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# The Impact of Deep-Brain Stimulation on Speech Comprehensibility and Swallowing in Patients with Idiopathic Parkinson's Disease

David E. Ryder
*University of Rhode Island*, ceec55@hotmail.com

# THE IMPACT OF DEEP-BRAIN STIMULATION ON SPEECH COMPREHENSIBILITY AND SWALLOWING IN PATIENTS WITH IDIOPATHIC PARKINSON'S DISEASE

BY

DAVID E. RYDER

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DAVID E. RYDER

APPROVED:

Dissertation Committee:

Major Professor Leslie Mahler

Dana Kovarsky

Walter Besio

Nasser H. Zawia
DEAN OF THE GRADUATE SCHOOL

UNIVERSITY OF RHODE ISLAND
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## ABSTRACT

**Objective:** This is a pilot study designed to assess speech and swallowing characteristics of participants with idiopathic Parkinson's disease (IPD) before deep brain stimulation surgery of the subthalamic nucleus (DBS-STN), after the DBS-STN surgery, and at follow up evaluation sessions.

**Method:** A within participant, single-subject experimental A-B-A-A design was used to measure changes in the dependent variables for each participant. The primary dependent variables were intelligibility scores of words and sentences, vowel space area (VSA), vocal sound pressure level (dB SPL) of sustained vowels, single words, and contextual speech, Multidimensional voice program (MDVP) analysis of phonatory stability of sustained vowel phonation, lip pressure, tongue pressure, maximum inspiratory pressure (MIP), maximum expiratory pressure (MEP), and diadochokinetic rates. The secondary dependent variables were: duration of sustained vowel phonation, visual analog scales (VAS) for communication characteristics and swallowing characteristics, the EAT-10 swallowing questionnaire, and the qualitative narrative of life with IPD before and after the DBS-STN surgery.

**Results:** DBS-01 had significant declines of intelligibility with individual words, but did not have statistically significant changes for complete sentences. The VSA declined over the course of the study. The MDVP analyses indicated general declines in phonatory stability, but not significantly. There was a statistically significant increase in dB SPL for sustained vowel phonation, but there were overall declines in loudness for connected speech. The duration of sustained

vowel phonation increased and the DDK rate varied across the evaluations. Left lip and tongue pressures had overall declines, but right and center lip pressures increased. MIP and MEP exhibited overall declines. The VAS for communication characteristics revealed worsening of symptoms. The VAS and the EAT-10 questionnaire for swallowing difficulties both recorded worsening of symptoms after surgery, and symptom improvements at follow up. The timed swallow test did not show any meaningful impairment in drinking or eating. The interviews revealed that IPD motor symptoms improved, speech characteristics declined, cognitive and emotional characteristics did not change, and swallowing symptoms slightly worsened across the evaluations.

DBS-02 had statistically significant gains of intelligibility with individual words after the DBS-STN surgery, but had statistically significantly declines at follow up. The changes in the intelligibility of complete sentences were not significant. The VSA contracted after the surgery, but it increased at follow up. The MDVP analyses indicated an overall significant increase of phonatory stability. The dB SPL had a statistically significant increase for sustained vowel phonation, but the connected speech loudness had mixed results. The duration of sustained vowel phonation increased after surgery, but then declined at follow up. The DDK rate varied across the evaluations. Lip and tongue pressures had overall increases. MIP and MEP exhibited overall increases. The VAS for communication characteristics revealed an overall improvement in symptoms. The VAS and the EAT-10 questionnaire for swallowing difficulties both recorded a decrease in symptoms after surgery, and an increase at follow up. The timed

swallow test did not show any meaningful impairment in drinking or eating. The interviews revealed that IPD motor symptoms improved, speech characteristics improved, cognitive and emotional characteristics improved, and swallowing symptoms did not change across the evaluations.

**Conclusions:** DBS-01 did not demonstrate significantly statistically significant changes in speech and swallowing characteristics following DBS-STN, although the delay in assessment after the surgery made distinguishing the effects of the surgery from progressive IPD symptoms difficult. DBS-02 made statistically significant improvements on selected dependent variables immediately following DBS-STN, and then declines towards the baselines were measured at follow up.

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# CHAPTER 1

## INTRODUCTION

### 1.1 Research Introduction

This research project was a pilot study designed to determine how deep brain stimulation of the subthalamic nucleus (DBS-STN) affected characteristics of speech and swallowing in participants with idiopathic Parkinson's disease (IPD). DBS-STN has been in use for over twenty years to treat motor dyskinesias (involuntary, faulty motor movements) caused by the long term use of levodopa. This procedure allows the drug regimens to be reduced, thereby attenuating dyskinesia symptoms. However, the impact of DBS-STN on speech and swallowing function is not clearly understood. The purpose of this project was to determine which variables related to speech and swallowing significantly changed based on a comparison of data obtained in evaluations collected prior to and following the DBS-STN surgery. This data was used to determine which variables were the most sensitive in detecting the impact of DBS-STN on speech and swallowing variables.

### 1.2 Idiopathic Parkinson Disease Background and Deep Brain Stimulation Treatment

IPD is an age related, progressive neurological disorder of unknown etiology that afflicts millions of people worldwide (Hammer, Barlow, Lyons, & Pahwa, 2010). The incidence rises steadily with age starting around forty years and peaking at eighty years and beyond (Schapira, Olanow, Greenamyre, & Bezard, 2014). IPD is characterized by the loss of dopamine and dopaminergic neurons located in the substantia nigra pars compacta region of the midbrain as well as widely dispersed regions of the brainstem and forebrain (Barker, & Foltynie, 2004; Braak, Ghebremedhim, Rüb, Bratzke, & Del Tredici, 2004).

The cardinal manifestations of IPD include bradykinesia, hypokinesia, rigidity, resting tremor, and postural instability. These symptoms result from progressive damage to the basal ganglia, and a reduction of dopamine in the striatum and dopamine receptors that can result in changes to motor and sensory control of speech and swallowing (Bergman & Deuschl, 2002). However, the neural mechanisms underlying the effects of dopamine loss and its impact on speech and voice are not well understood. Physiological abnormalities associated with speech and voice changes in people with IPD include reduced vocal fold adduction and asymmetrical patterns of vocal fold vibration (Perez, Ramig, Smith & Dromey, 1996; Smith, Ramig, Dromey, Perez, & Samandari, 1995); reduced neural drive to laryngeal muscles (Baker, Ramig, Luschei, & Smith, 1998); poor reciprocal suppression of laryngeal and respiratory muscles (Vincken et.al., 1984); and a reduction in respiratory muscle activation patterns (Solomon & Hixon, 1993). All of these changes contribute to the perceptual features of significantly decreased loudness, monopitch, and imprecise articulation in people with IPD. However, motor characteristics of rigidity, weakness, bradykinesia, and hypokinesia do not completely account for the speech abnormalities associated with IPD. Additional non-dopaminergic mechanisms such as sensory deficits in the internal monitoring of amplitude and maintaining amplitude of speech movements and volume of speech are significant factors that also contribute to decreased loudness, imprecise articulation, and limited pitch variation (Desmurget, Grafton, Vindras, Grea, & Turner, 2004; Sapir, Ramig & Fox, 2011). Impairment of the oropharyngeal muscles typically results in hypokinetic dysarthria, and can ultimately lead to dysphagia and its symptoms of diminished swallowing capacity, inadequate transfer of solids or liquids to the esophagus, and silent aspiration of food or liquids into the lungs (Pringsheim, Jette, Frolkis, & Steeves, 2014; Russell, Ciucci, Connor, & Schallert, 2010; Xie et al., 2010).

DBS-STN is well documented to alleviate motor-related side effects that result in response to excessive levels of the drug levodopa during treatment. Multiple studies have demonstrated that the effective dose of levadopa required for motor symptom control decreased for the majority of the patients that had the procedure (Barker, & Foltynie, 2004; Mate, Cobeta, Jiménez-Jiménez, & Figueiras, 2011). However, there is no consensus on the impact that DBS-STN surgery has on speech characteristics and communication. Some studies have shown overall increases, decreases, or mixtures of changes of communication difficulties. (Ahlberg, Laakso, & Hartelius, 2011; Åström et al., 2010; Lundgren et al., 2011; Skodda, 2012). There is also a lack of published research on the effects of DBS-STN surgery on swallowing ability in patients with IPD. Most of the studies of swallowing difficulty are only related to IPD without surgical intervention, and others only note dysphagia symptoms as side effects in passing. Most crucially, no primary research journal articles are known that examined DBS-STN and its effects on communication and swallowing characteristics concurrently in the same participants with IPD (Troche, Brandimore, Foote, & Okun, 2013).

## 1.3 Statement of Purpose

The purpose of this study was to assess specific effects of DBS-STN on the speech and swallowing characteristics of participants with IPD. The null hypothesis predicted that there would be no statistically significant changes between speech and swallowing variables prior to DBS-STN surgery compared to after surgery. The null hypothesis was assumed as this was an exploratory research project documenting the effects of DBS-STN and changes in stimulator settings on IPD symptoms without knowing the outcomes in advance. The specific aims for this study are to:

1. Address the lack of data describing the effects that DBS-STN surgery has on speech intelligibility, speech parameters and swallowing ability in the same individuals by using a wide variety of in-depth assessment tasks.
2. Determine which, if any, of these dependent variables show statistically significant differences pre and post-DBS-STN surgery, and use them to outline which assessment tasks can be streamlined for use in expanded studies.

## 1.4 Methodology

The goal of this project was to assess speech and swallowing deficits in participants before and after receiving DBS-STN surgery. It was a within subject, longitudinal study that had a pre surgery assessment, followed by a post surgery and follow up assessments designed to track symptom changes. The post surgery evaluation was designed to be less than a month after the surgery date. The assessments were divided up into eleven tasks that were administered at each section. These tasks were grouped into speech issues, motor support structures such as the tongue, lips, and respiratory support, and self assessment using scales and qualitative narratives. The assessments were based on a variety of twelve dependent variables on speech, speech support systems, and swallowing that were monitored and interpreted. Statistical analysis was used to determine if there were any significant changes for most of the dependent variables.

1.5 Delimitations of the study

The most important limitation of this study is that unless more than a small number of participants are recruited, the study will be confined to a within patient design. Without sufficient numbers of participants, the results cannot be meaningfully applied to a larger population, which in this case are participants with IPD who are undergoing DBS-STN surgery. Another limitation is that some tasks are likely to be more sensitive to changes in motor, speech or swallowing symptoms than others, although there is a redundancy of some of the tasks that aim to quantify the same dependent variable.

1.6 Technical Definitions

**DBS-STN:** Deep brain stimulation in the subthalamic nucleus region of the basal ganglia with electrical stimulation.

**EAT-10 Questionnaire:** a set of ten questions on swallowing difficulty where the participant must choose a whole number from 0-4 points to rate their response to each of the 10 questions. It was scored as a cumulative total from 0-40 points.

**MDVP-**Multidimensional Voice Program: a computer program used to measure a variety of speech characteristics extracted from sample sustained vowel phonation. It can chart changes in frequency, loudness, voice interruptions, and harmonics ratios.

**VAS:** Visual analog scale on swallowing or speech issues that asks participants to mark a continuous scale between opposing statements at either end. It is rated from 0-100 percent.

## 1.7 Scientific and clinical contributions

The wider purpose of this research project was to design and execute an innovative pilot research project that focuses on speech and swallowing disorders in the same participants before and after DBS-STN surgery. After streamlining the assessment process by eliminating redundant tests or tests that failed to accurately or sensitively document changes in speech and swallowing symptoms, this research design can be expanded in the future to include more patients, and inspire other research in a similar vein to counteract the lack of knowledge in this area of IPD research. Although there is a substantial body of literature on motor disorder symptoms in IPD, much more remains to be uncovered about speech and swallowing deficiencies. Dysarthria is a social disabling condition that results in patient isolation, and a breakdown in communications. Dysphagia is a potentially lethal condition that can cause premature death in patients. These are symptoms worthy of research in much more depth than is currently available in the literature, and the main goal of this research is to contribute to this vital area of inquiry.

# CHAPTER 2

# REVIEW OF LITERATURE

## 2.1 Parkinson's Disease Background

Parkinson's disease (PD) is an incurable, progressive, age-related (40-80 year old onset range), environmentally-triggered or genetically based, neurodegenerative disorder that degrades specific neural pathways over many years, especially in the basal ganglia. PD afflicts millions of individuals worldwide, and has an incidence rate of 1200-1500 per 100,000 in North America. A small percentage of PD cases have a genetic basis, but the majority of individuals are diagnosed with idiopathic PD (IPD) which is of unknown origin (Pringsheim, Jette, Frolkis, & Steeves, 2014). Research has documented that individuals with IPD suffer from physiological and psychiatric impairments including motor, cognitive, perceptual, speech, and swallowing impairments that progressively worsen over time (Bridges, Van Lancker Sidtis, & Sidtis, 2013; Khan, Westin, & Dougherty, 2013; Schapira, Olanow, Greenamyre, & Bezard).

### 2.1.1 Motor Dysfunction in Parkinson's Disease

Motor dysfunction is one of the earlier disease symptoms to emerge in IPD, and is caused by a failure of the motor control center in the substantia nigra pars compacta. The motor symptoms of IPD include impairment of limb motor control, speech, breathing, and the decline of motor control of respiratory, laryngeal, and supralaryngeal structures (Hammer, Barlow, Lyons, & Pahwa, 2010). The canonical motor symptoms of IPD include rigidity (muscle inflexibility and stiffness), bradykinesia (difficulty in initiating motor action), hypokinesia (reduced amplitude of motor action), postural instability (prone to falls), and resting tremor (involuntary motions when not executing a motor action), all of which greatly impair mobility (Bergman, & Deuschl, 2002; Duffy, 2013). Varying doses of levodopa and drugs to enhance their effectiveness are used in the earlier stages of the disease to alleviate symptoms caused by the lack of the dopamine (DA) neurotransmitter generating cells in the substantia nigra region of the midbrain (Bridges, Van Lancker Sidtis, & Sidtis, 2013; Khan, Westin, & Dougherty, 2013). The drug regimens help to ease the major motor symptoms, but levodopa causes substantial side effects that may be amplified over time as the dosage is increased. The continual loss of susceptible neurons in the substantia nigra in the later stages of the disease causes levodopa to become increasingly ineffective. The higher therapeutic doses of levodopa cause an increase in motor dyskinesias (unwanted, involuntary limb movements) and a wearing off of medication over shorter and shorter periods of time. Once the patient has reached this stage of the disease, then alternate treatments such as lesioning (deliberately destroying) specific regions of the basal ganglia or using deep brain electrical stimulation can be used to lower the drug doses and ease the side effects of dyskinesia (Barker, & Foltynie, 2004; Fasano et al., 2010; Fernandez, 2012).

### 2.1.2 Dysarthria in Parkinson's Disease

Damage to the nervous system caused by IPD spreads superiorly from the brainstem, causing other systems to be impacted including facial, speech, and swallowing muscles. The facial muscles can develop rigidity, which can lead to masked facial expression that reduces the appearance of emotional expression. Speech disorders are a frequent occurrence in individuals with IPD. Speech changes associated with IPD are characteristic of hypokinetic dysarthria which occurs at a 90% rate over the course of the disease (Arnold, Gehrig, Gispert, Seifried, & Kell, 2014). The speech symptoms of IPD include a slowed speech rate (although palilalia late in the disease course is a unique example of an accelerated, unintelligible speech rate), hypophonia (decibel sound pressure level of the voice is consistently subnormal), monopitch (changes in the frequency of speech is diminished), and monoloudness (changes in the decibel sound pressure level of speech is diminished). These symptoms impair functional speech communication, and pinpoint the damage to the basal ganglia (Darley, Aronson, & Brown, 1975; Duffy, 2013; Logemann, Fisher, Boshes & Blonsky, 1978; Xie et al., 2010). The pathophysiology of hypokinetic dysarthria in individuals with IPD can affect respiration, phonation, resonance, and articulation. Many individuals with IPD have non-motor components that contribute to speech disorders in addition to motor changes. Auditory sensory misprocessing of sound levels through interactions of higher order processing of the damaged basal ganglia can lead to individuals with IPD consistently overestimating their own volume level in conversation (Dromey, & Adams, 2000; Ho, Iansek, & Brawshaw, 1999). Experiments with functional magnetic resonance imaging (fMRI) have shown that hypophonia is linked to a faulty interplay between regions of the striatum prefrontal cortex that block the patient’s ability to self monitor appropriate speech loudness prior to the symptomatic phase of IPD. Intensive speech training is the only way to restore normal conversational loudness via external cueing (Arnold, Gehrig, Gispert, Seifried, & Kell, 2014).

### 2.1.3 Dysphagia in Parkinson's Disease

Individuals with IPD will experience dysphagia symptoms because speech and swallowing are overlaid functions and share a common pathophysiology. The musculature used for swallowing uses many of the same muscle groups as those used for speech; these include the face, jaw, lips, tongue, soft palate and pharynx (Solomon, 2006). Studies have shown that a majority of individuals with IPD experience changes in swallowing that cause dysphagia (the inability to properly transfer food or liquid from the oral cavity into the digestive tract). Dysphagia is associated with aspiration pneumonia in the latter course of the disease and can have significant health consequences. The pathogenesis of aspiration pneumonia is largely attributed to the presence of impaired muscle control of swallowing which leads to silent aspiration, which is defined as food or water entering the lungs without sensory awareness as evidenced by the lack of a cough response (Troche, Brandimore, Foote, & Okun, 2013). It is useful to assess inspiratory and expiratory pressures, since respiration is closely linked with dysphagia. Aspiration of food or liquids is more likely to occur if there is reduced respiratory support (Ramig et al., 2001). Many individuals with dysphagia also suffer from malnutrition, or dehydration. Aspiration pneumonia caused by inhaled food or liquids is a leading cause of death in individuals with IPD (Beyer, Herlofson, Arsland, & Larson, 2001; D'Amelio et al., 2006; Tjaden, 2008).

## 2.2 Deep Brain Stimulation and Parkinson's disease

Deep brain stimulation (DBS) is a surgical technique used as a means for treating the dyskinesia side effects by lowering the inhibition of signals to the motor area and allowing a reduction in the effective amount of levodopa and other drugs needed to treat IPD motor symptoms. There are a variety of targets in subcortical areas that can be stimulated in the case of IPD including the globus pallidus internal in the basal ganglia, the zona incerta in the subthalamus, and the subthalamic nucleus in the basal ganglia (Johansson et al., 2013, Perlmutter, & Mink, 2006). DBS of the subthalamic nucleus (DBS-STN) has been the most fully investigated of the three locations. Surgery at this site demonstrated the most significant clinical benefit of reducing motor symptoms and levodopa reduction for individuals with advanced IPD of all the possible stimulation sites (Ferreira et al., 2013; Kleiner-Fisman et al., 2006). DBS involves a set of implantable internal electronic devices designed to deliver adjustable periodic pulses of current to the stimulation site to treat a variety of neurological disorders, including IPD. A pre-surgery MRI is followed by electrode (or lead) implantation in either hemisphere or both using stereotactic surgery. The individual is typically awake during the procedure and is off levodopa medication in order to assess the isolated effects of DBS stimulation during device testing. The leads typically have four circumferential rings at the tip, are connected to subdermal leads that link up with either 1-channel, or 2-channel pattern pulse generators implanted subdermally in the chest region. Placement of the electrode tips need to be verified with microelectrodes during the implantation surgery or a MRI post-surgically to confirm the electrode position and stimulation amount of the subthalamic nucleus (Aviles-Olmos et al., 2014; Gross, Krack, Rodriguez-Oroz, Rezai, & Benabid, 2006; Larson, 2014). DBS-STN reduces the effective levodopa doses, resting tremor and bradykinesia symptoms. It carries the additional benefit of reducing the time spent in the off levodopa state of increased IPD symptoms (Fasano et al., 2010; Ferreira et al., 2013; Mate, Cobeta, Jiménez-Jiménez, & Figueiras, 2011). Neither the levodopa nor DBS-STN can stop or slow IPD progression, as they can only reduce its motor symptoms (Merola et al., 2011).

## 2.3 Deep Brain Stimulation's Effect on Speech and Swallowing

The pulse generators operate at a functional range of 0-4V amplitude, a frequency range (pulses per second) of 125-200 Hz, and a pulse width (stimulation duration) of 60-90 µs. They are adjusted to maximize limb motor movement. High stimulation frequencies of 50-200 Hz inhibit the subthalamic nucleus, and allow the beneficial effects that facilitate drug regimen curtailment. High potential stimulation (~4V) provide a distinct advantage to limb control, but often fails to improve speech. Lower stimulation settings (~2V) are not as beneficial for motor improvement, but frequently are less detrimental for speech. The differential symptom outcomes for the stimulation parameters is likely due to the fact that limb muscles have a coarser control system with a higher innervation ratio versus the precision control required for speech muscles (Åström et al., 2010; Dostrovsky, & Lozano, 2002; Skodda, 2012). There is consensus in the literature that properly placed electrodes are highly beneficial in partially offsetting the loss of motor control. The effect of DBS-STN on speech is far more diverse, with some studies reporting a decrease in speech impairments, and others reporting an increase (Tripoliti et al., 2014; Voon, Kubu, Krack, Houeto, & Tröster, 2006).

A review of the literature indicated that individuals who developed dysphagia as an adverse side effect from DBS-STN surgery was an uncommon occurrence. No study to date has systematically investigated how DBS in any location has affected dysphagia symptoms pre and post-surgery. There is an urgent need to uncover more information about the interaction of DBS-STN and IPD related dysphagia (Appleby, Duggan, Regenberg, & Rabins, 2007; El Sharkawi et al., 2002)

## 2.4 Need for the Present Study

We do not have a complete understanding of the underlying physiologic mechanisms of how the neuronal changes caused by DBS-STN improve the motor symptoms for individuals with IPD. The basic theory is that the DBS-STN mimics the effects of a lesion, but uses stimulation instead to inhibit, excite, or block neuronal firing. Even less is known about the effects of DBS-STN on the motor mechanics of speech and swallowing impairments. Some studies report a worsening of speech, voice and swallowing following DBS surgery even in the presence of improved limb mobility (Benabid, Chabardes, Mitrofanis, & Pollack; Duffy, 2013; Troche, Brandimore, Foote, & Okun, 2013; Wang, et al., 2006). Data from the current study can provide a better understanding of individuals with IPD who may have significant changes of speech and swallowing characteristics following surgery, and thus inform potential treatment options post-surgery.

# CHAPTER 3

# METHODOLOGY

## 3.1 Research Design

The primary objective of this study was to assess specific traits of speech and swallowing before and after DBS-STN surgery in patients with idiopathic Parkinson's disease (IPD). The symptoms of IPD are greater than a set of motor impairments; dysarthria (motor speech impairment) and dysphagia (swallowing impairment) are important disorders that have not been systematically measured together pre and post surgery. A pilot study was designed to study speech and swallowing in depth, with the expectation that this initial research would yield information on how DBS-STN would affect these variables. A single-subject A-B-A-A research design was used to fulfill this goal to detect whether DBS-STN had an impact on the characteristics of speech, voice and swallowing for two participants with Parkinson's disease.

All evaluations were conducted at the University of Rhode Island Speech and Hearing Centers located in Independence Square I (Pawtucket, Rhode Island) and Independence Square II (South Kingston, Rhode Island). The University of Rhode Island Institutional Review Board (HU1112-090) approved this research project.

## 3.2 Characteristics of the Study Population

Two participants diagnosed with IPD (DBS-01 and DBS-02) were recruited for the study. The speech and swallowing evaluation tasks that were administered were considered low risk, and were well tolerated by both participants. Both participants successfully completed a pre-surgery and two post-surgery evaluations.

DBS-01 was a 53-year-old male with IPD who was two years post diagnosis. He was a high school graduate retired from his job as a commercial fisherman due to disabling IPD symptoms. He was married and had a close relationship with his son, who became a fisherman like his father. His symptoms included muscle stiffness, difficulty maintaining balance, joint pain, freezing in gait, resting tremor, constipation, difficulty in urinating, and micrographia. He also reported memory problems, anxiety, and short periods of depression. Physical observations revealed a pronounced resting tremor in the right hand which abated when he was writing. His speech was reduced in volume with mildly imprecise articulation and decreased intonation variation. He was notably hypophonic and he occasionally had to repeat himself to be understood. Overall, his speech and voice characteristics were consistent with a hypokinetic dysarthria type of speech impediment. DBS-01 received bilateral electrode placements in the subthalamic nucleus. Stimulator settings for DBS-01 are in Table 1.

DBS-02 was a 58-year-old male with IPD who was five years post-diagnosis. He was a high school graduate. He worked in an insurance office, until IPD symptoms forced him into retirement. He had a passion for history, genealogy, and participating in theater productions. He lived alone and was a skilled model builder. His initial symptoms of PD were micrographia and a resting tremor in the right leg and arm. Additional symptoms included muscle slowness, rigidity, and vivid dreams. He also reported breathy voice, monotone pitch, and slurred speech. He reported the hypophonia as having a slow onset and becoming more pronounced over a two-year span; the participant occasionally had to repeat himself to be understood. The results of the motor speech examination were consistent with a diagnosis of hypokinetic dysarthria. Mild dysphagia was indicated by drooling and by food sticking in the throat. DBS-02 received unilateral electrode placement in the left subthalamic nucleus. Stimulator settings for DBS-02 are in Table 1. Deep brain stimulator lower and upper electrode settings obtained from reviewing the literature are also included in the table (Åström et al., 2010; Hammer, Barlow, Lyons, & Pahwa, 2010; Silveri et al., 2011; Skodda et. al., 2014; Spielman et al., 2011).

Table 1. DBS-01 and DBS-02 DBS-STN Stimulator Settings and Current Medications

| Categories | DBS-STN Ranges | | DBS-STN Participants | | | |
|---|---|---|---|---|---|---|
| | | | DBS-01 Assessments | | DBS-02 Assessments | |
| | Lower Limit | Upper Limit | 6FU | 9FU | Post | 3FU |
| Rate/ Frequency | 90 Hz | 200 Hz | Not Known | Not Known | Not Known | Not Known |
| Duration/ Pulse width | 60 µs | 120 µs | Not Known | Not Known | Not Known | Not Known |
| Amplitude/ Voltage | 0.0 V | 4.0 V | (L) 2.6 V<br>(R) 3.4 V<br>[(L) ≤4.0 V for tremors] | (L) 2.6 V<br>(R) 3.6 V<br>[(L/R) At 4.0 V → slurring] | (L) 2.4 V<br>±0.8 V | (L) 2.8 V day<br>(L) 2.0 V night |
| Impedance | 867 Ω | 1143 Ω | Not Known | Not Known | 1000 Ω | 1000 Ω |
| PD Medication | - | - | Sinemet 25-100<br>1:4 carbidopa/ levodopa<br>3x day<br>1/3 Pre dose | Sinemet 25-100<br>1:4 carbidopa/ levodopa<br>3x day | No<br>Took Sinemet before Pre | No |

3.3 Data Collection Schedule

The evaluations followed a structured format, although one of the two participants did not receive his evaluations at one month post surgery due to scheduling conflicts. An initial evaluation took place within one month prior to receiving surgery in the A phase, and the surgery took place in the B phase. A phase evaluations were also completed one month following surgery, and additional follow-up evaluations occurred at three-month intervals following surgery. The participants completed the evaluations on an optimized stimulation and medication dose to approximate the functional communication and swallowing behaviors of each participant in the study. Each evaluation took approximately 90 minutes to complete. The data analyzed for this dissertation were a subset of evaluations for each participant. The total duration of the study for each patient was approximately one year.

The schedule of evaluations described in the protocol is depicted in Table 2:

Table 2. Timeline for Assessments

| Baseline | Surgery | One month following surgery | Three months following surgery | Six months following surgery |
|---|---|---|---|---|
| Pre-DBS Evaluation (Med ON) | No Evaluation | Post-DBS Evaluation (Med ON) (Stim ON) | Follow-up DBS Evaluation (Med ON) (Stim ON) | Follow-up DBS Evaluation (Med ON) (Stim ON) |

3.4 Equipment Used

Equipment used for the research project included items needed for a motor speech evaluation: gloves, a mirror, a flashlight, stopwatch, and a tongue depressor. Video was recorded with a digital video camera (Cannon FS400), using a memory card (Transcend 32 GB/90 MB/s), and mounted on a 70 cm high tripod. Audio was recorded using a digital audio recording device (Marantz PMD671), using a compact flash memory card (SanDisk 2 GB/15 MB/s), and connected with a headset microphone (Countryman Association Incorporated H6 Omnidirectional). Lung pressures were measured using a respiratory pressure meter (RPM01) with flanged mouthpieces (MTH640), viral/bacterial filters (FIL6050), expiratory valves (ASS1221), inspiratory valves (ASS1222), and nose clips (3304), all of which were manufactured by Micro Direct of Lewiston, ME. Lingual strength was measured using a model 2.3 Iowa Oral Performance Instrument (IOPI™) device with connecting tubes and pressure bulbs, which were manufactured by IOPI Medical of Redmond, WA.

Other equipment used included a sound level meter (BK Precision model 735) with an adjustable 22-44 cm high tripod, an orchestral tuner (Korg OT-120), and a laptop computer (Toshiba Satellite® A665) to present the PowerPoint™ assessment files. Water, a measuring cup, a drinking glass, pureed food, and solid food were used for the swallowing evaluation.

3.5 Evaluation Tasks

The tasks included in this evaluation are commonly used by speech-language pathologists for clinical assessment of speech, swallowing, and cognitive-linguistic abilities in people with IPD. The following tasks were administered during each evaluation:

<u>Task 1: Sentence Reading:</u>

The participants read the sentence: “The boot on top is packed to keep” six times to supply the first and second formants (F1 and F2) for the corner vowels /a/, /i/, and /u/ used to calculate the vowel space area (Sapir, Spielman, Ramig, Story, & Fox, 2007).

<u>Task 2: Paragraph Reading</u>:

The participants read a phonetically balanced excerpt from the Farm Passage (Crystal & House, 1982).

<u>Task 3: Picture Description</u>:

The participants were presented with a picture depicting a picnic scene from the Western Aphasia Battery-Revised-R (Kertesz, 2006) and were asked to describe it as completely as possible for approximately one minute using complete sentences.

Task 4: Speech Intelligibility Tasks:

The participants read randomly selected word and sentence lists from the Speech Intelligibility Test (SIT, ver. R5; Yorkston, Beukelman, & Hakel, 2011), and sentence lists from the Hearing in Noise Test (HINT; Nilsson, Soli, & Sullivan, 1993).

Task 5: Task Description/Monologue:

The participants discussed a controlled topic of common interest until a speech sample of approximately one minute was obtained.

Task 6: Questionnaires Addressing Communication and Swallowing:

The participants filled out self-assessments including the EAT-10 questionnaire and a visual analog scale (VAS) for dysarthria and dysphagia. The EAT-10 questionnaire asked the participants to rate several factors about quality of life concepts related to swallowing (Belafsky et al., 2008). The VAS questionnaires asked a variety of questions about IPD symptoms, vocal problems, swallowing, and impact of IPD on daily life.

Task 7: Oral Motor Examination:

An oral motor examination was administered to each participant to assess facial symmetry, facial reflexes, lip movement, jaw movement, dentition, tongue movement, hard palate integrity, soft palate elevation and symmetry, the ability to follow oral motor commands, performance of the coup de glotte, volitional cough, dry swallow, diadochokinetic rates (DDK), and word and sentence repetition.

Task 8: Vowel Prolongation:

Participants sustained the vowel “ah” for as long as possible for a total of six repetitions.

Task 9: Swallow Evaluations:

Participants completed several tests to screen for symptoms of dysphagia. A timed test of swallowing involved drinking 150ml of water as quickly as possible. The number of swallows was counted as well as the time taken to swallow. Participants were also asked to swallow three presentations of pureed applesauce, and to eat several small cookies. Any foods requiring refrigeration were maintained at a safe temperature and were not used past the expiration date.

Task 10: Measuring Lip and Tongue Strength:

Lip and tongue strength were measured with the FDA approved Iowa Oral Performance Instrument model 2.3 (IOPI™) which was manufactured by IOPI Medical (Robin, Goel, Somodi, & Luschei, 1992). The IOPI™ measured lip and tongue strength using a pressure transducer with a soft, rubber bulb attached by thin rubber tube to the recorder. The bulb was placed between the lips to determine left, center & right lip pressures and between the alveolar ridge and the anterior tongue for tongue measurements. The goal was to obtain three values that differed by no more than 10%. Up to six repetitions of the task were allowed to be administered, if necessary, to reach this goal.

Task 11: Maximum Inspiratory and Expiratory Pressure:

Maximum inspiratory and expiratory pressures were measured with a RPM01 respiratory pressure meter manufactured by Micro Direct (Lewiston, ME). The participants placed a mouthpiece between the lips and teeth secured with a bite block between the teeth to perform maximum expiratory pressure (MEP) and maximum inspiratory pressure (MIP) tasks. The goal was to obtain three consecutive values that differed by no more than 10%. Therefore, up to six repetitions of each task were completed, if necessary, to reach this goal.

3.6 Dependent Variables

1. Speech Intelligibility:

Intelligibility was measured as percent intelligibility in single words and in sentences (SIT). Five listeners who were native English speakers and passed a hearing screening were asked to listen to words and sentences and then transcribe what they thought they heard verbatim, as the audio files were played on a laptop in a quiet room. The SIT word list included 50 separate words; the SIT sentence list included 30 sentences in pairs increasing in length from 5 to 15 words. The HINT sentence list included 10 short sentences from 4-7 words in length. Audio files were used to prevent visual gestures or other nonverbal cues from revealing the word or sentence meaning. The word percent intelligibility for each list was calculated by dividing the number of correctly transcribed words by the total number of words and multiplying by 100.

Rationale:

The speech intelligibility tasks were designed to measure the amount of change in comprehensibility to an individual's speech. The key factor was to compare intelligibility prior to, and after, DBS-STN. One of the primary focuses of this project was to document how DBS-STN impacted functional communication, both in isolated words and in contextual sentences.

2. Vowel Space Area (VSA):

Measurements of the first (F1) and second (F2) formants were obtained from the corner vowels /i/, /a/ and /u/ during six repetitions of reading the sentence, "The boot on top is packed to keep." The vowels were isolated and the F1 and F2 values were extracted using Praat (v. 5.4.09, 2015). The mean F1 and F2 values from six tokens were used to plot the VSA in $Hz^2$ using Microsoft Excel™ (Sapir, Spielman, Ramig, Story, & Fox, 2007).

Rationale:

Vowel space area represents an index of the accuracy of vowel articulation, which reflects gross motor control of the tongue and coordination of the jaw. Generally, F1 varies with tongue height such that the higher the tongue position, the lower the F1 frequency. F2 varies with advancement where the more anterior the tongue position, the higher the F2 frequency. Adult male speakers have a normal frequency range as follows: /a/ 720-810 Hz for F1, 1200-1350 Hz for F2; /i/ 268-380 Hz for F1, 2150-2393 Hz for F2; /u/ 326-405 Hz for F1, 1000-1500 Hz for F2 (Bradlow, 1995; Jacewitz, Fox & Salmons, 2007). The VSA is calculated using the F1 and F2 of the corner vowels in which the tongue is in three extreme positions, front/close for /i/, front/open for /u/, and back/close for /a/. Additionally, these vowels are perceptually and acoustically exceptional because they represent the extreme positions of the tongue during connected speech. These vowels were plotted out on a F1 versus F2 plot to show the range of the participant's tongue positioning and movements. Functional decline caused by dysarthria would restrict tongue range and speed, and cause the VSA triangle to contract.

3. Multidimensional Voice Program (MDVP):

MDVP is a dedicated acoustic software package manufactured by Kay Elemetrics (Lincoln Park, NJ); Multidimensional Voice Program (MDVP-Model 5105);

Computerized Speech Lab (CSL-Model 4500). It was used to measure a variety of speech properties, extracted from six repetitions of sustained /a/ at each evaluation. These measurements were referenced against normative data for age and sex threshold values. The measurements were grouped into four major categories as shown in Table 3 (Xie et al., 2010).

Table 3. Multidimensional Voice Program Categories and Individual Measurements

| Category | Measurement | Parameters |
|---|---|---|
| Changes in Pitch | Percent change in jitter (Jitt) | Percent period to period pitch variability with no smoothing |
| | Relative average perturbation (RAP) | Percent period to period pitch variability with three periods of smoothing |
| | Pitch perturbation quotient (PPQ) | Percent period to period pitch variability with five periods of smoothing |
| | Fundamental frequency variation ($vF_0$) | Percent mean standard deviation of period to period fundamental frequency variability |
| Changes in Amplitude | Percent change in shimmer (Shim) | Percent period to period amplitude variability with no smoothing |
| | Amplitude perturbation quotient (APQ) | Percent period to period amplitude variability with eleven periods of smoothing |
| Frequency Ratios | Noise to harmonic ratios (NHR) | Mean ratio of inharmonic spectral energy (1500-4500 Hz) over harmonic spectral energy (70-4500 Hz) |
| | Soft phonation index (SPI) | Mean ratio of lower frequency spectral energy (70-1600 Hz) over higher frequency spectral energy (1600-4500 Hz) |
| Other Ratios | Degree of voice breaks (DVB) | Percent ratio of total time of voice breaks over total time of voice sample length |
| | Degree of Voiceless (DUV) | Percent ratio of total inharmonic regions over total time of voice sample length |

<u>Rationale:</u>

MDVP analysis was useful to provide objective data of a participant's voice quality was affected both by the PD as well as the DBS-STN electrodes. The expectation was that a greater degree of dysarthria would be reflected by an increase of vocal quality abnormalities.

<u>4. Sound Pressure Level (dB at 40 cm distance):</u>

Sound pressure level, the acoustic correlate of loudness (dB SPL), was measured on a variety of tasks including: sustained vowel duration, sentence reading, picture description, reading single words and sentences from the SIT lists, reading sentences from the HINT lists, and monologue during task description.

Rationale:

One of the most notable speech symptoms of IPD is hypophonia, which is characterized as loudness significantly below the norm of 71-74 dB SPL measured at 30 cm distance from the participant's mouth during contextual speech (Awan, 1993; Gelfer & Young, 1997; Ryan & Gelfer, 1993). It was important to track the vocal loudness of the participants with a diverse set of speaking tasks because dB SPL can vary as a consequence of the cognitive-linguistic demands and length of speaking tasks.

5. Duration of Sustained Vowel Prolongation

The duration of sustained vowel phonation was measured in seconds and the mean of six repetitions was used for comparisons across evaluations.

Rationale:

The vowel used was /a/, which was sustained at a constant pitch level for as long as possible. This metric is an indication of the adequacy of vocal fold adduction and coordination of respiration and phonation; if compromised, it could diminish the amount of time the subject could hold the sustained vowel.

6. Diadochokinetic Rates (DDK)

DDK rate measures how quickly a person can accurately repeat a series of rapid, alternating phonetic sounds. These sounds are designed to test different parts of the mouth, tongue, and soft palate in the back of the throat. These tokens contain one, two, or three syllables. For example, of "puh", "puh-tuh", and "puh-tuh-kuh." DDK rates from the oral mechanism examination were based on the number of repetitions of "puh", "tuh", "kuh", and "puh-tuh-kuh" produced in five seconds.

Rationale:

DDK rate determines if there are any problems in motor skills or planning speech motor movements. Areas of the central nervous system involved in speech motor control include the frontal lobe, cerebellum, basal ganglia, and cranial nerves V, VII, IX, X, XI, and XII. Accurate speech production also depends on the muscles and bone structures in the face, mouth, and throat. The rapid repetition of speech sounds assessed strength, range of motion, accuracy, timing, and rapidly alternating speech movements. These results were important in diagnosing the type of dysarthria.

7. Lip and Tongue Pressures

The IOPI™ was used to assess lip strength in kilopascals on the right, left, and center portion of the lips, and tongue strength with the tip of the tongue against the alveolar ridge.

Rationale:

This test was designed to detect weakness in the lips and the tongue which would interfere with speech. The subnormal range for tongue and lip strength in males would be below the norm of 49-73 kPa for the anterior tongue, and below the norm of 27-32 kPa for the lips (Adams, Mathisen, Baines, Lazarus & Callister, 2013; Clark & Solomon, 2012). Muscle weakness could contribute to mispronunciations in the area of speech, and therefore increase difficulty of patients being understood by listeners.

8. Maximum Inspiratory and Expiratory Pressures (MIP & MEP):

A respiratory pressure meter was used to measure MIP in centimeters of water (cm $H_2O$) that the participant performed with while inhaling forcefully. MEP measured the maximum pressure in cm $H_2O$ that the participant performed while exhaling forcefully.

Rationale:

MIP and MEP were measured to determine the greatest pressure of inspired air achieved after a full expiration, and the greatest pressure of expired air achieved after a full inspiration as an indication of airway support. The weaker the subject inhaled and exhaled, the more diminished the loudness would be during speech.

The normal range for MIP and MEP using a flanged mouthpiece in 50-60 year males is 97-108 cm $H_2O$ for MIP, and 119-137 cm $H_2O$ for MEP (Evans & Whitelaw 2009).

9. Visual Analog Scale (VAS):

There were two types of visual analog scales used during the evaluations: one for dysarthria and one for dysphagia. The VAS for dysarthria included self-assessment on a scale from 0-100% on the following speech and communication variables: loudness, finding the right words, shaky voice, monotone, slurring, strained voice, mumbling, intelligibility, participation in conversation, and initiating a conversation. The VAS for dysphagia included self-assessment on a scale from 0-100% on the following swallowing and eating variables: weight loss, eating out, swallowing liquids, swallowing foods, swallowing pills, swallowing pain, swallowing pleasure, food sticking, coughing during eating, and swallowing stress. The VAS was completed by the participants to determine their perceptions of a variety of speech, voice, and communication characteristics on a line representing the extremes of a continuum. As an example, one of the lines represented “Never loud enough” on the left end of the continuum and “Always loud enough” on the right end.

<u>Rationale:</u>

The VAS tools are self-assessment instruments that allowed participants to estimate the degree of impact that dysarthria and dysphagia had on either functional communication or eating. It provided an additional qualitative dimension to the quantitative variables obtained by the research group, and provided insight on how the participants perceived their speech and swallowing impairments.

<u>10. EAT-10 Swallowing Questionnaire:</u>

The EAT-10 is a standardized swallowing questionnaire (40 points maximum) represented a total score based on a scale from 0-40 with 40 being the most severe type of swallowing impairment (Belafsky et.al., 2009 ).

<u>Rationale:</u>

The EAT-10 questionnaire is a self-assessment that was used by participants to estimate the degree of impact that dysphagia had on their daily lives. Like the VAS for dysphagia it added an extra dimension to quantitative assessment of the participant’s swallowing ability.

<u>11. Timed Swallow Assessment:</u>

Participants drank 150 ml of water as quickly as possible, with the number of swallows being counted while being timed. The number of swallows, volume swallowed and time measurements were converted into swallows/second and ml/second.

Rationale:

The timed dysphagia assessment was a way of quantifying how well the participant swallowed liquids, which is the most difficult type of liquid for a person with dysphagia to swallow. Any rate under 10 ml/second is considered at risk for a swallowing disorder (Nathadwarawala, Nicklin, & Wiles, 1992).

12. Qualitative Assessments:

Qualitative assessment of responses to questions about communication, speech, and swallowing associated with IPD were captured with audio and video recordings. A transcript of the participant's discussion of IPD, DBS-STN and their impact on their lives was produced from the recordings. Subsequently the quantity and type of responses were sorted into narrative themes based on the common descriptions that emerged from the transcription *a posteriori*. This method yielded the participants' perspectives about daily living with symptoms relating to IPD (Ahlberg, Laakso, & Hartelius, 2011).

Rationale:

Quantitative data do not tell the entire story of the effects of IPD as well as DBS-STN. The participants had experiences, setbacks, and stories that couldn't be reduced to simple numbers. Qualitative research methods added valuable insight on the lives of participants with PD, and how the DBS-STN was both beneficial and detrimental to their daily lives. Qualitative assessments enriched the useful information that was extracted from this pilot study.

3.7 Data Analyses

Data were collected pre and post STN-DBS surgery along with at least one follow up session. Qualitative data did not lend itself to statistical analysis, but it contributed useful insight and context to the investigation. The quantitative data was subjected to statistical analysis. The dB SPL tests had a sufficient amount of data to be able to perform distribution and homogeneity of variance testing. The Kolmogorov-Smirnov and Levene's test were used to test for sample distribution similarity and homogeneity of variance (HOV) respectively (Sapir, Ramig, Spielman, & Fox, 2010; Weintraub & Burn, 2003). If they passed both tests parametric group tests such as 1-way Analysis of variance (ANOVA), and Tukey's honest significant difference (Tukey HST) compared which of the three groups significantly differed. Welch's unpaired t-test (t-test) was used instead when there were only two groups to determine if the pair of groups significantly differed (Tripoliti et al, 2014). If they failed the distribution and HOV tests nonparametric Kruskal-Wallis 1-way ANOVA (Kruskal), and Wilcoxon rank sum tests (Wilcoxon) compared which groups were stochastically dominant (Karlsson et al., 2012, Merola et al., 2011). The percent intelligibility for words and sentences, corner vowel F1 and F2 changes for the VSA, and MDVP data, had insufficient numbers of values to determine HOV, so they were interpreted using ANOVA paired with the Tukey HST or Welch's t-test to determine which groups showed statistical significance (Tripoliti et.al., 2014). The Cohen's d test was used on all comparisons to note the effect size by determining the magnitude of the differences of the means from each other, and to determine which of the changes had clinical significance

(Cohen, 1992; Howell, 2002; Schuele & Justice, 2006; Sapir, Ramig, Spielman, & Fox, 2010). The VSA area, tongue & lingual strength, MIP & MEP, DDK rate, timed water swallow test, VAS scale for speech and swallowing, and EAT-10 questionnaire could not be subjected to significance testing. Instead changes over time were compared to each other. The statistical program R (v. 3.1.1) was used to run all the statistical tests on the quantitative variables.

# CHAPTER 4

# RESULTS

## 4.1 Findings

The purpose of this study was to examine speech and swallowing characteristics of two participants before and after deep brain stimulation of the subthalamic nucleus (DBS-STN) surgery to identify significant changes within the dependent variables. Three evaluation sessions for DBS-01 were completed at the following time points: prior to surgery (Pre), six months following surgery (6FU), and nine months following surgery (9FU). Three evaluation sessions for DBS-02 were completed at the following time points: prior to surgery (Pre), within one month following surgery (Post), and three months following surgery (3FU). The results are reported in the remaining sections.

## 4.2 Dependent Variable Results

1. Speech Intelligibility:

Intelligibility was measured as a percent of words understood in single words (SIT) and in sentences (SIT and HINT) based on the transcriptions from five listeners who recorded what they heard verbatim.

*DBS-01*

1. There were decreases in percent intelligibility for the SIT words from Pre to 6FU and from 6FU to 9FU. An ANOVA and Tukey *post-hoc* analysis revealed that the decrease in intelligibility scores was significant from Pre to 9FU with a change of 16.4% and a large effect size indicating the change was clinically significant. No other statistically significant comparisons were found.

2. There was a decrease in percent intelligibility for the SIT sentences from 6FU to 9FU. No statistically significant differences were found. SIT words were not used during the Pre session, no other comparisons could be made.

3. There was a decrease in percent intelligibility for the HINT sentences from Pre to 6FU followed by an increase from 6FU to 9FU. No statistically significant differences were found.

Table 4 shows the mean understandability scores, standard deviations, 1-way ANOVA, Tukey HST, and Cohen's d for DBS-01.

Table 4. Quantitative Changes in Speech Intelligibility for DBS-01

| Measure Percent Intelligibility | Average Pre (SD) | Average 6 Mo. FU (SD) | Average 9 Mo. FU (SD) | ANOVA p-value | Pre-6FU Tukey (Cohen's d) | Pre-9FU Tukey (Cohen's d) | 6FU-9FU Tukey (Cohen's d) |
|---|---|---|---|---|---|---|---|
| SIT word list[a] | 86.8% (11.2) | 74.8% (5.2) | 70.4% (4.6) | 0.0142 | 0.0686 (1.364) | 0.0136 (1.901) | 0.6435 (3.341) |
| SIT sentence list[b] | - | 95.0% (3.1) | 91.4% (3.5) | - | - | - | 0.1236[c] (1.089) |
| HINT sentence list | 97.6% (0.9) | 95.6% (3.0) | 98.0% (2.0) | 0.2030 | 0.3319 (0.903) | 0.9527 (-0.258) | 0.2168 (-0.941) |

a- SIT words used only twelve words for the Pre-list, but used the normal fifty words for 6FU and 9FU.
b- No SIT sentences were administered for Pre, but the normal 220 word lists were used for 6FU and 9FU
c- An unpaired Welch's t-test was used for significance testing between 6FU and 9FU

<u>*DBS-02*</u>

1. There was an increase in percent intelligibility for the SIT words from Pre to Post, followed by a decrease from Post to 3FU. An ANOVA and Tukey *post-hoc* analysis revealed that the changes in the intelligibility scores were significant in the comparisons from Pre to Post with an increase of 10.8% and from Post to 3FU with a decrease of 9.6%. Both comparisons had large effect sizes indicating the changes were clinically significant. No other statistically significant comparisons were found.

2. There was an increase in percent intelligibility for the SIT sentences from Pre to Post, followed by a decrease from Post to 3FU. No statistically significant differences were found.
3. There was no change in percent intelligibility for the HINT sentences from Pre to Post, followed by a decrease from Post to 3FU. No statistically significant differences were found.

Table 5 shows the mean understandability scores, standard deviations, 1-way ANOVA, Tukey HST, and Cohen's d for DBS-02.

Table 5. Quantitative Changes in Speech Intelligibility for DBS-02

| Measure Percent Intelligibility | Average Pre (SD) | Average Post (SD) | Average 3 Mo. FU (SD) | ANOVA p-value | Pre-Post Tukey (Cohen's d) | Pre-3FU Tukey (Cohen's d) | Post-3FU Tukey (Cohen's d) |
|---|---|---|---|---|---|---|---|
| SIT word list | 79.6% (6.2) | 90.4% (3.8) | 80.8% (5.8) | 0.0152 | 0.0203 (-2.100) | 0.9341 (-0.200) | 0.0381 (1.958) |
| SIT sentence list | 95.4% (2.4) | 97.8% (2.8) | 97.0% (1.4) | 0.2740 | 0.2562 (-0.920) | 0.5246 (-0.814) | 0.8452 (0.361) |
| HINT sentence list | 95.6% (1.7) | 95.6% (1.7) | 93.8% (5.0) | 0.5990 | 1.0000 (0.000) | 0.6532 (0.482) | 0.6532 (0.482) |

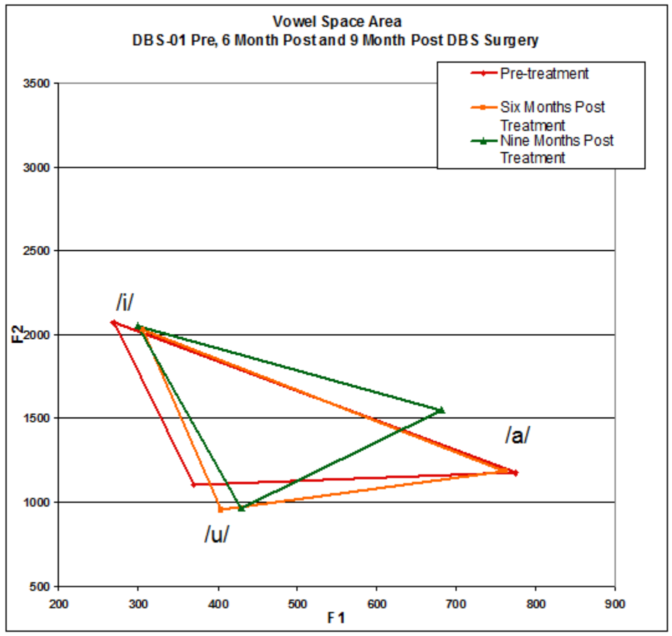
2. Vowel Space Area (VSA):

The first and second formants (F1 and F2) of the corner vowels /a/, /i/, and /u/ were extracted from six repetitions of the sentence "The boot on top is packed to keep" during each evaluation. The mean F1 and F2 values were used to plot the VSA for both participants in $Hz^2$.

*DBS-01*

Figure 1 shows that the vowel space area between the three corner vowels increased from 199,000 $Hz^2$ at Pre to 203,000 $Hz^2$ at 6FU, and decreased to 175,000 $Hz^2$ at 9FU.

Figure 1. Vowel Space Area Plot with F1 and F2 Values of the Corner Vowels for DBS-01



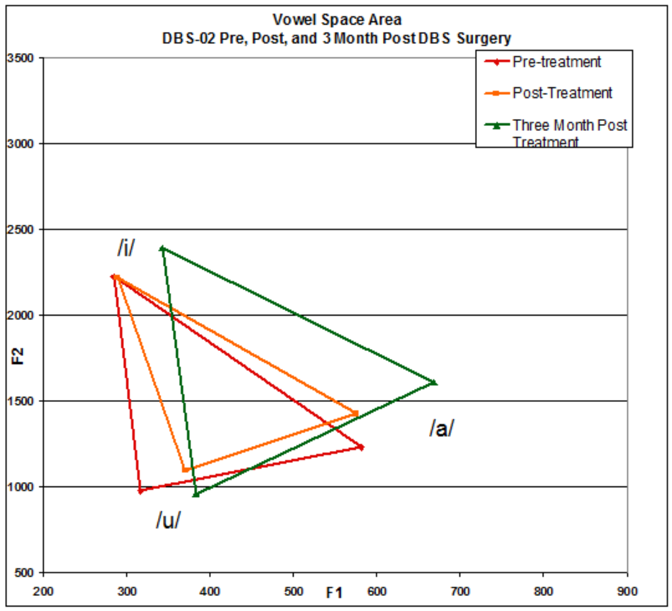

1. There was a decrease in the frequency for F1 of /a/ of 19 Hz from Pre to 6FU that was not statistically significant, followed by a 79 Hz decrease from 6FU to 9FU that was statistically significant with a large effect size. There was an increase in the frequency for F2 of /a/ of 11 Hz from Pre to 6FU that was not statistically significant, followed by a 365 Hz increase from 6FU to 9FU that was statistically significant with a large effect size. The F1 of /a/ decreases indicated the lifting of the tongue and the constraining of the pharyngeal space. The F2 of /a/ increases indicated an anterior tongue positioning and a decrease in the volume of the front oral cavity. F1 of /a/ values were within normal limits for a male adult at Pre and 6FU, but they were below normal limits at 9FU. F2 of /a/ values were within normal limits at Pre and 6FU, and they increased at 9FU.

2. There was an increase in the frequency for F1 of /i/ of 37 Hz from Pre to 6FU that was statistically significant with a large effect size, followed by a 6 Hz decrease from 6FU to 9FU that was not statistically significant. There was a decrease in the frequency for F2 of /i/ of 42 Hz from Pre to 6FU that was not statistically significant, followed by a 28 Hz increase from 6FU to 9FU that was not statistically significant. The F1 of /i/ increase indicated the dropping of the tongue and the enlargement of the pharyngeal space. The F2 of /i/ results indicated no significant change in tongue retraction, or in the volume of the front oral cavity. F1 of /i/ values were within normal limits for a male adult at Pre, 6FU and 9FU. F2 of /i/ values increased at Pre, 6FU, and 9FU.
3. There was an increase in the frequency for F1 of /u/ of 33 Hz from Pre to 6FU that was not statistically significant, followed by a 26 Hz increase from 6FU to 9FU that was not statistically significant. There was a decrease in the frequency for F2 of /u/ of 149 Hz from Pre to 6FU that was statistically significant with a large effect size, followed by a 12 Hz increase from 6FU to 9FU that was not statistically significant. The F1 of /u/ increases indicated the dropping of the tongue and the enlargement of the pharyngeal space. The F2 of /u/ decrease indicated a posterior tongue positioning and an increase in the volume of the front oral cavity. F1 of /u/ values were within normal limits for a male adult at Pre and 6FU, and they increased at 9FU. F2 of /u/ values were within normal limits at Pre, but they decreased at 6FU and 9FU.

*DBS-02*

Figure 2 shows that the DBS-02 vowel space area between the three corner vowels decreased from 170,000 $Hz^2$ at Pre to 129,000 $Hz^2$ at Post, and increased to 218,000 $Hz^2$ at 3FU.

Figure 2. Vowel Space Area Plot with the F1 and F2 Values of the Corner Vowels for DBS-02




1. There was a decrease in the frequency for F1 of /a/ of 6 Hz from Pre to Post that was not statistically significant, followed by a 123 Hz increase from Post to 3FU that was statistically significant with a large effect size. There was an increase in the frequency for F2 of /a/ of 192 Hz from Pre to Post that was statistically significant with a large effect size, followed by a 187 Hz increase from Post to 3FU that was statistically significant with a large effect size. The F1 of /a/ increase indicated the dropping of the tongue and enlargement of the pharyngeal space. The F2 of /a/ increases indicated an anterior tongue positioning and a decrease in the volume of the front oral cavity. F1 of /a/

values were below normal limits for a male adult at Pre, Post, and 3FU. F2 of /a/ values were within normal limits at Pre, but they increased at Post and 3FU.

2. There was an increase in the frequency for F1 of /i/ of 5 Hz from Pre to Post that was not statistically significant, followed by a 53 Hz increase from Post to 3FU that was statistically significant with a large effect size. There was a decrease in the frequency for of F2 of /i/ of 5 Hz from Pre to Post that was not statistically significant, followed by a 174 Hz increase from Post to 3FU that was statistically significant with a large effect size. The F1 of /i/ increases indicated the dropping of the tongue and enlargement of the pharyngeal space. The F2 of /i/ increase indicated an anterior tongue positioning and a decrease in the volume of the front oral cavity. F1 of /i/ values were within normal limits for a male adult at Pre, Post, and 3FU. F2 of /i/ values were also within normal limits at Pre, Post, and 3FU.
3. There was an increase in frequency for F1 of /u/ of 54 Hz from Pre to Post that was not statistically significant, followed by a 12 Hz increase from Post to 3FU that was not statistically significant. There was an increase in the frequency of F2 of /u/ of 118 Hz from Pre to Post that was not statistically significant, followed by a 135 Hz decrease from Post to 3FU that was not statistically significant. The F1 of /u/ increase indicated the dropping of the tongue and enlargement of the pharyngeal space. The F2 of /u/ results indicated that there was no significant change in the tongue positioning, or in the volume of the front oral cavity. F1 of /u/ values were below normal limits for a male adult at Pre, but they were within normal limits at Post and 3FU. F2 of /u/ values were

below normal limits at Pre and 3FU, but they were within normal limits at Post.

3. Multidimensional Voice Program (MDVP):

*DBS-01*

1. Four variables measured frequency changes: Jitter change in percent (Jitt), Relative average perturbation in percent (RAP), Pitch perturbation quotient in percent (PPQ), and Fundamental frequency variation in percent ($vF_0$).
   a. There was an increase in percent for Jitt from Pre to 6FU, followed by a decrease in percent from 6FU to 9FU. No statistically significant differences were found. The 6FU and 9FU means were abnormally high.
   b. There was an increase in percent for RAP from Pre to 6FU, followed by a decrease in percent from 6FU to 9FU. No statistically significant differences were found. The 6FU mean was abnormally high.
   c. There was an increase in percent for PPQ from Pre to 6FU, followed by a decrease in percent from 6FU to 9FU. No statistically significant differences were found. The 6FU mean was abnormally high.
   d. There was an increase in percent for $vF_0$ from Pre to 6FU, followed by a decrease in percent from 6FU to 9FU. No statistically significant differences were found. The 6FU mean was abnormally high.
2. Two variables measured amplitude changes: Shimmer change in percent (Shim), and Amplitude perturbation quotient in percent (APQ).
   a. There was an increase in percent for Shim from Pre to 6FU, followed by a decrease in percent from 6FU to 9FU. No statistically significant

differences were found. The Pre, 6FU, and 9FU means were all abnormally high.

b. There was an increase in percent for APQ from Pre to 6FU, followed by a decrease in percent from 6FU to 9FU. No statistically significant differences were found. The Pre, 6FU, and 9FU means were all abnormally high.

3. Two variables measured acoustic ratios: Noise to harmonic ratio (NHR), and Soft phonation index (SPI).

   a. There was an increase for NHR from Pre to 6FU, followed by a decrease from 6FU to 9FU. No statistically significant differences were found. The 6FU mean was abnormally high.

   b. There was a decrease for SPI from Pre to 6FU, followed by an increase from 6FU to 9FU. An ANOVA and Tukey *post-hoc* analysis revealed that the decrease in percent was significant from Pre to 9FU with a change of 5.552% along with a large effect size, and was significant from 6FU to 9FU with a change of 9.354% along with a large effect size. Both of the comparisons were clinically significant. No other statistically significant differences were found. The Pre, and 9FU means were abnormally high.

4. Two variables measured voice interruptions during speech: Degree of voice breaks in percent (DVB), and Degree of voiceless segments in percent (DUV).

   a. There was an increase in percent for DVB from Pre to 6FU, followed by a decrease in percent from 6FU to 9FU. No statistically significant differences were found. The 6FU mean was abnormally high.

b. There was an increase in percent for DUV from Pre to 6FU, followed by a decrease in percent from 6FU to 9FU. No statistically significant differences were found. The Pre, 6FU, and 9FU means were all abnormally high.

Table 6 shows the mean MDVP scores, standard deviations, abnormal thresholds, 1-way ANOVA, Tukey HST, and Cohen's d for DBS-01.

Table 6: DBS-01 Multidimensional Voice Program Tests

| MDVP Task | Average Pre (SD) | Average 6 Mo. FU (SD) | Average 9 Mo. FU (SD) | Threshold | ANOVA p-value | Pre-6FU Tukey (Cohen's d) | Pre-9FU Tukey (Cohen's d) | 6FU-9FU Tukey (Cohen's d) |
|---|---|---|---|---|---|---|---|---|
| Jitt | 0.751 | 1.497 | 1.070 | 1.040 | 0.3160 | 0.2872 | 0.7820 | 0.6491 |
| % | (0.368) | (1.022) | (0.920) | | | (-0.971) | (-0.455) | (0.439) |
| RAP | 0.396 | 0.910 | 0.641 | 0.680 | 0.2330 | 0.2057 | 0.6768 | 0.6250 |
| % | (0.245) | (0.621) | (0.542) | | | (-1.089) | (-0.583) | (0.462) |
| PPQ | 0.438 | 0.990 | 0.633 | 0.840 | 0.2190 | 0.2004 | 0.8007 | 0.4889 |
| % | (0.216) | (0.732) | (0.507) | | | (-1.023) | (-0.500) | (0.567) |
| $vF_0$ | 1.859 | 6.973 | 1.907 | 1.100 | 0.2400 | 0.3000 | 1.0000 | 0.3060 |
| % | (0.482) | (9.881) | (0.995) | | | (-0.731) | (-0.061) | (0.721) |
| Shim | 7.683 | 8.526 | 6.395 | 3.810 | 0.3510 | 0.8283 | 0.3243 | 0.3243 |
| % | (0.839) | (3.746) | (1.928) | | | (-0.311) | (0.715) | (0.715) |
| APQ | 6.759 | 7.309 | 4.888 | 3.070 | 0.0980 | 0.8697 | 0.2304 | 0.0990 |
| % | (0.681) | (2.850) | (1.435) | | | (-0.265) | (1.666) | (1.073) |
| NHR | 0.191 | 0.250 | 0.189 | 0.190 | 0.0809 | 0.1276 | 0.9973 | 0.1130 |
| | (0.037) | (0.063) | (0.044) | | | (-1.142) | (0.049) | (1.123) |
| SPI | 12.434 | 8.632 | 17.986 | 14.120 | 0.0000 | 0.0545 | 0.0054 | 0.0000 |
| | (2.897) | (1.626) | (2.989) | | | (1.618) | (-1.886) | (-3.888) |
| DVB | 0.000 | 2.358 | 0.000 | 1.000 | 0.3310 | 0.3979 | 1.0000 | 0.3979 |
| % | (0.000) | (5.294) | (0.000) | | | (-0.630) | - | (0.630) |
| DUV | 14.815 | 27.299 | 20.164 | 1.000 | 0.6120 | 0.5917 | 0.8009 | 0.9334 |
| % | (16.073) | (20.164) | (22.848) | | | (-0.715) | (-0.357) | (0.185) |

<u>*DBS-02*</u>

1. Four variables measured frequency changes: Jitt, RAP, PPQ, and $vF_0$.

a. There was a decrease in percent for Jitt from Pre to Post, followed by no change in percent from Post to 3FU. An ANOVA and Tukey *post-hoc* analysis revealed that the decrease in percent was significant from Pre to Post with a change of 3.414% along with a large effect size, and was significant from Post to 3FU with a change of 3.414% along with a large effect size. Both of the comparisons were clinically significant. No other statistically significant differences were found. The Pre, Post, and 3FU means were all abnormally high.

b. There were decreases in percent for RAP from Pre to Post, and from Post to 3FU. An ANOVA and Tukey *post-hoc* analysis revealed that the decrease in percent was significant from Pre to Post with a change of 2.206% along with a large effect size, and was significant from Post to 3FU with a change of 2.374% along with a large effect size. Both of the comparisons were clinically significant. No other statistically significant differences were found. The Pre mean was abnormally high.

c. There were decreases in percent for PPQ from Pre to Post, and from Post to 3FU. An ANOVA and Tukey *post-hoc* analysis revealed that the decrease in percent was significant from Pre to Post with a change of 3.467% along with a large effect size, and was significant from Post to 3FU with a change of 3.599% along with a large effect size. Both of the comparisons were clinically significant. No other statistically significant differences were found. The Pre mean was abnormally high.

d. There were decreases in percent for $vF_0$ from Pre to Post, and from Post to 3FU. An ANOVA and Tukey *post-hoc* analysis revealed that the decrease in percent was significant from Pre to Post with a change of 20.291% along with a large effect size, and was significant from Post to 3FU with a change of 20.978% along with a large effect size. Both of the comparisons were clinically significant. No other statistically significant differences were found. The Pre, Post, and 3FU means were all abnormally high.

2. Two variables measured amplitude changes: Shim, and APQ.
    a. There were decreases in percent for Shim from Pre to Post, and from Post to 3FU. An ANOVA and Tukey *post-hoc* analysis revealed that the decrease in percent was significant from Pre to Post with a change of 9.123% along with a large effect size, and was significant from Post to 3FU with a change of 12.536% along with a large effect size. Both of the comparisons were clinically significant. No other statistically significant differences were found. The Pre, Post, and 3FU means were all abnormally high.
    b. There was a decrease in percent for APQ from Pre to Post, followed by an increase in percent from Post to 3FU. An ANOVA and Tukey *post-hoc* analysis revealed that the decrease in percent was significant from Pre to Post with a change of 6.699% along with a large effect size, and was significant from Post to 3FU with a change of 6.323% along with a large effect size. Both of the comparisons were clinically significant. No other statistically significant differences were found. The Pre and Post means were abnormally high.
3. Two variables measured acoustic ratios: NHR, and SPI.
    a. There were decreases for NHR from Pre to Post, and from Post to 3FU. An ANOVA and Tukey *post-hoc* analysis revealed that the decrease was significant from Pre to Post with a change of 0.294 along with a large

effect size, and was significant from Pre to 3FU with a change of 0.320 along with a large effect size. Both of the comparisons were clinically significant. No other statistically significant differences were found. The Pre mean was abnormally high.

   b. There were decreases for SPI from Pre to Post, and from Post to 3FU. An ANOVA and Tukey *post-hoc* analysis revealed that the decrease was significant from Pre to 3FU with a change of 23.423 along with a large effect size, and was significant from Post to 3FU with a change of 20.871 along with a large effect size. Both of the comparisons were clinically significant. No other statistically significant differences were found. The Pre, Post, and 3FU means were all abnormally high.

4. Two variables measured voice interruptions during speech: DVB, and DUV.
   a. There was a decrease in percent for DVB from Pre to Post, followed by no change in percent from Post to 3FU. An ANOVA and Tukey *post-hoc* analysis revealed that the decrease in percent was significant from Pre to Post with a change of 34.481% along with a large effect size, and was significant from Pre to 3FU with a change of 34.481% along with a large effect size. Both of the comparisons were clinically significant. No other statistically significant differences were found. The Pre mean was abnormally high.
   b. There were decreases in percent for DUV from Pre to Post, and from Post to 3FU. An ANOVA and Tukey *post-hoc* analysis revealed that the decrease in percent was significant from Pre to Post with a change of

62.005% along with a large effect size, and was significant from Pre to 3FU with a change of 70.740% along with a large effect size. Both of the comparisons were clinically significant. No other statistically significant differences were found. The Pre and Post means were abnormally high.

Table 7 shows the mean MDVP scores, standard deviations, abnormal thresholds, 1-way ANOVA, Tukey HST, and Cohen's d for DBS-02.

Table 7: DBS-02 Multidimensional Voice Program Tests

| MDVP Task | Average Pre (SD) | Average 6 Mo. FU (SD) | Average 9 Mo. FU (SD) | Threshold | ANOVA p-value | Pre-Post Tukey (Cohen's d) | Pre-3FU Tukey (Cohen's d) | Post-3FU Tukey (Cohen's d) |
|---|---|---|---|---|---|---|---|---|
| Jitt % | 4.493 (2.225) | 1.079 (0.495) | 1.079 (0.265) | 1.040 | 0.0003 | 0.0013 (2.118) | 0.0006 (2.321) | 0.9368 (0.662) |
| RAP % | 2.838 (1.503) | 0.632 (0.319) | 0.464 (0.170) | 0.680 | 0.0003 | 0.0010 (2.030) | 0.0008 (2.220) | 0.9923 (0.657) |
| PPQ % | 4.086 (2.350) | 0.619 (0.289) | 0.487 (0.158) | 0.840 | 0.0005 | 0.0015 (2.071) | 0.0011 (2.171) | 0.9848 (0.567) |
| $vF_0$ % | 22.103 (17.186) | 1.812 (0.613) | 1.125 (0.085) | 1.100 | 0.0032 | 0.0079 (1.669) | 0.0062 (1.726) | 0.9921 (1.570) |
| Shim % | 17.649 (3.821) | 8.526 (3.746) | 5.113 (0.884) | 3.810 | 0.0000 | 0.0000 (3.808) | 0.0000 (4.509) | 0.5074 (1.372) |
| APQ % | 11.729 (2.295) | 5.030 (0.764) | 5.406 (1.545) | 3.070 | 0.0000 | 0.0000 (3.917) | 0.0000 (3.232) | 0.9190 (-0.309) |
| NHR | 0.452 (0.229) | 0.158 (0.007) | 0.132 (0.004) | 0.190 | 0.0085 | 0.0190 (1.815) | 0.0148 (4.561) | 0.9913 (1.976) |
| SPI | 40.353 (6.153) | 37.801 (5.199) | 16.930 (4.891) | 14.120 | 0.0000 | 0.6445 (0.448) | 0.0000 (4.214) | 0.0000 (4.135) |
| DVB % | 34.481 (25.551) | 0.000 (0.000) | 0.000 (0.000) | 1.000 | 0.0012 | 0.0028 (1.908) | 0.0028 (1.908) | 1.0000 - |
| DUV % | 70.907 (8.927) | 8.902 (6.714) | 0.167 (0.408) | 1.000 | 0.0000 | 0.0000 (7.850) | 0.0000 (11.195) | 0.0799 (1.837) |

4. Sound Pressure Level (dB SPL at 40 cm distance):

Sound pressure level, the acoustic correlate of loudness (dB SPL), was measured during sustained /a/, sentence reading, paragraph reading, picture description, monologue, SIT words, SIT sentences, and HINT sentences because loudness can vary across tasks depending on length and cognitive-linguistic complexity.

*DBS-01*

1. There was an increase in dB SPL for the sustained /a/ task from Pre to 6FU, followed by a decrease from 6FU to 9FU. A Kruskal-Wallis and Wilcoxon *post-hoc* analysis revealed that there was a statistically significant increase in dB SPL from Pre to 6FU (4.0 dB SPL; p=2.2E-16) along with a large effect size, a significant increase from Pre to 9FU (2.8 dB SPL; p=2.6E-8) along with a medium effect size, and a significant decrease from 6FU to 9FU (1.2 dB; p=0.0026) with a small effect size. The Pre to 6FU comparison was clinically significant.
2. There was a decrease in dB SPL for the sentences task from Pre to 6FU, followed by an increase from 6FU to 9FU. No statistically significant differences were found.
3. There were decreases in dB SPL for the paragraph reading task from Pre to 6FU, and from 6FU to 9FU. An ANOVA and Tukey *post-hoc* analysis revealed that there was a statistically significant decrease in dB SPL from Pre to 6FU (2.9 dB SPL; p=0.0103) along with a large effect size, and a significant decrease from Pre to 9FU (3.2 dB SPL; p=0.0029) along with a large effect size. Both comparisons were clinically significant. No other statistically significant differences were found.
4. There was a decrease in dB SPL for the picture description task from Pre to 6FU, followed by an increase from 6FU to 9FU. No statistically significant differences were found.
5. There was an increase in dB SPL for the monologue task from Pre to 6FU, followed by a decrease from 6FU to 9FU. An ANOVA and Tukey *post-hoc*

analysis revealed that there was a statistically significant increase in dB SPL from Pre to 6FU (2.8 dB SPL; p=0.0017) along with a medium effect size, and a significant decrease from 6FU to 9FU (2.9 dB SPL; p=3.1E-4) along with a medium effect size. No other statistically significant differences were found.

6. There were decreases in dB SPL for the SIT words task from Pre to 6FU, and from 6FU to 9FU. A Kruskal-Wallis and Wilcoxon *post-hoc* analysis revealed that there was a statistically significant decrease in dB SPL from Pre to 9FU (2.0 dB SPL; p=0.0063) along with a large effect size, and a significant decrease from 6FU to 9FU (1.2 dB SPL; p=0.0059) along with a medium effect size. The Pre to 9FU comparison was clinically significant. No other statistically significant differences were found.
7. There was an increase in dB SPL for the SIT sentences task from 6FU to 9FU. No statistically significant differences were found.
8. There was a decrease in dB SPL for the HINT sentences task from Pre to 6FU, followed by an increase from 6FU to 9FU. No statistically significant differences were found.

Table 8 shows the mean SPL values, standard deviations, the Kolmogorov-Smirnov (K-S) and Levene's normality tests, ANOVA or Kruskal-Wallis (Kruskal) tests, Tukey HST (Tukey) or Wilcoxon rank sum (Wilcoxon) tests, and Cohen's d for DBS-01.

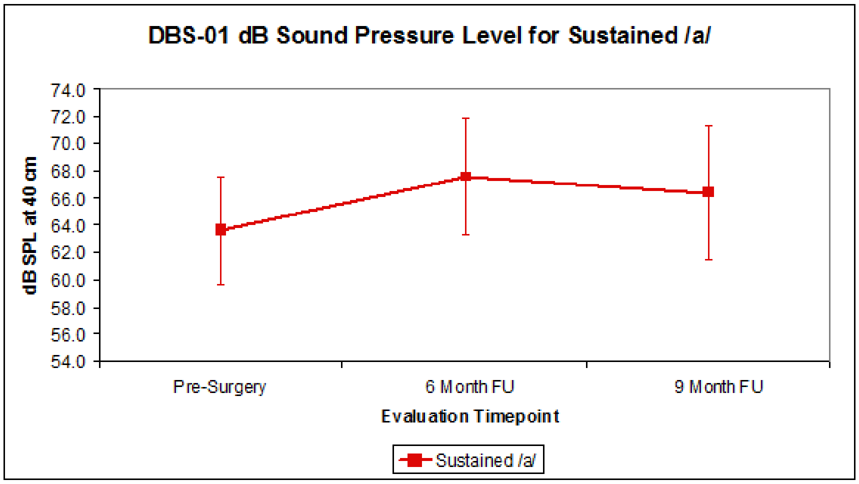
Table 8. Quantitative Changes in Decibel Sound Pressure Level for DBS-01

| Task SPL (dB) | Average Pre (SD) | Average 6 Mo. FU (SD) | Average 9 Mo. FU (SD) | p-value | Pre-6FU p-values (Cohen's d) | Pre-9FU p-values (Cohen's d) | 6FU-9FU p-values (Cohen's d) |
|---|---|---|---|---|---|---|---|
| Sustained /a/ | 63.6 (2.6) | 67.6 (4.3) | 66.4 (4.9) | (Levene) 0.0000 (Kruskal) 0.000 | (K-S) 0.0000 (Wilcoxon) 0.0000 (-1.126) | (K-S) 0.0000 (Wilcoxon) 0.0000 (-0.714) | (K-S) 0.0264 (Wilcoxon) 0.0026 (0.260) |
| Sentence | 61.7 (3.9) | 58.0 (2.3) | 59.5 (3.4) | (Levene) 0.9080 (ANOVA) 0.002 | (K-S) 0.2024 (Tukey) 0.1503 (0.603) | (K-S) 0.1457 (Tukey) 0.2516 (0.146) | (K-S) 1.0000 (Tukey) 0.9446 (-0.526) |
| Paragraph Reading | 62.1 (3.7) | 59.2 (3.3) | 58.9 (2.7) | (Levene) 0.2273 (ANOVA) 0.002 | (K-S) 0.0501 (Tukey) 0.0103 (0.829) | (K-S) 0.0253 (Tukey) 0.0029 (1.000) | (K-S) 0.2273 (Tukey) 0.8122 (0.100) |
| Picture Description | 60.4 (4.5) | 56.0 (0.6) | 56.8 (3.1) | (Levene) 0.0008 (Kruskal) 0.103 | (K-S) 0.2799 (Wilcoxon) 0.1117 (1.725) | (K-S) 0.7391 (Wilcoxon) 0.6187 (0.947) | (K-S) 0.2872 (Wilcoxon) 0.0507 (-0.432) |
| Monologue | 59.1 (3.0) | 61.9 (5.2) | 59.0 (3.3) | (Levene) 0.3103 (ANOVA) 0.000 | (K-S) 0.0201 (Tukey) 0.0017 (-0.660) | (K-S) 0.9546 (Tukey) 0.9979 (0.032) | (K-S) 0.0113 (Tukey) 0.0003 (0.666) |
| SIT Word List[a] | 58.9 (1.9) | 58.1 (2.9) | 56.9 (1.5) | (Levene) 0.0000 (Kruskal) 0.000 | (K-S) 0.9902 (Wilcoxon) 0.7572 (0.333) | (K-S) 0.0467 (Wilcoxon) 0.0063 (1.176) | (K-S) 0.0884 (Wilcoxon) 0.0059 (0.545) |
| SIT Sentence List[b] | - | 58.4 (2.9) | 59.5 (2.6) | (Levene) 0.6580 | - | - | (K-S) 0.8873 (t-test) 0.4947 (-0.400) |
| HINT Sentence List | 59.0 (2.7) | 57.8 (2.7) | 58.4 (2.2) | (Levene) 0.8803 (ANOVA) 0.761 | (K-S) 0.9887 (Tukey) 0.8107 (0.444) | (K-S) 0.9284 (Tukey) 0.7869 (0.244) | (K-S) 0.9999 (Tukey) 1.0000 (-0.244) |

a- SIT words used only twelve words for the Pre list, but used the normal fifty words for 6FU and 9FU.
b- SIT sentences were not used for Pre, but the normal 220 word lists were used for 6FU and 9FU

The summary charts for DBS-01 indicated dB SPL levels both before and after DBS-STN surgery. Without surgical intervention, IPD is a progressive disease with symptoms that cause dB SPL to drop over time, eventually resulting in hypokinetic dysarthria and hypophonia (Bridges, Van Lancker Sidtis, & Sidtis, 2013). Figure 3 shows for the sustained /a/ that there was an increase in dB SPL from Pre to 6FU followed by a slight decrease in dB SPL from 6FU to 9FU.

Figure 3. DBS-01 Sustained /a/ dB SPL at 40 cm Distance




Figures 4 and 5 show the connected speech tasks with red threshold bars showing the normal range of 71-74 dB SPL at 30 cm distance (Awan, 1993; Gelfer & Young, 1997; Ryan & Gelfer, 1993). All of the connected speech tasks performed by DBS-01 were consistently below the threshold. Figure 4 shows the overlaid contextual speech tasks, while Figure 5 shows the separate individual speech tasks with error bars. Figures 4, 5a, and 5c show that the sentence reading and the picture reading declined in dB SPL from Pre to 6FU followed by an increase in dB SPL from 6FU to 9FU. Figures 4 and 5b show the paragraph reading declined in dB SPL from Pre to 6FU, and from 6FU to 9FU. Figures 4 and 5d show the monologue increased in dB SPL from Pre to 6FU, and declined in dB SPL from 6FU to 9FU.

Figure 4. DBS-01 Contextual Speech dB SPL at 40 cm Distance

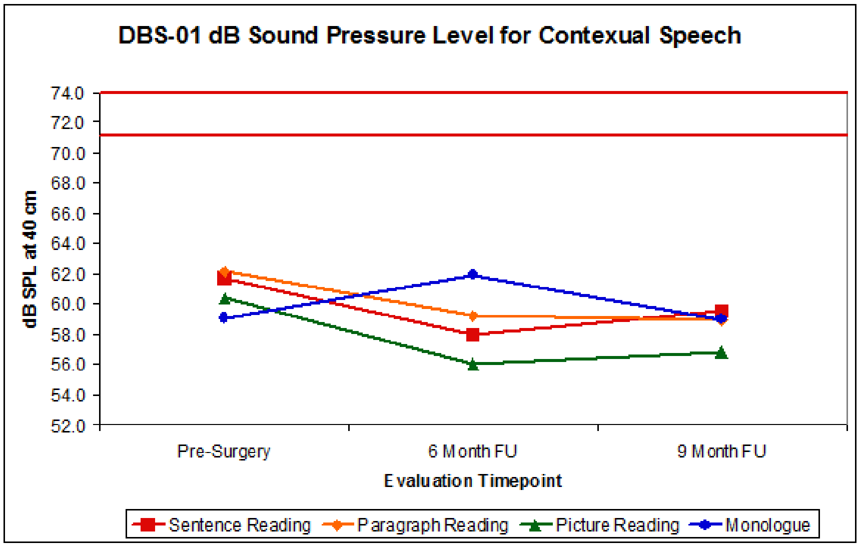



Figure 5. DBS-01 Individual Contextual Speech dB SPL at 40 cm Distance with Error Bars

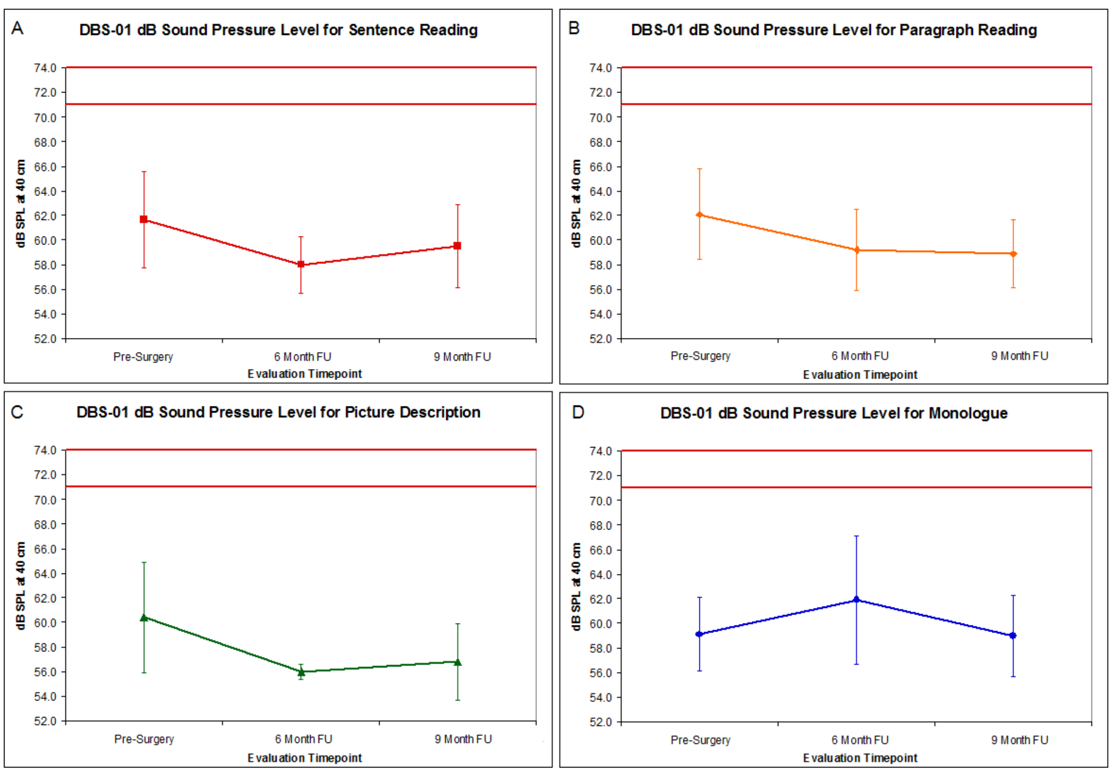
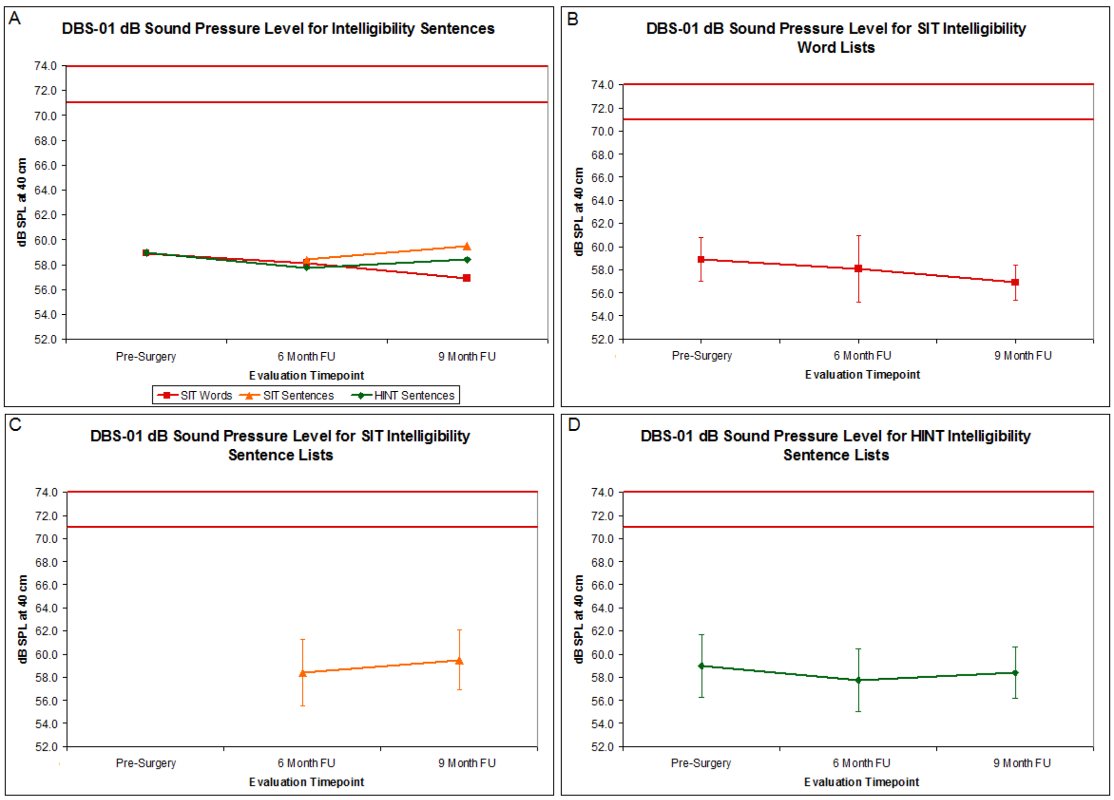



Figure 6 shows the intelligibility speech tasks with red threshold bars showing the normal range of 71-74 dB SPL at 30 cm distance. All of the intelligibility speech tasks performed by DBS-01 were consistently below the threshold. Figure 6a shows the overlaid intelligibility speech tasks, while Figures 6b-d show the separate individual speech tasks with error bars. Figures 6a and 6b show that the SIT words declined in dB SPL from Pre to 6FU, and from 6FU to 9FU. Figures 6a and 6c show that the SIT sentences had no time point at Pre, but increased in dB SPL from 6FU to 9FU. Figures 6a and 6d show that the HINT sentences declined in dB SPL from Pre to 6FU, and increased in dB SPL from 6FU to 9FU.

Figure 6. DBS-01 Individual Intelligibility Lists dB SPL at 40 cm Distance with Error Bars




*DBS-02*

1. There were increases in dB SPL for the sustained /a/ task from Pre to Post, and from Post to 3FU. A Kruskal-Wallis and Wilcoxon *post-hoc* analysis revealed that there was a statistically significant increase in dB SPL from Pre to Post (8.0 dB SPL; p=2.2E-16) along with a large effect size, a significant increase

from Pre to 3FU (12.2 dB SPL; p=7.1E-15) along with a large effect size, and a significant increase from Post to 3FU (4.2 dB; p=3.8E-14) with a large effect size. The Pre to Post, Pre to 3FU, and Post to 3FU comparisons were all clinically significant.

2. There was a decrease in dB SPL for the sentences task from Pre to Post, followed by an increase from Post to 3FU. An ANOVA and Tukey *post-hoc* analysis revealed that there was a statistically significant increase from Post to 3FU (2.6 dB SPL; p=0.0393) along with a large effect size, which indicated clinical significance. No other statistically significant differences were found.
3. There was a decrease in dB SPL for the paragraph reading task from Pre to Post, followed by an increase from Post to 3FU. A Kruskal-Wallis and Wilcoxon *post-hoc* analysis revealed that there was a statistically significant increase from Pre to 3FU (4.6 dB SPL; p=0.0013) along with a large effect size, and a significant increase from Post to 3FU (5.2 dB SPL; p=4.6E-5) along with a large effect size. Both comparisons were clinically significant. No other statistically significant differences were found.
4. There was a decrease in dB SPL for the picture description task from Pre to Post, followed by an increase from Post to 3FU. No statistically significant differences were found.
5. There were increases in dB SPL for the monologue task from Pre to Post, and from Post to 3FU. A Kruskal-Wallis and Wilcoxon *post-hoc* analysis revealed that there was a statistically significant increase in dB SPL from Pre to Post (1.6 dB SPL; p=0.0342) along with a small effect size, and a significant

increase from Pre to 3FU (2.8 dB SPL; p=0.0012) along with a medium effect size. No other statistically significant differences were found.

6. There were increases in dB SPL for the SIT words task from Pre to Post, and from Post to 3FU. No statistically significant differences were found.
7. There were increases in dB SPL for the SIT sentences task from Pre to Post, and from Post to 3FU. A Kruskal-Wallis and Wilcoxon *post-hoc* analysis revealed that there was a statistically significant increase in dB SPL from Pre to Post (1.8 dB SPL; p=0.0018) along with a large effect size, a significant increase from Pre to 3FU (5.5 dB SPL; p=5.0E-12) along with a large effect size, and a significant increase from Post to 3FU (3.7 dB; p=2.1E-6) with a large effect size. The Pre to Post, Pre to 3FU, and Post to 3FU comparisons were all clinically significant.
8. There were increases in dB SPL for HINT sentences task from Pre to Post, and from Post to 3FU. No statistically significant differences were found.

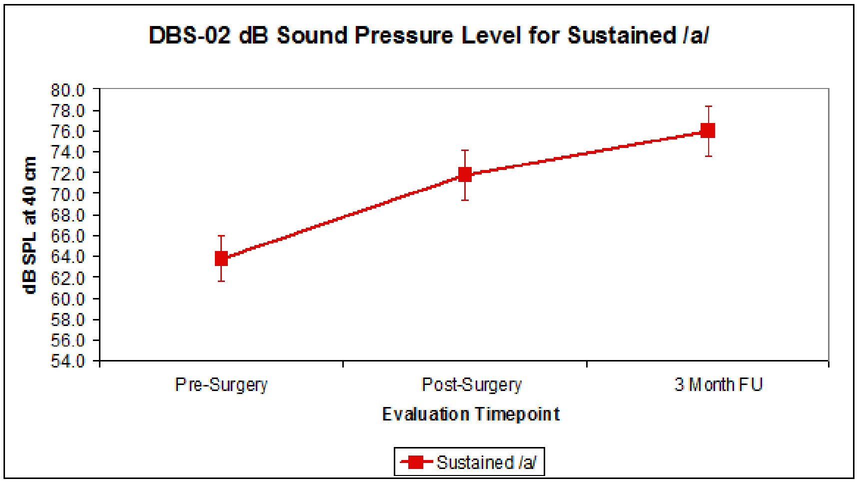
Table 9 shows the mean SPL values, standard deviations, the Kolmogorov-Smirnov (K-S) and Levene's normality tests, ANOVA or Kruskal-Wallis (Kruskal) tests, Tukey HST (Tukey) or Wilcoxon rank sum (Wilcoxon) tests, and Cohen's d for DBS-02.

Table 9. Quantitative Changes in Decibel Sound Pressure Level for DBS-02

| Task SPL (dB) | Average Pre (SD) | Average Post (SD) | Average 3 Mo. FU (SD) | p-value | Pre-Post p-values (Cohen's d) | Pre-3FU p-values (Cohen's d) | Post-3FU p-values (Cohen's d) |
|---|---|---|---|---|---|---|---|
| Sustained /a/ | 63.8 (2.2) | 71.8 (2.4) | 76.0 (2.4) | (Levene) 0.7816 (Kruskal) 0.000 | (K-S) 0.0000 (Wilcoxon) 0.0000 (-3.475) | (K-S) 0.0000 (Wilcoxon) 0.0000 (-5.299) | (K-S) 0.0000 (Wilcoxon) 0.0000 (-1.750) |
| Sentence | 59.5 (1.3) | 56.6 (0.6) | 59.2 (2.6) | (Levene) 0.0677 (ANOVA) 0.030 | (K-S) 0.0475 (Tukey) 0.0800 (2.864) | (K-S) 0.9812 (Tukey) 0.9612 (0.146) | (K-S) 0.1076 (Tukey) 0.0393 (-1.378) |
| Paragraph Reading | 58.8 (2.6) | 58.2 (1.7) | 63.4 (5.1) | (Levene) 0.0045 (Kruskal) 0.000 | (K-S) 0.8170 (Wilcoxon) 0.7221 (0.273) | (K-S) 0.0354 (Wilcoxon) 0.0013 (-1.136) | (K-S) 0.0000 (Wilcoxon) 0.0000 (-1.368) |
| Picture Description | 59.3 (3.4) | 58.1 (1.8) | 61.2 (4.1) | (Levene) 0.0080 (Kruskal) 0.081 | (K-S) 0.9517 (Wilcoxon) 0.5059 (0.441) | (K-S) 0.3309 (Wilcoxon) 0.1336 (-0.504) | (K-S) 0.0683 (Wilcoxon) 0.0343 (-0.979) |
| Monologue | 59.6 (3.9) | 61.2 (3.5) | 62.4 (4.1) | (Levene) 0.2625 (Kruskal) 0.004 | (K-S) 0.0417 (Wilcoxon) 0.0342 (-0.432) | (K-S) 0.0083 (Wilcoxon) 0.0012 (-0.700) | (K-S) 0.4279 (Wilcoxon) 0.2475 (-0.315) |
| SIT Word List | 59.8 (3.2) | 59.2 (3.0) | 60.7 (3.0) | (Levene) 0.4681 (ANOVA) 0.000 | (K-S) 0.8290 (Tukey) 0.4390 (0.193) | (K-S) 0.4234 (Tukey) 0.1300 (-0.290) | (K-S) 0.0426 (Tukey) 0.6917 (-0.500) |
| SIT Sentence List | 57.7 (1.6) | 59.5 (2.5) | 63.2 (3.9) | (Levene) 0.0000 (Kruskal) 0.000 | (K-S) 0.0726 (Wilcoxon) 0.0018 (-0.858) | (K-S) 0.0000 (Wilcoxon) 0.0000 (-1.845) | (K-S) 0.0018 (Wilcoxon) 0.0000 (-1.130) |
| HINT Sentence List | 59.4 (1.7) | 60.6 (3.4) | 62.1 (3.0) | (Levene) 0.5128 (ANOVA) 0.065 | (K-S) 0.9251 (Tukey) 0.0707 (-0.446) | (K-S) 0.1168 (Tukey) 0.3329 (-1.107) | (K-S) 0.2623 (Tukey) 0.6356 (-0.468) |

The summary charts for DBS-02 indicated changes in dB SPL both before and after DBS-STN surgery. Figure 7 shows for the sustained /a/ that there was an increase in dB SPL from Pre to Post followed by an increase from Post to 3FU.

Figure 7. DBS-02 Sustained /a/ dB SPL at 40 cm Distance




Figures 8 and 9 show the connected speech tasks with red threshold bars showing the normal range of 71-74 dB SPL at 30 cm distance. All of the connected speech tasks were below the threshold at all time points. Figure 8 shows the overlaid contextual speech tasks. Figure 8 and Figures 9a-c show that the sentence reading, paragraph reading and the picture reading all declined in dB SPL from Pre to Post followed by an increase in dB SPL from Post to 3FU. Figure 8 and Figure 9d show the monologue increased in dB SPL from Pre to Post, and also from Post to 3FU.

Figure 8. DBS-02 Contextual Speech dB SPL at 40 cm Distance

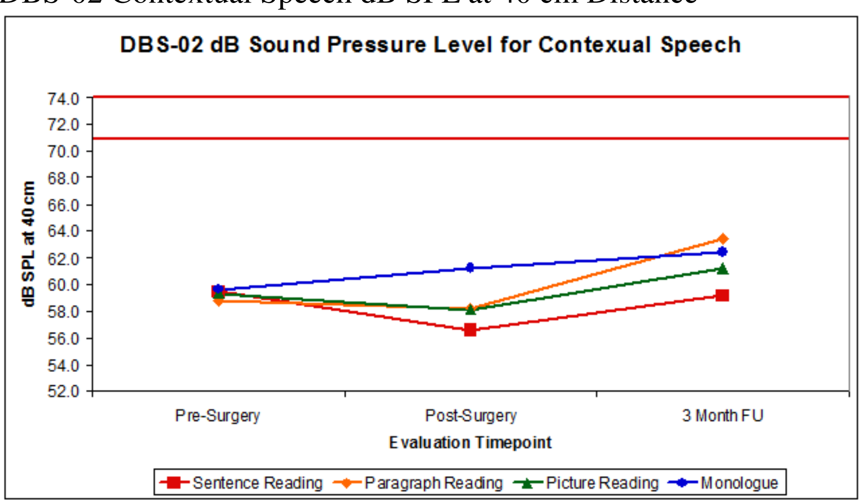


Figure 9. DBS-02 Individual Contextual Speech dB SPL at 40 cm Distance with Error Bars

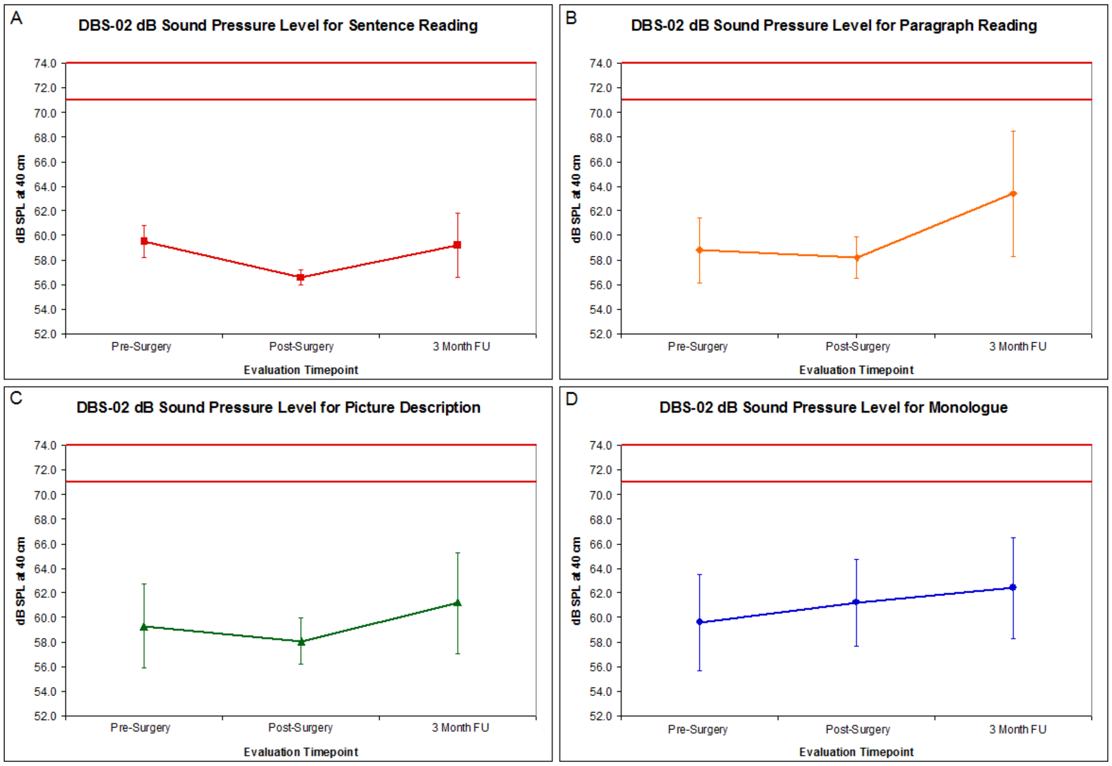
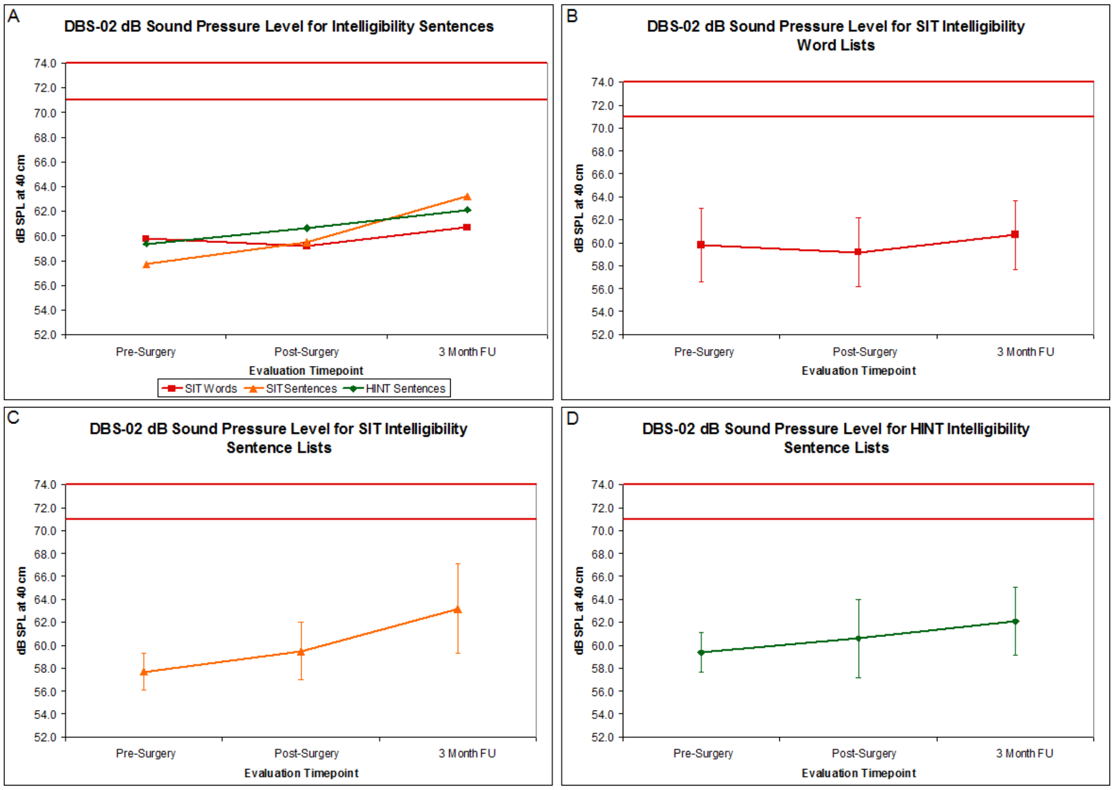



Figure 10 shows the intelligibility speech tasks with red threshold bars showing the normal range of 71-74 dB SPL at 30 cm distance. All of the intelligibility speech tasks were consistently below the threshold. Figure 10a shows the overlaid intelligibility speech tasks. Figures 10a and 10b show that the SIT words slightly declined in dB SPL from Pre to Post, and increased from Post to 3FU. Figures 10a and 10c show that the SIT sentences increased in dB SPL from Pre to Post, and also from Post to 3FU. Figures 10a and 10d show that the HINT sentences increased in dB SPL from Pre to Post, and also from Post to 3FU.

Figure 10. DBS-02 Individual Intelligibility Lists dB SPL at 40 cm Distance with Error Bars




5. Duration of Sustained Vowel Prolongation

*DBS-01*

Mean duration of sustained vowel phonation in seconds (SD) was measured during the sustained /a/ task. DBS-01 had an average time at Pre at 20.3 seconds (6.2). The average time at 6FU increased to 33.4 seconds (6.2). The average time at 9FU increased further to 36.0 seconds (3.8).

*DBS-02*

DBS-02 had an average time at Pre at 8.3 seconds (1.0). The average time at Post increased to 12.5 seconds (2.4). The average time at 3FU declined to 11.3 seconds (1.9).

6. Diadochokinetic Rates (DDK)

DDK rates measure the rate, accuracy, and timing of articulation during a repeated series of rapid, monosyllabic, or trisyllabic phonetic sounds.

*DBS-01*

The DDK rate for DBS-01 varied with the targets produced. "Puh", "Tuh", "Kuh", and "Puh-Tuh-Kuh" rates in targets/second all declined from Pre to 6FU. "Kuh" and "Puh-Tuh-Kuh" rates in targets/second increased from 6FU to 9FU. "Puh" and "Tuh" rates in targets/second decreased from 6FU to 9FU. Table 10 shows the DDK rate outcomes for DBS-01.

Table 10. Quantitative Changes in DDK Rates for DBS-01

| Measure | Pre<br># Repetitions<br>Seconds<br>DDK Rate | 6 Mo. FU<br># Repetitions<br>Seconds<br>DDK Rate | 9 Mo. FU<br># Repetitions<br>Seconds<br>DDK Rate |
|---|---|---|---|
| "Puh" | 8<br>2.0<br>4.0 | 11<br>4.0<br>2.7 | 10<br>6.0<br>1.7 |
| "Tuh" | 8<br>2.5<br>3.2 | 7<br>4.0<br>1.8 | 9<br>6.0<br>1.5 |
| "Kuh" | 10<br>4.0<br>2.5 | 5<br>4.0<br>1.3 | 8<br>5.0<br>1.6 |
| "Puh-Tuh-Kuh" | 8<br>4.0<br>2.0 | 5<br>5.0<br>1.0 | 13<br>6.0<br>2.2 |

*DBS-02*

The DDK rate for DBS-02 varied with the targets produced. "Puh", "Tuh", "Kuh", and "Puh-Tuh-Kuh" rates in targets/second all declined from Pre to Post. "Puh" and "Puh-Tuh-Kuh" rates in targets/second increased from Post to 3FU. The "Tuh" rate in targets/second declined from Post to 3 FU. The "Kuh" rate in targets/second did not change from Post to 3FU. Table 11 shows the DDK rate outcomes for DBS-02.

Table 11. Quantitative Changes in DDK Rates for DBS-02

| Measure | Pre<br># Repetitions<br>Seconds<br>DDK Rate | 6 Mo. FU<br># Repetitions<br>Seconds<br>DDK Rate | 9 Mo. FU<br># Repetitions<br>Seconds<br>DDK Rate |
|---|---|---|---|
| "Puh" | 15<br>4.5<br>3.3 | 3<br>3.5<br>0.9 | 11<br>5.0<br>2.2 |
| "Tuh" | 12<br>4.0<br>3.0 | 9<br>3.5<br>2.6 | 8<br>4.0<br>2.0 |
| "Kuh" | 12<br>4.0<br>3.0 | 6<br>3.0<br>2.0 | 7<br>3.5<br>2.0 |
| "Puh-Tuh-Kuh" | 10<br>5.0<br>2.0 | 7<br>4.0<br>1.8 | 12<br>5.0<br>2.4 |

7. Lip and Tongue Pressures

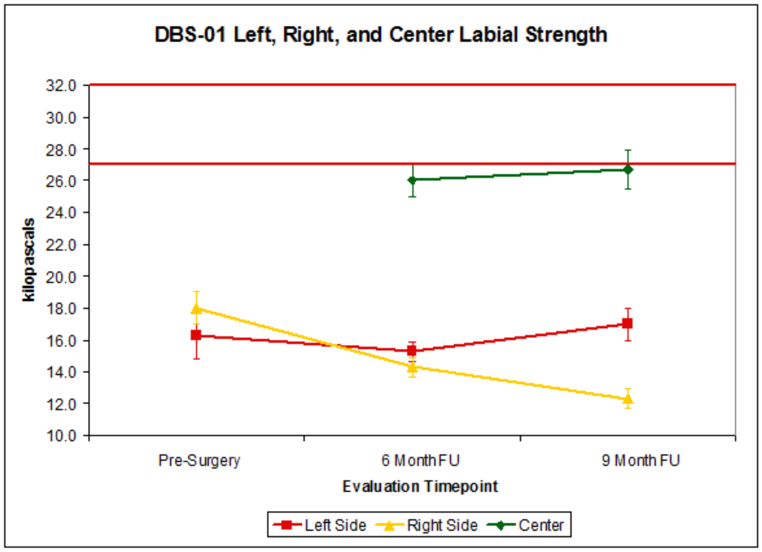
Lip strength, measured in kilopascals (kPa), was assessed on the right, left, and center portion of the lips. The center of the lips has a normal pressure range of 27-32 kPa (Clark & Solomon, 2012).

*DBS-01*

1. The center lip pressure was not assessed at Pre. The pressure in kPa increased from 6FU to 9FU. Both 6FU and 9FU were just below the normal pressure range.
2. The left lip pressure in kPa declined from Pre to 6FU, but then the pressure in kPa increased from 6FU to 9FU.
3. The right lip pressure in kPa declined from Pre to 6FU, and also from 6FU to 9FU.

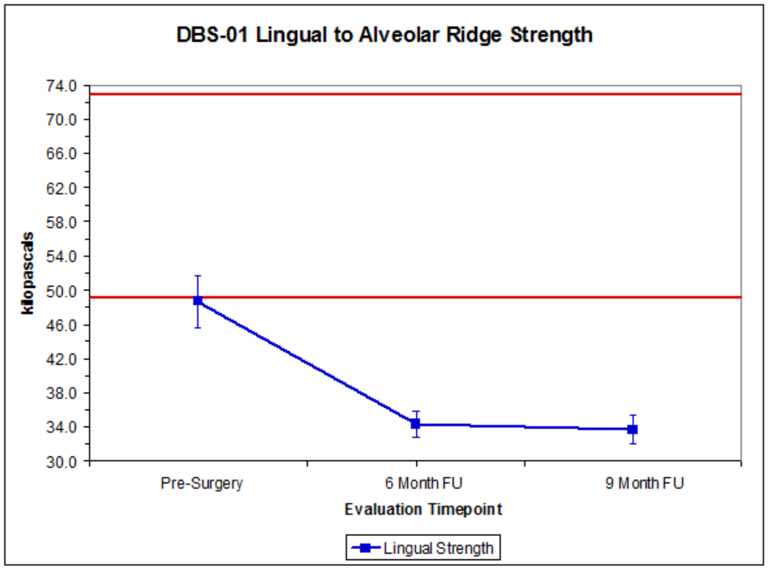
Figure 11 shows how the lip pressures in kPa for DBS-01 varied over time with red threshold bars showing the normal center lip range of 27-32 kPa.

Figure 11. DBS-01 Left, Right and Center Labial Pressure in Kilopascals




The lingual to alveolar ridge has a normal pressure range of 49-73 kPa (Adams, Mathisen, Baines, Lazarus & Callister, 2013). The pressure in kPa for DBS-01 was just below the normal range of 49-73 kPa at Pre. The pressure in kPa dropped from Pre to 6FU to a subnormal level, and remained at that level from 6FU to 9FU. Figure 12 shows the assessment of the lingual to alveolar ridge lip strength in kPa for DBS-01 with red threshold bars showing the normal tongue tip to alveolar ridge pressure range of 49-73 kPa.

Figure 12. DBS-01 Lingual to Alveolar Ridge Pressure in Kilopascals

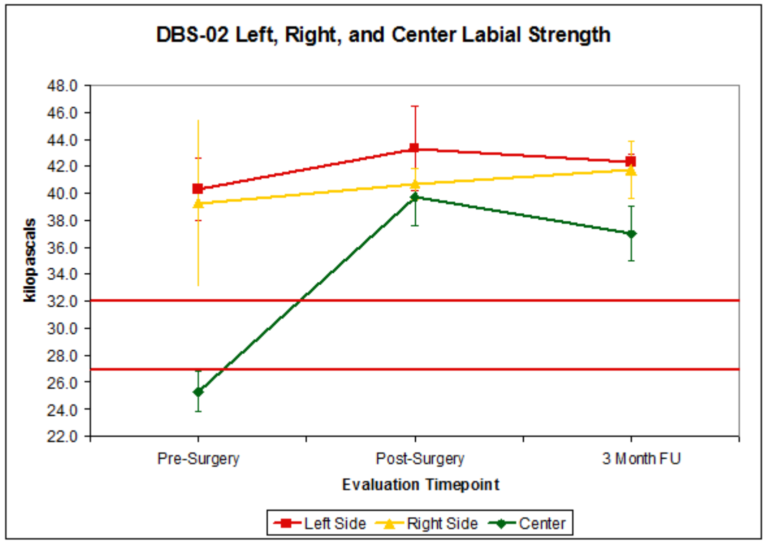



*DBS-02*

1. The center lip pressure in kPa increased from Pre to Post, but then the pressure in kPa declined from Post to 3FU. Only the Post and 3FU pressures in kPa were above the normal pressure range of 27-32 kPa.
2. The left lip pressure in kPa increased from Pre to Post, but then the pressure in kPa declined from Post to 3FU.
3. The right lip pressure in kPa increased from Pre to Post, and then the pressure in kPa continued to increase from Post to 3FU.

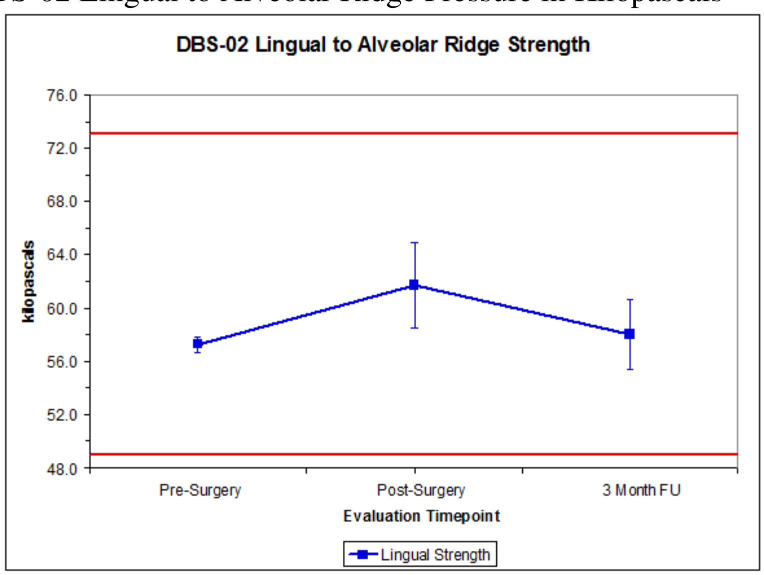
Figure 13 shows how the lip pressures in kPa for DBS-02 varied over time with red threshold bars showing the normal center lip pressure range of 27-32 kPa.

Figure 13. DBS-02 Left, Right and Center Labial Pressure in Kilopascals




The pressure in kPa for DBS-02 was within the normal range of 49-73 kPa at Pre, Post, and 3FU. The pressure in kPa increased from Pre to Post, but then the pressure in kPa dropped from Post to 3FU. Figure 14 shows the assessment of the lingual to alveolar ridge lip strength in kPa for DBS-02 with red threshold bars showing the normal tongue tip to alveolar ridge pressure range of 49-73 kPa.

Figure 14. DBS-02 Lingual to Alveolar Ridge Pressure in Kilopascals



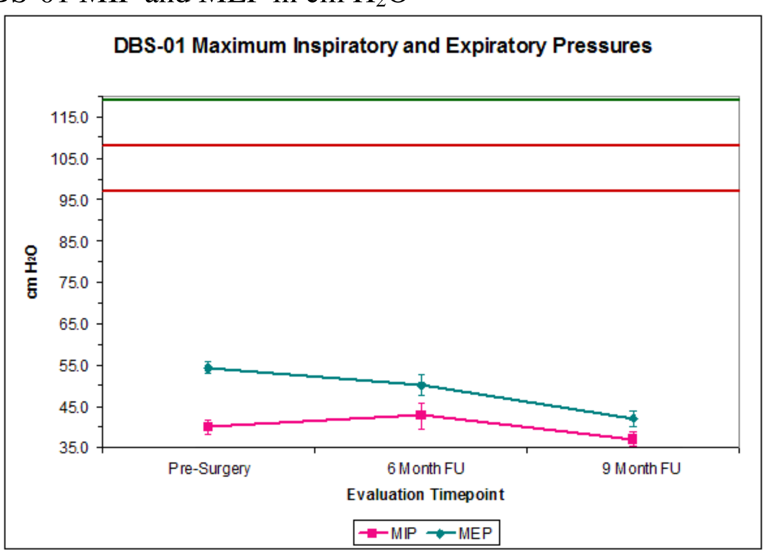
8. Maximum Inspiratory and Expiratory Pressures (MIP & MEP):

MIP and MEP were measured in cm $H_2O$ to assess changes in respiratory support capacity. The normal range for MIP and MEP using a flanged mouthpiece in 50-60 year males is 97-108 cm $H_2O$ for MIP, and 119-137 cm $H_2O$ for MEP (Evans & Whitelaw 2009).

*DBS-01*

DBS-01 was below the normal MIP threshold of 97-108 cm $H_2O$ at Pre, 6FU, and 9FU. MIP in cm $H_2O$ declined from Pre to 6FU, and then the pressure in cm $H_2O$ also declined from 6FU to 9FU. The participant was below the normal MEP threshold of 119-137 cm $H_2O$ at Pre, 6FU, and 9FU. MEP in cm $H_2O$ increased from Pre to 6FU, but the pressure in cm $H_2O$ declined from 6FU to 9FU. Figure 15 shows changes in MIP and MEP in cm $H_2O$ for DBS-01 with red threshold bars showing the normal range of 97-108 cm $H_2O$ for MIP, and a green threshold bar showing the lower end of the normal range of 119-137 cm $H_2O$ for MEP.

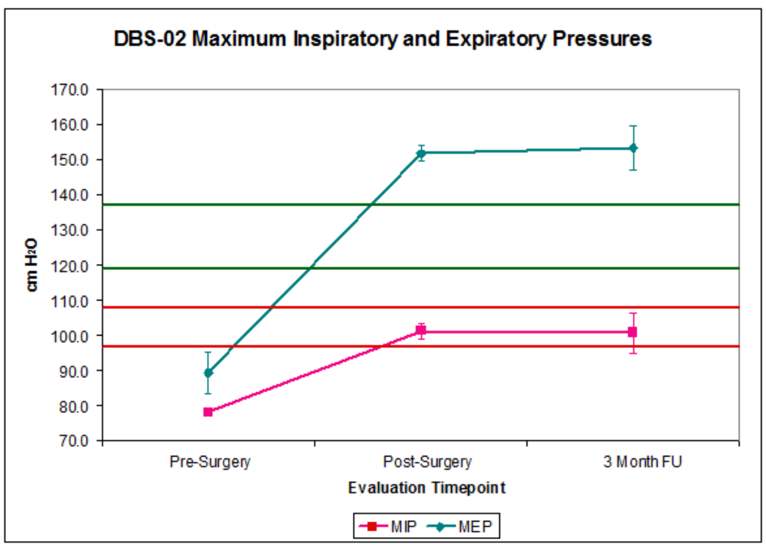
Figure 15. DBS-01 MIP and MEP in cm $H_2O$



*DBS-02*

DBS-02 was below the normal MIP threshold of 97-108 cm $H_2O$ at Pre, and then within the threshold at Post and 3FU. MIP in cm $H_2O$ increased from Pre to Post, and then the pressure in cm $H_2O$ also increased from Post to 3FU. The participant was below the normal MEP threshold of 119-137 cm $H_2O$ at Pre, and then above the threshold at Post and 3FU. MEP in cm $H_2O$ increased from Pre, but then the pressure in cm $H_2O$ declined from Post to 3FU. Figure 16 shows changes in MIP and MEP in cm $H_2O$ for DBS-02 with red threshold bars showing the normal range of 97-108 cm $H_2O$ for MIP, and green threshold bars showing the normal range of 119-137 cm $H_2O$ for MEP.

Figure 16. DBS-02 MIP and MEP in cm $H_2O$




<u>9. Visual Analog Scale (VAS):</u>

The Visual analog scales of communication and eating difficulties were used to track changes in participant self perceptions of specific abnormalities in speech and swallowing, and indicated symptom worsening or abatement. For the purposes of this discussion, the following impairment ranges were arbitrarily set as follows: mild ranged from 80-100%, moderate ranged from 60-79%, and severe ranged from 0-59%.

*DBS-01*

1. DBS-01 started at Pre with moderate impairment (ranging from 65-70%) in difficulties with loudness, finding words, voice shakiness, slurring, voice strain, mumbling, understandability, and conversation initiation and participation. He also displayed severe impairment (53%) for difficulties with the monotone voice.
2. Nine out of ten categories decreased, and one category increased from Pre to 6FU. At 6FU, he displayed moderate impairment (ranging from 64-78%) in difficulties with voice strain and conversation initiation and participation. He also displayed severe impairment (ranging from 15-50%) in difficulties with loudness, finding words, voice shakiness, monotone voice, slurring, voice strain, mumbling, and understandability.
3. Eight out of ten categories decreased, and two categories increased from 6FU to 9FU. At 9FU, he displayed severe impairment (ranging from 21-48%) in difficulties with all ten of the communication categories.

Table 12 shows changes in speech self-perceptual issues for DBS-01.

Table 12: DBS-01 Results of the VAS of Communication Difficulties Expressed as a Percentage

| Test | Pre Percent | 6FU Percent | 9FU Percent |
|---|---|---|---|
| Loudness | 70 | 47 | 39 |
| Finding the right words | 70 | 50 | 36 |
| Shaky voice | 70 | 39 | 35 |
| Monotone | 53 | 15 | 21 |
| Slurring | 72 | 31 | 33 |
| Strained voice | 69 | 78 | 35 |
| Mumbling | 67 | 45 | 37 |
| Understandability | 65 | 36 | 31 |
| Conversation Participation | 67 | 66 | 48 |
| Initiation Conversation | 67 | 64 | 47 |

1. DBS-01 started at Pre with mild impairment (ranging from 87-97%) in difficulties with weight loss, eating out, swallowing liquids, swallowing solids, swallowing pills, swallowing pain, eating pleasure, food sticking, coughing during eating, and swallowing stress.
2. Eight out of ten categories decreased, and two categories did not change from Pre to 6FU. At 6FU, he displayed mild impairment (ranging from 91-95%) in difficulties with eating out, swallowing pain, eating pleasure, and swallowing stress. He also displayed moderate impairment (ranging from 68-77%) in difficulties with weight loss, swallowing liquids, swallowing solids, swallowing pills, food sticking, and coughing during eating.
3. Five out of ten categories decreased, and five categories increased from 6FU to 9FU. At 9FU, he displayed mild impairment (ranging from 80-88%) in difficulties with weight loss, eating out, swallowing liquids, swallowing solids, swallowing pills, swallowing pain, eating pleasure, coughing during eating, and swallowing stress. He also displayed moderate impairment (65%) in difficulty with food sticking.

Table 13 shows changes in eating self-perceptual issues for DBS-01.

Table 13: DBS-01 Results of the VAS of Swallowing Difficulties Expressed as a Percentage

| Test | Pre Percent | 6FU Percent | 9FU Percent |
|---|---|---|---|
| Weight loss | 91 | 77 | 88 |
| Eating out | 91 | 91 | 87 |
| Liquid swallowing | 87 | 70 | 87 |
| Solid swallowing | 88 | 70 | 87 |
| Pill swallowing | 97 | 68 | 86 |
| Swallowing pain | 94 | 94 | 84 |
| Eating pleasure | 96 | 95 | 81 |
| Food sticking | 97 | 70 | 65 |
| Coughing during eating | 95 | 68 | 80 |
| Stress over swallowing | 93 | 91 | 81 |

<u>*DBS-02*</u>

1. DBS-02 started at Pre with mild impairment (ranging from 81-85%) in difficulties with slurring, mumbling, and conversation initiation and participation. He displayed moderate impairment (76-78%) for difficulties with finding words, voice strain, and understandability. He also displayed severe impairment (ranging from 41-56%) in difficulties with loudness, voice shakiness, and a monotone voice.
2. One out of ten categories decreased, and nine categories increased from Pre to Post. At Post, he displayed mild impairment (ranging from 83-91%) in difficulties with loudness, voice shakiness, slurring, voice strain, mumbling, understandability, and conversation initiation and participation. He displayed moderate impairment (77%) in difficulties with finding words. He also displayed severe impairment (51%) in difficulties with a monotone voice.
3. Seven out of ten categories decreased, and three categories increased from Post to 3FU. At 3FU, he displayed mild impairment (ranging from 81-85%) in

difficulties with loudness, finding words, voice shakiness, voice strain, mumbling, understandability, and conversation initiation and participation. He also displayed moderate impairment (ranging from 68-78%) in difficulties with a monotone voice, and slurring.

Table 14 shows changes in speech self-perceptual issues for DBS-02.

Table 14: DBS-02 Results of the VAS of Communication Difficulties Expressed as a Percentage

| Test | Pre Percent | Post Percent | 3FU Percent |
|---|---|---|---|
| Loudness | 56 | 87 | 85 |
| Finding the right words | 78 | 77 | 85 |
| Shaky voice | 56 | 83 | 85 |
| Monotone | 41 | 51 | 68 |
| Slurring | 81 | 83 | 78 |
| Strained voice | 76 | 85 | 83 |
| Mumbling | 84 | 85 | 84 |
| Understandability | 78 | 84 | 82 |
| Conversation Participation | 82 | 91 | 81 |
| Initiation Conversation | 85 | 91 | 81 |

1. DBS-02 started at Pre with mild impairment (ranging from 88-97%) in difficulties with weight loss, eating out, swallowing liquids, swallowing solids, swallowing pills, swallowing pain, eating pleasure, food sticking, coughing during eating, and swallowing stress.
2. Two out of ten categories decreased, six out of ten categories increased, and two categories did not change from Pre to Post. At Post, he displayed mild impairment (ranging from 86-97%) in difficulties with weight loss, eating out, swallowing liquids, swallowing solids, swallowing pills, swallowing pain, eating pleasure, food sticking, coughing during eating, and swallowing stress.
3. Ten out of ten categories decreased from Post to 3FU. At 3FU, he displayed mild impairment (ranging from 83-85%) in difficulties with weight loss, eating

out, swallowing liquids, swallowing solids, swallowing pain, eating pleasure, food sticking, and swallowing stress. He displayed moderate impairment (71%) in difficulty with coughing during eating. He also displayed severe impairment (50%) in difficulty with swallowing pills.

Table 15 shows changes in eating self-perceptual issues for DBS-02.

Table 15: DBS-02 Results of the VAS of Swallowing Difficulties Expressed as a Percentage

| Test | Pre Percent | Post Percent | 3FU Percent |
|---|---|---|---|
| Weight loss | 89 | 96 | 84 |
| Eating out | 90 | 93 | 85 |
| Liquid swallowing | 90 | 94 | 84 |
| Solid swallowing | 88 | 93 | 83 |
| Pill swallowing | 89 | 94 | 50 |
| Swallowing pain | 90 | 93 | 84 |
| Eating pleasure | 97 | 95 | 85 |
| Food sticking | 87 | 86 | 85 |
| Coughing during eating | 97 | 97 | 71 |
| Stress over swallowing | 97 | 97 | 85 |

10. EAT-10 Swallowing Questionnaire:

The EAT-10 swallowing questionnaire was used to track difficulties with eating in participant self perceptions of specific abnormalities in swallowing, and indicated symptom worsening or abatement.

*DBS-01*

DBS-01 had no swallowing difficulties reported at Pre. Five out of ten categories increased, and five out of ten did not change from Pre to 6FU. At 6FU, he reported a change from no to mild impairment in difficulties with swallowing liquids, swallowing solids, swallowing pills, food sticking, and coughing during eating. Four out of ten categories decreased, and six out of ten did not change from 6FU to 9FU. At 9FU, he reported a change from mild impairment to no impairment with difficulties with swallowing liquids, swallowing solids, swallowing pills, and coughing during eating. He also reported mild difficulty with food sticking. Table 16 shows changes in eating self-perceptual issues for DBS-01.

Table 16. DBS-01 Results of the EAT-10 Questionnaire of Swallowing Difficulties

| Test<br>0-4 score (Normal-Severely Impaired) | Pre | 6FU | 9FU |
|---|---|---|---|
| Weight loss | 0 | 0 | 0 |
| Eating Out | 0 | 0 | 0 |
| Liquid swallowing | 0 | 1 | 0 |
| Solid swallowing | 0 | 1 | 0 |
| Pill swallowing | 0 | 1 | 0 |
| Swallowing pain | 0 | 0 | 0 |
| Swallowing pleasure | 0 | 0 | 0 |
| Food sticking | 0 | 1 | 1 |
| Coughing during eating | 0 | 1 | 0 |
| Stress over swallowing | 0 | 0 | 0 |
| Total Score | 0/40 | 5/40 | 1/40 |

*DBS-02*

DBS-02 had mild swallowing difficulties reported at Pre involving swallowing solids, swallowing liquids, swallowing pills, and food sticking. Three out of ten categories decreased, and seven out of ten did not change from Pre to Post. At Post, he reported a change from mild to no impairment in difficulties with swallowing liquids, swallowing solids, and swallowing pills. He reported no change in difficulty with food sticking. One of ten categories decreased, two out of ten categories increased, and seven out of ten did not change from Post to 3FU. At 3FU, he reported a change from mild impairment to no impairment with difficulties with food sticking. He also reported a change from no impairment to mild impairment with difficulties with swallowing pills, and coughing during eating. Table 17 shows changes in eating self-perceptual issues for DBS-02.

Table 17. DBS-02 Results of the EAT-10 Questionnaire of Swallowing Difficulties

| Test<br>0-4 score (Normal-Severely Impaired) | Pre | Post | 3FU |
|---|---|---|---|
| Weight loss | 0 | 0 | 0 |
| Eating Out | 0 | 0 | 0 |
| Liquid swallowing | 0 | 0 | 0 |
| Solid swallowing | 1 | 0 | 0 |
| Pill swallowing | 1 | 0 | 1 |
| Swallowing pain | 1 | 0 | 0 |
| Swallowing pleasure | 0 | 0 | 0 |
| Food sticking | 1 | 1 | 0 |
| Coughing during eating | 0 | 0 | 1 |
| Stress over swallowing | 0 | 0 | 0 |
| Total Score | 4/40 | 1/40 | 2/40 |

11. Timed Dysphagia Assessment:

The timed swallow test was used to quantify swallowing rates in swallows per second (swallows/s) and milliliters per second (ml/s). It was used to quantify issues with swallowing water as well as to note problems with swallowing food. A swallowing rate under 10 ml/second is considered a swallowing impairment (Nathadwarawala, Nicklin, & Wiles, 1992).

*DBS-01*

DBS-01 was able to swallow applesauce, cookies, and the full 150 ml of water without any choking or aspiration for Pre, 6FU, and 9FU. The swallowing rate in swallows/s decreased from Pre to 6FU, and then the rate remained constant from 6FU to 9FU. The swallowing rate in ml/s increased from Pre to 6FU, and then the rate remained constant from 6FU to 9FU, but it was in the normal range at Pre, 6FU, and 9FU. Table 18 shows changes in swallowing rates for DBS-01.

Table 18. Swallowing Rates for DBS-01

| Measure | Pre | 6 Mo. FU | 9 Mo. FU |
|---|---|---|---|
| Volume of water swallowed in ml | 150 | 150 | 150 |
| Number of Swallows | 8 | 5 | 5 |
| Time in Seconds | 8.4 | 6.4 | 6.0 |
| Swallowing rate in Swallows/seconds | 1.0 | 0.8 | 0.8 |
| Swallowing rate in ml/second | 19 | 30 | 30 |

*DBS-02*

DBS-02 was able to swallow applesauce, cookies, and the full 150 ml of water without any choking or aspiration for Pre, Post, and 3FU. The swallowing rate in swallows/s remained constant from Pre to Post, and then the rate increased from Post to 3FU. The swallowing rate in ml/s increased from Pre to Post, but then the rate declined from Post to 3FU, but it was in the normal range at Pre, Post, and 3FU. Table 19 shows changes in swallowing rates for DBS-02.

Table 19. Swallowing Rates for DBS-02

| Measure | Pre | 6 Mo. FU | 9 Mo. FU |
|---|---|---|---|
| Volume of water swallowed in ml | 150 | 150 | 150 |
| Number of Swallows | 10 | 6 | 8 |
| Time in Seconds | 13.4 | 9.1 | 8.0 |
| Swallowing rate in Swallows/seconds | 0.7 | 0.7 | 1.0 |
| Swallowing rate in ml/second | 15 | 25 | 19 |

12. Qualitative Assessments:

The qualitative assessments were used to examine the narrative of the participant's lives with IPD, the DBS-STN surgery and symptoms, and condense this information into broad themes *a posteriori*.

*DBS-01*

1. The first theme developed was physical motor symptoms from IPD, and the effects of DBS-STN surgery. DBS-01 reported on a number of pre-surgery symptoms, "Stiffness, tremor, gait issues, my balance. I just have pain. All of

the joints are painful. I have a frozen shoulder, I can't really move it. I have lower back pain, knee pain, wrist, elbow pain, just body pain. My writing is really cramped and small. Most people would have no idea what I was writing. I have severe constipation and frequent urination." He also mentioned a progressive worsening of symptoms over a two year time period, and a resting tremor in his right hand. IPD symptoms forced him to retire, and take a drug treatment regimen for IPD symptoms, although he still helped out his family when they went fishing. He stayed active by going to a gym. He described the DBS-STN surgery in detail, "The surgery was quite interesting to say the least. It was a little scary. The day of the surgery I woke up and asked myself, 'Is this real?' Everything happened so fast. I was awake when they drilled. I don't feel any movement of the [implanted] wires, and there are no restrictions of movement." After the bilateral surgery, he reported that the DBS-STN stimulators were set to 3.4 V on the right side, and 2.6 V on the left at 6FU. Later, the voltage on the right side was increased to 3.6 V at 9FU, while the voltage on the left side was not changed. He mentioned at 6FU, "I play with the settings a lot up and down. I adjust my meds. I want to get it just right. 4.0V is the level required to totally get rid of the tremor…The tremor has definitely gotten worse. My tremor is stubborn even when I change the settings." Side effects noted included that the Sinemet 25/100 dose was cut to 1/3$^{rd}$ of the Pre-surgery level, that the DBS-STN stimulation was able to reduce, but not eliminate the resting tremor, improve ease of writing if not legibility, although it did not alleviate fatigue.  He noted, "I went to [LSVT®]

Big and I'd recommend it to anyone. It is really intense. I was jogging, or at least what I would call a jog, and sprinting. I'm going to do a 5k." He mentioned at 9FU, "Before I got PD, I never thought about how important movement is to walking, using the bathroom, speaking, and swallowing. I [still] work on boats. My body is fatigued too. I'm usually out by nine or ten o'clock." He reported that the Sinemet 25/100 dose was unchanged, and that the DBS-STN stimulation did not help his micrographia.

2. The second theme developed was cognitive and emotional symptoms from the IPD, and the surgery. He reported numerous pre-surgery symptoms, "I have been moody. I have a lot of nonmotor stuff: anxiety and depression. I take something for depression. I've always had a bad memory. I'm not sure if it's gotten worse. I have trouble reading and finishing tasks. Staying focused and remembering what I read is hard. I have trouble finding the right words" He reported, at 6FU after the surgery, "My memory is the same. There may be mood changes, but I can't tell if it was the surgery or PD. I know what I want to say, but I can't always recall it. I get very tired to stay awake to read." He had similar comments at 9FU, "My memory is the same. Sometimes I can't find the right word, but I don't think it's gotten much worse because of the surgery. I have trouble reading because I'm so tired."
3. The third theme developed was communication issues from the IPD, and the surgery. DBS-01 initially remarked that he had few communication issues as a result of IPD symptoms. He then reported substantial pre-surgery symptoms, "I don't talk much. I have a wife and son at home. I don't say words clearly. I

mumble or slur somewhat. I focus on speaking clearly. My wife says ‘what’ a lot when I talk. People don’t lean in to hear me better that much. My tone is low.” He also reported hypophonia, monotone, feeling out of breath during speech, but not fatigue, and being intelligible 95% of the time. He did not use speech in a professional capacity, but he still used the phone regularly, and talked to friends and family several hours a day despite his speech issues. Many years prior to the IPD diagnosis, he had had speech therapy for an unrelated issue. He reported at 6FU after the surgery, “The medicine and the DBS both have an effect on my speech. I speak quieter because I don’t want to slur. I find it embarrassing, and people keep asking ‘what’, and asking ‘What did you say?’ It’s like I’m talking a different language. I think it’s a combination of the slurring and softer voice.” He mentioned that his vocal fatigue, monotone, hypophonia, slurring, and being understood had worsened; he did not have pain or breathlessness during speech, his pitch and speech rate were the same, and he was intelligible 70% of the time. He also reported, “I speak a little bit more now, because before I didn’t speak too much. I would guess a couple of hours, say 2-3. I talk with my kids, my wife, [and] my friends. I talk to my business partners on the phone, sometimes in person. I adjust myself when I’m out for dinner by lowering the settings. I shake a bit more. I put it back up to move.” He reported at 9FU, “My voice is a bit slurred, maybe a little softer. I notice it more when I’m getting tired. With the speech I have trouble with slurring, and I get tired, and it is a strain to talk. It is more of an effort to talk when I am tired. I notice people strain to understand me. It takes more of an effort to speak. I've been really fatigued at the end of the day with my voice." He mentioned that his vocal fatigue, monotone, hypophonia, and being understood had worsened; his speech rate was faster, he had not had any speech therapy since the surgery, and he was intelligible 80% of the time. He also reported, "I don't speak enough. It is like three hours a day. I communicate with my wife, my kids on the telephone, on boats, with friends and family. I go out and chit-chat; more of a social thing. I don't speak less because I make a conscious effort to talk. It is very noisy on boats and I have to speak over it."

4. The final theme developed was swallowing and eating issues from the IPD and surgery symptoms. Pre-surgery, he noted, "I sometimes drool at night. I try to eat better." He did not report issues with coughing during meals, swallowing food, increased eating time, or unwanted weight loss. He reported at 6FU after the surgery, "The swallowing didn't seem to change. Every so often food seems to get stuck; almost like a gagging reflex. It's not an everyday occurrence. I don't think I choke on water. Drooling is no more or less than before. A little bit more coughing for some reason. It's not food versus water. Swallowing is harder at the end of the day." He also mentioned that he did not have to take longer to eat, lose weight unexpectedly, but he had some trouble making food go down after swallowing. He mentioned at 9FU, "My swallowing hasn't changed. It actually has been pretty good. There are really no problems with swallowing. Luckily, my swallowing hasn't gotten worse. I'm eating the same as before."

*DBS-02*

1. The first theme developed was physical motor symptoms from the IPD, and the effects of DBS-STN surgery. DBS-02 reported on a number of pre-surgery symptoms, “The first symptom was in the summer of 2009, which was a small tremor in my hand. Then in the fall was my right leg. I have a right side resting tremor, slowness of movement, rigidity, muscle stiffness, soft voice, and a lot of fatigue. No shuffling. I used to go to a gym before this happened.” He also reported difficulty in writing. IPD symptoms forced him to retire, although he did not remain on a drug regimen to treat the IPD symptoms, partly because the Sinemet™ caused a urinary tract infection and constipation. After surgery, he described the DBS-STN electrode adjustments, “When it was first turned on, it felt like you were sticking your finger in an electrical outlet when you were a kid. This latest adjustment, I felt nothing. I am 99% tremor free, and no medication.” He also reported that the left side unilateral DBS-STN stimulator was initially set up as 1.6 V; it was eventually ramped up to 2.4 V at Post. Later, the voltage was increased to 2.8 V during the day and 2.0 V during the night at 3FU. The impedance was fixed at 1000Ω. The stimulators could be adjusted by the participant. Side effects included the comment that the DBS-STN stimulation reduced his fatigue, and reduced the amplitude of the resting tremor. He noted at Post, “My first [IPD] symptom was handwriting. It’s gotten a little bit better, a little bit easier…I know a lot of Parkinson’s patients get a masked face, where the muscles don’t want to work. Before the surgery I felt like I was expressionless. In the mornings since the surgery, I still have the

dreams, and I find it harder to wake up. I have to lay there, be cognizant of my breathing, and breathe in and out before I get up." He reported at 3FU, "Prior to the surgery, there was no way I could have done the [historical society] tours. Before the surgery my brain was two steps ahead of what I was doing. My brain is clicking, but it revs up the tremors. Post DBS, I can do the tours and get no tremors whatsoever."

2. The second theme developed was cognitive and emotional symptoms from the IPD, and the surgery. He reported several pre-surgery cognitive and emotional symptoms, "I have vivid dreams. I don't have a lot of problems with memory. I do genealogy for my family, and I can remember a lot of dates and special events. I still do theater. I don't read if it is real long or doesn't hold my interest. Then I will just put it aside. My depression has gotten worse. I take Trazodone™. To sum up my priorities use PAD: Parkinson's, anxiety and depression, in that order. Depression can precede Parkinson's." He also said he was able to find the right words, and read without difficulty. He reported at Post after the surgery, "My mood is better because I feel better. I'm not really a reader. I have to be interested in the subject. I have no problem expressing myself." He also mentioned that there were no changes to his memory. He reported at 3FU, "The dreams went away after the surgery, but about a month later they began to kick in again. I am also diagnosed with PSTD on top of that which makes these vivid dreams even worse. I have more issues with anxiety than depression. I see grey skies in the winter and my mood plummets. My mood is bad because of the fall. It's not DBS related." He also reported finding

words was not difficult, and his memory was unchanged. He mentioned, "I've been reading more than I have in the past. If a story has no interest to me, I will tune it out after the first sentence. Once you have the surgery, and the tremors are gone and your body can just relax, you want everyone to leave you alone."

3. The third theme developed was communication issues from the IPD, and the surgery. DBS-02 never had speech treatment prior to the study. He reported pre-surgery symptoms, "The soft voice came on slowly. People have asked me to speak up in noisy environments. I have noticed it has gotten softer in the past two years. Sometimes I don't want to talk. I'd rather sit back and be quiet. If someone can't hear me, I take a sip of water and speak as loud as I can. I have slight slurring, but no mumbling. I used to be able to sing before Parkinson's." He also mentioned his voice quality improved when he was using drugs to treat IPD symptoms, but his voice quality declined when he stopped using the medication. He described having a lower pitched, monotone, unchanged rate, soft, breathy, subdued, and tired voice, and was intelligible about 75% of the time. He did not use speech in a professional capacity, but he still used the phone regularly, and talked to friends and family about two hours a day without running out of breath despite his speech issues. He reported at Post after the surgery, "Some of the speech, volume has been a little bit better. After the second adjustment on July 13, my speech was slightly slurred…but it has improved. It lasted 16 hours, [and] then was gone. Other have made comments to me basically as, 'Oh, you sound a lot better.' I have a lot going on with the family, and have a speaking engagement in Dartmouth [MA] for a PD

support group in September. I agreed to speak to them about the whole DBS process." He also reported in increase in voice loudness, the voice was slightly less monotone, oral communication had become easier, the vocal fatigue had lessened, the words were clear, the vocal pitch did not change, he did not run out of breath when talking, there was no pain, the speech rate had not changed, he spoke more often, he did not repeat himself more frequently, and his intelligibility was about 90-95%. He reported at 3FU, "I've had compliments on my speech. I did the presentation at the council for the aging in Dartmouth [MA], and the title of it was 'DBS: a personal perspective.'…It was from 2006, from my first symptoms right up to my surgery. I had a lot of questions. I speak professionally when I give the tours and the theater. I just accepted a small role in a theater in New Bedford [MA]. I can do tours [at the historical society] which take an hour and a half each. I speak with friends and family. I would say about 2-3 hours [a day]." He also reported in increase in voice loudness, oral communication had become easier, the vocal fatigue had decreased, the words were clearer, the vocal pitch dropped, he did not run out of breath when talking, there was no pain, there was no slurring or mumbling, the speech rate had not unconsciously changed, he spoke more often, he repeated himself less frequently, and his intelligibility was about 95%.

4. The final theme developed was swallowing and eating issues from the IPD and surgery symptoms. Pre-surgery, he reported, "I don't have any swallowing issues currently, but I have in the past…Before I was diagnosed, I would eat and the food would get stuck right here [throat]. I couldn't breathe, and I

would have to jump up and down…I still have swallowing problems now, but not as often. Now I eat a little more slowly and carefully. I just don't eat a lot of fatty foods. I don't avoid hard to swallow foods." He also mentioned prior swallowing issues, although it was a temporary condition due to an illness, and not related to IPD. He reported drooling at night, taking longer to eat, not having any significant weight changes, and not coughing during meals. He reported at Post after the surgery, "I haven't noticed any increase or decrease in [swallowing] issues. No choking at all. Sometimes water goes down the wrong pipe, but it isn't worse than before. I drool less since the surgery, and only at night." He also mentioned that he did not take more time to eat, had no further changes in his diet, food was sticking in the throat less, and his weight had not changed, and he had not had recent bouts of pneumonia. He noted at 3FU, "I haven't had any swallowing issues for well over a year. I notice drool in the morning, but it hasn't changed." He also reported that he didn't cough during mealtimes, did not take more time to eat, did not change his diet, food wasn't sticking in the throat, his weight was stable, and he had not had any bouts of pneumonia.

# CHAPTER 5

# DISCUSSION

## 5.1 Discussion Summary

The purpose of this study was to determine how DBS-STN surgery impacted speech and swallowing characteristics in two participants with IPD based on evaluations administered prior to and after DBS-STN surgery. Changes in the dependent variables were analyzed in depth to provide an assessment of the impact of the surgery on individual participants.

*DBS-01*

DBS-01 had statistically significant declines of single word intelligibility from Pre to 9FU. The Pre for sentence intelligibility was higher than for single word intelligibility, but the changes in sentence intelligibility from Pre to 9FU were not statistically significant. This indicated that context might have supported the perceptions of the listeners. The VSA increased from Pre-6FU, but the increase was not maintained at 9FU possibly due to IPD symptom progression. The MDVP analyses indicated an overall loss of phonatory stability that did not reach statistical significance. There was a statistically significant increase in dB SPL for sustained vowel phonation that did not carry over to connected speech. Loudness during sustained vowel phonation is one continuous phoneme gesture making it easier to achieve than during the rapid dynamic phoneme gestures required during speech tasks. The DDK rate declined from Pre to Post, and increased from Post to 3FU reflecting changes in the accuracy and precision of tongue movements. Left lip and tongue pressures declined from Pre to 9FU; however right lip pressure increased from Pre to 9FU, and the center lip pressure increased from 6FU to 9FU. The differences in pressure changes for the left and right lips indicated that they were not equally impaired. The contralateral DBS-STN electrodes, increased between 6FU and 9FU evaluations for the right electrode, and remained the same for the left electrode. The center lip pressure was not assessed at Pre, but the 6FU to 9FU results indicated no decline over time. The VAS for communication difficulties revealed a decline of loudness, finding words, shaky voice, monotone, slurring, voice strain, mumbling, understandability, and conversation participation and initiation from Pre to 9FU. The VAS for swallowing difficulties revealed an increase in dysphagia symptoms from Pre to 6FU, and a decrease in symptoms from 6FU to 9FU for weight loss, swallowing liquids, swallowing solids, swallowing pills, food sticking, and coughing during eating. The EAT-10 questionnaire followed a similar pattern. These results indicated positive changes for swallowing following surgery but not for speech. Results from the timed swallow test indicated that dysphagia symptoms were not severe for this participant during the experiment. The overall trend indicated that there was no significant alleviation of speech and swallowing symptoms from Pre to 6FU. The symptoms worsened from 6FU to 9FU.

*DBS-02*

DBS-02 had statistically significant gains of single word intelligibility from Pre to Post but had declines from Post to 3FU that failed to reach statistical significance. There were no statistically significant changes for sentence intelligibility from Pre to 3FU; however, it was difficult to detect a change because of a potential ceiling effect since Pre intelligibility of sentences was already above 93%. The results indicated that there was a short term improvement in single word intelligibility, and also suggested that context improved the listener perceptions in sentences. The VSA contracted from Pre to Post, which indicated reduced tongue dexterity to form the corner vowels. It expanded from Post to 3FU, as the surgery suggested improvements in tongue dexterity from Post to 3FU.  Two of the three corner vowels became more centralized and one became less centralized at 3FU. The MDVP analyses indicated an overall statistically significant gain of phonatory stability. There was a statistically significant increase in dB SPL for the sustained vowel phonation that did not carry over to connected speech except for the paragraph reading and the SIT sentence list.  The duration of sustained vowel phonation increased from Pre to Post, and declined from Post to 3FU which might have indicated improved coordination of respiration and phonation. The DDK rate declined from Pre to Post, and increased from Post to 3FU as tongue dexterity was temporarily impaired after the surgery. Right, left and center lip and tongue pressures increased from Pre to Post, but the center and left side declined from Post to 3FU. These results revealed an increase at post, but a decline in motor ability by 3FU. The VAS for communication difficulties revealed an increase of loudness, finding words, shaky voice, monotone, voice strain, mumbling, and understandability from Pre to 3FU.  The VAS for swallowing difficulties revealed a decrease in symptoms from Pre to Post, and an increase in symptoms from Post to 3FU for weight loss, eating out, swallowing liquids, swallowing solids, swallowing pills, eating pleasure, and food sticking. The EAT-10 questionnaire followed a similar pattern. These suggest there were improvements for speech and for swallowing after the surgery before progressive declines manifested by follow up. The timed swallow test did not uncover any major issues, as dysphagia symptoms were not severe for the participant during this experiment and the test was not sensitive enough to detect mild changes in swallowing. The overall trend indicated that DBS-STN surgery might have resulted in an alleviation of speech and swallowing symptoms in the short term. However by the follow up, some of the symptoms had worsened back to baseline.

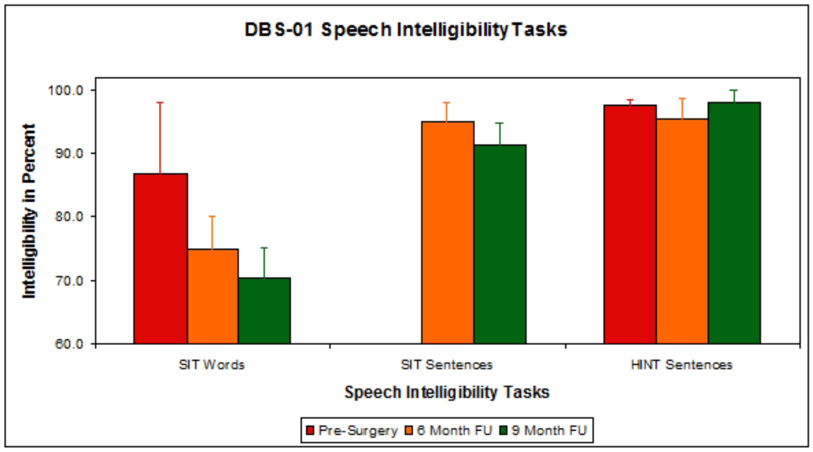
5.2 Dependent Variables

1. Speech Intelligibility:

*DBS-01*

Figure 17 shows the comparison of the Intelligibility of word and sentence lists in percent for DBS-01. The percent intelligibility for DBS-01 significantly declined from baseline for single words from Pre to 9FU, but failed to significantly change for sentences from Pre to 9FU and returned to the baseline. Connected speech is easier to interpret because contextual clues are lacking in isolated words. In the case of DBS-01, after the DBS-STN surgery, there was a negative impact on intelligibility of isolated words with statistically significant changes but there was not a significant effect on complete sentences, likely due to the fact that gaps of comprehension in sentences could be inferred through contextual words that were understood by the listeners. None of the intelligibility tasks followed similar patterns of changes from Pre to 9FU.

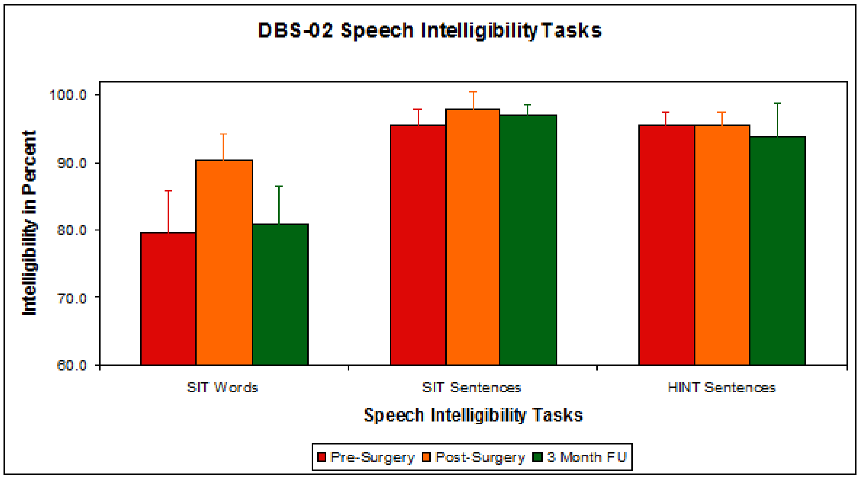
Figure 17. DBS-01 Intelligibility of Word and Sentence Lists in Percent




*DBS-02*

Figure 18 shows the comparison of the Intelligibility of Word and Sentence lists in percent for DBS-02. The percent intelligibility for DBS-02 significantly increased from the baseline for isolated words from Pre to Post, but then significantly decreased from Post to 3FU back to the baseline, unlike the consistent decrease recorded for DBS-01. Intelligibility failed to significantly change for sentences from Pre to 3FU and closely resembled the baseline for DBS-01. Complete sentences consistently scored higher on this task than single words because of contextual clues. Intelligibility of sentences did not vary significantly from pre to post surgery likely due to the fact that misheard words could be filled in using surrounding words. None of the intelligibility tasks followed similar patterns of changes from Pre to 3FU. Intelligibility was a sensitive test for speech disorders.

Figure 18. DBS-02 Intelligibility of Word and Sentence Lists in Percent




<u>2. Vowel Space Area (VSA):</u>

<u>*DBS-01*</u>

The VSA expanded from Pre to 6FU, and then it contracted from 6FU to 9FU indicating a more constrained VSA at 9FU than at Pre. An increase in F1 was inversely related to an increase in tongue height, while an increase in F2 was directly related to tongue advancement.  Both of these shifts would direct the VSA to a normative value (Hillenbrand, Getty, Clark, & Wheeler, 1994). The corner vowels F1 for /a/, had a clinically significant decrease from the baseline, while /i/ and /u/ increased above the baseline, although only the rise for /u/ was clinically significant. The corner vowels F2 for /a/ had a clinically significant increase from the baseline, while /i/ and /u/ decreased below the baseline, although the changes failed to reach significance. The results indicated a general deterioration of vocal quality and tongue dexterity. The overall indications were that from Pre to 9FU, F1 and F2 for /a/ and /u/ moved out of the normal ranges, F1 for /i/ was within the normal ranges, and F2 for /i/ was consistently subnormal. The results indicated a restriction in the tongue positioning after the DBS-STN surgery.

*DBS-02*

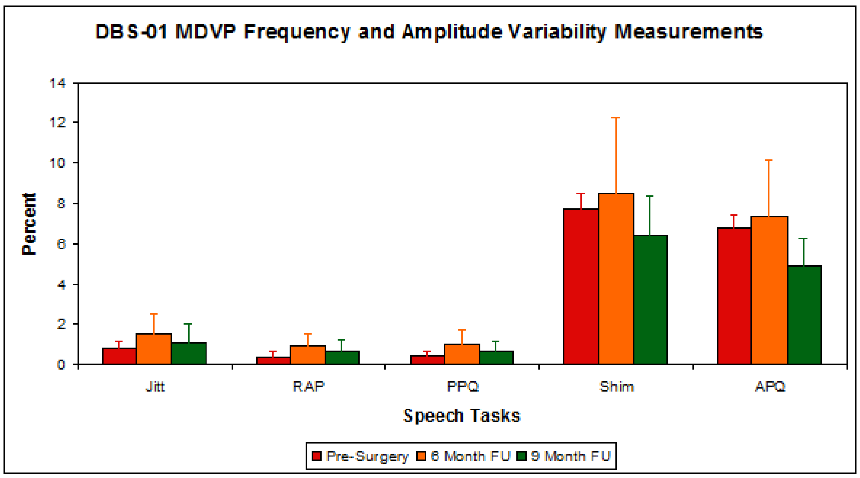
The VSA contracted from Pre to Post, and then it expanded from Post to 3FU indicating a more expansive VSA at 3FU than at Pre. The corner vowels F1 for /a/, /i/ and /u/ all increased above the baseline, with /a/ and /i/ achieving clinical significance. This result contrasted with the declines in /a/ below the baseline for DBS-01. The corner vowels F2 for /a/ and /i/ had clinically significant increases from the baseline, while /u/ decreased below the baseline, although the change failed to reach significance. This result contrasted with the declines in /i/ below the baseline for DBS-01. The overall indications were that after the DBS-STN surgery from Pre to 3FU, F1 for /a/ was consistently subnormal, F2 for /a/ moved above the normal range, F1 and F2 for /i/ remained within the normal ranges, F1 for /u/ moved into the normal range, and F2 for /u/ moved into and out of the normal ranges. The results indicated an improvement in the tongue positioning after DBS-STN surgery. The increase in the VSA indicated increased tongue dexterity, unlike the decline seen in DBS-01. The VSA was a sensitive test for noting speech disorders.

3. Multidimensional Voice Program (MDVP):

*DBS-01*

Figure 19 shows the comparison of the MDVP frequency and amplitude variation in percent for DBS-01. The values increased above Pre for nine of the ten MDVP tests from Pre to 6FU, but not significantly, indicating that phonatory stability had not been significantly compromised. The values decreased for nine of the ten MDVP tests from 6FU to 9FU, but not significantly, indicating that phonatory stability had not been significantly improved. Only three of the ten tests returned to the baseline. The overall result was that the speech characteristics did not significantly improve following DBS-STN surgery, meaning that the participant did not have clearer speech. Jitt, RAP, and PPQ, the three MDVP tasks comparing variability of frequency, all displayed an increase from Pre to 6FU, and a decrease from 6FU to 9FU. Shim and APQ, the two MDVP tasks comparing variability of amplitude both displayed an increase from Pre to 6FU, and a decrease from 6FU to 9FU.

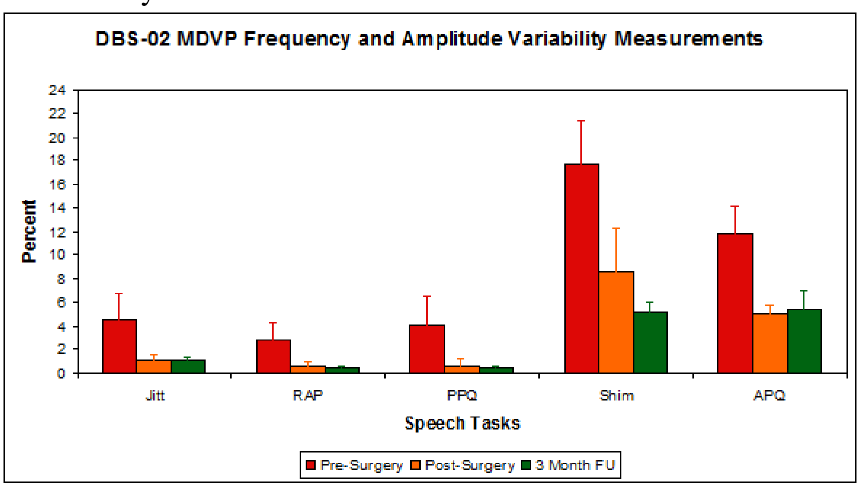
Figure 19. DBS-01 Multidimensional Voice Program Analysis of Frequency and Amplitude Variability in Percent




*DBS-02*

Figure 20 shows the comparison of the MDVP frequency and amplitude variation in percent for DBS-02. The values had statistically significant declines below the baselines for nine of the ten MDVP tests from Pre to Post indicating that there was statistically significant improvement in phonatory stability. This result was in the opposite direction to DBS-01. The values decreased for eight of the ten MDVP tests from Post to 3FU, but not significantly, indicating that phonatory stability had not significantly improved. This was a similar outcome to DBS-01. None of the tests returned to the baseline. The overall result was that the speech characteristics significantly improved following DBS-STN surgery, and it was maintained at 3FU, meaning that the participant did have clearer speech, unlike the declines seen for DBS-01. RAP, and PPQ, two of the three MDVP tasks comparing variability of frequency both displayed a decrease from Pre to Post, and Post to 3FU. Jitt decreased from Pre to Post, but did not change from Post to 3FU. Shim and APQ, the two MDVP tasks comparing variability of amplitude both displayed a decrease from Pre to Post, but Shim decreased and APQ increased from Post to 3FU. The MDVP was sensitive for identifying acoustic irregularities but only if the vocal qualities of the sustained /a/ voice samples were stable at a given evaluation.

Figure 20. DBS-02 Multidimensional Voice Program Analysis of Frequency and Amplitude Variability in Percent

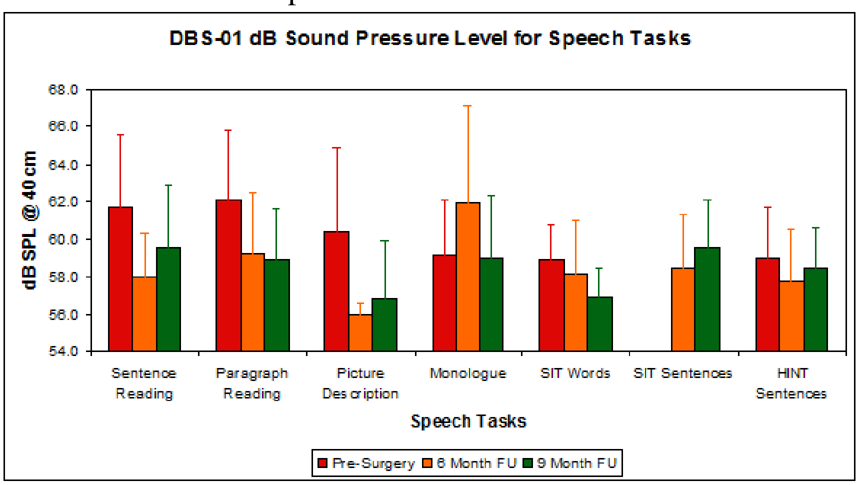



4. Sound Pressure Level (dB at 40 cm distance):

*DBS-01*

Figure 21 shows the comparison of the dB SPL of connected speech tasks at 40 cm for DBS-01. The participant exhibited significantly increased loudness for the sustained vowel phonation task from Pre to 9FU. However five out of seven of the connected speech tasks had declines in loudness from Pre to 6FU, one of them increased in loudness from Pre to 6FU, and one was missing the Pre assessment. Only two out of six of significantly changed from 6FU to 9FU. Only two of seven values returned to the baselines. The sustained vowel phonation task did not require tongue or lip movement, therefore it was the speech task that was the least likely to be affected by dysarthria. All of the connected speech tasks were below the normal loudness threshold. Contextual speech for DBS-01 did not improve after DBS-STN surgery as loudness was reduced, resulting in an increased likelihood of communication difficulties along with notable hypophonia symptoms. The speech tasks that displayed a decline from Pre to 6FU, and then an increase from 6FU to 9FU were: Sentence reading, Picture description, and HINT sentences.

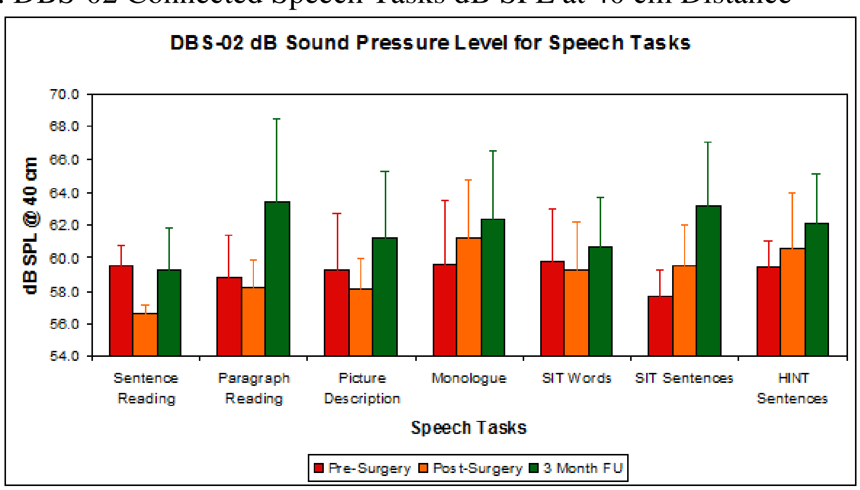
Figure 21. DBS-01 Connected Speech Tasks dB SPL at 40 cm Distance




*DBS-02*

Figure 22 shows the comparison of the dB SPL of connected speech tasks at 40 cm for DBS-02. The participant exhibited significantly increased loudness for the sustained vowel phonation task from Pre to 3FU, and the value did not return to the baseline, in a similar manner to DBS-01. However four out of seven of the connected speech tasks displayed declines in loudness from Pre to Post, and three of them increased in loudness from Pre to Post. All seven of the tasks increased in loudness from Post to 3FU, and four of them increased significantly.  Only two of seven values returned to the baselines. These changes were nearly opposite to the declines seen in DBS-01. Performance on the sustained vowel phonation task was improved by the DBS-STN surgery, but producing the sound did not require a fine degree of motor control.  All of the speech tasks were below the normal loudness threshold. The net result was an overall increase in loudness, resulting in a decreased likelihood of communication difficulties, although the hypophonia symptoms were not mitigated. Except for the increase in sustained vowel phonation, and the fact that both participants were consistently hypophonic, DBS-02 displayed net increases in dB SPL as opposed to the declines seen in DBS-01. The speech tasks that displayed a decline from Pre to Post, and then an increase from Post to 3FU were: Sentence reading, Paragraph reading, Picture description, and SIT words. The speech tasks that displayed an increase from Pre to Post, and Post to 3FU were: Monologue, SIT sentences, and HINT sentences. The dB SPL was a sensitive test for noting hypophonia.

Figure 22. DBS-02 Connected Speech Tasks dB SPL at 40 cm Distance



5. Duration of Sustained Vowel Prolongation

*DBS-01*

There was a steady increase in the amount of time that DBS-01 could sustain the /a/ vowel at a constant loudness level from Pre to 9FU, so it did not return to the baseline. After the surgery, the ability to sustain a steady, stable, vowel phonation was improved.

*DBS-02*

There was a steady increase in the amount of time that DBS-02 sustained vowel phonation at a constant loudness level from Pre to Post, and a slight decrease in the time the vowel phonation could be sustained from Post to 3FU. DBS-01 in comparison remained at a lower dB SPL level, so the phonation time could be extended. The sustained vowel phonation was sensitive to changes in respiratory support.

6. Diadochokinetic Rates (DDK)

*DBS-01*

The “Puh-Tuh-Kuh” and “Kuh” DDK rates for DBS-01 declined from Pre to 6FU, but later increased from 6FU to 9FU. The individual “Puh”, and “Tuh” rates declined from Pre to 6FU, and also from 6FU to 9FU. Only the “Puh-Tuh-Kuh” rate returned to the baseline.

*DBS-02*

The “Puh-Tuh-Kuh” and “Puh” DDK rates for DBS-02 declined from Pre to Post, but later increased from Post to 3FU. The individual “Tuh” sound rate declined from Pre to Post, and also from Post to 3FU. The “Kuh” sound rate declined from Pre to Post, but did not change from Post to 3FU. None of the DDK rates returned to the baselines. Both participants displayed a similar pattern of changes. The DDK rate was a sensitive test for tracking lingual dexterity for specific phonemes.

7. Lip and Tongue Pressures

*DBS-01*

The left and right lip pressures for DBS-01 declined from Pre to 6FU, and the right side pressure continued to decline from 6FU to 9FU. However, the left side pressure increased from 6FU to 9FU. None of the values returned to the baselines. There was an increase in the voltage of the contralateral right electrode, but no change in voltage on the contralateral left electrode affecting the right lip. There was no Pre assessment, so the center lip pressure increased from 6FU to 9FU and was just below the normal pressure range of 27-32 kPa (Clark & Solomon, 2012). The anterior lingual pressure sharply dropped off from just below the normal pressure range of 49-79 kPa from Pre to 6FU and did not return to baseline from 6FU to 9FU (Adams, Mathisen, Baines, Lazarus & Callister, 2013). The overall results indicated that the right lip and tongue tip pressures were more compromised than the other locations after the DBS-STN surgery.

*DBS-02*

The left and right lip pressures for DBS-02 increased from Pre to Post, and held steady from Post to 3FU. The subnormal center lip pressure increased to normal pressure levels from Pre to Post, and declined from Post to 3FU although it did not drop into the subnormal range. None of the values returned to baseline. The anterior lingual pressure increased from Pre to Post and although it dropped roughly back to the baseline from Post to 3FU, all three time points were within the normal range. The overall results indicated that lip and tongue tip pressures increased after the DBS-STN surgery, but some of the gains were partly lost by the follow up evaluation. DBS-02 had higher pressures for all of the tasks, indicating less motor impairment than DBS-01. The lip and tongue pressures were sensitive indicators of oral motor strength.

8. Maximum Inspiratory and Expiratory Pressures (MIP & MEP):

*DBS-01*

The MIP and MEP pressures for DBS-01 were below normal limits (97-108 cm $H_2O$ for MIP and 119-137 cm $H_2O$ for MEP) from Pre to 9FU (Evans and Whitelaw, 2009). MIP increased from Pre to 6FU, but then declined from 6FU to 9FU; MEP steadily decreased from Pre to 9FU. None of the values returned to the baselines. The results indicated the already compromised airway support was declining after surgery.

*DBS-02*

The MIP and MEP pressures for DBS-02 were below normal limits at the Pre evaluation, but MIP was within the normal range, and MEP was above the normal range for the Post and 3FU evaluations. MIP and MEP both increased Pre to Post, but then stabilized from Post to 3FU. None of the values returned to baseline. The statistically significant increases in respiratory support with DBS-02 strongly contrasted with the declining respiratory support in DBS-01.

9. Visual Analog Scale (VAS):

*DBS-01*

There were numerous changes for DBS-01 on the self-perception of communication and swallowing difficulties from Pre to 9FU. There was a clear negative impact on his self-perception of the communication difficulty symptoms an average of 20% and swallowing difficulty symptoms an average of 14% from Pre to 6FU, but there was a later decline in his self-perception of the communication difficulty symptoms an average of 11% and an increase in his self-perception of his swallowing difficulty symptoms an average of 4% by 9FU. None of the values returned to baseline. His answers to the swallowing questions indicated a combination of increasing impairment in some categories, and no change in others from Pre to 9FU. There was a clear negative impact on the self-perception of the communication difficulty symptoms after surgery, but there was a lesser effect on the self-perception of the swallowing difficulty symptoms. This suggested that the dysarthria symptoms were declining faster, and emerging earlier than the dysphagia symptoms after the surgery.

*DBS-02*

There were numerous changes for DBS-02 to the self-perception of communication and swallowing difficulties from Pre to 3FU. None of the values returned to baseline. All of the participant's answers to the communication questions indicated decreasing difficulty with verbal communication from Pre to Post, followed by variable declines and improvements from Post to 3FU. His answers to the swallowing questions indicated an improvement in most symptoms from Pre to Post, but followed by declines in all of the categories from Post to 3FU. There was a clear positive impact on his self-perception of the communication difficulty symptoms an average of 11% and swallowing difficulty symptoms an average of 3% after surgery, but there were later declines in his self-perception of the communication difficulty symptoms an average of 1% and swallowing difficulty symptoms an average of 14%

by 3FU. DBS-01 had worsening speech symptoms from Pre to 9FU, in contrast to DBS-02 where there were improvements in speech symptoms from Pre to 3FU. DBS-01 had worsening swallowing symptoms from Pre to 9FU, in contrast to DBS-02 where most symptoms improved from Pre to Post, but later worsened from Post to 3FU. The VAS scales for speech and swallowing difficulties were sensitive tests for participant self-reporting dysarthria and dysphagia symptoms.

10. EAT-10 Swallowing Questionnaire:

*DBS-01*

DBS-01 reported increases in five out of ten swallowing difficulty categories from Pre to 6FU which indicated a worsening of swallowing symptoms. However, he reported decreases from 6FU to 9FU in four of the ten categories which indicated an improvement of swallowing symptoms. All but one of the categories returned to baseline values. The EAT-10 questionnaire reported symptoms of eating difficulties initially worsening after surgery but showed improvement by the follow up evaluation.

*DBS-02*

DBS-02 reported decreases in three out of ten swallowing difficulty categories from Pre to Post which indicated an improvement of swallowing symptoms. However, he reported one decrease and two increases out of ten from Post to 3FU which indicated a worsening of swallowing symptoms. DBS-02 reported a decline in three out of ten dysphagia symptoms from Pre to Post, and reported one decrease and two increases out of ten from Post to 3FU. Seven out of ten of the categories returned to baseline values. The EAT-10 questionnaire results suggested that there was an improvement in dysphagia symptoms after the DBS-STN surgery. DBS-01 had declines in swallowing symptoms and then later increases in contrast to DBS-02 where the symptoms decreased and then did not change. The EAT-10 questionnaire was not a sensitive indicator of changes in swallowing difficulty for either DBS-01 or DBS-02 as compared to the more responsive VAS for swallowing difficulties test.

11. Timed Swallow Assessment:

*DBS-01*

DBS-01 drank 150 ml of water at each evaluation session. The swallowing rate diminished from Pre to 9FU, but the amount of water per swallow increased from Pre to 6FU, and remained constant from 6FU to 9FU. The rates did not return to baseline levels. The swallowing rate in ml/second was in the normal range at Pre, 6FU, and 9FU (Nathadwarawala, Nicklin, & Wiles, 1992). The results suggested that liquid swallowing deficiencies and choking on the water are symptoms that did not worsen after surgery.

*DBS-02*

DBS-02 drank 150 ml of water at each evaluation session. The swallowing rate was unchanged from Pre to Post, but it improved from Post to 3FU. The amount of water per swallow increased from Pre to Post, but declined from Post to 3FU. The rates did not return to baseline levels. The swallowing rate in ml/second was in the normal range at Pre, Post, and 3FU. There was a positive effect on the ability of the participant to swallow water after the DBS-STN surgery. DBS-01 had a decline in the swallowing rate in swallows per seconds, unlike the increase in the rate for DBS-02. Additionally, DBS-01 had an increase in the swallowing rate in ml of water per second, where DBS-02 displayed an increase followed by a decline. The timed swallowing assessment may be more sensitive if the dysphagia symptoms for the participants worsen.

12. Qualitative Assessments:

*DBS-01*

The results from DBS-01's questionnaires and responses on the VAS identified four major areas of concern: physical motor issues for IPD, cognitive and emotional symptoms of IPD, the impact of IPD and the DBS-STN surgery on communication issues, and the impact of IPD and the DBS-STN surgery on swallowing issues. He had bilateral surgery as the physical impairments were on both sides of the body, although the motor issues were more pronounced on the right side. He reported several motor issues that were alleviated by increasing the amplitude of the stimulators. He reported mental impairments, some of which were not clearly attributable to IPD symptoms or by the surgery. In his case there was more of a decline in comprehensible speech than in swallowing ability after the surgery.

*DBS-02*

DBS-02 identified the same four areas of concerns identified by DBS-01. He had unilateral surgery on the left side as the physical impairments were confined to the right side of his body. He reported on motor issues that were alleviated by increases in the stimulation amplitude. He also reported mental impairments, some of which improved after the surgery. In his case there were short-term increases in comprehensible speech as well as in swallowing ability after surgery. DBS-01 had improvements for motor issues, impairments for speech issues, and little change for swallowing and cognitive issues in his daily life after the DBS-STN surgery. In contrast, DBS-02 had improvements for motor, speech, and cognitive issues, and little change for swallowing issues in his daily life after the DBS-STN surgery. IPD is a multifaceted disease, and DBS-STN surgery can have unpredictable consequences and risks as no two patients or outcomes will ever be entirely identical. To this end, qualitative measures had an important role in identifying issues related to DBS-STN that the quantitative variables did not capture.

# CHAPTER 6

# CONCLUSIONS

## 6.1 Fulfillment of Research Aims

The purpose of this study was to determine what specific effects of DBS-STN and the adjustment of the stimulation parameters had on speech and swallowing characteristics of participants with IPD. The primary aims of this study were as follows:

1. To assess data the impact of STN-DBS surgery on speech intelligibility, speech parameters and swallowing ability concurrently in the same research participants. In this case the study was successful. Some of the orthogonal tasks used pointed to similar results. One example was that hypophonia was confirmed in both participants using dB SPL measurements, VAS scales for speech difficulties, and the qualitative narrative. Another example was that increasing difficulties in speech was occurring at a much faster pace than swallowing issues. This indicates in these specific cases that dysarthria symptoms were emerging earlier than dysphagia symptoms.
2. To determine which of the dependent variables displayed pre-surgery to post-surgery changes with statistical significance, and use those results to determine which of the tests would be most useful to be included in an expanded study.
   a. Many of the tests were sensitive and accurate in detecting participant changes from pre surgery to post surgery for DBS-STN. The VSA F1 and F2 plots, dB SPL tests, lip pressures, tongue tip to alveolar ridge pressures, MIP and MEP, the VAS scales for speech and swallowing difficulties, DDK rates, and

qualitative narratives were all informative and should be included in any future studies. The timed swallow test did not show much variation in response to the STN-DBS surgery, electrode stimulation changes, or the natural progression of IPD. However it is likely that swallowing difficulties were not yet indicative of significant dysphagia in either of the participants. However, it is useful for participants whose swallowing difficulties have progressed further so this task should be used in further research.

b. Speech Intelligibility was assessed by three different tests: one for words, and two for sentences. As there were no uniform changes across evaluations between DBS-01 and DBS-02, neither of the sentence tests should be excluded from further studies. Intelligibility varied much more than the sentence tests, so it should also be retained for future use.

c. Multidimensional Voice Program covered aberrant vocal qualities uncovered during sustained phonation. Three of the variables measured variation in frequency: Jitt, RAP, and PPQ with only the smoothing factor differing between the tests. Jitt responded differently over time as compared to RAP and PPQ, so it should be included in future experiments. RAP and PPQ demonstrated similar patterns of variation for both participants, so only PPQ should be used, as it was more sensitive to patient vocal qualities than RAP. Two of the variables measured changes in amplitude: only the smoothing factor differed between Shim and APQ. These variables did not respond in the same way for both participants, which suggest both should be retained for future studies. All of the remaining MDVP variables measured unique qualities so all of them should be used again.

d. Sound pressure level in decibels was assessed on seven connected speech tasks. However, as the tasks ranged from less to more cognitively demanding tasks, no clear pattern of variation emerged for either participant. The speech tasks that shared similar cognitive loads and results were the SIT sentence and HINT sentence tasks. The SIT sentence lists contained 30 sentences compared to the HINT sentence test's 10. Thus it would be more logical to collect dB SPL for the SIT sentence list and not the similar HINT list, as the longer SIT sentences provide more data.

e. The VAS for Swallowing issues and the EAT-10 questionnaire for swallowing difficulties contained the same set of ten questions, but differed in how the participant assessed the level of their impairment. The EAT-10 questionnaire displayed a lack of sensitivity as the discrete rating scale from registered far less responsiveness to self awareness of swallowing difficulties than the continuous VAS scale for swallowing issues. The difference is that when using a forced choice ordinal scale the participants had a tendency to underestimate the extent of their disability. Both tests showed the same overall trends across the evaluations. Additionally, the VAS for speech difficulties accurately reflected both patient narrative and objective tests, indicating that marking on a continuous scale provided a relatively accurate assessment of participant disability. The EAT-10 can be eliminated from future studies without losing sensitivity as the VAS for swallowing difficulties is adequate for tracking self reported changes in dysphagia symptoms.

The null hypothesis predicted that the DBS-STN surgery would not significantly change the participant's speech and swallowing assessment outcomes from pre surgery to post surgery. In the case of DBS-01, due to the long interval between the pre-surgery assessment and the follow up assessment, there was failure to reject the null hypothesis. Although he exhibited statistically significant declines in a wide spectrum of tasks, the effects of the IPD symptoms and the DBS-STN surgery could not be fully separated from Pre to 6FU. The progression of the IPD symptoms, or changes in the stimulation settings of the electrodes are potential factors that could negatively impact multiple tasks from 6FU to 9FU. However, although clear declines were revealed, the causes behind them could not be causally determined. In the case of DBS-02, there were proper intervals between the pre-surgery, post-surgery and follow up session. The null hypothesis was rejected as the participant exhibited substantial improvements as measured by multiple tasks immediately after the stimulation surgery followed by moderate declines later on. These results strongly suggest that STN-DBS surgery itself, or the stimulation correlated to benefits to speech and swallowing symptoms. It cannot be causally determined whether the benefits were due to electrode stimulation changes, or surgery induced microlesioning at the site of electrode implantation. Natural IPD progression explaining the changes from Pre to Post was unlikely due to the short gap in time between assessments. Many of the gains at Post were partly reversed by 3FU, but the underlying cause behind it cannot be determined using the current experimental design. Possibilities include changes in electrode settings, natural IPD progression, or microlesions healing up which triggered a loss in their beneficial properties.

### 6.2 Limitations

The first limitation for this study was that the number of participants recruited (n=2) was too low to perform any kind of significance testing between patients. Only a within patient design across multiple evaluations could be tested for significance. The low number of participants prevented generalizing the assessment outcomes to a broader field of IPD patients electing to undergo STN-DBS surgery.

The second limitation was that only DBS-02 followed the expected time intervals between evaluations, which were within a month before surgery, less than a month after surgery, and three months after the surgery. Those intervals were chosen specifically so that the effects of STN-DBS on IPD symptoms could be isolated from the natural progression of the disease. The follow up session was used to see which changes from the surgery and stimulation changes were transitory, and which represented longer term changes. DBS-01 had the assessment before surgery, but the follow up sessions were six months and nine months after surgery. Those intervals meant it was impossible to separate the effects of the STN-DBS surgery from the normal progression of IPD symptoms and stimulator changes from Pre to 6FU.

The final limitation is that some of the assessment tasks used to test the dependent variables had limitations with sensitivity and accuracy. The MDVP variables depended on consistency of sustained vowel phonation samples. DBS-02 demonstrated greater vocal stability than DBS-01. There were significant changes of vocal qualities detected for DBS-02, but not for DBS-01. Another example is that the

VSA only used three vowels to detect the frequency area, which is more sensitive to Formant shifts than constructs with four or more vowels. A final example is that the VSA for swallowing difficulties and the EAT-10 questionnaire of swallowing issues were both self perception tests of dysphagia symptoms, but the VAS scale exhibited much more variation in responses as compared to some of the same questions used in the EAT-10 questionnaire. This meant the EAT-10 questionnaire was less useful in detecting swallowing changes than the VAS scale.

## 6.3 Future Directions

The purpose of this project was to determine which variables related to speech and swallowing in participants with IPD significantly changed from pre to post DBS-STN surgery and at follow up evaluations. The results of this study contribute to the literature on DBS by describing speech and swallowing characteristics in two people with Parkinson's disease. Many prior studies focused solely on the impact on DBS-STN on speech of participants with IPD. The literature failed to reach a consensus on whether DBS-STN surgery was beneficial or detrimental to speech. Other studies focused on swallowing disorders in participants with IPD, but the DBS-STN surgery wasn't involved. No known studies were found that focused on speech and swallowing characteristics in participants with IPD before and after the DBS-STN surgery. The results from this preliminary study demonstrated that speech disorders worsened at a greater rate than swallowing disorders following surgery. More studies are needed to explore this vital subject.

Future studies should recruit enough patients so that the between subject analysis can be added to the within subject analysis. Extending the project to include more follow up sessions could shed light on how the progressive nature of IPD can interact with the STN-DBS surgery, and changes in stimulation settings. The swallowing tests should include a modified barium swallow to complement the timed swallow test, and accurately gauge the extent of participant dysphagia. The Unified Parkinson's disease rating scale Hoehn and Yahr staging on the severity of Parkinson's disease (UPDRS V) should also be included to add a quantitative assessment of motor dysfunction. Additional correlative statistics should be completed to determine which of the tests were most responsive to changes in other tests.

## APPENDIX A

DBS-STN Participant Changes in the Articulation Measures of the F1 and F2 Corner Values.

Table 20 shows the mean F1 and F2 frequency values, standard deviations, 1-way ANOVA, Tukey HST, and Cohen's d for DBS-01.

Table 20. Quantitative Changes in the Articulation Measures of the F1 and F2 Corner Values for DBS-01

| Vowel (Hz) | Average Pre (SD) | Average 6 Mo. FU (SD) | Average 9 Mo. FU (SD) | ANOVA p-value | Pre-6FU Tukey (Cohen's d) | Pre-9FU Tukey (Cohen's d) | 6FU-9FU Tukey (Cohen's d) |
|---|---|---|---|---|---|---|---|
| F1 /a/ | 774 (59) | 761 (13) | 682 (13) | 0.0000 | 0.8144 (0.304) | 0.0012 (2.154) | 0.0042 (6.077) |
| F1 /i/ | 269 (8) | 306 (39) | 300 (8) | 0.0014 | 0.0412 (-1.314) | 0.0938 (-3.875) | 0.8978 (0.2130) |
| F1 /u/ | 371 (27) | 404 (33) | 430 (54) | 0.0604 | 0.3364 (-1.095) | 0.0495 (-1.382) | 0.5044 (-0.581) |
| F2 /a/ | 1175 (73) | 1186 (25) | 1551 (75) | 0.0000 | 0.9812 (-0.202) | 0.0000 (-5.080) | 0.0000 (-6.529) |
| F2 /i/ | 2069 (55) | 2027 (38) | 2055 (52) | 0.3390 | 0.3189 (0.889) | 0.8706 (0.262) | 0.5905 (-0.615) |
| F3 /u/ | 1103 (86) | 954 (41) | 966 (56) | 0.0017 | 0.0029 (2.212) | 0.0548 (1.888) | 0.9449 (-0.245) |

Table 21 below shows the shows the mean F1 and F2 frequency values, standard deviations, 1-way ANOVA, Tukey HST, and Cohen's d for DBS-02.

Table 21. Quantitative Changes in the Articulation Measures of the F1 and F2 Corner Values for DBS-02

| Vowel (Hz) | Average Pre (SD) | Average Post (SD) | Average 3 Mo. FU (SD) | ANOVA p-value | Pre-Post Tukey (Cohen's d) | Pre-3FU Tukey (Cohen's d) | Post-3FU Tukey (Cohen's d) |
|---|---|---|---|---|---|---|---|
| F1 /a/ | 582 (76) | 576 (34) | 699 (27) | 0.0100 | 0.9702 (0.102) | 0.0251 (-1.525) | 0.0158 (-3.029) |
| F1 /i/ | 285 (29) | 290 (29) | 343 (12) | 0.0014 | 0.9333 (-0.172) | 0.0024 (-2.614) | 0.0050 (-2.388) |
| F1 /u/ | 317 (30) | 371 (82) | 383 (20) | 0.0951 | 0.2065 (-0.875) | 0.1009 (-2.589) | 0.9058 (-0.201) |
| F2 /a/ | 1233 (75) | 1425 (33) | 1612 (84) | 0.0300 | 0.0000 (-3.314) | 0.0000 (-4.760) | 0.0000 (-2.930) |
| F2 /i/ | 2222 (47) | 2217 (47) | 2391 (62) | 0.0000 | 0.9889 (0.106) | 0.0000 (-3.072) | 0.0000 (-3.163) |
| F3 /u/ | 975 (93) | 1093 (258) | 958 (39) | 0.3080 | 0.4245 (-0.618) | 0.9826 (1.888) | 0.3353 (0.732) |

APPENDIX B

DBS-STN Participant Consent Form.

**Speech and swallowing characteristics following deep brain stimulation surgery**

Leslie A. Mahler, PhD, Principal Investigator

CONSENT FORM FOR RESEARCH: Participant
Version 2: March 5, 2013

The University of Rhode Island
Department of Communicative Disorders
25 W Independence Square, Suite I
Kingston, RI 02881

**Purpose of the Consent:**
You have been invited to take part in a research project described below. The purpose of the consent form you are about to read is to provide you with details regarding the research study and to inform you of your rights should you agree to participate in the study. Your participation is completely voluntary. The researcher will explain the project to you in detail. You should feel free to ask questions. If you have more questions later you can call, Dr. Leslie Mahler, the person mainly responsible for this study, at 401-874-2490. You must be at least 18 years old to be in this research project.

**Description of the project:**
This is a research project designed to look at speech and swallowing characteristics of adults who have Parkinson disease and have decided to receive deep brain stimulation surgery. All speech and swallowing evaluations will be conducted at one of two University of Rhode Island locations; in Independence Square on the Kingston Campus at 25 West Independence Way, Kingston or in Independence Square at 500 Prospect Street in Pawtucket.

You are being asked to be in this study because we want to determine the impact of deep brain stimulation surgery is on speech and swallowing function. We are looking for 75 people who have Parkinson disease and have already decided to receive deep brain stimulation surgery. Participation in this study is entirely your choice.

If you decide to take part in this study, you should understand that the evaluations investigational and you may not experience any benefit from participation. Participation may also involve additional risks as listed in the Risks Section. Make sure that you understand that tasks included in the study before you decide to take part in the study. You may also quit the study at any time.

Subject initials:__________

**What will be done:**

If you agree to take part in this study, you will be asked to complete six 60-90 minute evaluations. Evaluations will take place within one month before to surgery, one month following surgery, and four follow-up evaluations at 3, 6, and 12 months following surgery. The evaluations will include a variety of speaking tasks such as reading sentences and describing a picture, an assessment of how your muscles move during speech and non-speech tasks, a cognitive screening, an interview, a clinical swallowing evaluation, and questionnaires regarding your communication and swallowing in everyday situations. The clinical swallowing evaluation will include drinking water, eating a semisolid such as applesauce, and chewing a solid such as a graham cracker or cookie. Three to five presentations of each consistency will be included depending on the individual participant.

The length of participation in the study will be approximately one year. All speech and swallowing evaluations will be conducted in a quiet private room at one of the University of Rhode Island Speech and Hearing Clinic locations.

**Potential risks and discomforts:**

There are minimal foreseeable risks associated with these evaluations. An examination of the muscles you talk with involves using a tongue blade and flashlight to look into your mouth. This may be uncomfortable or possibly make you feel like gagging. You may not like the flavor of the items chosen for the swallowing evaluation. There have been no reported adverse affects from clinical evaluation of speech and swallowing. There may be some unknown or unanticipated risks, but every precaution will be taken to ensure your personal safety.

**Purpose and benefits of the study:**

The purpose of this study is to evaluate the impact of deep brain stimulation on speech and swallowing function. The information obtained is important because it will help us to understand how surgery affects communication and swallowing of people who have Parkinson disease. This is an investigational study and there is no guaranteed benefit to your communication or swallowing as a result of participation in this research study.

**Drugs, devices or instruments to be used:**

Drugs will not be used in this study. The equipment for the evaluations include: microphone, sound level meter, tongue blade, a soft bulb to measure lip and tongue strength, a breathing device to measure respiration, a digital tuner, tape recorder, and video cameras. All equipment used to collect data is considered non-invasive.

**Cost to participant:**

There is no cost to you for participation in the evaluations. Parking is available for free.

Subject initials:__________

**Confidentiality:**

Your part in this study is confidential. Your individual privacy will be maintained in all published and written data resulting from this study. No names of participants will be published or included in written data resulting from this study. Results of this study may be used for purposes of research, educational lectures, and/or professional presentations. When you are entered into the study you will be assigned a code. For example, the first participant will be coded as DBS01. The code number will be used on all response forms and in the analysis of the data.

Dr. Mahler and her research team will have sole access to all contact information and evaluation results containing your name. This information will be kept in a locked filing cabinet in a locked office. However, the U.S. Department of Health and Human Services, and the University of Rhode Island Institutional Review Board have the right to inspect all of your records relating to this research for the purpose of verifying data. Because of the need to release information to these parties, absolute confidentiality cannot be guaranteed. Following completion of this project, contact information will be destroyed for those participants who wish, for any reason, not to be contacted in the future. All other information will be archived and kept in a locked filing cabinet with the study results at the University of Rhode Island. All research data will be retained for a minimum of 5 years following completion of the study and then will be destroyed. Research data will be located in a locked filing cabinet in the principal investigator's locked office.

Evaluations will be audio and video recorded to allow for data analyses. At times these recordings can be useful for teaching students or professionals about treatment of dysarthria. Please indicate by signing below whether you give your permission to use your samples for lectures and presentations. If you agree, you will never be identified by name in the presentations or lectures. Your decision to give permission to use audio and/or video samples in lectures has no impact on your participation in the study.

____________________Yes, I give permission to use audio samples in lectures and presentations.

____________________Yes, I give permission to use video samples in lectures and presentations.

_____________________No, I do not want audio samples used except for research analysis.

_____________________No, I do not want video samples used except for research analysis.

Subject initials:__________

**In case there is any injury to you during the study:**
If this study causes you any injury, you should immediately contact Dr. Leslie Mahler at (401) 874-2490 or contact the University of Rhode Island Speech and Hearing Clinic at (401) 874-5969. You may also call the office of the Vice President for Research, 70 Lower College Road, University of Rhode Island, Kingston, RI at (401) 874-4328. If you are injured during an evaluation or during treatment every effort will be made to get you medical attention but you will be responsible for paying for the medical treatment needed.

**Decision to quit at any time:**
The decision to take part in this study is up to you. You do not have to participate. If you decide to take part in the study, you may quit and stop participating in this study at any time. You have the right to refuse to answer any question(s) or participate in any procedure for any reason. Deciding not to participate will have no effect on your potential to receive services from a speech-language pathologist. If you wish to quit, simply inform Leslie Mahler at 874-2490 of your decision. If you wish to pursue an alternative treatment instead of completing the study you will be provided with information on how to obtain those services.

**Rights and complaints:**
If you are not satisfied with the way this study is performed, you may discuss your complaints with Dr. Leslie Mahler, or you may contact the office of the Vice President for Research for concerns or any questions about your rights as a research subject at: 70 Lower College Road, University of Rhode Island, Kingston, RI at (401) 874-4328 and speak to them anonymously if you choose.

**Authorization:**
Your authorization means that you have read this paper and know the purpose of the study and the possible risks and benefits. It also means you know that being in this study is voluntary and you choose to be in this study. You can also withdraw at any time. Your questions have been answered. Your signature on this form means that you understand the information and you agree to participate in this study.

| | |
|---|---|
| ______________________ | ______________________ |
| Signature of Participant | Signature of Researcher |
| ______________________ | ______________________ |
| Participant Typed/printed Name | Researcher Typed/printed name |
| ______________________ | ______________________ |
| Date | Date |

***Please sign both consent forms, keeping one for yourself.***

Subject initials:__________

# APPENDIX C

## DBS-STN Participant Pre-surgery Interview Form.

Participant Pre-Surgery Interview

Version #1: 2-2-13
Speech and swallowing characteristics following deep brain stimulation
Leslie Mahler, PhD, CCC-SLP, Principal Investigator

**Subject: #__________** **Date: __________________**

When were you diagnosed with Parkinson disease? _______________________________

What were your symptoms at that time?______________________________________________

________________________________________________________________________________

What are your symptoms now? _____________________________________________________

________________________________________________________________________________

What is your communication like?___________________________________________________

________________________________________________________________________________

What were your first speech symptoms? ________________________________________

What are your current speech symptoms? _______________________________________

________________________________________________________________________________

Are you experiencing any symptoms of a swallowing disorder? ______________________

What are your current swallow symptoms? ______________________________________

________________________________________________________________________________

What would you say is your most significant problem with speech or swallowing today?

________________________________________________________________________________

Did you experience any changes in your speech or swallowing *before* your diagnosis? ________

________________________________________________________________________________

Does medication affect your speech or voice or swallowing? _________ If yes, in what way?

____________________________________________________________________________

**Speech**

How many hours of speaking do you do in a day? _____________________________________

What is a typical day of communicating like for you? ___________________________________

________________________________________________________________________________

Have you noticed changes in the quality of your voice? __________ If yes, explain ____

____________________________________________________________________________

Does your voice feel fatigued at the end of the day? _______________________________

Have you ever used your voice professionally? ________________________________________

Does your speech/voice sound today like it usually does? _________________________________

Have you noticed if your voice is monotone in pitch? ___________________________________

Have you noticed if your voice is reduced in loudness? _________________________________

Do you pronounce your words clearly? _______________________________________________

Do people ask you to repeat yourself? ________________________________________________

Do people have a hard time understanding you? ________________________________________

What do you do when you want to be as easy to understand as possible? ___________________

_________________________________________________________________________________

What percent of your speech do you think is understandable? ____________________________

Has your neurological diagnosis caused you to talk less? _________________________________

If so, how much less? _____________ Why? ______________________________________

_________________________________________________________________________________

Do you feel like you run out of breath during speech? __________________________________

Do you feel your speaking voice is higher or lower in pitch now compared to before?

_______________________________________________________________________________

Does it ever hurt to speak? ______ If so, explain __________________________________

Have you noticed any slurring or mumbling in your speech? _______________________

Has the rate of your speech changed? ___________________ If yes, please describe ____

_____________________________________________________________________________

**Swallowing**

Do you have any difficulty with swallowing? _____________________________________

Do you notice more drooling since being diagnosed with PD? ___________

Do you cough during mealtimes? ________________

Do you cough more with water or solid food? ________________________________________

Do you have difficulty making the food go down (need to swallow twice)? _____________

Does it take you longer to finish a meal? _________________

Have you experienced any unintentional recent weight loss? ______________

Have you ever been diagnosed with pneumonia? _____________ If yes, when? ______________

Have you changed your diet since your neurological diagnosis? ___________

If yes, what did you modify? _____________________________________________________

**Previous Treatment**

Have you had previous speech or swallow treatment?

______________________________________________

If yes, please describe (when, what) ____________________________________________________

__________________________________________________________________________________

Was it beneficial? _________________________________________________________________

If yes, what changes did you notice? __________________________________________________

__________________________________________________________________________________

**Employment**

Are you employed? _________________________________________________________________

Type of employment ________________________________________________________________

How do you use your voice at your job? _______________________________________________

__________________________________________________________________________________

Did the stroke affect your employment? _______________________________________________

__________________________________________________________________________________

**Other**

Have you noticed any difficulty with your memory? ________________________________

Have you experienced any changes in your mood? __________________________________

Is it difficult for you to pay attention long enough to finish a task? _____________________

Do you have any difficulty reading? ______________________________________

Do you have any difficulty writing? ______________________________________

Do you have difficulty finding words? ____________________________________________

Any other comments about your communication abilities:

______________________________________________________________________________

______________________________________________________________________________

APPENDIX D

DBS-STN Participant Post-surgery Interview Form.

**Participant Post-Surgery Interview**
Version #1: 2-2-13
Speech and swallowing characteristics following deep brain stimulation
Leslie Mahler, PhD, CCC-SLP, Principal Investigator

**Subject: #__________** **Date: __________________**

When did you have the DBS surgery? _______________________________

What are your current settings (if you know)? _______________________________________

_______________________________________________________________________________

Did your speech change following the surgery? If so, how did it change? _________________

_______________________________________________________________________________

Did your swallowing change following the surgery? If so, how did it change? ______________

_______________________________________________________________________________

What would you say is your most significant problem with speech or swallowing today?

_______________________________________________________________________________

Has your medication changed since receiving the surgery? ___________

_______________________________________________________________________________

Does medication affect your speech or voice or swallowing? _________ If yes, in what way?

___________________________________________________________________________

**Speech**

How many hours of speaking do you do in a day? _____________________________________

What is a typical day of communicating like for you? ___________________________________

_______________________________________________________________________________

Have you noticed changes in the quality of your voice? __________ If yes, explain ____

___________________________________________________________________________

Does your voice feel fatigued at the end of the day? ________________________________

Have you ever used your voice professionally? _______________________________________

Does your speech/voice sound today like it usually does? ________________________________

Have you noticed if your voice is monotone in pitch? __________________________________

Have you noticed if your voice is reduced in loudness? _________________________________

Do you pronounce your words clearly? _____________________________________________

Do people ask you to repeat yourself? ______________________________________________

Do people have a hard time understanding you? ________________________________________
Is this different than before you had the DBS surgery? __________________________________
________________________________________________________________________________
What percent of your speech do you think is understandable? _____________________________
Has your DBS surgery caused you to talk less? _______________________________________
If so, how much less? _____________ Why? _____________________________________
________________________________________________________________________________
Do you feel like you run out of breath during speech? __________________________________
Do you feel your speaking voice is higher or lower in pitch now compared to before surgery?
______________________________________________________________________________
Does it ever hurt to speak? ______ If so, explain _________________________________
Have you noticed any slurring or mumbling in your speech? _______________________
Has the rate of your speech changed? __________________ If yes, please describe ____
____________________________________________________________________________

**Swallowing: Since the surgery**

Do you have any difficulty with swallowing now? ____________________________________
Do you notice more drooling since receiving the surgery? ___________
Do you cough during mealtimes? _______________
Do you cough more with water or solid food? ________________________________________
Do you have difficulty making the food go down (need to swallow twice)? ____________
Does it take you longer to finish a meal? ________________
Have you experienced any unintentional recent weight loss? _____________
Have you ever been diagnosed with pneumonia? ____________ If yes, when? _____________
Have you changed your diet since your neurological diagnosis? ___________
If yes, what did you modify? ____________________________________________________

**Previous Treatment**

Have you had any speech or swallowing treatment following the surgery? ________________
If yes, please describe (when, what) _____________________________________________
______________________________________________________________________________
Was it beneficial? _________________________________________________________________
If yes, what changes did you notice? ________________________________________________
______________________________________________________________________________

**Employment**

Did the surgery have an impact on your employment?

_______________________________________________________________________

Type of employment ______________________________________________________

How do you use your voice at your job? _________________________________________

_______________________________________________________________________

**Other: Since the surgery**

Have you noticed any difficulty with your memory? ___________________________

Have you experienced any changes in your mood? ______________________________

Is it difficult for you to pay attention long enough to finish a task? __________________

Do you have any difficulty reading? ____________________________________

Do you have any difficulty writing? ____________________________________

Do you have difficulty finding words? ____________________________________

Any other comments about your communication abilities:

_______________________________________________________________________

_______________________________________________________________________

APPENDIX E

DBS-STN Participant Oral Mechanism Exam Collection Form.

**Deep Brain Stimulation Assessment Procedures**
**Leslie Mahler, Ph.D., CCC-SLP**

***Task 1:*** Interview using EAT-10 and visual analog scale
***Task 2:*** Oral motor examination: Use this form to score the results-needs to be an SLP.
**Evaluate:**

1. **Facial symmetry:**
   a. Check Tone: WNL ↓R ↓L
   b. Raise Eyebrows: WNL ↓R ↓L
   c. Wrinkle Forehead: WNL ↓R ↓L
2. **Lips:**
   a. Lip Closure: Resistance with tongue depressor WNL ↓R ↓L
   b. Lip Closure: Puff cheeks with air WNL ↓R ↓L
   c. Root Reflex: Brush above lip midline Absent Present
   d. Pucker:
      i. Symmetrical ↓R ↓L
      ii. Normal strength↓ROM
   e. Smile:
      i. Symmetrical retraction of lips ↓R ↓L
      ii. Normal ROM ↓ROM
   f. Alternate Pucker/Smile (as fast as you can)
      i. Symmetrical ↓R ↓L
      ii. Normal ROM ↓ROM
      iii. Normal Speed Slow Irregular
3. **Jaw:**
   a. Open/close
      i. Normal ROM ↓ROM
   b. Open/close as fast as you can
      i. Normal Speed Slow Irregular
   c. Resistance: open mouth, crook finger, close mouth (gently resist)
      i. Normal ↓Strength

4. **Oral Cavity Dentition:**
   a. Open mouth (use tongue depressor to move cheeks)
      i. Hard palate appearance
         1. Palatal torus? Yes No
      ii. Soft palate appearance
      iii. Tongue fasciculations
      iv. Dentures Absent Teeth
   b. Tongue:
      i. Size: Normal Small Large
      ii. Symmetry: Normal ↓R ↓L
      iii. Stability: Normal Tremor Fasiculations

5. **Tongue**:
    a. Stick tongue straight out
        i. Symmetry: Normal →R →L
    b. Protrude tongue to the left and then right against tongue depressor
        i. Resistance WNL Decreased resistance
    c. Tongue Elevation
        i. Symmetry: Normal ↓Strength ↓ROM
    d. Tongue Depression
        i. Symmetry: Normal ↓Strength ↓ROM
    e. Tongue Resistance (with tongue depressor):
        i. Midline: Normal ↓Strength
        ii. Right: Normal ↓Strength
        iii. Left: Normal ↓Strength
    f. Rapid tongue lateralization: side to side lingual movement (speed/accuracy)
        i. Speed: Normal Slow Fast
        ii. Accuracy: Regular Irregular
        iii. Cues: Models Verbal Tactile
6. **Hard Palate** (use flashlight)
    a. Normal Abnormal
7. **Soft Palate** (use flashlight)
    a. At rest: Normal Fistulas Holes
    b. Puff out cheeks with tongue extended between teeth
    c. Movement during sustained "ah":
        i. Velum: Symmetrical →R →L ↓ROM
        ii. Faucial Pillars: Symmetrical ↓ROM
    d. Movement during Coup de glotte:
        i. Symmetrical →R →L ↓ROM
        ii. Elevation: Normal Mild Moderate No elevation
8. **AOS Commands:**
    a. Lick your lips: Normal Abnormal
    b. Blow: Normal Abnormal
    c. Whistle: Normal Abnormal
9. **Coup de Glotte**: Normal Weak
10. **Volitional cough**: Normal Weak
11. **Dry Swallow:** Laryngeal elevation
    a. Normal ↓Elevation Delayed Initiation

**12. Diadochokinetic rates (DDK)**

a. Puh: _____# in five seconds
   i. Artic: Normal ↓Precision
   ii. Duration: Normal ↓Duration
   iii. Rate: Normal ↓Rate ↑Rate
   iv. Rhythm: Normal Irregular

b. Tuh: _____# in five seconds
   i. Artic: Normal ↓Precision
   ii. Duration: Normal ↓Duration
   iii. Rate: Normal ↓Rate ↑Rate
   iv. Rhythm: Normal Irregular

c. Kuh: _____# in 5 seconds
   i. Artic: Normal ↓Precision
   ii. Duration: Normal ↓Duration
   iii. Rate: Normal ↓Rate ↑Rate
   iv. Rhythm: Normal Irregular

d. Puh-Tuh-Kuh: _____# in 5 seconds
   i. Artic: Normal ↓Precision
   ii. Duration: Normal ↓Duration
   iii. Rate: Normal ↓Rate ↑Rate
   iv. Rhythm: Normal Irregular

   Note: if the patient can't do Puh-tuh-kuh, then try having them say "buttercup".

**13. Do these tasks:**

**b.** Lick your lips
**c.** Blow
**d.** Pretend you are licking a lollipop
**e.** Whistle

**14. Repeat these words:**

| | | |
|---|---|---|
| zip | Zipper | zippering |
| jab | Jabber | jabbering |
| charm | charming | charmingly |
| thought | thoughtful | thoughtfully |
| care | careless | carelessness |

**15. Repeat these sentences:** (use a mirror under the nose to determine if there is nasal leakage.)

1. The valuable watch was missing.
2. The shipwreck washed up on the shore.
3. Momma made lemon jam.
4. Suzy slipped on the ice.
5. The blue spot is on the key.
6. The stewpot is packed with peas.

APPENDIX F

DBS-STN Participant Evaluation Data Collection Form.

**Evaluation Protocol: Total Speech Treatment**
**Leslie Mahler, PhD, CCC-SLP**

**Subject #:** ______________ **Day, Date & Time:** _________________________

**Recording:** Pre1 Post1 FU3mo FU6mo FU12mo

**Equipment Check:**

- Head microphone to mouth distance of 8cm – clip microphone also
- SLM to mouth distance of 40cm – turn on
- Turn on computer & open PowerPoint presentation *Mahler Research 2013*
- Turn on computer to collect acoustic signal and Open Goldwave
- Turn on digital camera for a head shot and check for sufficient memory on card
- Turn on Flash Drive recorder and load a memory card

**Procedures:**

- Open GoldWave; New, sampling rate 22 kHz, mono
- Click on red round button to record and blue square button to stop
    - ***Name file for participant#, session, and date***
- Start recording on flash drive recorder, numbers will increase when recording
- Start recording on video camera

**Data Collection:**

**1. Sentence Reading: "The boot on top is packed to keep." SLM and Digital Recorder**

***1*** ______________________________________
***2*** ______________________________________
***3*** ______________________________________
***4*** ______________________________________
***5*** ______________________________________

***A blank page is in between each sentence to pace administration of the stimulus items.***

***Comments:***

________________________________________________________________________

**2. Read the Farm Passage: First few sentences only if reading is difficult. SLM/Digital Recorder**

***Comments:***

**3. Picture description: Sound level meter and digital recorder**

***Comments:***

**4. Single Word Speech Intelligibility Test: SLM and digital recorder**
**Say the number of each word prior to the participant so listeners can track where they are in the list.**

***Comments:***

**4a. Hearing-in-Noise Test Sentences**
**Use the randomization chart to select one of the 25 sets of 10 sentences. Read the sentence aloud and the participant will repeat the sentence. SLM and digital recorder**

***Comments:***

**5. Monologue/discussion on the following topics:** ***(Choose only one per evaluation session and proceed in order)***

1. *(Pre) Favorite sport*
2. *(Post) What would you order in an ice cream shop*
3. *(FU 3mo) Your happiest day*
4. *(FU 6mo) Favorite thing to do with your family or on vacation*
5. *(FU 9mo) First job*
6. *(FU 12mo) What would you order for your favorite meal?*

**6. Maximum duration sustained phonation: 6 "Ah's" Sound level meter and digital recorder.**

***1*** ________________________________________

***2*** ________________________________________

***3*** ________________________________________

***4*** ________________________________________

***5*** ________________________________________

***6*** ________________________________________

**7. Swallowing evaluation. Oral motor examination. Diadochokinetic rates.**
***Puh's*** ________ ***Tuh's*** _________ ***Kuh's*** _________ ***Puh, tuh, kuh's*** _________

**Timed swallow test*: Amount of liquid:*** _____________***No. of swallows/second*** _______

***Comments:***
___________________________________________________________________________

**<u>8. IOPI</u> Lip and tongue pressures; Maximum effort for 3 consecutive trials – record in kPascals (kPa)**
***Wash a new IOPI bulb for each evaluation with Dawn liquid detergent. Cut off the end of the tubing for attachment to the IOPI. The goal is to obtain 3 trials that vary by no greater than 10% from each other or stop at 6 trials.**

| ***Trial*** | ***Lips*** | ***Tongue Tip*** |
|---|---|---|
| ***#1*** | | |
| ***#2*** | | |
| ***#3*** | | |
| ***#4*** | | |
| ***#5*** | | |
| ***#6*** | | |

**9. MIP & MEP Maximum effort for 3 consecutive trials – record in cm $H_20$**

***Wash a new mouthpiece for each evaluation with Dawn liquid detergent. The goal is to obtain 3 trials that vary by no greater than 10% from each other or stop at 6 trials.**

| ***Trial*** | ***MIP*** | ***MEP*** |
|---|---|---|
| ***#1*** | | |
| ***#2*** | | |
| ***#3*** | | |
| ***#4*** | | |
| ***#5*** | | |
| ***#6*** | | |

**General Comments about the evaluation session: Be sure to note any threats to validity of the data**

**Comments or special considerations for this recording session:**

**Signature of person collecting the data:**

APPENDIX G

DBS-STN Participant Timed Swallowing Test Data Collection Form.

**PI; Leslie Mahler, PhD, CCC-SLP Participant Code: ______**

**Timed Test of Swallowing Capacity for Neurological Patients**

**Pre-Test:**

- **Give the participant a tablespoon (approximately 10 ml) to drink. If they swallow without overt signs of coughing or choking proceed with the test.**

**Timed Swallow Test:**

- **Give the participant 150 ml of cold tap water to drink from a standard glass.**
- **The instructions are to drink the water as quickly as possible when I tell you to begin.**
- **Once the examiner says go, time how long it takes to finish all the water and how many swallows were needed.**
- **If there is residual water in the cup then measure how much to determine the amount of water that was swallowed.**
- **Calculation:**
    - **Divide the total number of ml swallowed by the number of swallows to determine swallows/second**
    - **Results=**

- **Interpretation**
    - **Swallowing speech <10 ml/second is a sensitive indicator of swallowing problems in neurological patients (Nathadwarawala, Nicklin, & Wiles (1992). A timed test of swallowing capacity for neurological patients. *Journal of Neurology, Neurosurgery, and Psychiatry, 55,* 822-825.)**

APPENDIX H

DBS-STN Participant EAT-10 Questionnaire.

EATING ASSESSMENT TOOL (EAT-10)

Date: ________________

Name: ________________________________________________ MR#: ___________________

Height: _______________________________________________Weight: __________________

Please briefly describe your swallowing problem.

_______________________________________________________________________________

_______________________________________________________________________________

Please list any swallowing tests you have had, including where, when, and the results.

_______________________________________________________________________________

_______________________________________________________________________________

To what extent are the following scenarios problematic for you?

| **Circle the appropriate response** | 0=No problem 4=Severe problem | | | | |
|---|---|---|---|---|---|
| 1. My swallowing problem has caused me to lose weight. | 0 | 1 | 2 | 3 | 4 |
| 2. My swallowing problem interferes with my ability to go out for meals. | 0 | 1 | 2 | 3 | 4 |
| 3. Swallowing liquids takes extra effort. | 0 | 1 | 2 | 3 | 4 |
| 4. Swallowing solids takes extra effort. | 0 | 1 | 2 | 3 | 4 |
| 5. Swallowing pills takes extra effort. | 0 | 1 | 2 | 3 | 4 |
| 6. Swallowing is painful. | 0 | 1 | 2 | 3 | 4 |
| 7. The pleasure of my eating is affected by my swallowing. | 0 | 1 | 2 | 3 | 4 |
| 8. When I swallow food sticks in my throat. | 0 | 1 | 2 | 3 | 4 |
| 9. I cough when I eat. | 0 | 1 | 2 | 3 | 4 |
| 10. Swallowing is stressful. | 0 | 1 | 2 | 3 | 4 |
| | | | | **Total Eat-10:** | |

APPENDIX I

DBS-STN Participant Visual Analog Scale for Speech and Swallowing.

**Visual Analog Scale Perceptual Rating Form**

Client: ________ Date: ________ Relation to Client: ________

Please mark the place on the line that best represents the client's typical speech:

| | |
|---|---|
| Always loud enough | Never loud enough |
| Always finds the right words | Never finds the right words |
| Never a shaky voice | Always a shaky voice |
| Never monotone | Always monotone |
| Never slurs | Always slurs |
| Never a "strained" voice | Always a "strained' voice |
| Never mumbles | Always mumbles |
| Always speaks so others can understand | Never speaks so others can understand |
| Always participates in a conversation | Never participates in a conversation |
| Always starts a conversation | Never starts a conversation |

**Visual Analog Scale Swallowing Rating Form**

Client: ________ Date: ________ Relation to Client: ________________

Please mark the place on the line that best represents your or the client's typical swallowing:

Causes me to lose weight

No problem ______________________________ Severe problem

Interferes with my ability to eat out

No problem ______________________________ Severe problem

Swallowing liquids

No extra effort ______________________________ A lot of extra effort

Swallowing solid foods

No extra effort ______________________________ A lot of extra effort

Swallowing pills

No extra effort ______________________________ A lot of extra effort

Swallowing is painful

Never ______________________________ Always

The pleasure of eating is affected by my swallowing

Never ______________________________ Always

Food sticks in my throat

Never ______________________________ Always

I cough when I eat and drink

Never ______________________________ Always

Swallowing is stressful

Never ______________________________ Always

APPENDIX J

DBS-STN Participant Intelligibility Transcription Forms for Words and Sentences.

**Hearing in Noise Test**
**Sentence Intelligibility/Transcription Answer Sheet**

Subject: ______________________________ Date Administered: ___________
Transcriber: ___________________________ Today's Date: ________________

**Key** **Transcribed Sentences**

1: ________________________________________________________________________

2: ________________________________________________________________________

3: ________________________________________________________________________

4: ________________________________________________________________________

5: ________________________________________________________________________

6: ________________________________________________________________________

7: ________________________________________________________________________

8: ________________________________________________________________________

9: ________________________________________________________________________

10: _______________________________________________________________________

**Correct (Y/N)**

1: _____ Subject: ______________________________

2: _____ Date Administered: ______________________________

3: _____ Transcriber: ______________________________

4: _____ Today's Date: ______________________________

5: _____ HINT List: ______________________________

6: _____

7: _____ Total Words Intelligible: ______________________________

8: _____ Total Words Unintelligible: ______________________________

9: _____ % Words Intelligible: ______________________________

10: _____ % Words Unintelligible: ______________________________

Tot. Correct:___/ ___ Comments: ______________________________

______________________________

______________________________

**Assessment of Intelligibility of Dysarthric Speech**
**Words in Sentence Intelligibility/Transcription Answer Sheet**

Subject: ______________________________ Date Administered: ____________
Transcriber: ___________________________ Today's Date: ________________

**Key** **Transcribed Sentences**

5A: ________________________________________________________________________
5B: ________________________________________________________________________
6A: ________________________________________________________________________
6B: ________________________________________________________________________
7A: ________________________________________________________________________
7B: ________________________________________________________________________
8A: ________________________________________________________________________
8B: ________________________________________________________________________
9A: ________________________________________________________________________
9B: ________________________________________________________________________
10A:________________________________________________________________________
10B:________________________________________________________________________
11A:________________________________________________________________________
11B:________________________________________________________________________
12A:________________________________________________________________________
12B:________________________________________________________________________
13A:________________________________________________________________________
13B:________________________________________________________________________
14A:________________________________________________________________________
14B:________________________________________________________________________
15A:________________________________________________________________________
15B:________________________________________________________________________

**Number Correct**

| | | |
|---|---|---|
| 5A: _____ | Subject: | ______________________________ |
| 5B: _____ | Date Administered: | ______________________________ |
| 6A: _____ | Transcriber: | ______________________________ |
| 6B: _____ | Today's Date: | ______________________________ |
| 7A: _____ | AIDS-SIT List: | _______________________________ |
| 7B: _____ | | |
| 8A: _____ | Total Words Intelligible: | ______________________________ |
| 8B: _____ | Total Words Unintelligible: | ______________________________ |
| 9A: _____ | Percent Words Intelligible: | ______________________________ |
| 9B: _____ | Percent Words Unintelligible: | ______________________________ |
| 10A:____ | | |
| 10B:____ | Comments: | ______________________________ |
| 11A:____ | | ______________________________ |
| 11B:____ | | ______________________________ |
| 12A:____ | | |
| 12B:____ | | |
| 13A:____ | | |
| 13B:____ | | |
| 14A:____ | | |
| 14B:____ | | |
| 15A:____ | | |
| 15B:____ | | |

Total Correct:_______/220

**Assessment of Intelligibility of Dysarthric Speech**
**Single Word Intelligibility/Transcription Answer Sheet**

Subject: ______________________________ Date Administered: ____________
Transcriber: ___________________________ Today's Date: ________________

**Key** **Transcribed Words**

1: ________________________________ 26: ___________________________________
2: ________________________________ 27: ___________________________________
3: ________________________________ 28: ___________________________________
4: ________________________________ 29: ___________________________________
5: ________________________________ 30: ___________________________________
6: ________________________________ 31: ___________________________________
7: ________________________________ 32: ___________________________________
8: ________________________________ 33: ___________________________________
9: ________________________________ 34: ___________________________________
10: _______________________________ 35: ___________________________________
11:________________________________36: ___________________________________
12:________________________________37: ___________________________________
13:________________________________38: ___________________________________
14:________________________________39: ___________________________________
15:________________________________40: ___________________________________
16:________________________________41: ___________________________________
17:________________________________42: ___________________________________
18:________________________________43: ___________________________________
19:________________________________44: ___________________________________
20:________________________________45: ___________________________________
21:________________________________46: ___________________________________
22:________________________________47: ___________________________________
23:________________________________48: ___________________________________
24:________________________________49: ___________________________________
25:________________________________50: ___________________________________

**Number Correct**

| | | | |
|---|---|---|---|
| 1: _____ | 26: _____ | Subject: | ______________________ |
| 2: _____ | 27: _____ | Date Administered: | ______________________ |
| 3: _____ | 28: _____ | Transcriber: | ______________________ |
| 4: _____ | 29: _____ | Today's Date: | ______________________ |
| 5: _____ | 30: _____ | AIDS-SIT List: | ______________________ |
| 6: _____ | 31: _____ | | |
| 7: _____ | 32: _____ | Tot.Wds. Intell.: | ______________________ |
| 8: _____ | 33: _____ | Tot.Wds. Unintell.: | ______________________ |
| 9: _____ | 34: _____ | % Words Intell.: | ______________________ |
| 10: ____ | 35: _____ | % Words Unintell.: | ______________________ |
| 11: ____ | 36: _____ | | |
| 12: ____ | 37: _____ | Comments: | ______________________ |
| 13: ____ | 38: _____ | | ______________________ |
| 14: ____ | 39: _____ | | ______________________ |
| 15: ____ | 40: _____ | | |
| 16: ____ | 41: _____ | | |
| 17: ____ | 42: _____ | | |
| 18: ____ | 43: _____ | | |
| 19: ____ | 44: _____ | | |
| 20: ____ | 45: _____ | | |
| 21: ____ | 46: _____ | | |
| 22: ____ | 47: _____ | | |
| 23: ____ | 48: _____ | | |
| 24: ____ | 49: _____ | | |
| 25: ____ | 50: _____ | | |

Total Correct:_____/50

APPENDIX K

DBS-STN Participant F1 and F2 Vowel Analysis for /a/, /i/, and /u/.

**Vowel Analyses: "The boot on top is packed to keep."**

**Analyzer:** ____________________ **Date of Analysis:** ______________

**Subject:** __________ **Vowel:** ___/a/__

---

**Vowel 1:** **Onset:** ________ **Offset:** ________ **Duration:** ________**ms**
**F1 (Hz);** ________ **F2 (Hz):** ________ **Adjustments?** ____________________________
**Comments:** ___________________________________________________________________

**Vowel 2:** **Onset:** ________ **Offset:** ________ **Duration:** ________**ms**
**F1 (Hz);** ________ **F2 (Hz):** ________ **Adjustments?** ____________________________
**Comments:** ___________________________________________________________________

**Vowel 3:** **Onset:** ________ **Offset:** ________ **Duration:** ________**ms**
**F1 (Hz);** ________ **F2 (Hz):** ________ **Adjustments?** ____________________________
**Comments:** ___________________________________________________________________

**Vowel 4:** **Onset:** ________ **Offset:** ________ **Duration:** ________**ms**
**F1 (Hz);** ________ **F2 (Hz):** ________ **Adjustments?** ____________________________
**Comments:** ___________________________________________________________________

**Vowel 5:** **Onset:** ________ **Offset:** ________ **Duration:** ________**ms**
**F1 (Hz);** ________ **F2 (Hz):** ________ **Adjustments?** ____________________________
**Comments:** ___________________________________________________________________

**Calculate the Average and Standard Deviation**

**Average F1 =** _______________

**Standard Deviation =** _________________

**Average F2 =** _______________

**Standard Deviation =** _________________

**Vowel Analyses: "The boot on top is packed to keep."**

**Analyzer:** ____________________ **Date of Analysis:** ______________

**Subject:** __________ **Vowel:** ___/i/__

---

**Vowel 1:** **Onset:** ________ **Offset:** ________ **Duration:** ________**ms**

**F1 (Hz);** ________ **F2 (Hz):** ________ **Adjustments?** ____________________________

**Comments:** ___________________________________________________________________

**Vowel 2:** **Onset:** ________ **Offset:** ________ **Duration:** ________**ms**

**F1 (Hz);** ________ **F2 (Hz):** ________ **Adjustments?** ____________________________

**Comments:** ___________________________________________________________________

**Vowel 3:** **Onset:** ________ **Offset:** ________ **Duration:** ________**ms**

**F1 (Hz);** ________ **F2 (Hz):** ________ **Adjustments?** ____________________________

**Comments:** ___________________________________________________________________

**Vowel 4:** **Onset:** ________ **Offset:** ________ **Duration:** ________**ms**

**F1 (Hz);** ________ **F2 (Hz):** ________ **Adjustments?** ____________________________

**Comments:** ___________________________________________________________________

**Vowel 5:** **Onset:** ________ **Offset:** ________ **Duration:** ________**ms**

**F1 (Hz);** ________ **F2 (Hz):** ________ **Adjustments?** ____________________________

**Comments:** ___________________________________________________________________

**Calculate the Average and Standard Deviation**

**Average F1 =** _______________

**Standard Deviation =** _________________

**Average F2 =** _______________

**Standard Deviation =** _________________

## Vowel Analyses: "The boot on top is packed to keep."

**Analyzer:** ____________________ **Date of Analysis:** ______________

**Subject:** __________ **Vowel:** ___/u/__

---

**Vowel 1:** **Onset:** ________ **Offset:** ________ **Duration:** ________ms

**F1 (Hz);** ________ **F2 (Hz):** ________ **Adjustments?** ____________________________

**Comments:** ___________________________________________________________________

**Vowel 2:** **Onset:** ________ **Offset:** ________ **Duration:** ________ms

**F1 (Hz);** ________ **F2 (Hz):** ________ **Adjustments?** ____________________________

**Comments:** ___________________________________________________________________

**Vowel 3:** **Onset:** ________ **Offset:** ________ **Duration:** ________ms

**F1 (Hz);** ________ **F2 (Hz):** ________ **Adjustments?** ____________________________

**Comments:** ___________________________________________________________________

**Vowel 4:** **Onset:** ________ **Offset:** ________ **Duration:** ________ms

**F1 (Hz);** ________ **F2 (Hz):** ________ **Adjustments?** ____________________________

**Comments:** ___________________________________________________________________

**Vowel 5:** **Onset:** ________ **Offset:** ________ **Duration:** ________ms

**F1 (Hz);** ________ **F2 (Hz):** ________ **Adjustments?** ____________________________

**Comments:** ___________________________________________________________________

## Calculate the Average and Standard Deviation

**Average F1 =** _______________

**Standard Deviation =** _________________

**Average F2 =** _______________

**Standard Deviation =** _________________

APPENDIX L

DBS-STN Participant Data Summary Sheet.

**Results: Participant # _______________**

| DBS Summary Evaluation Data | | | | |
|---|---|---|---|---|
| **dB SPL measured @ 40cm** | **Pre** | **Post** | **FU 3mo** | **FU 6mo** |
| **Date** | | | | |
| **RBANS imm memory** | | | | |
| **RBANS visuo/spatial** | | | | |
| **RBANS language** | | | | |
| **RBANS attention** | | | | |
| **RBANS delayed memory** | | | | |
| **RBANS total scale** | | | | |
| **Labial Strength (kPa)** | | | | |
| **Lingual Strength (kPa)** | | | | |
| **Ah Loud (dB SPL)** | | | | |
| **Ah Duration (seconds)** | | | | |
| **Sentence Reading (dB SPL)** | | | | |
| **Paragraph Reading (dB SPL)** | | | | |
| **Picture Description (dB SPL)** | | | | |
| **Sentence Intelligibility Test Single words (dB SPL)** | | | | |
| **Sentence Intelligibility Test Sentences (dB SPL)** | | | | |
| **Sentence Intelligibility Test (Word Intelligibility in %)** | | | | |
| **Sentence Intelligibility Test (Sentence Intelligibility in %)** | | | | |
| **Monologue (dB SPL)** | | | | |
| **Maximum Inspiratory Pressure MIP (cm $H_2O$)** | | | | |
| **Maximum Expiratory Pressure MEP (cm $H_2O$)** | | | | |
| **DDK's (puh-tuh-kuh in 5")** | | | | |
| **Swallowing: (Swallows/ml), (Swallows/s)** | | | | |
| **EAT-10 (40 max)** | | | | |

**Results: Participant # _______________**

| DBS Summary Evaluation Data | | | | |
|---|---|---|---|---|
| **dB SPL measured @ 40cm** | **Pre** | **Post** | **FU 3mo** | **FU 6mo** |
| **Date** | | | | |
| **VAS loudness** | | | | |
| **VAS finding the right words** | | | | |
| **VAS shaky voice** | | | | |
| **VAS monotone** | | | | |
| **VAS slurring** | | | | |
| **VAS strained voice** | | | | |
| **VAS mumbling** | | | | |
| **VAS understandability** | | | | |
| **VAS participation in conv.** | | | | |
| **VAS initiating conversation** | | | | |
| **VAS Perceptual Average** | | | | |
| **VAS weight loss** | | | | |
| **VAS eating out** | | | | |
| **VAS liquid swallowing** | | | | |
| **VAS solid swallowing** | | | | |
| **VAS pill swallowing** | | | | |
| **VAS swallowing pain** | | | | |
| **VAS eating pleasure** | | | | |
| **VAS food sticking** | | | | |
| **VAS coughing when eating** | | | | |
| **VAS stress over swallowing** | | | | |
| **VAS Swallowing Average** | | | | |

**Results: Participant # _______________**

| DBS Summary Evaluation Data | | | | |
|---|---|---|---|---|
| **dB SPL measured @ 40cm** | **Pre** | **Post** | **FU 3mo** | **FU 6mo** |
| **Date** | | | | |
| **MDVP relative average pertubation** | | | | |
| **MDVP percent perturbation quotient** | | | | |
| **MDVP voice turbulence index** | | | | |
| **HINT (dB SPL)** | | | | |
| **HINT (% words intelligible)** | | | | |
| **F1 /u/ (Hz)** | | | | |
| **F2 /u/ (Hz)** | | | | |
| **F1 /a/ (Hz)** | | | | |
| **F2 /a/ (Hz)** | | | | |
| **F1 /i/ (Hz)** | | | | |
| **F2 /i/ (Hz)** | | | | |
| **Vowel Spare Area ($Hz^2$)** | | | | |

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