Effects of sub-thalamic deep brain stimulation on speech production in Parkinson's Disease: A Critical Review of the Literature

Les effets de la stimulation cérébrale profonde d'un noyau sous-thalamique sur la production de la parole chez les personnes atteintes de la maladie de Parkinson : un compte rendu critique des publications

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Abstract
This critical review examined the effects of subthalamic nucleus deep brain stimulation (STN-DBS) on speech in individuals with Parkinson's disease in eight studies. Study designs included: seven quasi-experimental studies and one case study. Overall, the evidence failed to provide support for the beneficial effects of STN-DBS on speech production in Parkinson's disease. It is suggested that the STN-DBS procedure requires additional refinements in order to be optimized for the treatment of speech symptoms. Additional studies involving more subjects, randomization procedures, control of severity level, and systematic manipulations of stimulation settings and locations are recommended.

Abrégé
Le présent compte rendu critique porte sur huit études, soit sept recherches quasi expérimentales et une étude de cas, qui traitant des effets de la stimulation cérébrale profonde d'un noyau sous-thalamique (SCP-NST) sur la parole des personnes atteintes de la maladie de Parkinson. Dans l'ensemble, il manque des données probantes pour appuyer les effets bénéfiques de la SCP-NST sur la production de la parole chez les parkinsoniens. Il faudrait améliorer la procédure de SCP-NST pour qu'elle agisse de manière plus optimale lors du traitement des symptômes de la parole. Il est recommandé de mener d'autres études faisant appel à davantage de participants, , à des procédures de randomisation, au contrôle du degré de sévérité ainsi qu'à la manipulation systématique des paramètres et des zones de stimulation.

Key words: Parkinson's, deep brain stimulation, subthalamic nucleus, speech

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Introduction

Marsden (1994) defined Parkinson's Disease (PD) as "a progressive degeneration of dopamine producing cells in the substantia nigra, resulting in increased inhibitory output of the basal ganglia to the thalamus and the brainstem locomotive center." The subthalamic nucleus (STN) provides excitatory input to the basal ganglia which in turn increases the inhibitory output of the basal ganglia to the thalamus, consequently resulting in more inhibition of the motor cortex. These changes in neural activity ultimately translate into disturbances in gait and facial expression, postural instability, akinesia, bradykinesia, rhythmic tremors, and rigidity of movement, which are the hallmarks of PD. In addition to the aforementioned characteristics, disturbances in speech and swallowing can also result and often co-occur in PD. Speech symptoms can include reduced perceptual loudness (hypophonia), a change in voice quality (i.e., breathiness, harshness, or tremor), monopitch, monoloudness, reduced stress, rapid speech rate, short rushes of speech, imprecise consonants, inappropriate silences, and reduced intelligibility overall (Duffy, 2005 p.189; pp.194-198).

Deep Brain Stimulation (DBS) has been documented in the literature to be a relatively recent and successful method of managing the overall gross motor symptoms associated with PD. The National Institute of Neurological Disorders and Stroke (NINDS, 2006) describes DBS as "a surgically implanted, battery operated device called a neurostimulator---similar to a heart pacemaker and approximately the size of a stopwatch---that delivers electrical stimulation to targeted areas of the brain that control movement, blocking the abnormal nerve signals that cause tremor and PD symptoms." For a number of years, the target areas for DBS treatment of PD symptoms were the thalamus and globus pallidus. The effects of these early surgical procedures on speech have been previously reviewed (Schultz & Grant, 2000; Maruska, Smit, Killer, & Garcia, 2000). Currently, the most common target area for DBS treatment of PD is the subthalamic nucleus (STN). (NINDS deep brain stimulation for PD, 2006). Subthalamic nucleus deep brain stimulation is currently considered superior to globus pallidus DBS because "the anti-akinetic effect seems to be more pronounced, allows a more marked reduction of anti-parkinsonian medication, and requires less stimulation energy." (Volkmann, 2004).

While there are a large number of reports describing the effectiveness of STN-DBS in reducing most motor symptoms associated with PD (i.e., tremors, rigidity, akinesia, and postural instability) (Hamani, Richter, Schwalb, & Lozano, 2005; Rodriguez-Oroz, Obeso, Lang et al., 2005), the number of studies examining the secondary effects of STN-DBS on speech in PD is limited. A critical review of the effects of STN-DBS treatment on speech is considered to be important to the field of speech-language pathology because many individuals with PD who are undergoing or considering STN-DBS treatment are dealing with a speech disorder and are attending a speech-language pathology clinic. These individuals will often seek advice from speech-language pathologists and other health care providers about the potential risks and benefits of STN-DBS treatment. In addition, if a critical review of the literature suggests that STN-DBS treatment is associated with the development of speech symptoms or a worsening of speech symptoms, this information needs to be communicated to speech-language pathologists who are working with individuals with Parkinson's disease.

Objectives

The primary objective of this paper was to outline and critically evaluate selected studies that have examined the effects of STN-DBS on speech production in patients with PD. A secondary objective was to evaluate information related hemispheric effects (left or right STN) and stimulation parameter settings on speech production in STN-DBS.

Methods

Search Strategy. Computerized databases, including PubMed, Medline, CINAHL, JNNP (online), Science Direct, CommDisDOME, PsycINFO, and the University libraries search engine were searched using the following search strategy: (Parkinson's Disease) AND (Deep Brain Stimulation) AND (Speech). The search was limited to English language and journal articles or reviews published before February 2007.

Selection Criteria. Studies included in this critical review were required to examine the effects of subthalamic deep brain stimulation (STN-DBS) on speech in patients with Parkinson's disease. All patients studied suffered from levodopa-responsive PD. No limits were set on the demographics (age, gender, culture, race, or socioeconomic status) of research participants, or type of speech parameter (e.g., vocal intensity, intelligibility, intonation, respiration, phonation, etc.) investigated. Studies included those conducted in North America, as well as those conducted in Europe and Australia.

Data Collection. Results of the literature search yielded eight articles consistent with the selection criteria: One case study and seven group studies involving quasi-experimental designs. Our intention was to review all peer-reviewed articles that have focused on the effect of STN-DBS on speech production in PD.

Results

Case-study. Hoffman-Ruddy, Schultz, Vitek, and Evatt (2001) looked at the effects of bilateral STN-DBS on voice and speech characteristics in a single male PD patient who had been living with PD symptoms for 7 years. The test protocol consisted of four conditions: (1) OFF-stimulation, OFF-medication; (2) ON-stimulation, OFF-medication; (3) OFF-stimulation, ON-medication; and (4) ON-stimulation, ON-medication. Speech tasks were administered by a speech-language pathologist (S-LP) and included three repetitions of maximum sustained vowel phonations, pitch glides, syllable repetition, short consonant-vowel-consonant (CVC) words and oral reading of a standardized passage. All recordings were analyzed using a Computerized Speech Lab (CSL) and Multi-Dimensional Voice Program (MDVP).

The largest changes in speech measures occurred between the ON-stimulation/ON-medication condition and the OFF-stimulation/OFF-medication condition. For the purposes of the present review, a comparison of the effect of stimulation in the OFF medication conditions is of greatest interest. Relative to the OFF-stimulation/OFF-medication condition, the ON-stimulation/OFF-medication condition was associated with the following: increased F0 (+18%), increased pitch range (+40%), increased sound pressure level in sentences (+18%), decreased jitter and shimmer (-42% and -52%), decreased standard deviation of voice onset time (-65%), and increased rate of syllables/sec (+160%).

Overall, these results suggest that STN stimulation can be associated with improvements in multiple speech and voice acoustic parameters in selected individuals with PD. These positive STN-DBS results need to be interpreted with caution, as they may not generalize to other individuals with PD.

Group Study #1. Gentil, Pinto, Pollak and Benabid (2003) examined non-speech oral force control and speech acoustics in 16 individuals who had received bilateral STN-DBS for the treatment of PD. Oral force control and speech acoustics were measured under two conditions: during bilateral STN stimulation and 30 minutes after stopping stimulation. Speech tasks included: (1) sustained /a/ and /i/ vowels; (2) repetition of the phrase "*Le petit chat joue avec la balle*" without stopping for 30 seconds; (3) production of short sentences at a conversational speaking rate; and (4) repetition of the nonsense word "*pataka*" as fast as possible 10 times.

The results for the non-speech oral force tasks indicated that the upper lip, lower lip, and tongue were associated with significantly larger maximal force, more rapid force rise-time and more accurate force tracking during the STN stimulation condition. For these non-speech force results the authors provided appropriate t-values and descriptive statistics. With regard to the results for the speech tasks, the authors state that they obtained significant results for a number of the acoustic measures but they failed to provide the appropriate t-values and descriptive statistics (i.e. standard deviation). The following acoustic measures of speech were reported to be significantly improved during STN stimulation: maximum phonation time (increased), diadochokinetic rate (increased), pause time (decreased), speech intensity (increased), and F0 variability in sustained vowels (decreased). These positive speech results need to be treated cautiously because of the inadequate reporting of statistical results.

Group Study #2. Dromey, Kumar, Lang, and Lozano (2000) investigated the effects of STN-DBS on acoustic measures of voice in seven patients with PD who received bilateral STN-DBS. Pre-surgery and 6 month follow-up data were reported. At both time points, speech recordings were made while patients were in an OFF-medication and an ON-medication state. Speech tasks included sustained vowel phonation and a 30 second monologue on a self-selected topic.

Mean and standard deviation of the fundamental frequency and speech intensity during sustained vowels were obtained with acoustic analysis software (Multi Dimensional Voice Program). A series of Wilcoxon signed ranks tests were used to evaluate changes in the acoustic measures across conditions. Intrameasurer reliability was reported (0.9987 to 0.9997).

For the purposes of the present review, the STN stimulation conditions in the unmedicated state were the most relevant. The comparisons of the stimulator on versus stimulator off conditions (both unmedicated) failed to show significant differences in any of the speech variables examined. In addition, the effects of STN stimulation on the individual patients were reported to be "modest and inconsistent." For example, four of the seven patients showed a small decrease in speech intensity while the other three patients showed a slight increase in speech intensity during STN stimulation.

Overall, the results of this study fail to provide evidence for an improvement in speech following STN-DBS. The authors acknowledge that the overall impact of these speech results is not substantial and would not represent a functionally useful change in speech performance.

Group Study #3. Wang, Verhagen Metman, Bakay, Arzbaecher and Bernard (2003) investigated the effect of unilateral stimulation of the STN on speech production in six right-handed PD patients with mild to moderate dysarthria. Three patients received implantation of the STN-DBS stimulator in the right STN, and three in the left STN. Speech recordings were made in the OFF-medication state (12 hours without medication) during a baseline pre-surgery condition, and at three months post-surgery in stimulator "on" and stimulator "off" conditions. Evaluators were blinded to the stimulator conditions until after the data were analyzed. The speech task included six maximally sustained vowel phonations. Four acoustic measures were obtained from these prolonged vowels: mean intensity, duration, mean F0 and jitter.

A mixed two-factor analysis of variance with repeated measures ($p < 0.05$) was used to evaluate speech performance across the stimulation conditions and the side of stimulation. None of the comparisons involving the STN stimulation "on" versus STN stimulation "off" conditions were associated with a significant change in the four speech variables examined (intensity, duration, mean F0, jitter). A non-significant trend was noted for the comparisons of left versus right STN stimulation effects in the intensity and duration data. Right STN stimulation tended to be associated with an increase in the intensity and duration of the prolonged vowels whereas left STN stimulation tended to be associated with a decrease in the intensity and duration of the prolonged vowels. These potential hemispheric effects need to be examined in future studies that include a greater number of subjects.

Overall, these results do not provide support for a beneficial effect of STN-DBS on speech production in PD.

Group Study #4. Subsequent to the above study, Wang, Verhagen Metman, Bakay, Arzbaecher, Bernard, and Corcos (2006) reported the results of a larger study that included the same series of patients plus additional patients. This inclusion of some subjects from the earlier study violates the statistical assumption of independent samples and therefore reduces the potential importance of the results. This study examined the effects of unilateral left versus right STN-DBS in twenty right-handed subjects with PD. Ten subjects received unilateral left STN-DBS and 10 received right STN-DBS. The side of STN-DBS was selected on the basis of the side of the body with the most severe motor impairments. Subjects were tested in the OFF-medication state (12 hours without medication) at baseline pre-surgery, and 3 months post-surgery with and without stimulation. The speech tasks included fast repetitions of the syllables "*puh*", "*tuh*" and "*kuh*". Three trials were obtained for each syllable repetition task. The first 4 seconds of each trial were used in the analysis. Twenty listeners (graduate students in S-LP) rated the samples on articulatory accuracy and speaking rate using a 0-4 rating scale. Acoustic measures obtained for each sample included: syllable rate, syllable duration, vowel duration, voice onset time (VOT), and fundamental frequency (F0). A mixed three-factor analysis of variance with repeated measures ($p< 0.05$) was used to evaluate the side of stimulation, test condition, and syllable type.

One of the main findings was that articulatory accuracy was rated as significantly worse when the STN stimulator was turned on relative to when the stimulator was off or relative to the pre-treatment baseline condition. In addition, left STN stimulation was associated with a significantly greater negative impact on articulatory accuracy than right STN stimulation. Hemispheric effects were also noted for speaking rate. Speech and syllable rates decreased significantly with left STN stimulation but remained unchanged or increased with right STN stimulation. The left and right STN stimulation had no significant effect on VOT or F0.

Overall, the results of this study fail to provide support for a beneficial effect of STN-DBS on speech production. In contrast, these results suggest a negative effect of STN-DBS on speech. The authors of this 4th group study suggest that this negative effect may be greatest in left sided STN-DBS. A major concern with this latter conclusion is that differences in the severity of the initial speech symptoms may have biased these apparent hemispheric effects in DBS. At baseline, the subjects in the left side group had poorer articulatory accuracy and slower speech rates than those in the right side group. It is possible that subjects with more severe speech symptoms respond differently to STN-DBS than those with less severe speech symptoms. If so, the differences observed in this study may have been directly related to the greater severity of speech symptoms in the left side group rather than any real differences in left versus right hemispheric effects of STN-DBS on speech. Future studies of hemispheric effects will need to control for the severity of speech symptoms.

Group Study #5. Santens, De Letter, Borsel, De Reuck, and Caemaert (2003) analyzed the effects of left and right STN stimulation separately on different aspects of speech in seven PD patients who had been implanted with a bilateral STN-DBS system. Speech tasks included a 200 word reading passage, and a sustained "*ah*" vowel in four different STN stimulation conditions: (1) left ON, right OFF; (2) right ON, left OFF; (3) bilateral stimulation OFF; and (4) bilateral stimulation ON. The four conditions were randomized within patients to avoid order effects. All speech samples were video-recorded. The video-taped reading of the passage was randomly presented to 22 S-LPs, blinded to the stimulator conditions, who provided visual analogue ratings for six different aspects of speech production: prosody, articulation, intelligibility, voice quality, loudness and speech rate. Inter-rater reliability was reported (ranging from 0.86 to 0.97). Effects of stimulation conditions on different characteristics were estimated using Friedman's non-parametric test for related samples ($p< 0.05$). Post-hoc Wilcoxon signed ranks tests were performed.

A primary finding from this study was that the comparison between bilateral stimulation "on" versus bilateral stimulation "off" revealed no significant changes in any of the ratings of the six speech parameters examined. For the comparisons involving the right versus left STN-DBS, only one significant finding was observed. In particular, selective stimulation of the left STN produced a significant negative effect (more abnormal) on the rating of prosody. There was also a non-significant trend for the left STN stimulation to produce negative effects on articulation and intelligibility. The results for the comparison of the right STN stimulation versus no STN stimulation produced no significant effects on any of the six speech parameters. Finally, the results for the duration of the prolonged vowel "*ah*" across the various stimulation conditions produced no significant effects.

In general, this perceptual rating study fails to provide support for a beneficial effect of bilateral STN-DBS on speech production. In contrast, these results suggest that there may be a moderate negative effect of left-sided STN-DBS on speech prosody.

Group Study #6. A study by Tornqvist, Schalen, and Rehncrona (2005) examined the effects of different STN-DBS parameter settings on speech performance in PD. Speech recordings were obtained from ten subjects with PD under 11 different parameter settings. The order of the 11 settings was randomized in each subject. For each parameter setting condition, the patients were required to read a standard running text in Swedish and then five syntactically correct nonsense sentences from a dysarthria test. The recorded speech samples were randomized and presented to a panel of ten listeners (including five S-LPs) who were blinded to the experimental conditions. The listeners orthographically transcribed the words in the nonsense sentences. These transcriptions were used to determine the patients' intelligibility scores. Listeners also used a visual analogue scale to rate the overall intelligibility, precision of articulation, and quality of voice for all reading samples. Rate of speech was calculated as syllables per second using the time counter on the recording instrument.

Intra and inter-rater reliability of the judges were calculated with the Spearman rank correlation coefficient. For each patient and each tested parameter setting, the mean value of the 10 listeners' evaluations was calculated for further statistical analysis ($p < 0.05$; $r > 0.70$). Effects of stimulation conditions on the different speech characteristics were examined statistically with two non-parametric tests; the Wilcoxon test for matched pairs and Friedman's test followed by Dunn's procedure for multiple comparisons ($p < 0.05$).

With regard to the objectives of the present review, one of the most important findings of this study was that STN stimulation was associated with a decrease in speech intelligibility scores (-25%) when compared to the no STN stimulation condition. This result approached statistical significance ($p = 0.058$). With regard to the effects of changes in the stimulation parameter settings, two important results were reported. First, an increase in the amplitude of the stimulators, to 25% above usual levels, was found to produce a significant deterioration in the intelligibility and articulation ratings. Second, reducing the frequency of stimulation, from usual levels of about 130Hz down to 70Hz, was found to produce a significant improvement in the intelligibility and articulation ratings ($p = 0.01$).

Overall the results of this study fail to provide support for a beneficial effect of STN-DBS on speech production. In contrast, these results provide weak support for a negative effect of STN-DBS on speech. In addition, this study suggests that adjustments in the amplitude and frequency of the stimulus parameters may reduce the negative consequences of STN-DBS on speech production.

An important limitation of the study was that it included three patients who were previously treated with unilateral ablation neurosurgery (thalamotomy) for PD.

Group Study #7. A study by Tripoliti, Dowsey-Limousin, Tisch, Borrell, and Hariz (2006) compared the effects of medication and STN-DBS on speech production in 16 patients with PD. The 16 patients were randomized to two treatment groups: Eight patients continued to receive their regular anti-parkinson medication only and eight patients received bilateral STN-DBS treatment (and a parallel decrease in their anti-parkinson medication). All patients were assessed on and off medication at baseline and 1 year later (post STN-DBS insertion). At the 1 year assessment, the STN-DBS patients were evaluated with the stimulator on and off. The speech tasks included sustained phonation, sentence reading, and one minute of monologue. Speech measures included intelligibility scores (CAIDS), the intensity of sustained phonation, and the long-term average spectrum (LTAS) of the sentences and monologue. Statistical analysis involved matched pairs t-tests to compare the baseline and one year results and independent samples t-tests to compare the medication only and STN-DBS treatments ($p < 0.05$).

One important finding was that, relative to the baseline, there was no significant change in speech intelligibility following the STN-DBS treatment. The authors also note that two patients showed a fairly large (40%) decrease in intelligibility following STN-DBS. The results for the intensity of sustained phonation are difficult to interpret. The intensity of sustained phonation was significantly higher for the STN stimulator "on" (and medicated) condition when compared to the baseline condition. Unfortunately, the study did not report the results for the comparisons of the stimulator "on" versus "off" conditions or the comparisons involving the unmedicated conditions. These limitations make it difficult to evaluate the effects of STN-DBS on speech in this study. With regard to the results for the long-term average spectra, this study failed to find a significant difference between the baseline condition and the STN-DBS condition.

Overall, the results of this study failed to provide support for the beneficial effects of STN-DBS on selected measures of speech intelligibility and intensity. The results also suggest that STN-DBS can have a substantial negative effect on speech intelligibility in some individuals.

Discussion

The evidence from these eight studies needs to be interpreted with caution because all of the studies included fairly small sample sizes. The sample sizes for the seven group studies ranged from 6 to 20 subjects and most of these group studies (five out of seven) had less than 10 subjects. In addition, the experimental methodologies used in these studies were quite diverse which made it difficult to make comparisons across studies. For example, the types of speech tasks used across these studies included maximum sustained vowels, pitch glides, syllable repetitions, sentence repetitions, reading aloud, and monologue. One study also included a non-speech oral force task. A diversity of speech measures were obtained from these speech tasks. These included acoustic measures of speech intensity, fundamental frequency, jitter, shimmer, voice onset time, long-term average spectra, and syllable durations. The various perceptual speech measures included listener ratings of articulatory accuracy, speech rate, prosody, intelligibility, voice quality, and loudness. Despite the sample size limitations and the diversity of experimental speech procedures used, some important trends emerged. First, almost all (six out of seven) of the group studies failed to find support for a beneficial effect of bilateral STN-DBS on various measures of speech production. These included both acoustic measures (i.e. SD of F0, intensity of sustained phonation, maximum phonation time (MPT), jitter, long-term average spectra (LTAS)) and perceptual measures (i.e. articulatory accuracy, intelligibility, prosody, voice quality, loudness). Second, four of the seven group studies reported negative effects of STN-DBS on speech production. Speech parameters associated with negative effects included intensity of sustained phonation, MPT, articulatory accuracy, prosody and intelligibility. In addition, three of these studies provided preliminary evidence that left-sided STN stimulation is associated with a greater negative effect on speech production than right-sided STN stimulation. Finally, the two studies that reported positive effects of STN-DBS stimulation included a case study and a group study that failed to provide sufficient statistical information to allow for an accurate evaluation of the experimental evidence. Therefore, the evidence for positive effects of STN-DBS on speech is considered very limited. Although the present review suggests a fairly consistent trend in the evidence across the eight studies, it should be noted that some of the studies were associated with minor concerns related to their experimental procedures. In order to reduce these concerns, it is recommended that future studies of STN-DBS give consideration to including the following experimental procedures: an evaluation of STN-DBS subjects when they are both on and off their anti-parkinson medications, a detailed reporting of time periods between medication ingestion and experimental testing, a clear and detailed description of perceptual and acoustic speech measurement procedures, an inclusion of connected speech and conversational speech samples, an inclusion of outcome measures based on self-reporting procedures, and a careful and detailed reporting of statistical procedures.

The overall conclusion of this review is that bilateral STN-DBS is not generally associated with a beneficial (positive) effect on speech production in PD. In contrast, several studies report negative effects of STN-DBS on speech. These negative effects may be more apparent for left-sided STN stimulation than right-sided STN stimulation. In addition, there appears to be a fair bit of individual variation in the speech response to STN-DBS. Across the eight studies reviewed, there were several reports of individual subjects showing either a substantial positive or negative effect of STN-DBS. The source of this substantial inter-subject variation needs to be addressed in future STN-DBS studies of speech outcomes. Some potential sources of variation that may need to be evaluated include: the duration and stage of PD, the age of onset of PD (i.e. young onset versus older onset), the severity of dysarthria, the prominence of specific speech deficits (i.e. hypophonia, rapid speech, dysfluency, etc.), the combined effects of STN-DBS and anti-parkinson medications, the effects of previous surgical procedures (i.e. thalamotomy plus STN-DBS), and the duration of time since STN-DBS (i.e. long-term effects of STN-DBS on speech) .

The novel results from the study by Tornqvist, et al., (2005) indicate that the STN-DBS parameter settings can have important positive and negative effects on speech production. Additional systematic studies of the effects of parameter settings on speech are required. It is anticipated that the results of these types of studies will lead to important refinements in the STN-DBS procedure and improved outcomes in speech production. Additional refinements may also be achieved through studies that systematically examine the effects of different STN stimulator locations on speech production. Currently, the STN procedure is usually focused on placing the stimulator into STN locations that are most likely to provide maximum benefit to the non-speech limb symptoms. Potential benefits to the speech symptoms do not usually factor into the decision about the final location of the STN stimulator. Additional studies involving the placement of stimulators into new STN locations that are involved in speech production are required. It is anticipated that these STN studies involving targeted speech locations may lead to improved speech outcomes in the STN-DBS procedure. Unfortunately, studies involving focused speech target STN-DBS locations may need to await the development and regular use of stimulators with the capability of providing multiple sites of STN stimulation. It should be noted that there have been a few preliminary reports involving new multiple site thalamic stimulation electrodes used in the treatment of tremor (Foote & Okun, 2005; Lim, Khandhar, Heath, Ostrem, Ringel, Starr, 2007). Until these multi-location stimulators are developed for placement in the STN, it is unlikely that speech sites will be given priority over the standard non-speech limb sites in STN-DBS treatment.

The conclusion from the present review, that bilateral STN-DBS does not generally produce beneficial effects on speech, is in marked contrast to the numerous reports of significant positive effects of STN-DBS on most of the non-speech, limb symptoms in PD (Hamani, et al., 2005). This finding appears to be consistent with the growing evidence that interventions that lead to fairly consistent improvements in non-speech motor control (especially limb movements) often have neutral or negative outcomes for speech in Parkinson's disease (Kent, 2003). This may be related to the unique genetic, developmental, functional and phenotypical properties of the speech muscles (Kent, 2003) and/or fundamental differences in the role of dopaminergic processes in the regulation of speech and limb movements (Kompoliti, Wang, Goetz, Leurgans, and Raman, 2000).

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