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Fundamental Frequency Characteristics of Parkinsonian Speech after Subthalamic Nucleus Deep Brain Stimulation

Ping Fan[1], *Wentao Gu*[1], *Dawei Gong*[2], *and Wenbin Zhang*[2]

[1]Institute of Linguistic Science and Technology, Nanjing Normal University, China
[2]Nanjing Brain Hospital, Nanjing Medical University, China
fpshida2010@126.com, wtgu@njnu.edu.cn, david4232@sina.com, wenbinzhang@njmu.edu.cn

Abstract

This study employed three tasks to investigate the effects of subthalamic nucleus deep brain stimulation (STN-DBS) on fundamental frequency (F0) characteristics of parkinsonian speech. Ten STN-DBS treated PD patients conducted speech recording for sustained vowels, repeated syllables, and reading passage after their surgery in three states, i.e., stimulation off one month after operation (OFF), stimulation on after internal pulse generator (IPG) on for one month (ON1), and stimulation on after IPG on for three months (ON2), respectively. All three states were off medication. The results showed that the only significant effects were on F0 range and F0 variability, which became larger at the ON2 state than at the OFF state only in reading passage. The positive effect of STN-DBS on parkinsonian speech seems to be chronic, and is only observed in passage reading, suggesting that speech task has direct impact on the results of speech ability assessment.

Index Terms: fundamental frequency, Parkinson's disease, subthalamic nucleus, deep brain stimulation

1. Introduction

Parkinson's disease (PD) is one of the neurodegenerative diseases in the middle-aged and elderly people, with typical motor impairments such as bradykinesia, hypokinesia, akinesia, muscle rigidity, and rest tremor [1]. The majority of PD patients suffer from hypokinetic dysarthria which is manifested in all dimensions of speech production and is characterized by monotone, monoloudness, abnormal speech rate, hoarse voice, imprecise articulation, etc. [2, 3].

Deep brain stimulation in the subthalamic nucleus (STN-DBS) is an effective surgical treatment to alleviate cardinal motor impairments for advanced PD patients who have developed motor fluctuations with the effects of levodopa wearing off [4, 5], but the effects of STN-DBS treatment on speech production are still controversial [6].

Subjective assessment of PD's speech in terms of item 18 of the Unified Parkinson's Disease Rating Scale (UPDRS) or other quantitative clinical scales have demonstrated both positive effects [7] and negative effects [8-10] of STN-DBS treatment. However, item 18 of UPDRS is still too simple to give a comprehensive evaluation of speech abilities. There still lacks an objective metric to evaluate parkinsonian speech.

Some acoustic studies reported that PD's speech after STN-DBS treatment showed more stable fundamental frequency (F0) in sustained vowels [11, 12], slower speech rate and more variable voice onset time in repeated syllables [13], and larger range as well as variability of F0 in sentences and passages [11, 14-16]. Xie et al., however, found no significant F0 difference in sustained vowels, repeated syllables or sentences [17]. The results in previous studies were not always consistent, possibly due to different speech tasks and different DBS settings. Speech outcome depends on the laterality of stimulation and the DBS parameters. Stimulation of the left STN has worse effects on speech than that of the right [18, 19]. STN-DBS with high-voltage amplitude and high frequency usually reduces the intelligibility of speech [20, 21], while STN-DBS with low frequency improves the intelligibility [22, 23].

Most previous studies on the effects of STN-DBS were on PD's speech in western languages. The present study, however, aimed to investigate the effects on F0 characteristics of Mandarin PD's speech, by combining all three speech tasks, i.e., sustained vowels, repeated syllables, and reading passage.

2. Method

2.1. Participants

Ten patients with idiopathic PD (2 males and 8 females) were recruited from Nanjing Brain Hospital after they received bilateral STN-DBS treatments. Before surgery, all patients were assessed by neurologists systematically with a series of scales, including the third part (UP III) and the fifth part (i.e., modified H&Y) of the Unified Parkinson's Disease Rating Scale (UPDRS), Mini-Mental State Examination (MMSE), Hamilton Anxiety Scale (HAMA), and Hamilton Depression Scale (HAMD). All ten participants suffered from mild or moderate speech disorders (item 18 of UPDRS scored 1 or 2), and had no dementia (MMSE > 24), no severe emotional disturbance (HAMA < 14 and HAMD < 20), and no reported history of speech therapy. The detailed information of all PD participants is listed in Table 1.

Table 1: *Information of PD patients (mean ± sd.).*

Age (year)	61.80 ± 7.96
UP III	34.80 ± 9.71
UP III-18	1.30 ± 0.46
Modified H&Y	3.05 ± 0.52
MMSE	27.60 ± 1.56
HAMA	5.40 ± 3.58
HAMD	6.30 ± 4.52
Disease duration (year)	8.10 ± 1.76

2.2. Surgical procedure

The target was localized using 3.0T MRI and CT. Bilateral micro electrodes were inserted into STN, and then were

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recorded to determine the optimal trajectories. The final long-term four-contact electrodes were inserted after withdrawing the bilateral micro electrodes. To test the clinical effects of different contacts, external stimulator was adopted to provide constant stimulation. Finally, internal pulse generator (IPG) was implanted in the subclavicular area on both sides.

About one month after the STN-DBS operation, the patients returned to hospital to have IPG turned on. The neurologists adjusted the stimulation parameters (including frequency, amplitude, and pulse width) for each PD patient to get the best clinical effects with the minimized side effects. The patients returned to hospital as frequently as necessary for adjustment of stimulation to improve clinical effects. After three months' adjustment, the frequency of the stimulation ranged from 130Hz to 150Hz, the amplitude ranged from 1.5V to 2.5V, and the pulse width ranged from 60ms to 90ms.

2.3. Speech recording

Speech recording was conducted in a quiet room with a portable digital recorder Zoom H4n, digitized at 44.1 kHz and 16-bit precision. Recording was done at three states, i.e., stimulation off one month after operation (OFF), stimulation on after IPG on for one month (ON1), and stimulation on after IPG on for three months (ON2). All three states were off medication.

At each state, the participants were asked to do three recording tasks in the following order at their normal speech rate, pitch, and loudness after they got familiar with the materials: (1) sustain the vowel /a/ for at least 2 seconds in a single breath cycle; (2) repeat the syllable /p^{h}a/ for at least 5 times in a single breath cycle; and (3) read aloud a short story *The North Wind and the Sun* which is composed of 185 syllables.

3. Results

Both prosodic features (including F0 and timing) and articulatory features (for both vowels and stops) of PD's speech were analyzed using Praat.

The F0 parameters were analyzed in all three tasks. They included the min, the max, the mean, the range, and the standard deviation of F0 in the utterance, measured in semitone (St) with reference to 50Hz.

The timing parameters were analyzed only in repeated syllables and reading passage. They included speech rate, articulation rate (i.e., the rate of the articulated portions of speech), pause ratio, mean duration of vocalic intervals, mean duration of consonantal intervals, percentage of vocalic duration in the utterance, standard deviation of vocalic durations, standard deviation of consonantal durations, and voice onset time of the aspirated stop /p^h/.

For reading passage, the formants F1 and F2 of three nominal vowels /a, i, u/ were measured to calculate vowel space area and vowel articulation index.

For repeated syllables and reading passage, the normalized minimum intensity during closures of stops were measured to examine the quality of stops.

3.1. General results on fundamental frequency

In each speech task, repeated-measures ANOVAs among the three states were conducted on all parameters mentioned above. The results showed that the only significant differences were observed on F0 features. Figures 1-3 show the statistical results of three F0 parameters, i.e., mean F0, F0 range (the difference between the maximum and minimum F0s), and F0std (standard deviation of F0), for sustained vowel /a/, for repeated syllable /p^{h}a/, and for reading passage, respectively. The only significant effects were found in reading passage, both in F0 range [F (2, 58) = 6.59, $p < 0.05$] and in F0std [F (2, 58) = 13.29, $p < 0.001$]. Bonferroni post hoc test showed that both F0 range (t = -2.934, $p < 0.05$) and F0std (t = -5.033, $p < 0.01$) were significantly larger in the ON2 state than in the OFF state, while there was no significant difference between ON1 and the other states.

3.2. Comparison of individual results

Figure 4 further compares the results on F0 range and F0std in reading passage for each individual patient. Among all PD patients, PD3, PD4, PD5, PD6, PD8, and PD9 show obvious improvement in comparing ON2 to OFF, while PD1, PD2, PD7, and PD10 show little improvement.

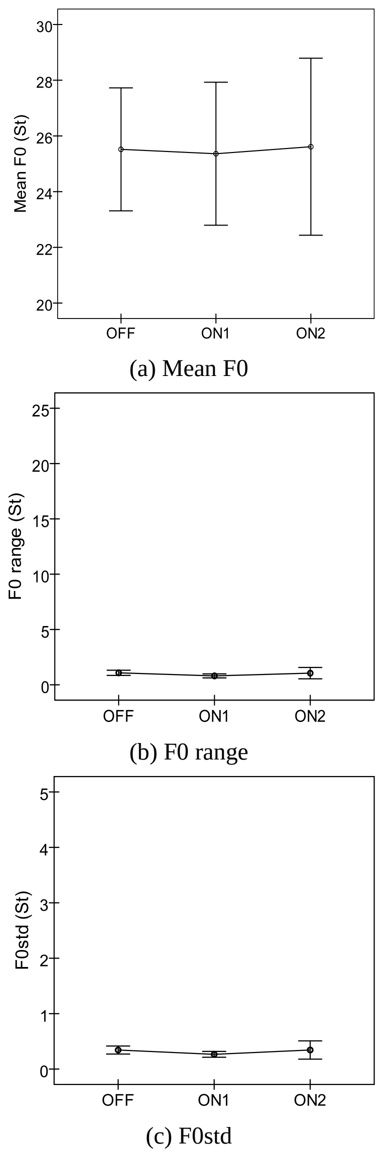
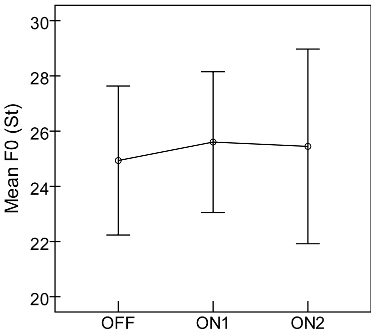
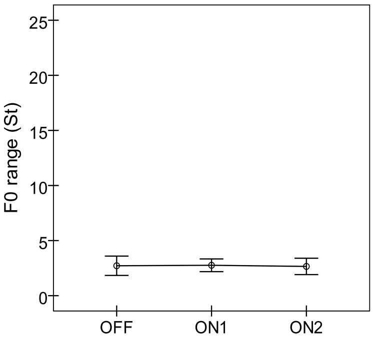


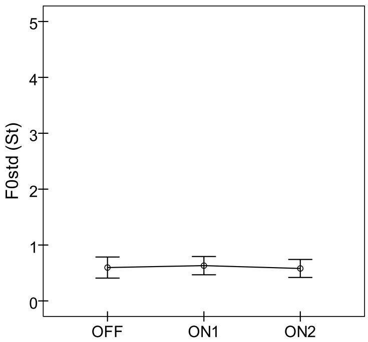
Figure 1: *Mean F0, F0 range and F0std in sustained /a/.*



(a) Mean F0

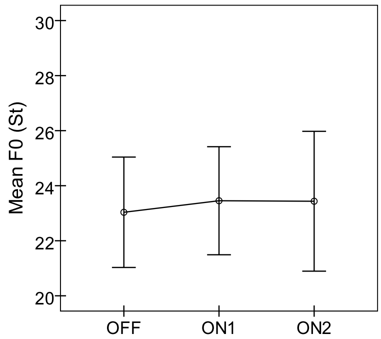


(b) F0 range

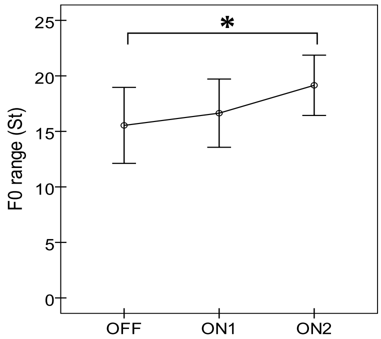


(c) F0std

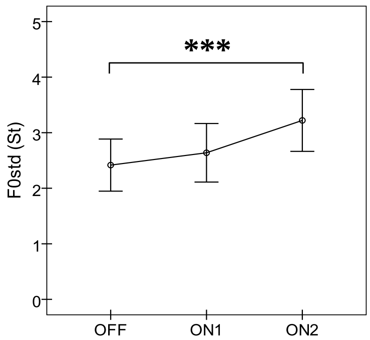
Figure 2: *Mean F0, F0 range, and F0std of repeated /pʰa/.*



(a) Mean F0



(b) F0 range



(c) F0std

Figure 3: *Mean F0, F0 range, and F0std of reading passage.* (*Note:* ***$p < 0.05$, ******$p < 0.001$)

4. Discussion

4.1. Effects of STN-DBS on speech

Narrow F0 range and small F0std relate to the perceived monotone characteristics of speech. Thus, the results here indicate that STN-DBS is beneficial to reducing the monotone symptom and increasing prosodic expressiveness of speech in PD patients. This positive effect on speech was also found in previous studies [11, 14-16].

However, the positive effects of STN-DBS on speech occur much later (3 months after IPG on) than on motor symptoms (immediately after IPG on). Also, there was no significant difference between ON1 (i.e., one month after IPG on) and the other states, suggesting that the effects of STN-DBS on speech are chronic.

It should be noted that the effects of STN-DBS on PD's speech as revealed in previous studies are controversial – some coincide with our results (e.g., increased F0 range and F0 variability in reading sentences/passages [11, 14-16]) while the others contradict (e.g., on F0 stability in reading passages [17]). There are two possible reasons for these inconsistencies.

First, it has been shown that high-frequency and high-amplitude STN-DBS usually improves motor functions but reduces the intelligibility of speech [20, 21], while low-frequency STN-DBS improves the intelligibility of speech [22, 23]. The frequency of stimulation in this study is 130-150Hz which lies at the lower part of the usual setting 130-180Hz, and the amplitude of stimulation is 1.5-2.5V which is also lower than the usual setting 3.0-3.5V. Therefore, our study verifies that low-amplitude and low-frequency stimulation helps improve speech production after operation.

Second, these studies investigated the effects at different time stages, and hence cannot be compared directly. The effect three months after IPG on is still short-term, but a long-term effect may be confounded by further progress of PD. So, the time stage after operation is a complex factor that needs to be considered more carefully in the study.

4.2. Influence of speech tasks

This study investigated the effects of STN-DBS on PD speech using three speech tasks, i.e., sustained vowel /a/, repeated syllable /p^{h}a/, and reading passage. Significant differences were observed only in reading passage, where F0 range and F0std were significantly larger in ON2 than in OFF. This suggests that speech task has great impact on the results [24, 25]. It may be easier for PD patients to complete the former two tasks than reading passage which requires more careful coordination of articulators. Another possible reason for the insignificant effect in sustained vowel is that producing isolated vowels is not a typical syndrome of hypokinetic dysarthria [26]. Therefore, in studying the effects of STN-DBS on speech, the difficulty of speech tasks should be taken into account to avoid the ceiling or floor effects.

4.3. Individual differences

Individual differences in the effects of STN-DBS on PD speech may be related to different symptoms of PD. In terms of the ratio of the tremor score (i.e., the average of items 16 and 20-26) to the non-tremor score (i.e., the average of items 5, 7, 12-15, 18, 19 and 27-44) in UPDRS, Lewis et al. classified PD patients into three types, i.e., tremor dominant, bradykinetic-rigid dominant, and mixed-type [27]. It was reported that tremor dominant PD patients generally had better speech performance after STN-DBS than those who suffered from rigidity or akinesia [13]. Also, a significant negative correlation was found between the score of motor ability before operation and the speech performance after operation [28].

Among our PD patients, PD3, PD4, PD5 and PD8 were tremor dominant, PD2, PD7 and PD10 were bradykinetic-rigid dominant, while among the remaining three mixed-type patients, PD1 had higher UPIII score (42) than PD6 (30) and

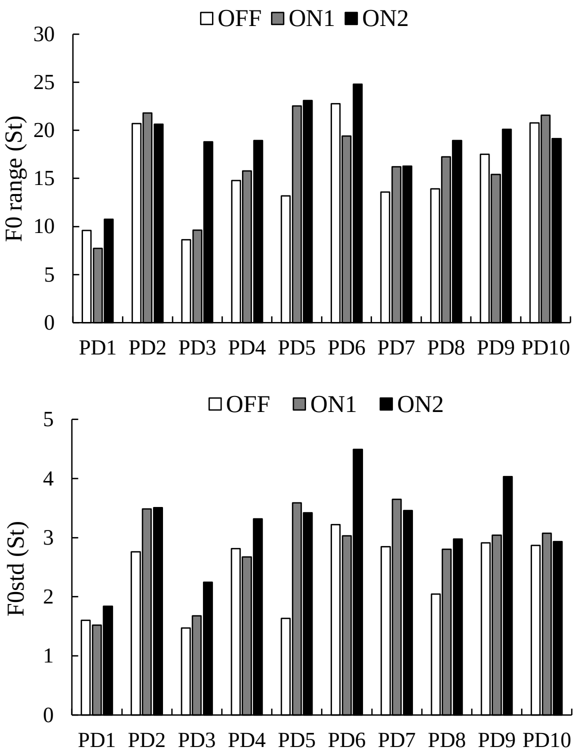


Figure 4: *F0 range and F0std of reading passage for each individual PD patient.*

PD9 (20). From the current data, it can be speculated that the effects of STN-DBS on speech are better on the tremor dominant PD and the mixed-type PD with light motor disorders. So, the type of PD and the motor ability may be good predictors of the effects on speech of STN-DBS. This result will be helpful for developing targeted treatments for PD patients with different symptoms.

5. Conclusions

The present study investigated the effects of STN-DBS on PD's speech from ten PD patients after their surgery treatment. Sustained vowel /a/, repeated syllable /p^{h}a/, and reading passage were collected at three off-medication states, i.e., stimulation off one month after operation (OFF), stimulation on after IPG on for one month (ON1), and stimulation on after IPG on for three months (ON2).

Results of acoustic analyses showed that STN-DBS had positive but chronic impacts on increasing F0 range/variability. In other words, STN-DBS alleviates the monotone symptom of PD's speech. Moreover, the effects tended to be stronger on the tremor dominant PD patients and the mixed-type PD patients with light motor disorders. So far, we have only tested three speech tasks within four months after surgery. A long-term test using more speech tasks (e.g., spontaneous speech) will be conducted in our future study.

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