Effect of unilateral electrostimulation of the subthalamic nucleus on different speech subsystems in Parkinson's disease

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ABSTRACT

This paper reports our findings on the articulatory subsystem from an on-going investigation of the effect of unilateral deep brain stimulation (DBS) in Subthalamic Nucleus (STN) on different speech subsystems in Parkinson's disease (PD). Previously, we have reported findings on the respiratory/phonatory subsystems. Speech recordings were made under three clinical conditions: before the surgery in the medication-off state (Baseline), and three months post surgery in the medication-off state with the Stimulation-off, and with Stimulation-on, in six consecutive subjects with a clinical diagnosis of idiopathic PD (five males, one female). The mean age was 55 (SD 9) years and the mean duration of disease 14.33 (SD 2.25) years. Based on which side of the body was more impaired, three of the six patients had the stimulator implanted in the left STN and three in the right STN. The off-medication state was achieved with the subjects withholding their PD medications for at least 12 hours before the assessment. Evaluators and subjects were blinded to the subjects' stimulator condition until after the data were analyzed. Speech tasks included six maximally sustained vowel phonation (MSVP), three diadochokinetic rates, reading sentences with varying stress, and a structured monologue. Acoustic analyses of diadochokinetic rates were reported. The results were compared to the subjects' performance on non-speech motor tasks and measures in the respiratory/phonatory subsystems, both were reported previously [7]. It was found that for non-speech tasks, stimulation-on improved performance in all six subjects. For speech tasks, significant improvement in the respiratory/phonatory subsystems was only associated with the right STN stimulation. Measures in the articulatory subsystem was much less consistent across different testing conditions, indicating that the responses to the DBS in STN may not be as uniform in different speech subsystems.

1. INTRODUCTION

Idiopathic Parkinson's disease (PD) is a neurodegenerative disorder that affects one's motor function including speech production [1,2]. The surgical procedure of deep brain stimulation (DBS) of the Subthalamic Nucleus (STN) is becoming the treatment of choice for managing advanced PD [3]. DBS in STN has successfully reduced motor symptoms such as tremor, rigidity, and drug-induced dyskinesia [4]. Bilateral DBS in STN has been reported to have some positive effects on speech and voice when the subjects were tested on-stimulation vs. off-stimulation, although the effects are far less substantial than those observed in limb movements [5, 6]. However, there have been no reports on changes in voice and speech when subjects undergo unilateral chronic DBS in STN. Further, since DBS in STN is a relatively new treatment procedure, there have been no detailed efforts to separate the effect of micro lesions (i.e. the side effects from the surgical procedure itself), from the real effect by the DBS in STN on the different speech subsystems. Previously, we have reported our findings on the respiratory/phonatory subsystems from an on-going investigation of the effect of unilateral DBS in STN on different speech subsystems in PD [7]. This paper reports findings on the articulatory subsystem.

2. METHOD

Subjects

Six consecutive subjects with a clinical diagnosis of PD who received unilateral implantation of deep brain stimulator in STN at the Rush-Presbyterian-St. Luke's Medical Center in Chicago participated in this study. The subjects met the strict inclusion criteria for the surgical intervention, which included a good response to levodopa, the presence of severe motor fluctuations and levodopa-induced dyskinesias. Speech dysfunction was not a criterion for the surgical protocol. All six subjects were right-handed, English speaking individuals with functional hearing and free from dementia and depression. Their mean age was 55 SD 9 years and the mean duration of disease 14.33 SD 2.25 years. Based on which side of the body was more impaired, three of the six subjects had the stimulator implanted in the left STN and three in the right STN (see table 1).

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Table 1. Subject characteristics at base-line evaluation in the medication-off state.

S	Age (yr.)	Gen.	STN side	H & Y* 'off'	UPDRS -III 'off'	Speech *
1	59	M	Right	3	46	1
2	38	F	Right	4	47	1
3	52	M	Right	4	25	3
4	59	M	Left	4	42	2
5	63	M	Left	2	19	0
6	58	M	Left	4	62.5	2

H & Y 'off', Hoehn and Yahr Scale; Speech, UPDRS rating (item 18), coded as follows: 0=none; 1=slight loss of expression diction or volume; 2=monotone, slurred but understandable; moderately impaired; 3=marked impairment, difficult to understand; 4=unintelligible.

Testing Procedures and Data Analyses

Speech recordings were made under three clinical conditions: before the surgery in the medication-off state (Baseline), and three months post surgery in the medication-off state with the stimulator-off (Stim-off), and with stimulator-on (Stim-on). Evaluators and subjects were blinded to the subjects' stimulator condition until after the data were analyzed. The off-medication state was achieved with the subjects withholding their PD medications for at least 12 hours before the assessment. Tasks included six maximally sustained vowel phonation (MSVP), three diadochokinetic rates, reading sentences with varying stress, and a structured monologue. Subjects' performance on non-speech motor tasks was rated by the second author, L.V., a movement disorder neurologist, using the motor section of the Unified Parkinson's Disease Rating Scale (UPDRS-III) [8]. Results on acoustic analyses of MDVP, and on non-speech motor tasks were reported previously [7]. In this paper, temporal acoustic measures of diadochokinetic rates (i.e., repetitions of syllables “puh”, “tuh”, and “ kuh”) are reported, which include measures on articulatory rate (syllable repetitions per second), and on error rate. Diadochokinetic rates or syllable repetitions produced as fast as possible have been commonly used in speech research and clinical evaluation of motor speech disorders to measure articulatory agility or performance of the jaw, lips and anterior and posterior tongue during speech movement [9]. If the STN stimulation has a clear effect on the supralaryngeal articulators (e.g., jaw, lips and tongue), one may expect to see well-defined syllable repetitions at speaking rates that are comparable to those produced by normal speakers.

Speech signals were recorded in a sound-treated room onto a digital audiotape deck (Sony 60ES) via a preamplifier (Symetrics SX202) and a SHURE (SM10A) professional unidirectional head-worn dynamic microphone with a mouth-microphone distance of 5 cm. The subjects were asked to say the syllables as fast as they could following the instruction (e.g., “Take a breath and say ‘puh-puh-puh-puh’ as fast as you can until I tell you to stop”) and a model. The subjects were allowed to practice until they were sure about the task. Each subject produced three syllable trains of 5 seconds each for ‘puh’, ‘tuh’, and ‘kuh’. The recorded speech signals were digitized at 22 kHz into a Power Macintosh 8100 computer using the SoundEdit™ program [10]. For each syllable train, the first two syllables were discarded to eliminate the onset effect. Next, an approximately 3-second sample of syllable repetitions was selected. The number of syllables in each sample was determined based on visual inspection of acoustic waveform and listening. The number of syllables per sample ranged from 17 to 23. For each sample, the articulatory rate (syllable repetitions/s) was obtained by dividing the total number of syllables with the actual sample duration in seconds. This measure would provide the information on maximum speaking rate that reflects directly on articulatory agility. Next, a measure on error rate was obtained for each sample. Each syllable repetition was examined to see if it was well defined acoustically with clear release of the stop consonant and clear syllable boundaries. Syllables that were not well defined were counted as errors. They were those termed as “blurred contrast” by Kent and Rosenbek [11]. A percent (%) error score was obtained for ‘puh’, ‘tuh’, and ‘kuh’ respectively, under each testing condition (i.e., baseline, stimulation-off, and stimulation-on) for each subject. The percent (%) error score was calculated by dividing the total number of syllables with the number of syllables judged as errors in each sample. The percent (%) error score would reveal whether target undershoot or “blurred contrast” [11] has occurred under the three different testing conditions.

3. RESULTS

Figure 1 shows that the mean syllable rates were similar for ‘puh’ (6.68, SD .47) and ‘tuh’ (6.69, SD .41), but slightly lower for ‘kuh’ (6.26, SD .49). These values are comparable to the syllable rates produced by normal speakers [9].

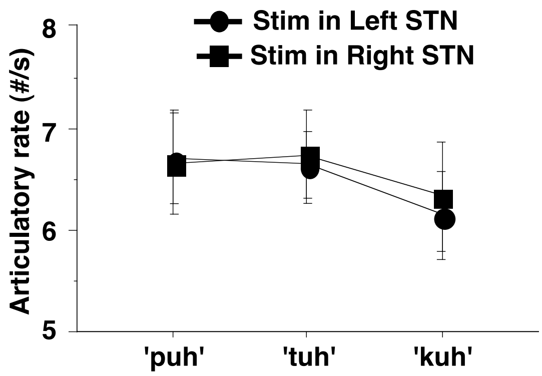

Fig. 1. Mean articulatory rate (right-STN vs. left-STN) for three syllable types averaged across three testing conditions. The error bars indicate one standard deviation.

It is shown in Figure 2 that when the stimulator was in the right STN (filled square), the syllable rates were slightly higher (6.89, SD .36) in the stimulation-on condition when compared to the baseline (6.25, SD .61) and stimulation-off (6.58, SD .36) condition. However, this difference did reach any statistical significance.

ISBN 1-876346-48-5

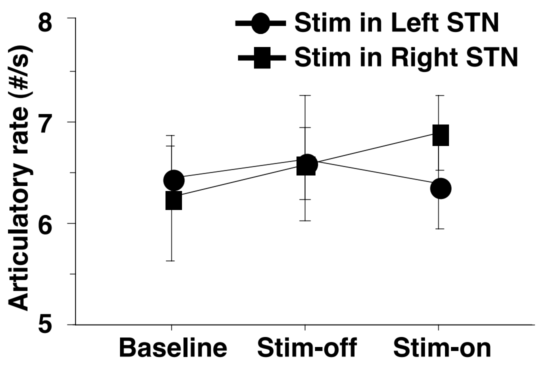

Fig. 2. Mean articulatory rate (right-STN vs. left-STN) averaged across syllable types (i.e., 'puh', 'tuh', and 'kuh') under three testing conditions. The error bars indicate one standard deviation.

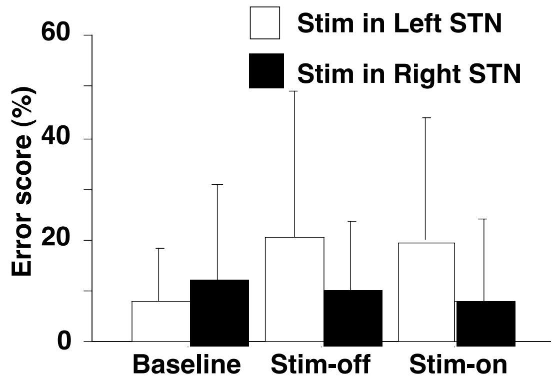

Fig. 3. Mean percent (%) error scores averaged across syllable types (i.e., 'puh', 'tuh', and 'kuh') under three testing conditions. The error bars indicate one standard deviation.

To see if these normal syllable rates were achieved by the subjects at the expense of articulatory accuracy, the percent (%) error score was calculated. As shown in Figure 3, the error score increased from the baseline to stimulation-off and stimulation-on when the stimulator was in the left STN. However, it decreased slightly when the stimulator was in the right STN. The difference was not statistically significant. Nonetheless, this trend was more prominent in some subjects than in the others as it was clearly demonstrated by the percent error scores of S2 who had the stimulator in the right STN (see Figure 4).

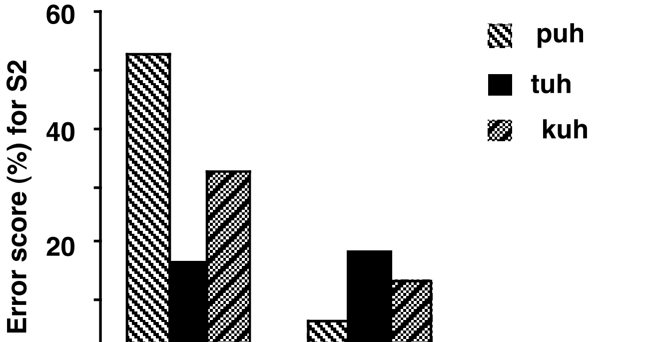

Fig. 4. Percent (%) error scores for S2 who had stimulator in the right STN

Subject 2 had appreciable speech impairment prior to the surgery. It can be seen in Figure 4 that her Baseline percent error score has decreased dramatically to zero or near zero in the stimulation-on condition. What is worth mentioning is that she achieved the high articulatory accuracy without sacrificing her articulatory rate. Her Baseline articulatory rate (syllables/s) was 6.99 for 'puh', 7.21 for 'tuh', and 5.41 for 'kuh'. In the Stim-off condition, the rates were 7.04, 7.11, and 6.23, for 'puh', 'tuh', and 'kuh', respectively. In the Stim-on condition, the rates were 7.32, 7.39, and 6.99, for 'puh', 'tuh', and 'kuh', respectively.

4. DISCUSSION

In our previous report [7], we confirmed what was reported in the literature that chronic stimulation in STN significantly improves all subjects' performance on non-speech motor tasks [3, 4]. As it was discussed earlier, based on which side of the body was more impaired, three of the six subjects had the stimulator in the left STN and three in the right STN. For non-speech motor tasks, all six subjects showed a clear response to the unilateral stimulation in STN regardless of the side of STN [7]. For speech tasks, Stimulation-on improved maximally sustained vowel phonations (MSVP) significantly in the three subjects who received right STN stimulation (filled square in figure 5), but not so in the three subjects who received left STN stimulation (filled circle in Figure 5) [7]. The authors speculated that the difference seen in vocal intensity and duration associated with the side of STN was likely due to a micro lesion caused by the surgical procedure to the corticobulbar fibers that run in the left internal capsule. Recent imaging studies demonstrate that approximately 95% of normal right-handed subjects have left-hemispheric dominance for language [12]. It seems that when the stimulation is in the left STN for the right-handed subjects (likely in their dominating hemisphere), there is a very good chance that their respiratory/phonatory subsystems may be compromised due to micro lesion effect.

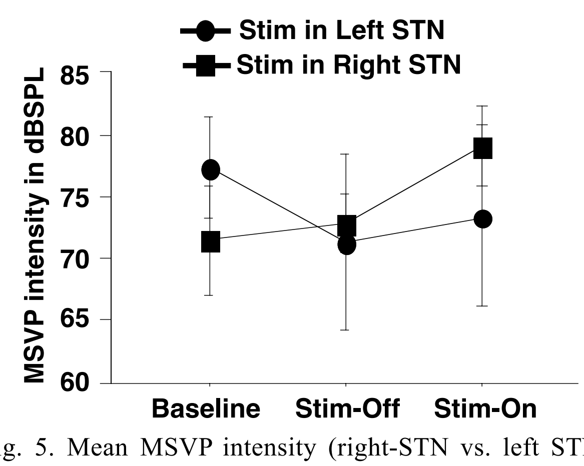

Fig. 5. Mean MSVP intensity (right-STN vs. left STN) under three testing conditions. The error bars indicate one standard deviation.

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Although comparing to the respiratory/phonatory subsystems, a similar trend was observed in the effect of unilateral DBS in STN on articulartory subsystem in the same six subjects, the variability was considerably large (see Figure 3), and the effect much less uniform. It is possible that different speech subsystems respond to unilateral STN stimulation differently due to different innervation of the nerve systems. Most of the supralaryngeal articulators are controlled bilaterally except for the lower face and tongue, which are predominantly contralaterally controlled [13], therefore, even if a micro lesion to the internal capsule might have occurred unilaterally, due to the bilateral innovation, the damage might have been compensated. And further, this compensation, if it did occur, might differ in one subject from the next, possibly due to individual differences in terms of neuronal control of language and the innovation of the articulators in a particular subject, or due to other factors such as gender difference. As it was shown in Figure 4, when the data were examined individually, the subject whose data demonstrated most consistent changes was S2. She was able to, in the stimulation-on condition, increase her articulatory rate on all three syllables. At the same time, she was able to decrease her percent (%) error score as well. Her data clearly demonstrate real positive changes in her articulatory subsystem associated with the DBS in STN. Again, the majority of the subjects did not show such a uniform pattern. Therefore, to draw a definite conclusion on how different speech subsystems will respond to DBS in STN in Parkinson’s disease, more data are needed from a greater number of subjects.

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