The effects of STN-DBS on motor speech: A longitudinal articulographic study

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Brain Stimulation 16 (2023) 1598–1600

Contents lists available at ScienceDirect

Brain Stimulation

journal homepage: www.journals.elsevier.com/brain-stimulation

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Dear Editor,

Speech deficits in Parkinson's disease (PD) manifest as hypokinetic dysarthria comprising reduced ability to modulate speech melody and loudness, and imprecise articulation [1]. The latter results from smaller, slower, and less precise articulatory movements further leading to reduced intelligibility [1]. The effect of deep brain stimulation of the subthalamic nucleus (STN-DBS) on speech is under debate. Whereas some studies report improvement, e.g. Refs. [2–4], others report a deterioration of speech functions, e.g. Refs. [5–7]. Thus, the aim of this study was to investigate speech changes on the kinematic, acoustic, and perceptual levels before and after STN-DBS in individuals with PD.

Thirteen mild dysarthric individuals with PD (dysarthria severity was rated by an SLP) and thirteen age- and sex-matched healthy controls (HC) participated in this study (supplementary Table A1). Individuals with PD were assessed OFF medication (at least 12 hours after PD medication withdrawal) before DBS implantation and nine months (SD = 3) postoperatively again OFF medication with deactivated and activated STN-DBS (randomized order of DBS settings with 30 minutes wash-out/wash-in time between conditions). Participants had bilaterally implanted electrodes within the STN (supplementary Figure A1), using regular stimulation settings (supplementary Table A2) as per clinical routine at our center.

Subjects' motor function was assessed by using the UPDRS III. Participants also completed a speech production task that elicited semi-spontaneous sentence production. Speech was recorded with an electromagnetic articulograph (AG 501, Carstens) to simultaneously obtain acoustic and kinematic signals. To track the kinematic data, sensors were attached to the lower lip, the tongue tip and the tongue body. The experimental set-up, the speech task and the speech material were described previously [8]. Speech measures included acoustic and kinematic variables which are explained in supplement B. Intelligibility of the recorded speech samples was rated by 165 naive listeners on a two-sided visual analog scale (VAS) ranging from 1 to 101.

Results of the motor assessment are reported in the supplementary Table A3. Speech (UPDRS item 18) was better in HC compared to the PD group in both OFF conditions, but comparable to DBS-ON condition.

Preoperative speech in individuals with PD was less intelligible compared to HC ($\beta = 1.496$, $p < .001$, supplementary Table A4). While none of the acoustic parameters were able to differentiate both groups (supplementary Table A5), differences were detected on the kinematic level (Fig. 1, supplementary Table A6): Lower lip movements were slower (mean difference = −0.02044, p = .008) and tongue tip movements were longer in the PD group (mean difference = 20.70, p = .018). Thus, especially consonantal sound production involving lower lip and tongue tip movements was slowed down in individuals with PD studied here.

When comparing the preoperative med-OFF and postoperative DBS-OFF condition, intelligibility did not differ between both conditions ($p > .05$), which contrasts previous findings [7]. While the majority of acoustic parameters did not change, acoustic vowel durations were prolonged in DBS-OFF condition compared to preoperative baseline (mean difference = 22.760, p = .002). At the kinematic level, tongue patterns changed (Fig. 1, supplementary Table A6): Tongue tip movements became smaller (mean difference = −0.85240, p = .001) and slower (mean difference = −0.00882, $p < .001$) after electrode implantation. Reduction in amplitude (mean difference = −0.9058, p = .029) and slowness (mean difference = −4.18e-03, p = .029) were also observed for tongue body movements, reflecting a downsizing of amplitude and speed of the complete tongue system. Thus, the production of vowels and alveolar sounds was particularly affected compared to the preoperative baseline condition. This is in line with previous literature that reported articulatory imprecision [5] and slower jaw speeds [6].

When compared to deactivated STN-DBS, activated STN-DBS improved speech intelligibility ($\beta = 0.234$, $p < .001$, Table A4) and speech loudness (mean difference = 2.372, $p < .001$). No STN-DBS effect was observed for any other acoustic parameter (supplementary Table A5). At the kinematic level, preoperative slowness of the lower lip was compensated under activated STN-DBS as movements were faster (mean difference = 0.00853, $p < .001$) and larger (mean difference = 1.025, $p < .001$) and comparable to the HC group. Tongue movements remained unaffected (Fig. 1, supplementary Table A6). Thus, activated STN-DBS has a beneficial effect on lower lip movements [4], while tongue movements do not change under STN-DBS.

Besides limitations (small sample, missing PD control group not treated with DBS), this study is the first to demonstrate a pre-vs. post-surgery kinematic speech analysis in individuals with PD undergoing STN-DBS. Our study has two main findings.

First, the kinematic analysis revealed that lips and tongue respond differently to STN-DBS: Lip movements improved, whereas tongue movements remained unaffected. Based on this new finding, we hypothesize, that these apparently opposing DBS effects on the articulators might explain the contradictory results reported in the literature. For example, if STN-DBS improves the function of a certain articulator but at the same time reduces the function of another articulator to the same extent, overall speech does not change. If improvement overweighs deterioration, the net effect is improvement or vice versa. This might explain why some patients present improved speech after DBS while others present no change or even deterioration.

Second, postoperative assessments without active stimulation surprisingly revealed a change of speech parameters compared to preoperative baseline. Detailed analysis did not reveal any relationship to patient characteristics or other common confounders i.e. disease progression, cognitive decline, poorly placed electrodes, a long-lasting

https://doi.org/10.1016/j.brs.2023.10.013
Received 8 September 2023; Received in revised form 20 October 2023; Accepted 24 October 2023
Available online 29 October 2023

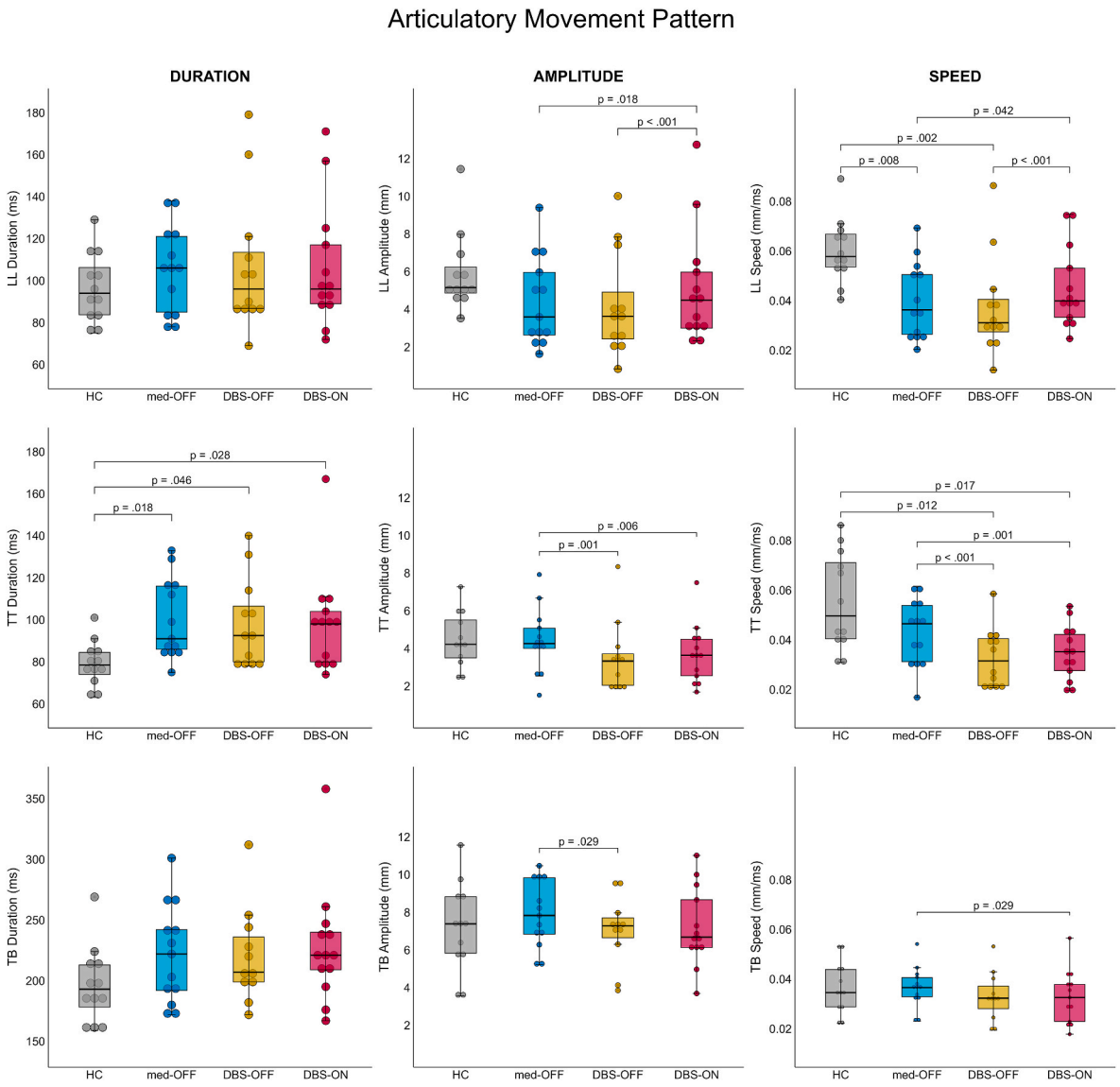

Fig. 1. Articulatory results for lower lip (LL), tongue tip (TT) and tongue body (TB) movements per group and condition.

micro-lesioned effect or an incomplete medication washout (Supplement C). To minimize the influence of the established chronic DBS we chose a generous wash-in/wash-out time of 30 minutes, even though a previous study demonstrated stabilization of speech parameters within 2 min after DBS cessation [9].

Still, it remains unclear, whether this remarkable observation corresponds to permanent impairments due to perioperative lesioning and/or definitive lead placement or corresponds to a prolonged stimulation effect mediated by neuroplastic processes or even structural reorganization. Previous observations on other DBS-induced side effects indicate that specific DBS effects only gradually subside beyond hours. E.g. antibradykinetic effects of subthalamic DBS subside with a steep initial decline within minutes, but demonstrate a prolonged subsequent slope with detectable residual therapeutic effects for nearly an hour after DBS cessation [10,11]. Also, DBS-induced gait ataxia in individuals with essential tremor treated with thalamic (VIM)-DBS does not immediately resolve with DBS cessation, but gradually resolves within the following 72h. Functional neuroimaging provides evidence that antidromic neuroplastic maladaptation in the cerebellum might be responsible for this phenomenon [12–14].

We speculate that our findings are preliminary evidence of prolonged DBS-induced speech changes due to chronic subthalamic stimulation, implicating possible reorganization or maladaptation of neural speech networks. This hypothesis needs to be addressed and clarified in future studies including longer wash-out periods.

Movement durations are presented in the first column, movement amplitudes in the second column, and average movement speed in the third column. Significant results of post-hoc analyses are indicated.

Ethics

The study was approved by the local ethics committee of the University Hospital of Cologne (protocol code: 18–425; date of approval: 8 February 2019). Informed consent was obtained from all subjects involved in the study.

Funding sources

This work was supported by the German Research Foundation (DFG) as part of the SFB 1252 “Prominence in Language” [Project-ID 281511265] in project A04 “Dynamic Modelling of Prosodic Prominence” at the University of Cologne and by the a.r.t.e.s. Graduate School for the Humanities at the University of Cologne.

Data availability

The data used to support this study's findings are available from the corresponding authors upon reasonable request.

Author contributions

TT: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Visualization, Writing - original draft.

HJ: Investigation, Methodology, Validation, Visualization, Writing - review & editing.

DM: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing - review & editing.

GR: Interpretation, Writing - review & editing.

VVV: Resources, Writing - review & editing.

SP: Conceptualization, Methodology, Validation, Writing - review & editing.

MTB: Conceptualization, Investigation, Methodology, Project administration, Supervision, Resources, Writing - review & editing.

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.

Acknowledgements

We thank Theo Klinker, Simon Roessig and Lukas Henne for their technical support. In addition, we thank Jane Mertens and Gilly Shapira-Mertens for their creativity and the artistic realization of the stimuli.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.brs.2023.10.013.

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