Acoustic changes along a modified speech rate continuum in Parkinson's disease

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Background

Parkinson's disease (PD): 70-90% of people with PD develop *hypokinetic dysarthria*, characterized by imprecise articulation, speech rate abnormalities, monopitch/monoloudness[1]. For some, speech impairment worsens following deep brain stimulation surgery[2].

Speech rate reduction: Common therapeutic goals to improve speech intelligibility in people with PD & dysarthria[3] and is associated with[4-10]:

- Increased segment durations
- Increased acoustic distinctiveness
- Increased speech intensity

Puzzle: Many people with PD and dysarthria do not see improvements in speech intelligibility when they slow their speech rate down[11]. Faster speech is not necessarily associated with "worse" speech for some talkers with PD[12]. Most studies have only elicited one or two speech rates[3]. What other speech changes are occurring when talkers change their rate of speech?

Purpose

Explore the acoustic changes (phonatory and articulatory) that occur along a modified speech rate continuum for talkers with and without PD.

Methods

Participants & Experiment

Participants

3 groups

- Older Controls (n = 17)
- PwPD w/out DBS (n = 22)
- PwPD w/ DBS (n = 17)

Speech task

"Please say aCVd again" *

- 24 nonce words
- C: /p, t, k, b, d, g/
- V: /i, u, ae, a/

* *Part of a larger battery of speech tasks*

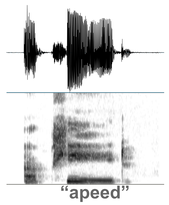
Speech rate

- **Blocked magnitude production:** 7 rate conditions (habitual, 3 fast, 3 slow) elicited via magnitude production:
  "Please speak at a rate that feels 2x/3x/4x faster/slower"
- **Order:** Habitual rate always elicited first. Modified rates were elicited in a graded order within a block (2x, 3x, 4x), and order of block (fast vs. slow) counter balanced.
- **Practice & facilitation:** Participants underwent a brief practice period at the start of each condition. A practice utterance was recorded and played back every ~10 trials as an anchor to facilitate target rate production.
- **Proportional rate:** Actual speech rate was binned into 5 categories based on individuals' proportional rates.

Slowest | Slower | Habitual | Faster | Fastest

Analysis

Acoustic analysis



- Words per minute (WPM) of the carrier phrase
- Vowel intensity
- Vowel harmonics-to-noise
- 4-Vowel articulation index (QVAI)[13]
- Voice onset time (VOT)

Statistical analysis

- Modelled acoustic variables as a function of group, rate, and other variables of interest as appropriate using linear mixed effects regression[14,15]*.

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DV ~ Group*Rate + … + (…|Participant) + (1|Item)
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- Additional variables were iteratively added as appropriate (e.g., consonant voicing), and kept if model fit improved.
- **Comparisons for primary variables of interest:**
  - **Group**: 1) OC vs. Clinical (PD + DBS), 2) PD vs. DBS (Helmert contrasts)
  - **Rate**: Each proportional rate bin compared to habitual speech using treatment contrasts (slower, slowest, faster, fastest vs. habitual).
  - Post-hoc pairwise comparisons[16] of individual variable levels.

**Exception: Speech rate group differences compared using Welch 2-sample t-tests.*

Results & Discussion

Speech rate

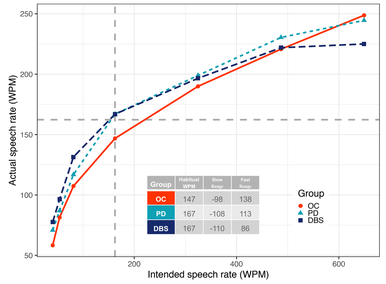

Figure 1: Actual speech rate (WPM; y-axis) x intended speech rate (rate condition; x-axis). Grey dotted lines represent grand means.

- **Habitual speech:** Both PD groups had faster habitual speech rate than OC ($p < 0.05$). PD and DBS did not differ from one another (n.s.).
- **Slow rates:** Groups did not significantly differ from each other (n.s.).
- **Fast rates**: OC produced wider range than DBS group ($p < 0.01$). PD did not significantly differ from either of the other groups.

Vowel intensity

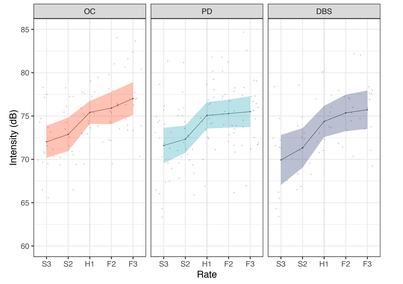

Figure 2: Vowel intensity (dB) by speaker group and speech rate, averaged over participants. Shaded band represents the 95% confidence interval.

- **Rate effect:** Overall, Compared to habitual speech, all groups demonstrated lower speech intensity at slower rates ($p < 0.001$) and did not significantly differ at faster rates.
- **Group effect:** No significant group differences.
- **Group x rate:** Overall, DBS showed steeper decline in slow speech ($p < 0.001$).

Vowel harmonics-to-noise

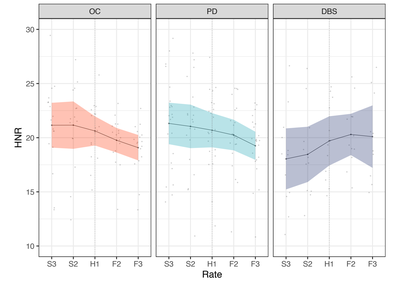

Figure 3: Vowel harmonics-to-noise ratio by speaker group and speech rate, averaged across participants. Shaded band represents the 95% confidence interval.

- **Rate effect:** Overall, Compared to habitual speech, talkers produced worse voice quality (higher HNR) at most modified rates ($p < 0.001 – 0.08$).
- **Group effect:** No significant group differences.
- **Group x rate:** OC & PD demonstrated better voice quality in slow speech ($p < 0.001 – 0.03$) and a n.s. trend for worse voice quality in fast speech. DBS group showed *opposite effect.*

Voice onset time

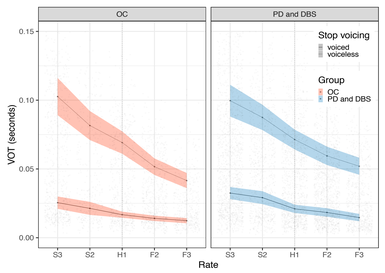

Figure 4: VOT by group, rate, and stop voicing, averaged across participants. Shaded band represents the 95% confidence interval.

- **Rate effect:** Overall, longer VOT in slower speech & shorter VOT in faster speech ($p < 0.001$).
- **Group effect:** OC > PD > DBS ($p = 0.02 – 0.06$)
- **Group x rate:** No significant interaction.
- **Group x rate x voicing:** OC showed greater voicing contrast at their slowest rates ($p < 0.05$), and smaller voicing contrast at all faster rates. PD & DBS did not differ from one another. Pairwise comparisons showed group differences were usually greatest for voiced stops.

Vowel space and vowel articulation index

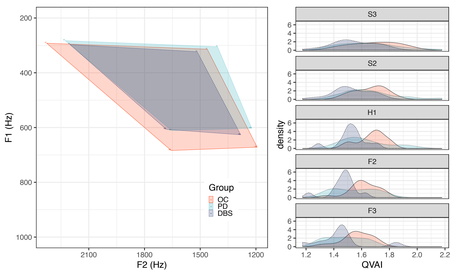

Figure 5: *Left*: Vowel polygons produced in the first and second formant space by each speaker group. *Right*: density plots showing the distribution of QVAI for each group at each rate (ordered top to bottom from slow to fast).

- **Rate effect:** Smaller QVAI in fast speech ($p < 0.001$), trend for larger QVAI in slow speech ($p = 0.04 – 0.12$).
- **Group effect:** OC > PD > DBS ($p < 0.05$).
- **Group x rate:** No significant interactions.
- More variability of QVAI at slower rates (flatter distribution in Panel B).

References available upon request

Summary

Across a rate continuum, PwPD:

- Made *similar* proportional adjustments to their rate of speech from very slow to very fast when compared to older controls.
- Made *smaller* adjustments in consonant voicing distinctiveness at both slower and faster ends of the continuum.

At slower rates:

- Quieter, poorer quality speech for all talkers (and especially those with DBS).

At faster rates:

- Phonatory and vowel space changes did not significantly differ compared to habitual speech.
- Some talkers with DBS actually became louder and had better voice quality.

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