Deep brain stimulation may contribute to dysarthria in patients with Parkinson's disease as detected by objective measures

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Abstract

Dysarthria is found in approximately 80% of patients with Parkinson's Disease (PD) and significantly limits communication as the severity worsens. Surgical implantation of deep brain stimulators (DBS) into the subthalamic nucleus (STN) has become more common and is an effective treatment for the motoric symptoms of PD. However, the effect of DBS on speech is equivocal. We have developed computer algorithms that quickly and objectively analyze the speech of PD patients, allowing clinicians to assess the effect of speech on DBS programming or other therapies. 15 PD patients and 8 Normal subjects are recorded during speech tasks using a solid state digital recorder. Their speech is analyzed using our algorithms, which measure syllable rate and regularity, stop consonant spirantization, and other quantities. Rate and regularity assess speech agility, while spirantization is a measure of articulatory precision.

Our results show that objective measures of speech reveal differences between treatment conditions for PD. It also shows that DBS causes speech production to be less stable than when patients are treated with L-dopa alone. Finally, the variation within patients underlines the need for a method of objectively tracking speech changes with DBS setting in order to optimize a patient's communication ability.

In previous work, we only assessed the /ka/ repetition task. Across all conditions, PD patients' speech is more irregular, and often slower, than normal controls'. When on-stim or untreated, PD patients' speech is also slower and more irregular than when they are on L-dopa medication alone. Thus, the meds-only condition appears to be the most similar to normal speech in terms of rate and regularity. Spirantization measures show the same pattern: L-dopa makes speech more similar to normal than most DBS settings, and DBS makes it more similar to the untreated condition. Furthermore, the effect on speech of varying DBS settings differs greatly across patients, highlighting the need for a sensitive, rapid method of assessing speech after each setting change.

In this study, we will also assess the other speech tasks as well, including the sustained 'ah', /pa/, /ta/, /pa-ta-ka/, and the rainbow passage, to determine if speech rate is slower for all speech tasks, not just the /ka/.

Why Speech? Ability to communicate with others is important to quality of life in PD patients, so it is important to improve speech along with other motor functions. Also, speech measurements are non-invasive and easy to make.

Why The Tests and Measurements We Chose?
The tests are standard components of an oral mechanism exam, and reveal the function of the larynx and major articulators. The measurements reflect acoustic features corresponding to the perceptual features that are disordered in Parkinson's.

Specific Aims of this Project: Our goal for this project is to use our device to assess objective measures of speech pre- and post-DBS surgery:

1. Explore changes in speech function as a result of systematically varying DBS parameters, a noninvasive method of investigating the neural circuitry of the basal ganglia.
2. Develop speech measures specifically targeted to assess hypokinetic dysarthria from PD.

Subjects

Candidates for this study are patients with PD whose symptoms can no longer be managed by medication alone, who are candidates for a DBS implant, who present with no neurological or psychiatric conditions (other than PD), and who score ≥2 (of 4) on question II.5 or on question III.18, the speech-related questions, of the United Parkinson's Disease Rating Scale (UPDRS).

15 PD patients, ranging in age from 48 to 70, participated in the study; 3 were female and 12 male. All patients were recorded pre-surgery, both off and on medication. They were also recorded post-surgery, off and on stimulation. Some patients returned for multiple DBS adjustment visits over periods varying from several weeks to a few months and were recorded each time.

In addition, 9 normal subjects (6 female, 3 male; age range 26-61) were recorded as controls, once each. The recordings of one normal female subject were later excluded due to perceptual and measured anomalies.

Methods

Speech Tasks:

***Alternating Motion Rate (AMR) task*:** This task assesses rate, rhythm, precision, and range of motion of the jaws, lips, and tongue. Patients repeat three monosyllabic phrases as rapidly and accurately as possible, on one breath each: "pa-pa-pa…", "ta-ta-ta…", and "ka-ka-ka…".

***Sequential Motion Rate (SMR) task*:** This task determines the ability to program rapid speech movements in succession. It involves the repeated production of the three sounds included in the AMR tasks. The phrase is "pa-ta-ka…"

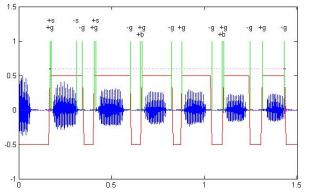
***Sustained Vowel task*:** This task assesses the respiratory and laryngeal contributions of speech. The subject sustains the "ahhh" sound for as long as possible.

***Rainbow Passage*:** This is a phonetically balanced passage that subjects read. It requires more muscular and cognitive resources than simply producing individual syllables. Therefore, it may reveal speech deficits not apparent in simpler speech tasks. The passage reads:

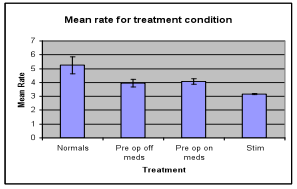
When the sunlight strikes raindrops in the air, they act like a prism and form a rainbow. The rainbow is a division of white light into may beautiful colors. These take the shape of a long round arch, with its path high above, and its two ends apparently beyond, the horizon. There is, according to legend, a boiling pot of gold at one end. People look, but no one ever finds it. When a man looks for something beyond his reach, his friends say he is looking for the pot of gold at the end of the rainbow.

Together, these tasks require less than five minutes' time.

Results



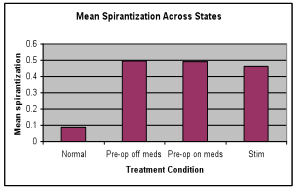
This figure is a trace of a verbal sound waveform over time represented by a graphic version of the output of our system. Each blue region corresponds to one syllable (in this case, in the "pa-pa-pa" task). Notations above each syllable indicate aspects of production of the onset and offset of each syllable. This patient's syllables are becoming shorter and more faint over time, as indicated by the shrinking height and length of each blue region.



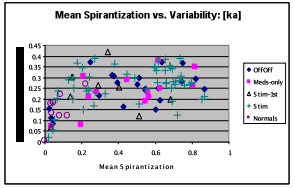
Mean Rate across treatment condition. Mean rate for all subjects across treatment conditions. On-stim, the mean rate is slower compared to Meds-only and Off-meds (pre-op).

(1) ** Normal vs. pre op off meds ($p < 0.005$)
** Normal vs. pre op on meds ($p < 0.005$)
(2) ** Pre op on meds vs. stim ($p < .005$)
* Pre op off meds vs. stim ($p < .05$)
*** Normal vs. stim ($p < .0001$)

Pre op on meds vs. pre op off meds: No statistical difference

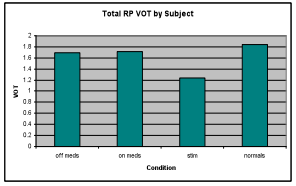


Mean Spirantization by State: Normal subjects are shown to be significantly different from all conditions ($p<0.001$), indicating that normal controls have less consonant weakening compared to patients with Parkinson's Disease at any condition. All other measures are non-significant. ($p>0.05$).

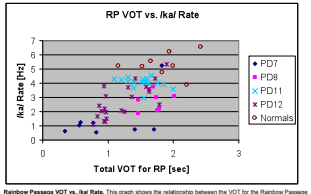


Spirantization, Mean and Variation. Most subjects and states produce greater spirantization than Normals. Meds-only generally shows the least overall increase, but with higher standard deviation. Notice that most On-stim sessions show even greater spirantization than OffOff (no treatment).

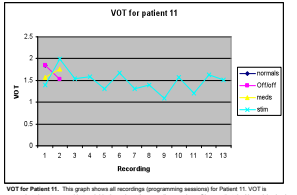
Voice Onset Time (VOT) is the amount of time between when a consonant is released and when vibration of the vocal cords begin (voicing).



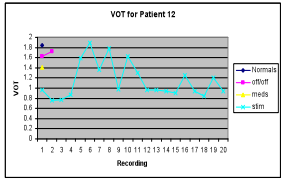
Total VOT by Subject. This figure shows the total Voice Onset Time obtained from the rainbow passage for each subject. The general trend suggests that DBS may shorten VOT in Patients with Parkinson's Disease, reflecting generally poorer articulatory precision and clarity of speech.



Rainbow Passage VOT vs. /ka/ Rate. This graph shows the relationship between the VOT for the Rainbow Passage and the /ka/ rate. This scatter plot suggests that a lower rate is correlated with a lower voice onset time, and a higher rate is correlated with a higher VOT. However, each speaker has his/her own cluster, generally far from the Normals.



VOT for Patient 11. This graph shows all recordings (programming sessions) for Patient 11. VOT is somewhat close to normal but variable throughout the recording sessions. Observe that the Normals' value is 1.8 sec.



VOT for patient 12. Stimulation appears to make VOT highly variable throughout recording sessions for patient 12, showing that, by this measure at least, articulatory precision and speech clarity could be optimized (made similar to Normals') but is otherwise subject to substantial interference, far below OffOff.

Summary

1. We can detect subtle differences in speech with objective acoustic measures. With the development of our product, we can use it to better understand how DBS affects speech in patients with PD and better understand brain mechanisms associated with speech in general.
2. Speech in PD patients is *slower* and *less regular* when they are on-stim (with no attempt to program for speech performance) or untreated than when they are on meds-only.
3. Normal subjects are shown to have less spirantization than all PD subjects on meds, off meds and on stimulation.
4. DBS stimulation of the STN makes patients' speech more variable than medication or no treatment. Unless patients' stimulators are specifically adjusted to optimize speech, their speech will most likely not improve in parallel with other symptoms.
5. We expanded our traditional acoustic measures and looked at Voice Onset Time for PD patients. Our data suggests that stimulation may decrease VOT, reflecting an interference with normal articulation, and may be positively correlated with speech rate.
6. Our processing allows a tracking tool that can be used to analyze the speech of patients during parameter changes of their DBS. It helps clinicians to monitor patients speech and adjust settings accordingly.
7. The data this study yields can help us to:
   - Develop a tool to quantify the effects of PD progression and treatments
   - Refine measurements that can be made automatically on speech to help optimize DBS settings
   - Explore subcortical speech-production mechanisms
   - Understand the influence of DBS on speech production.

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