k obědu! Prostřete k obědu.*, English translation – *Can you set the table? Set the table! Set the table*. All patients signed an informed consent form that has been approved by the local ethics committee.

We extracted the following speech features [8, 13]: harmonics-to-noise ratio (HNR), noise-to-harmonics ratio (NHR), glottal-to-noise excitation ratio (GNE), first three formant frequencies (F1 – F3), first three formant bandwidths (B1 – B3), formant periodicity correlation (FPC), fundamental frequency (F0), short-time energy (STE) Teager energy operator (TEO), fraction of locally unvoiced frames (FLUF), voice turbolence index (VTI), soft phonation index (SPI), number of voice breaks (NVB), degree of voice breaks (DVB), total speech time (TST), net speech time (NST), total pause time (TPT), total speech rate (TSR), net speech rate (NSR), total pause time (pauses longer than 50 ms) (TPT 50), articulation rate (AR) and speech index of rhytmicity (SPIR). F0 contour was extracted using Praat acoustic analysis software [14]. Speech features were computed using Neurological Disorder Analysis Tool (NDAT) [15, 8] developed at the Brno University of Technology.

Next, we computed a set of statistical functionals to describe statistical properties of the features: range (R), interdecile range (IDR), relative interdecile range (rIDR), interpercentile range (IPR), relative interpercentile range (rIPR), mean, median, std, coefficient of variation (CV), $5^{th}$ percentile ($5^{th}$ p), $95^{th}$ percentile ($95^{th}$ p) and slope of linear regression (sLR) [8, 13].

To quantify a relationship between speech features and FOG-Q, correlation analysis was employed. In this work, we analysed all sub-scores and total scores of FOG-Q, where individual questions (Qx) are summarized in parts (part 1, 2) and the total score (part $1 = Q1 + Q2$, part $2 = Q3 + Q4 + Q5 + Q6$ and total $=$ part $1 +$ part 2) [12]. We used Pearson's correlation coefficient ($r_p$) to determine the strength of a linear relationship between the speech features and FOG-Q. Spearman's correlation coefficient ($r_s$) was used to determine the strength of a monotonic relationship between the speech features and FOG-Q. The significance level of correlation of $\alpha = 0.05$ was selected.

## 3 RESULTS

The results of the correlation analysis are summarized in Table 2. The table shows the most statistically significant correlations between the speech features and the FOG-Q elements. As can be seen, quantification of speech articulation resulted into most significant correlations in all cases. Specifically, negative relationship between the range of articulatory organs' mobility and FOG-Q was found.

In HD, rigidity and limited muscular control of the larynx, articulatory organs, and other physiological support mechanisms for speech has already been reported [16]. Considering the connection between articulation and gait impairment in PD, we can hypothesize that monitoring the deterioration of articulatory organ's mobility can be used to indirectly monitor FOG.

To obtain additional visual impression about the relationship between the speech features and FOG-Q, see the correlation graphs in Figure 1. The figure shows the distribution of the values of FOG-Q total score depending on the severity of articulatory impairment present in the set of patients in the dataset.

Furthermore, in 7 elements of the total number of 9 elements, analysis of indicative sentence was found the most appropriate speech task indicating that no additional stress in speech is demanded to describe the connection between HD and FOG. This observation is particularly important for the speech tasks selection optimization. If relatively short indicative sentence showed promising potential of the methodology, addition of free speech should in theory provide more precise characterization of the relationship between HD and FOG in PD.

**Table 2:** Results of correlation analysis.

| FOG-Q part | speech task (sentence) | speech dimension | speech feature | $r_s$ | $p_s$ | $r_p$ | $p_p$ |
|---|---|---|---|---|---|---|---|
| Q1 | indicative | articulation | F1 ($95^{th}$ p) | -0.38 | 0.0008 | -0.42 | 0.0002 |
| Q2 | interrogative | articulation | F2 (rIPR) | -0.35 | 0.0022 | -0.30 | 0.0092 |
| Q3 | indicative | articulation | F1 (IPR) | -0.40 | 0.0004 | -0.38 | 0.0009 |
| Q4 | indicative | articulation | F1 (IPR) | -0.38 | 0.0007 | -0.35 | 0.0023 |
| Q5 | imperative | articulation | F1 ($95^{th}$ p) | -0.36 | 0.0014 | -0.31 | 0.0070 |
| Q6 | indicative | articulation | F1 (IPR) | -0.37 | 0.0013 | -0.35 | 0.0021 |
| part 1 | indicative | articulation | F1 ($95^{th}$ p) | -0.35 | 0.0023 | -0.40 | 0.0004 |
| part 2 | indicative | articulation | F1 (IPR) | -0.40 | 0.0036 | -0.39 | 0.0006 |
| total | indicative | articulation | F1 (IPR) | -0.41 | 0.0003 | -0.39 | 0.0006 |

[1] FOG-Q part – Freezing of gait questionnaire (FOG-Q) [12] part, (Qx) are summarized as follows: part $1 = Q1 + Q2$, part $2 = Q3 + Q4 + Q5 + Q6$ and total score $=$ part $1 +$ part 2; $r_s$ – Spearman's correlation coefficient; $r_p$ – Pearson's product-moment correlation coefficient; $p_s$ – significance level of correlation ($r_s$); $p_p$ – significance level of correlation ($r_p$), $\alpha = 0.05$.

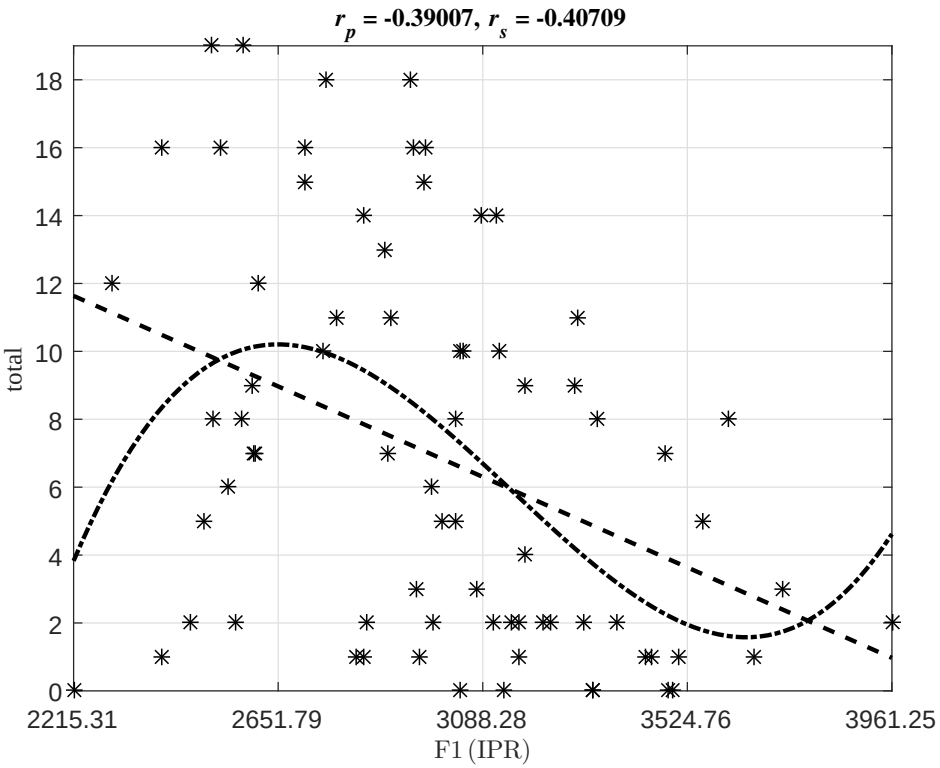


**Figure 1:** Correlation graph of the speech feature significantly correlated with the total score of Freezing of gait questionnaire (FOG-Q) [12]. The dashed line represents Pearson's correlation coefficient ($r_p$) ($1^{sd}$ order polynomial fit curve). The dot-dashed line represents Spearman's correlation coefficient ($r_s$) ($3^{sd}$ order polynomial fit curve).

## 4 CONCLUSION

In this work, we showed that imprecise articulation in HD is strongly related with FOG in PD. This observation emphasize the fact that acoustic analysis of HD can be used as a potential marker of gait impairment in PD. These results however need to be verified by subsequent research. Nevertheless, the examination of FOG using FOG-Q [12] requires patients' presence at the clinic, which can be a serious problem especially in the later stages of PD. In contrast, speech signals can be self recorded using a variety of smart devices. If suitable speech features are extracted frequently, the clinicians can be provided with further information about the clinical state of the patients. The data can be used to monitor and adjust the treatment when necessary to achieve the most efficient treatment.

In our future studies we will focus on the analysis of other clinical rating scales developed to assess various symptoms of PD such as depression, sleeping disorders, dementia, etc. in direction of objective, non-invasive, quick and inexpensive assessment of the disease using sophisticated speech processing algorithms, statistical analysis and machine learning techniques.

## ACKNOWLEDGEMENT

This work was supported by the grant of the Czech Ministry of Health NV16-30805A (Effects of non-invasive brain stimulation on hypokinetic dysarthria, micrographia, and brain plasticity in patients with Parkinson's disease).

## REFERENCES


[1] M. C. de Rijk, et al., Prevalence of Parkinson's disease in Europe: A collaborative study of population-based cohorts, Neurology 54 (2000) 21–23.

[2] O. Hornykiewicz, Biochemical aspects of parkinson's disease, Neurology 51 (1998) S2–S9.

[3] P. Brodal, The Central Nervous System: Structure and Function, Oxford University Press, 3 edition, 2003.

[4] M. C. de Rijk, et al., Prevalence of parkinsonism and Parkinson's disease in europe: the europarkinson collaborative study. european community concerted action on the epidemiology of Parkinson's disease, J. Neurol. Neurosurg. Psychiatry 1 (1997) 10–5.

[5] F. L. Darley, A. E. Aronson, J. R. Brown, Differential Diagnostic Patterns of Dysarthria, J. Speech. Hear. Res. 12 (1969) 246–269.

[6] N. Giladi, R. Kao, S. Fahn, Freezing phenomenon in patients with parkinsonian syndromes, Movement Disorders 12 (1997) 302–305.

[7] J. Mekyska, Z. Smekal, M. Kostalova, M. Mrackova, S. Skutilova, I. Rektorova, Motor aspects of speech impairment in Parkinson's disease and their assessment, Cesk. Slov. Neurol. N. 74 (2011) 662–668.

[8] J. Mekyska, E. Janousova, P. Gomez-Vilda, Z. Smekal, I. Rektorova, I. Eliasova, M. Kostalova, M. Mrackova, J. B. Alonso-Hernandez, M. Faundez-Zanuy, K. L. de Ipina, Robust and complex approach of pathological speech signal analysis, Neurocomputing 167 (2015) 94–111.

[9] N. Giladi, H. Shabtai, E. Rozenberg, E. Shabtai, Gait festination in Parkinson's disease, Parkinsonism Relat. Disord. 7 (2001) 35–138.

[10] N. Giladi, T. A. Treves, E. S. Simon, H. Shabtai, Y. Orlov, B. Kandinov, D. Paleacu, A. D. Korczyn, Freezing of gait in patients with advanced Parkinson's disease, Journal of Neural Transmission 108 (2001) 53–61. J

[11] J. Shine, S. Naismith, S. Lewis, The pathophysiological mechanisms underlying freezing of gait in Parkinson's disease, Journal of Clinical Neuroscience 18 (2011) 1154–1157.

[12] N. Giladi, H. Shabtai, E. S. Simon, S. Biran, J. Tal, S. D. Korczyn, Construction of freezing of gait questionnaire for patients with parkinsonism, Parkinsonism Relat. Disord. 6 (2000) 165–170.

[13] Z. Galaz, J. Mekyska, Z. Mzourek, Z. Smekal, I. Rektorova, I. Eliasova, M. Kostalova, M. Mrackova, D. Berankova, Prosodic analysis of neutral, stress-modified and rhymed speech in patients with parkinson's disease, Comput. Methods. Programs. Biomed. 127 (2016) 301–317.

[14] P. Boersma, D. Weenink, Praat: Doing Phonetics by Computer (Version 5.3.10), 2012.

[15] I. Eliasova, J. Mekyska, M. Kostalova, R. Marecek, Z. Smekal, I. Rektorova, Acoustic evaluation of short-term effects of repetitive transcranial magnetic stimulation on motor aspects of speech in Parkinson's disease, J. Neural Transm. 120 (2013) 597–605.

[16] J. Kegl, H. Cohen, H. Poizner, Articulatory Consequences of Parkinson's Disease: Perspectives from Two Modalities, Brain Cogn. 40 (1999) 355–86.