

Short communication

Influence of hypokinetic dysarthria severity level on the long-term outcome of repetitive transcranial magnetic stimulation therapy

Krystof Novotny^{a,b}, Lubos Brabenec^b, Jiri Mekyska^{a,b}, Andrea Moravska^{b,c}, Pedro Gómez-Vilda^{d,e}, Andrés Gómez-Rodellar^f, Irena Rektorova^{b,g,*}

^a Department of Telecommunications, Brno University of Technology, Brno, Czech Republic

^b Applied Neuroscience Research Group, Central European Institute of Technology – CEITEC, Masaryk University, Brno, Czech Republic

^c Faculty of Medicine, Masaryk University, Brno, Czech Republic

^d NeuSpeLab, CTB, Universidad Politécnica de Madrid, Madrid, Spain

^e Escuela Técnica Superior de Ingeniería Informática, Universidad Rey Juan Carlos, Madrid, Spain

^f St. Louis Missouri University, Madrid, Spain

^g First Department of Neurology, Faculty of Medicine and St. Anne's University Hospital, Masaryk University, Brno, Czech Republic



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ABSTRACT

Introduction: Hypokinetic dysarthria (HD) is a common and disabling symptom of Parkinson's disease (PD) for which established pharmacological and surgical treatments bring only limited, often short-term improvement in speech. The aim of this study was to investigate whether the long-term acoustic effects of repetitive transcranial magnetic stimulation (rTMS) over the right superior temporal gyrus (STG) depend on the baseline severity of HD. **Methods:** 26 PD patients were randomized to active STG-targeted rTMS ($n = 15$) or sham stimulation ($n = 11$) and followed across five recording sessions over 14 weeks, alongside one session of matched healthy controls. HD severity at baseline was quantified using 3F test subscores and used to stratify patients into milder (0) and more severe (1) subgroups. The STG 1 subgroup combined greater motor and speech impairment with shorter disease duration. Multiple acoustic features from sustained phonation and free monologue were extracted, normalized to controls, adjusted for sex, and analyzed using non-parametric statistics and descriptive visualisations. **Results:** Patients with more severe HD receiving active stimulation (STG 1) showed consistent, long-lasting improvements in phonation-related parameters, whereas milder HD (STG 0) and sham groups (SHAM 0, SHAM 1) exhibited only limited or transient changes. **Conclusion:** Given this observation, STG-targeted rTMS appears particularly beneficial for PD patients with more advanced HD, supporting auditory-motor network modulation as a therapeutic strategy and motivating larger, multi-centre trials to confirm these stratified effects and their clinical impact.

1. Introduction

Hypokinetic dysarthria (HD), a common speech disorder in Parkinson's disease (PD), is characterized by reduced pitch and loudness variability, imprecise articulation, harsh voice quality, and abnormal speech timing [1]. Impaired auditory feedback processing is central to HD pathophysiology and underlies behavioral interventions such as Lee Silverman Voice Treatment [2,3]. Neuroimaging studies demonstrate abnormal activation and connectivity of the right posterior superior temporal gyrus (STG) [4,5], a key region for auditory feedback processing [6]. Yet conventional therapies offer limited benefit:

dopaminergic medication improves only selected voice aspects [7], and deep brain stimulation, although effective for motor symptoms, can even worsen speech intelligibility [8], underscoring the need for alternative interventions.

Repetitive transcranial magnetic stimulation (rTMS) has emerged as a promising non-invasive approach to improve speech in PD [9]. In our previous study, multiple sessions of low-frequency rTMS over the right STG produced long-lasting improvements in HD, accompanied by increased activation and connectivity within the articulatory network [10]. These effects, documented by speech-language pathologists, were most pronounced in articulation, prosody, and intelligibility. Here, we

* Corresponding author. First Department of Neurology, Faculty of Medicine and St. Anne's University Hospital, Masaryk University, Pekarska 53, 656 91, Brno, Czech Republic.

E-mail address: irena.rektorova@fnusa.cz (I. Rektorova).

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extend this work using acoustic analyses of speech recordings and examine whether baseline HD severity modulates the long-term efficacy of STG-targeted rTMS, aiming to identify patient subgroups most likely to benefit from neuromodulation.

2. Methodology

2.1. Database

The cohort comprised 26 PD patients (20 M / 6 F; age 69.11 ± 8.03 y) divided into two groups. The active stimulation group (STG; 15 participants, age 68.67 ± 8.13) received low-frequency rTMS over the right STG as described in Ref. [10], delivered in ten sessions over two weeks at the Central European Institute of Technology, Masaryk University. The control group (SHAM; 11 participants, age 69.71 ± 8.26 y) underwent identical procedures with a device producing no magnetic field. Speech recordings were obtained at five sessions: pre-stimulus T0 and post-stimulus T1 (2 weeks), T2 (6 weeks), T3 (10 weeks), and T4 (14 weeks) after stimulation. Because not all participants attended all sessions, we analyzed two datasets: 26 patients (15 STG / 11 SHAM) who completed T0–T2, and a subset of 20 patients (11 STG / 9 SHAM) who completed all sessions. All patients were recorded in the ON medication state.

In addition, matched healthy controls (HC; 15 M / 6 F, age 68.73 ± 5.86 y) were selected from the set of participants presented in Ref. [11]. Group comparability was verified using a chi-square test for sex and a *t*-test for age, which found no significant differences between HC and PD groups. HC participants performed the same speech tasks as PD participants in a single session: the longest possible sustained phonation of the vowel [a:] and a free monologue of at least 90 s.

We confirm that we have read the Journal's guidelines on ethical publication and that this work complies with them. The studies were approved by the local Ethics Committee, and all participants provided written informed consent.

2.2. Acoustic feature extraction

Acoustic parameters were extracted from sustained phonation and free monologue tasks; a detailed list and descriptions are provided in the Supplementary material. To ensure uniformity and avoid transient phenomena, only the segment from 2 s to 4 s of sustained phonation was used for acoustic analysis (except for maximum phonation time, MPT), with features listed in Supplementary material A, Table 1. Free monologue features (Supplementary material A, Table 2) were computed in three variants: without pause removal, with pauses > 250 ms removed, and with pauses > 50 ms removed.

2.3. Data post-processing

All parameters were adjusted so that worsening of the symptom corresponded to increasing parameter values; parameters with the opposite trend were multiplied by -1 . Spearman's correlations with Benjamini–Hochberg correction in the HC cohort revealed no association between acoustic parameters and age but did show a correlation with sex. The effect of sex was therefore regressed out of all acoustic parameters by fitting linear regression lines in HC and using their slopes to correct both HC and PD data. For each parameter, the HC median ($P_{50, HC}$) and 95th percentile ($P_{95, HC}$) were then used to define the normative range. PD values were normalized using the following formula, yielding (D_{PD}) as the relative distance of the investigated value (V_{PD}) for patient k at session T from the HC norm:

$$D_{PD,k,T} = \frac{V_{PD,k,T} - P_{50,HC}}{P_{95,HC} - P_{50,HC}} \quad (1)$$

2.4. Stratification

To test whether rTMS effects depend on HD severity, the 26 PD patients were stratified using three subscores of the 3F test at T0. The 3F test (Faciokinesis–Phonorespiration–Phonetics) is a structured diagnostic tool developed to assess dysarthria severity and profile in Czech-speaking individuals. It evaluates motor aspects of speech across 45 items in three subdomains, yielding a Dysarthria Index (maximum 90 points). The test provides quantitative severity grading and qualitative characterization of motor speech deficits, with normative values established in healthy adults [12].

The silhouette method supported the presence of two distinct clusters, which were obtained using Ward's hierarchical clustering. Mann–Whitney *U* tests confirmed significant differences in all three subscores between the two PD clusters and between each cluster and HC (see Fig. 1). The cluster with milder HD manifestations (8 STG and 7 SHAM in the full 26-patient set; 7 STG and 5 SHAM in the 20-patient subset) was labeled 0, and the cluster with more severe HD (7 STG and 4 SHAM in the full set; 4 STG and 4 SHAM in the subset) was labeled 1.

Mann–Whitney *U* tests showed no between-group differences in age ($p = 0.12$, confirming that the influence of age did not need to be subtracted in the regression), cognitive function (MMSE, $p = 0.27$), or levodopa equivalent dose ($p = 0.36$, hence its effect also did not need to be subtracted in the covariate cleaning). Disease duration differed at a borderline level ($p = 0.05$), with group 1 having a shorter duration, and motor scores (UPDRS III) were markedly worse in group 1 ($p < 0.01$), indicating more severe motor symptoms of parkinsonism.

2.5. Evaluation

Acoustic parameters were compared across four cohorts defined by HD severity and stimulation type: STG 0, STG 1, SHAM 0, and SHAM 1. In addition to statistical tests assessing clinical differences between cohorts, two visualization approaches were used to evaluate treatment efficacy from acoustic parameters.

The first approach used stacked grouped bar graphs to quantify therapy success. For each parameter, one plot contained four clusters corresponding to the four cohorts (STG 0, STG 1, SHAM 0, SHAM 1). Each cluster comprised four bars showing the percentages of participants who improved or deteriorated relative to T0. The n -th bar represented the percentage of participants who improved in at least n post-stimulus sessions, with the fourth bar indicating improvement in all post-stimulus sessions.

The second approach mapped treatment effects over time using descriptive statistics. For each parameter, line plots showed the median and interquartile range for each cohort across sessions. To enhance visualization of change, time series for each group were vertically shifted so that T0 was aligned to 0.

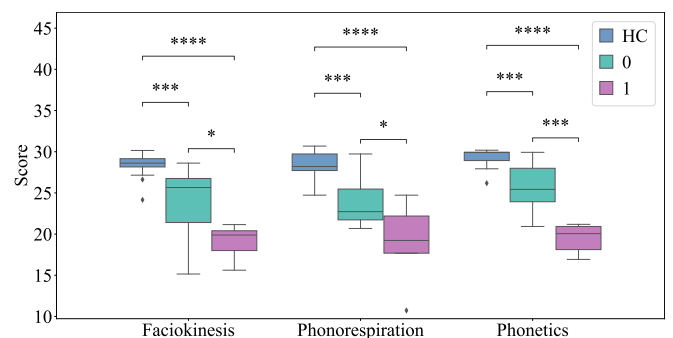


Fig. 1. Comparison of 3F test subscores for stratified PD groups and HC using boxplots and Mann–Whitney *U* test (* for $p < 0.05$, ** for $p < 0.01$, *** for $p < 0.001$).

3. Results

In the STG 1 group, several parameters showed consistent improvement after stimulation. In the stacked grouped bar graphs, this is reflected by a maximal reduction to just 75 % in the bar representing patients who improved relative to T0 in all post-stimulus sessions. For the evolution of the median over time, this improvement is observable, thanks to the normalization performed (polarization of the trend of worsening manifestation, relating values to HC, vertical shift to T0), by a strong decrease in value between T0 and T1. These patterns are most evident for shimmer (APQ), harmonics-to-noise ratio (HNR), maximum phonation time (MPT), and jitter (PPQ) derived from sustained phonation. The findings were concordant in both the subset of patients who completed all post-stimulus sessions and the extended set who completed only T0–T2. Fig. 2 illustrates these results for the full-session subset.

In the STG 0 group, the most favorable pattern was observed for the median pause duration (DurMED) parameter from the free monologue task: 57 % of participants improved in all post-stimulus sessions

compared with T0. The median of the parameter also decreased between T0 and T1 but subsequently returned to baseline values.

4. Discussion

Our results show that HD severity modulates the long-term speech effects of rTMS over the STG in PD. The subgroup with more severe dysarthria receiving real rTMS (STG 1) exhibited consistent, long-lasting improvements in phonation-related acoustic parameters. Across all post-stimulation sessions, measures of voice quality and stability, i.e. HNR and perturbation indices (PPQ, APQ), remained enhanced, reflecting clearer, more stable voice and improved phonatory control. A modest increase in MPT suggests improved respiratory support. In contrast, patients with milder dysarthria receiving real stimulation (STG 0) and those receiving sham stimulation (SHAM 0 and SHAM 1) did not sustain comparable gains.

The distinct responsiveness of the STG 1 subgroup likely reflects its clinical profile. These patients had more severe motor and speech deficits but shorter disease duration, suggesting relatively preserved cortical



Fig. 2. Stacked grouped bar graphs and median time evolutions for selected parameters comparing the four analyzed cohorts (STG 0, STG 1, SHAM 0, SHAM 1). Results for the set of patients who completed all 4 post-stimulus sessions according to the protocol.

structures and greater capacity to respond to rTMS. Consistent with this, additional analyses (Supplementary material C, Fig. 19) revealed higher cortical thickness in the stimulated area among STG 1 participants. More severe baseline impairment also permits larger observable gains, whereas milder cases may be limited by ceiling effects. Stimulation of the auditory feedback area likely strengthened auditory-motor integration in speech, particularly benefiting patients with initially poor phonation; previous work has shown that rTMS over the STG increases auditory-motor pathway connectivity in PD, supporting network-level mechanisms underlying the sustained speech improvements. Overall, these findings highlight the potential value of early rTMS intervention for PD patients with pronounced motor and speech deficits, who may benefit more than those with milder dysarthria.

4.1. Limitations

The main limitation of this study is the relatively small sample, which becomes even more restricted after stratification and incomplete follow-up, reducing statistical power and the robustness of subgroup comparisons. The single-centre, single-language cohort further limits generalisability to broader PD populations. In addition, the study was not powered to detect functional or quality-of-life outcomes.

5. Conclusion

This study demonstrates that the long-term acoustic effects of rTMS over the right STG in PD are strongly modulated by baseline HD severity. Patients with more severe HD showed consistent, sustained improvements in phonation-related parameters, while those with milder HD or sham stimulation exhibited only limited or transient change. These findings support STG-targeted rTMS as a promising neuromodulatory approach for speech deficits in PD and highlight the importance of patient stratification. They also justify larger, robustly powered, multi-centre, longitudinal trials with integrated neuroimaging, functionally oriented designs, and broader clinical and patient-reported outcome measures.

CRedit authorship contribution statement

Krystof Novotny: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Lubos Brabenec:** Data curation, Formal analysis, Investigation, Methodology, Supervision, Writing – review & editing. **Jiri Mekyska:** Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Writing – review & editing. **Andrea Moravska:** Investigation, Visualization. **Pedro Gómez-Vilda:** Supervision. **Andrés Gómez-Rodellar:** Supervision. **Irena Rektorova:** Data curation, Project administration, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.parkreldis.2026.108175>.

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