2014

INTENSIVE TREATMENT OF DYSARTHRIA IN AN ADULT WITH A TRAUMATIC BRAIN INJURY

Jaclyn Scheimer
University of Rhode Island, jaclyn_schiemer@my.uri.edu

INTENSIVE TREATMENT OF DYSARTHRIA IN AN ADULT WITH A TRAUMATIC BRAIN INJURY

BY

JACLYN SCHIEMER

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

MASTERS OF SCIENCE

IN

SPEECH-LANGUAGE PATHOLOGY

UNIVERSITY OF RHODE ISLAND

2014

MASTER OF SCIENCE THESIS

OF

JACLYN SCHIEMER

APPROVED:

Thesis Committee:

Major Professor Leslie Mahler

Dana Kovarsky

Matthew Delmonico

Nasser H. Zawia
DEAN OF THE GRADUATE SCHOOL

UNIVERSITY OF RHODE ISLAND

2014

ABSTRACT

Objective: This study investigated the impact of an intensive articulation treatment on acoustic and perceptual measures of speech in an individual with spastic dysarthria acquired from a traumatic brain injury (TBI).

Method: A single-subject A-B-A-A experimental design was used to measure the effects of an intensive articulation treatment that incorporated principles of motor learning to evaluate the impact on speech and communication. The primary dependent variables were single word intelligibility and vowel space area. Additional dependent variables included vocal sound pressure level (dB SPL) during a variety of speech tasks, acoustic measures of voice, and listener perceptual ratings of voice quality and speech.

Results: Multiple comparisons with t-tests were used to determine statistically significant changes in primary and secondary dependent variables. Statistically significant ($p<0.05$) changes were present immediately post-treatment with single word intelligibility ($p=0.00$), vowel prolongation duration ($p=0.00$), and lip pressure exerted (0.04) and six months following treatment with vowel duration prolongation ($p=0.01$) and Noise-to-Harmonics Ratio ($p=0.02$). There were no statistically significant ($p<0.05$) changes with listener preference studies, vowel space area, and vocal dB SPL across vowel prolongation and speech tasks immediately post-treatment and six months following treatment.

Conclusions: These data demonstrate that this individual with spastic dysarthria secondary to a traumatic brain injury responded positively to an intensive articulation treatment on selected variables, particularly on tasks practiced directly in treatment.

Generalization of a treatment effect outside of treatment was not demonstrated. Further research is needed to determine whether the lack of generalization was due to the treatment or specific characteristics of the individuals who are treated.

Keywords: Traumatic Brain Injury, dysarthria, articulation, motor learning, speech disorder, speech treatment, behavioral treatment

ACKNOWLEDGMENTS

I would like to acknowledge Dr. Leslie Mahler, Dr. Dana Kovarsky, Dr. Matthew Delmonico, Dr. Blaire Gagnon, and the Department of Communicative Disorders for their support and contribution to this research study. I would also like to thank TBI02 and his family for their participation and support in the research treatment and the undergraduate and graduate speech-language pathology students, especially Lauren Ferrara and Octavia Miller, at the University of Rhode Island for their assistance in listener tasks. In addition, I am grateful to my family and friends for their constant love, support, and belief in me.

PREFACE

Manuscript format is used. This article is prepared for submission to the Archives of Physical Medicine and Rehabilitation.

CONTENTS

TABLES

TABLE **PAGE**

FIGURES

FIGURE **PAGE**

"Intensive Treatment of Dysarthria in an Adult with a Traumatic Brain Injury"

by

Jaclyn M. Schiemer[1]; Leslie A. Mahler[2]

is prepared for submission to the Archives of Physical Medicine and Rehabilitation

[1] M.S. Candidate, Department of Communicative Disorders, The University of Rhode Island, Kingston, RI 02881 Email: jaclyn_schiemer@my.uri.edu

[2] Associate Professor, Department of Communicative Disorders, The University of Rhode Island, Kingston, RI 02881 Email: lmahler@uri.edu

CHAPTER 1

1.0 Introduction

Traumatic brain injury (TBI) is one of the leading causes of disability in the United States, affecting approximately 1.7 million people each year (Center for Disease Control and Prevention, 2012). A TBI is a change in normal brain function caused by either a closed head injury or a penetrating head injury, which can result in multiple disabilities (Center for Disease Control and Prevention, 2012; Brain Injury Association of America, 2013). Previous studies reported that approximately one third of individuals with TBI develop dysarthria (McAuliffe et al, 2010; Yorkston, 1996). Dysarthria tends to be more persistent and stable following the acute phase of TBI and may result in decreased social participation, reduced quality of life, and depression after discharge from rehabilitative services (Brady et al, 2011; McAuliffe et al, 2010). Therefore, treatment studies to ameliorate dysarthria secondary to TBI are needed to identify the potential of specific individuals to benefit from treatment (Yorkston, 1996).

Dysarthria is characterized by abnormalities in strength, speed, range, timing, and/or accuracy of articulatory movements caused by damage to the nervous system that can result in reduced communicative intelligibility, comprehensibility, and naturalness (Mackenzie & Lowit, 2007). Intelligibility refers to how accurately a speaker's acoustic signal is received by a listener (Hustad, 2008). Comprehensibility refers to how accurately a speaker's acoustic signal is received when paired with speaker, listener, and environmental support (Mackenzie & Lowit, 2007). Reduced intelligibility and comprehensibility can result in disrupted and unsuccessful communicative interactions, which diminishes an individual's quality of life secondary to limited social and vocational participation, coupled with acquired communicative avoidance strategies (Brady, Clark, Dickson, Paton, & Barbour, 2011; Walshe, Miller, Leahy, & Murray, 2008).

The literature on dysarthria treatment provides evidence of behavioral, medical, and prosthetic approaches used to improve functional communication (Duffy, p. 405, 2012; Mackenzie & Lowit, 2007). Behavioral management is the most frequently published approach for increasing intelligibility in individuals with dysarthria (Duffy, p. 415, 2012, Mackenzie & Lowit, 2007; Mahler & Jones, 2012; Mahler, Ramig, & Fox, 2009). Increasing intelligibility is a critical component of dysarthria management because of its relationship with improved functional communication, cognition, and quality of life (Mackenzie & Lowit, 2007). However, there is little evidence available in the literature describing specific treatment approaches for improving intelligibility in individuals with dysarthria, due to the heterogeneity of the disorder (Sellars, Hughes, & Langhorne, 2005; Yorkston, 1996).

Furthermore, few reports analyze treatment efficacy of dysarthria in individuals, particularly for individuals with a TBI, because it is often accompanied by other complex cognitive-linguistic disorders (Centers for Disease Control and Prevention, 2013). There is growing evidence regarding the relationship between dysarthria management and the motor-learning literature (Maas, Robin, Austermann Hula, Freedman, Wulf, Ballard, Schmidt, 2008). Behavioral speech treatments based on principles of motor learning have potential to improve the treatment of dysarthria in individuals with TBI (Mahler & Jones, 2012; Mahler & Ramig, 2012; Wenke, Theodoros, Cornwell, 2008). Therefore, the purpose of the current investigation is to determine the impact of an intensive articulation treatment that incorporates principles of motor learning on the intelligibility of an individual with spastic dysarthria secondary to a TBI. It is hypothesized that an individual with spastic dysarthria secondary to TBI will improve intelligibility for functional communication following an intensive articulation treatment.

1. It is hypothesized that this individual's single word intelligibility will improve secondary to an intensive articulation treatment.
2. It is hypothesized that this individual's vowel space area will increase secondary to an intensive articulation treatment.

CHAPTER 2

2.0 Methodology

2.1 *Study overview*

A single subject A-B-A-A experimental design was selected for this Phase I research study. Single subject designs are critical in determining treatment effectiveness with one individual, as well as, providing pilot data to justify group treatment efficacy studies (Robey, 2004). A single subject A-B-A-A experimental design was important for making an initial determination of response to an intensive articulation treatment for an individual with dysarthria secondary to TBI. The primary dependent variables were listener intelligibility scores based on 50 single words (Bunton, Leddy, & Miller, 2007) and vowel space area analysis calculated through first and second formant frequencies. Additional dependent variables included vocal sound pressure level measured in dB SPL during reading of sentences, picture and task descriptions, and maximal vowel prolongation; acoustic measures of phonatory stability during maximal vowel prolongation; and listener perceptual ratings of speech comparing pre- and post-treatment samples and pre- and follow-up treatment samples.

The participant received repeated measures of the dependent variables under control conditions during the A phases of the study. Four individual one-hour treatment evaluations were completed the week immediately prior to treatment (A1), after treatment (A2), and six months post-treatment (A3) to allow for trend analysis and visual inspection of data (Beeson & Robey, 2006; Parsonson & Baer, 1992). Repeated evaluation tasks under controlled conditions included: sustained vowel prolongation, single word intelligibility (Bunton et al., 2007), sentence reading (five repetitions of “The boot on top is packed to keep.”) and paragraph reading (The Farm Passage, Crystal & House, 1982), picture description (picnic scene from the Western Aphasia Battery (WAB), Kertesz, 1982), task description (e.g. Describe your favorite sport.), and lip and tongue pressure measures (three repetitions of each that varied no more than 10%). The *Bunton, Leddy, & Miller* single-word intelligibility test (2007) was administered during Pre4, Post1, and Follow-up 1 evaluation sessions to assess single word intelligibility. The *Bunton et al.* (2007) single word intelligibility test is an intelligibility test that was originally developed for individuals with Down syndrome. It consists of 53 single words from the *Kent, Weismer, Kent, and Rosenbek* single word intelligibility test (1989), which was designed to examine the acoustic-phonetic contrasts that contribute to speech intelligibility in individuals with dysarthria (Bunton et al., 2007; Kent, Weismer, & Kent, 1989; Mackenzie & Lowit, 2007). This intelligibility test (Bunton et al., 2007) was selected for TBI02 to accommodate his cognitive-linguistic and reading deficits for reliable intelligibility testing. An intensive articulation treatment was administered during four individual one-hour treatment sessions a week for four weeks during the B phase of the study. This research study was approved by the University of Rhode Island Institutional Review Board #HU0910-140.

2.2 *Participant*

The participant (TBI02) was a 38-year-old male, who sustained a TBI secondary to a motor vehicle accident 20 years prior to participation in this study. His communication was characterized by a combination of speech, language, and cognitive impairments, as well as, unilateral moderate hearing loss in his left ear. His speech pattern was consistent with a diagnosis of spastic dysarthria, primarily including strained vocal quality, hypernasality, imprecise consonants, and distorted vowels. Communicative breakdowns occurred at the word, phrase, and conversational levels due to moderately unintelligible speech and telegraphic speech. He spoke primarily using one to three word utterances containing content words (e.g., nouns and verbs), which may have been an acquired strategy used over the past 20 years. He required moderate-to-maximum verbal cues to use complete, grammatical sentences, which also limited successful communicative interactions. TBI02 spoke English as his first language and passed a hearing screening at 25 dB for 500, 1000, and 2000 Hz, which indicated adequate hearing for conversation. TBI02 signed a consent form following education on the description, benefits, and risks of participating in this research study and confidentiality.

TBI02 was selected based on a confirmed diagnosis of TBI and resulting dysarthria. TBI02 was diagnosed with spastic dysarthria by a speech-language pathologist (LM) with experience in the diagnosis and management of individuals with dysarthria. He also demonstrated language and cognitive-linguistic deficits secondary to his traumatic brain injury. Therefore, further evaluations were completed during pre-treatment evaluations to assess language deficits using the aphasia quotient (AQ) of the Western Aphasia Battery (WAB; Kertesz, 1982) and cognitive-linguistic deficits using the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS; Randolph, 1998). His AQ on the WAB was 71.8/100.0 with a Spontaneous Speech Total of 12.0/20.0, Auditory Verbal Comprehension Total of 9.0/10.0, Repetition Total of 7.4/10.0, and Naming and Word Finding Total of 7.5/10.0. His

Immediate Memory Index Score was 44/160 and Language Index Score was 74/160 on the RBANS. RBANS subtests for Visuospatial/Constructional, Attention, and Delayed Memory Index Scores were not administered due to bilateral spasticity of TBI02's upper extremities. Results of the WAB AQ revealed relatively preserved auditory comprehension, reading at the sentence level, and moderate word-retrieval deficits. Results of the RBANS subtests revealed moderate cognitive-linguistic deficits, including decreased working-memory that could potentially interfere with new learning. Therefore, the intensive articulation treatment used a single motor organizing theme of increasing speech clarity to improve TBI's spastic dysarthria and compensate for his cognitive and language deficits.

2.3 *Equipment and recording procedures*

Each pre-, post-, and follow-up evaluation session occurred in an IAC sound-treated booth at the University of Rhode Island Speech and Hearing Center. A head-mounted microphone, model Isomax B3, was adjusted to a mouth-to-microphone distance of 8 cm. A sound level meter (SLM - Radio Shack 33-2055) was 40 cm away from TBI02's lips and level with his mouth to collect vocal intensity data during speech tasks in real time (Matos, 2005). Mouth-to-microphone and SLM distances remained constant across the three weeks of evaluations for reliable data collection.

The head-mounted microphone and SLM signals were digitized directly to a computer and simultaneously recorded onto a flash recorder, Marantz PMD670. A pre-amplifier (Universal Audio 4110) was used to assure quality signal acquisition with the microphone. Speech was sampled at 44.1 kHz using Adobe Audition 2.1 software and standard speech and voice analysis procedures, which were previously discussed in the literature (Ramig, Countryman, Thompson, & Horii, 1995). Each evaluation session was recorded by a HandyCam DCR-DVD92 digital video camera.

2.4 *Treatment*

An intensive articulation treatment was administered during four one-hour treatment sessions a week for four weeks for a total of 16 individual treatment sessions. The articulation treatment implemented traditional articulation tasks, including minimal pairs and exaggerated articulation. The actual tasks completed each treatment session are commonly used by speech-language pathologists, but not supported in the literature for treatment of spastic dysarthria secondary to a TBI. Administration of the treatment was novel because it incorporated principles of motor learning to promote neural restructuring for increased intelligibility for functional communication. The articulation treatment was driven by principles of motor learning for clinical rehabilitation of dysarthria, which has been previously discussed in the literature (Kleim & Jones, 2008; Mahler et al., 2009; Ramig, Sapir, Countryman, Pawlas, O'Brien, Hoehn, & Thompson, 2001a; Ludlow, Hoit, Kent, Ramig, Strand, Yorkston, Sapienza, 2008). The literature discusses neural plasticity, which refers to the ability of the central nervous system to change and/or adapt to environmental influences for both learning in normal brains and relearning in damaged brains (Ludlow et al., 2008; Kleim & Jones, 2008). Key principles of neuroplasticity, including dosage intensity, salience, and complexity, are not commonly used in speech-language intervention today. However, new advances in neurorehabilitation demonstrate that the brain can compensate after an acquired neurological injury with repetitive and intensive application of behavioral treatment based on specific motor principles (Kleim & Jones, 2008). Therefore, the research treatment implemented traditional articulation tasks and based administration on the motor learning principles of dosage intensity, salience, and complexity to initiate changes in neuroplasticity for long-term retention of new motor programs for clear speech production.

Treatment was intensive in both dosage (four treatment sessions per week for four weeks with daily homework and carryover assignments) and number of repetitions within each session. Salient, functional materials were incorporated during treatment sessions, homework, and carryover assignments. Four weeks of intensive speech treatment was chosen to increase opportunities for retrieval of motor programs, which facilitated neural restructuring for greater retention of motor movements (Maas et al., 2008). Mass practice was also incorporated through intensive, high effort exercises that targeted exaggerated articulation across various speech tasks within each session. Saliency was incorporated through meaningful communication topics to motivate TBI02 to use clear speech techniques. Meaningful communication increased activation of attentional brain networks for neutral function underlying clear speech production (Ludlow et al., 2008; Maas et al., 2008).

The motor learning principle of complexity was established through the exercise-dependent articulation tasks completed each treatment session. Speech is a complex motor task that can be divided into component parts to practice (Maas et al., 2008). Therefore, the first half of each treatment session utilized tasks that were overlearned, which reduced cognitive-linguistic demands, but were real speech tasks since the goal of treatment was increased intelligibility. This approach was particularly useful for TBI02 because concentration on a single aspect of speech decreased the cognitive demands of the speaking task to accommodate his complex cognitive-linguistic deficits. The second half of each treatment session used a hierarchy of speech tasks for complexity and specificity of practice, which systematically facilitated TBI02 to use clear speech techniques during functional communication. Overall, the treatment incorporated intensive, high effort speech tasks to drive stability of recall for the complex coordination of motor patterns for speech.

Treatment sessions were completed at the University of Rhode Island's Speech and Hearing Clinic by a graduate speech-language pathologist student (JS) under the supervision of a speech-language pathologist certified by the American Speech-Language and Hearing Association (LM). Appendix A illustrates procedures and purpose of each treatment task. First, TBI02 completed maximal effort lip and tongue exercises using the Iowa Oral Performance Instrument (IOPI). The IOPI measured exerted pressure (kPa) to determine the appropriate level of effort for labial and lingual exercises. It was placed midline between TBI02's lips for lip exercises and between the tongue tip and the alveolar ridge for tongue exercises by the clinician to compensate for upper extremity spasticity. Lip and tongue exercises emphasized tongue positioning and high effort training for clear speech. Intensity of practice was established through multiple repetitions of treatment tasks within a treatment session across an intensive dosage of treatment.

TBI02 sustained "ah" at his habitual pitch for speech to improve the coordination of respiration and phonation, strengthen vocal fold adduction, and increase vocal loudness. Previous intelligibility studies indicated that increased loudness can improve intelligibility and vocal quality (Lam, Tjaden, & Wilding, 2007; Dromey, 2000; Goberman & Elmer, 2005; Pichney, Durlack, & Braida, 1986; Ramig et al., 2001a; Trail, Fox, Ramig, Sapir, Howard, & Lai, 2005). Therefore, duration of sustained phonation and loudness measured in dB SPL were collected. TBI02 then counted to 15, an automatic speech task with low cognitive load, to incorporate high effort training of articulation and vocal loudness. Loudness measured in dB SPL was collected.

TBI02's most salient speech sound errors, final /t/ and /d/ and final /g/ and /k/, were targeted through minimal pair tasks (i.e., pairs of words that differ by only one sound; e.g., "sat" and "sad"). Targeted speech sounds were selected through analysis of the Bunton et al. (2007) word intelligibility test. He read minimal pairs targeting his speech errors using high effort, clear speech. For example, TBI02 overarticulated word pairs such as "back" and "bag." The accuracy of sound productions during minimal pair tasks was tracked throughout treatment. Appendix B displays TBI02's minimal pair word lists for final /t/ and /d/ and final /g/ and final /k/.

The remainder of each session included a hierarchy of speech tasks controlled for length, complexity, and specificity of practice, which gradually increased over the four week treatment period. Tasks began with reading of word, phrase, and sentence length material, progressed to functional, structured dialogue (i.e., scripted conversation), and finished with spontaneous conversation. Pictures of content words were presented above sentence length material and scripted conversations to reduce cognitive demands and support reading deficits. Topics were salient and based on TBI02's interests and hobbies to facilitate generalization outside of treatment. For example, TBI02 used clear speech during reading of a hospital simulation script to increase intelligibility with medical professionals after hip replacement surgery.

Clinician models of clear speech and the verbal cue, “speak clearly,” emphasized production of target phonemes to increase intelligibility. The single concept of “clear speech” targeted improvements across multiple speech subsystems, including articulation, phonation, and/or respiration with limited cognitive demands on TBI02. Reduced verbal explanations transitioned control of clear speech to the participant to promote carry-over of skills. Frequency and type of cueing decreased over the four week progression to promote self-evaluation of speech production and internalize the effort needed for clear speech. Homework consisting of treatment tasks and a carryover task (e.g., using clear speech during functional communication) were assigned each day for treatment intensity and to enhance generalization of clear speech outside of the clinic during daily communication. Summary data for treatment tasks are displayed in Table 1.

Table 1. Summary data of treatment tasks

Session	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Lips (kPa)	21	24	21	26	32	33	35	39	39	40	38	42	46	43	43	45
Tongue (kPa)	56	59	61	57	56	64	61	61	56	60	61	61	60	62	63	60
Ah Loudness (dB SPL)	90	89	89	94	90	91	89	89	91	92	90	89	93	92	92	94
Ah Duration (seconds)	5.4	5.0	5.0	5.6	7.8	7.1	7.5	5.6	8.4	9.4	9.4	9.7	8.6	9.7	9.5	9.6
Sentences (dB SPL)	73	73	74	76	74	74	75.0	75	75	75	74	75	74	73	74	73

*Note: Vocal dB SPL was measured at 40cm from mouth to SLM.

2.5 *Listener Intelligibility and Perception Tests*

Ten undergraduate and graduate communicative disorder students with normal hearing and no history of neurological disorder served as listeners for intelligibility testing. Listeners signed a consent form following review of the purpose of the study and confidentiality. Listeners were unfamiliar with TBI02 to represent a typical communication situation since the literature has shown that familiarization with a speaker increases intelligibility (Garcia & Cannito, 1996). Listeners were blind to the time of a recording of 50 phonetically balanced words (Bunton et al., 2007) that were collected during Pre 4, Post 1, and Follow-up 1 evaluation sessions. Listeners circled the word that they heard through a multiple-choice format of the target word and three foil words, which were chosen for the interpretation of vowel and consonant errors perceived by listeners. A blank column was provided for listeners to write in a word they heard that was not presented in the list. The total number of words accurately identified by the blind listeners was used to calculate percent single word intelligibility score (Kent et al., 1989).

Blind listeners then listened to pairs of 25 identical sentences (e.g., "The boot on top was packed to keep.") to control for speech content, limit listener bias, and maintain reliability across listeners. The sentence, "The boot on top is packed to keep," which was read five times and collected during each pre-, post-, and follow-up evaluation session, was randomly presented to the listeners for a total of 25 paired sentence comparisons at each evaluation. Sentence pairs were randomized based on presentation (e.g., pre-, post-, follow-up) and sentence token number (e.g., 1-25). Listeners were presented two speech samples at a time and asked to rate the second sample (B) relative to the first sample presented (A) based on naturalness (e.g., vocal loudness, vocal quality, pitch variability, and speech clarity). Listeners were instructed to rate Sample B relative to Sample A by placing a vertical line along a horizontal line scale representing a continuum from -50 to +50. Negative values indicated that Sample B was worse than Sample A and positive values indicated that Sample B was better than Sample A. A rating of zero signified no difference between speech samples, which indicated that the samples were equivalent in naturalness. Listener preference percentages were calculated by dividing the distance between zero and the rating by half of the total length of the line scale.

Vowel Space Area

Previous literature has demonstrated that acoustic measures are sensitive to articulatory movements during vowel and consonant production in speakers with spastic and mixed dysarthria (Kent et al., 1989; Kent, Weismer, Kent, Vorperian, & Duffy, 1999; Roy, Leeper, Blomgren, Cameron, 2001). Reduced vowel space area calculated from F1 and F2 of corner vowels has been associated with speakers with dysarthria. The literature shows that centralization of the first and second formant frequencies (F1 and F2) and reduced articulatory movements of vowels account for decreased intelligibility of dysarthric speech (Roy et al., 2001; Mahler & Ramig, 2012). An increase in vowel space area has been correlated with improved intelligibility scores during perceptual studies (Liu, Tsao, & Kuhl, 2005). Therefore, acoustic analysis of vowel space area was performed to determine the impact of the intensive articulation treatment on speech intelligibility, as well as, overcome the limitations of subjective, listener intelligibility studies (Collins, 1984).

Vowel area was calculated from vowel triangles obtained from the sentence, "The boot on top is packed to keep." The sentence was read five times during each pre-, post-, and follow-up evaluation session, resulting in a total of 20 tokens at each evaluation. F1 and F2 values were determined through wideband spectrographic displays and linear predictive coding spectra using Time-Frequency Analysis Software (TF32), a Windows-based version of CSpeech software (Milenkovic, 2001, Madison, WI). F1 and F2 values were obtained from the corner vowels /u/, /a/, and /i/ measured at the temporal midpoint of each vowel production to avoid interference of coarticulation.

Vocal Sound Pressure Level (dB SPL)

Vocal sound pressure level measured in dB SPL was collected during sentence reading (e.g. "The boot on top is packed to keep."), reading of the Farm Passage (Crystal & House, 1982), picture description of the picnic scene from the Western Aphasia Battery-Revised (Kertesz, 2006), and task description, which varied for each evaluation session. Vocal dB SPL was chosen as a dependent variable to determine the impact of vocal loudness on increased intelligibility and comprehensibility across various speech tasks.

Acoustic Measures

Acoustic measures of phonatory stability, an indirect measure of vocal fold vibration regularity, were collected pre-, post-, and follow-up treatment during maximal vowel phonation using the Multidimensional Voice Profile (MDVP Advanced; CSL 4500), which the literature has shown to be reliable for the analysis of neurological voice (Kent, Vorperian, Kent, & Duffy, 2003). Relative average perturbation (RAP), pitch perturbation quotient (PPQ), and noise-to-harmonics ratio (NHR) were used as measures of vocal fold vibration regularity and indirect measures of phonatory stability. An inverse relationship exists between RAP, PPQ, and NHR values and phonatory stability. For example, lower RAP, PPQ, and NHR values indicate greater phonatory stability and higher values indicate greater vibration variability. RAP, PPQ, and NHR data were analyzed based on 24 maximal vowel prolongations collected during pre-treatment, 24 post-treatment, and 24-follow-up (6 "ah"s from each of the evaluation sessions). A three second sample of each sustained phonation was selected through visual inspection of the sound wave in MDVP Advanced. RAP, PPQ, and NHR data were retrieved from the middle portion of each maximal vowel prolongation to avoid vibratory irregularities at the start and end of phonation.

2.6 *Statistical analyses*

Multiple comparisons with t-tests were completed to determine whether a significant difference occurred for single word intelligibility, vowel space area, vocal dB SPL, RAP, PPQ, and NHR values, and lip and tongue pressure exerted. Effect size was calculated using Cohen's d to determine the magnitude of the treatment effect, if one was present. The means of F1 and F2 from 20 vowel tokens of /u/, /a/, and /i/ were used to create pre-, post-, and follow-up mean vowel space area and calculate vowel space area percent change. Average percentages and standard deviations of listener ratings were calculated to determine listener preference of treated speech and magnitude of preference

2.7 *Measurement Reliability*

The clinician who administered the intensive articulation treatment (JS) did not participate in pre-, post-, and follow-up evaluation sessions to limit bias and reactive behaviors during data collection. Acoustic measures were analyzed by the treating clinician (JS) and an interdisciplinary neuroscience doctoral student (OM) trained in acoustic analysis. Inconsistent measurements were resolved by an ASHA certified speech-language pathologist (LM) with experience in acoustic analysis of dysarthria speech. The two analyzers completed analyses of vowel space area to determine interrater reliability. The interrater percent agreement for pre-, post-, and follow-up F1 and F2 values of /u/, /a/, and /i/ was r=64.44. In addition, perception listeners heard speech samples in an IAC sound-treated booth with the volume adjusted to a comfortable level, which remained constant throughout listener tasks. A random number generator was used to randomize treatment sessions and sentence tokens for the listener perception task. Twenty percent of sentence pair combinations were randomly selected and repeated to determine reliability of each listener. The lowest and highest outliers (i.e., values one standard deviation below and above the mean) for listener ratings for pre-, post-, and follow-up single word intelligibility were omitted to decrease error variance and increase normality of data. In addition, TBI02 did not receive additional speech treatment during participation in the research study.

CHAPTER THREE

3.0 Results

3.1 *Single Word Intelligibility*

Single word percent accuracy increased from 24% pre-treatment to 73% post-treatment, revealing a 49% increase following treatment. The pre-post t-test was 0.00, which was statistically significant ($p<0.05$), with a large effect size at 0.97. The follow-up single word intelligibility decreased to 21% follow-up treatment, revealing a 3% decrease. The pre-follow-up t-test was 0.17, which was not statistically significant ($p<0.05$), with a small effect size at 0.29. Quantitative changes of single word percent intelligibility from pre-, post-, to follow-up treatment are displayed in Table 2.

Table 2. Quantitative changes in single word percent intelligibility

Listeners	1	2	3	4	5	6	7	8	Avg. (SD)
Pre-Tx	24%	20%	32%	22%	28%	28%	30%	10%	24% (7%)
Post-Tx	68%	74%	78%	70%	68%	78%	72%	74%	73% (4%)
FU-Tx	20%	20%	18%	20%	22%	22%	22%	20%	21% (1%)

3.2 *Listener Perception Tasks*

The listeners who compared pre-post speech samples preferred post-treatment speech at the sentence level 51.7% of the time. The listener responses indicated that the magnitude of preference for post-treatment speech was an average of 33.9% (out of 100%) compared with pre-treatment speech. The listeners who compared pre-follow-up speech samples preferred follow-up speech at the sentence level 48.2% of the time. The listener responses indicated that the magnitude of preference for follow-up speech was an average of 21% (out of 100%). Tables 3 and 4 illustrate quantitative changes in pre-post and pre-follow-up listener ratings of sentences, respectively.

Table 3. Quantitative changes in pre-post listener ratings of sentences

	L21	**L22**	**L3**	**L4**	**L5**	**L7**	**L8**	**Avg. (SD)**
Frequency Preferred	69.2%	61.5%	76.9%	53.9%	23.1%	30.8%	46.2%	51.7% (19.71)
Magnitude Preferred	50.5% (33.0)	35.7% (7.0)	33.2% (9.8)	19.6% (6.1)	37.5% (36.7)	29.3% (21.4)	31.5% (22.7)	33.9% (12.4)

Table 4. Quantitative changes in pre-follow-up listener ratings of sentences

	L28	**L3**	**L5**	**L7**	**L16**	**Avg. (SD)**
Frequency Preferred	76.5%	47.1%	29.4%	47.1%	41.2%	48.2% (17.4)
Magnitude Preferred	25.9% (19.4)	27.4% (10.4)	10.3% (7.2)	20.9% (12.2)	20.51% (11.72)	21.0% (4.5)

3.3 *Vowel Space Area*

Pre-, post-, and follow-up vowel triangles were obtained by analyzing F1 and F2 values of vowels /u, a, i/ to calculate vowel space area. Vowel space area for pre-treatment was 193,802 Hz^2 and for post-treatment was 214,463 Hz^2, indicating a 20,661 Hz^2 change. Vowel space area for follow-up treatment was 253,886 Hz^2, indicating a 60,084 Hz^2 change compared to pre-treatment. The pre-post t-test was 0.52, which was not statistically significant ($p<0.05$), with a small to medium effect size of 0.38. The pre-follow-up t-test was 0.05, which was not statistically significant ($p<0.05$), with a medium to large effect size of 0.74. Table 5 illustrates quantitative changes for pre-, post-, and follow-up treatment vowel space area. Figures 1 and 2 present a visual depiction of pre-post and pre-follow-up vowel space areas.

Table 5. Quantitative changes in vowel space area

Pre-Post T-Test	Effect Size	Cohen's d	Pre-FU T-Test	Effect Size	Cohen's d
0.52	0.38	0.19	0.05	0.74	2.19

Figure 1. F1 and F2 plot of pre- and post-treatment vowel triangles using /u, a, i/

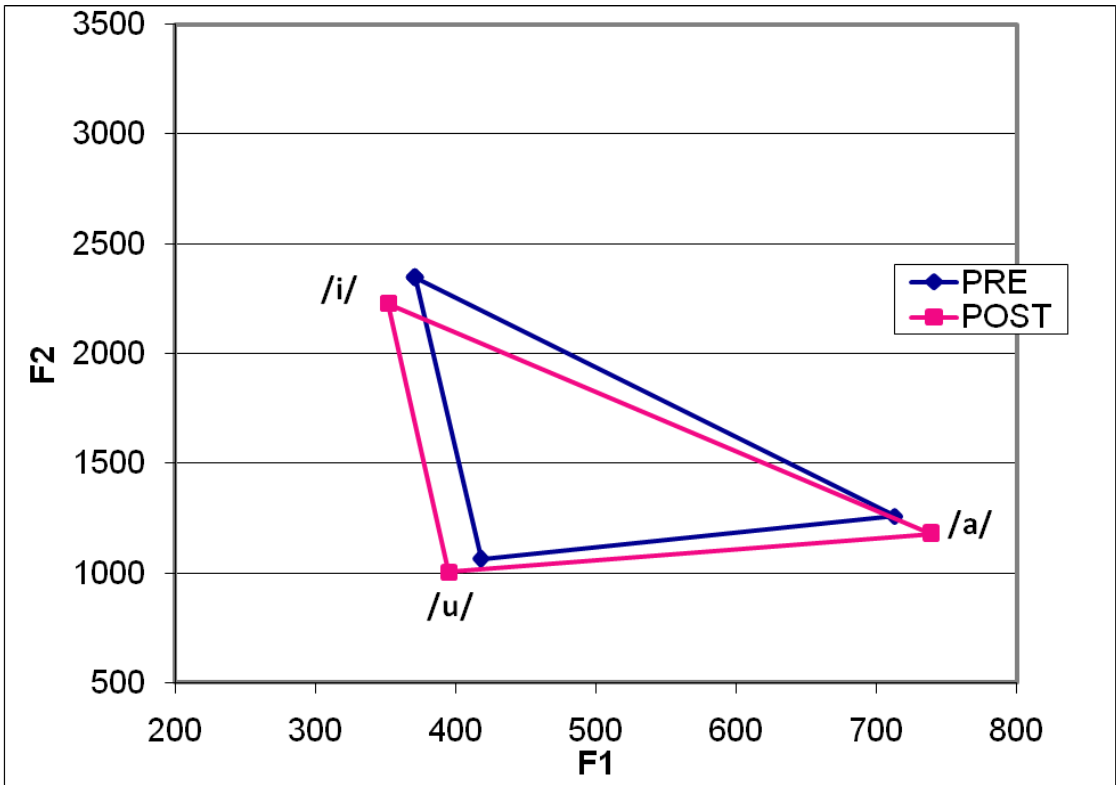
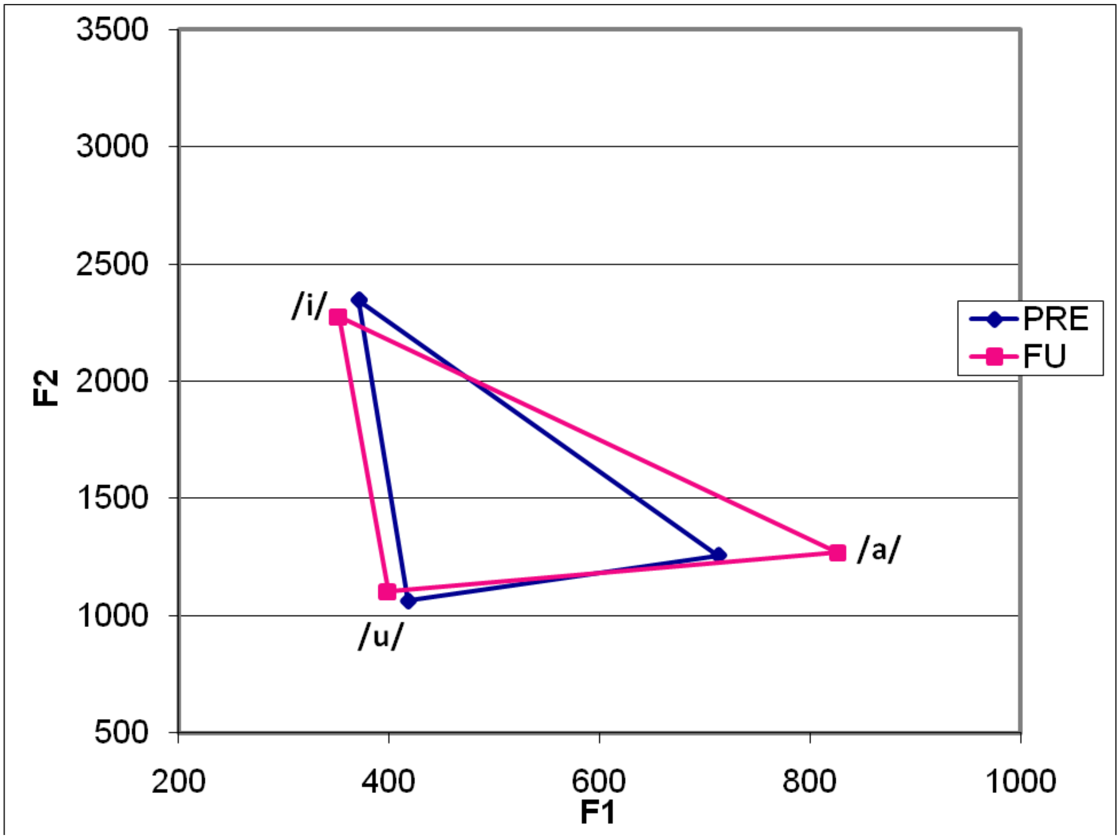


Figure 2. *F1 and F2 plot of pre- and FU-treatment vowel triangles using /u, a, i/*



Average formant frequencies of vowels based on gender and age have been previously established in the literature for normative values (Hillenbrand, Getty, Clark, & Wheeler, 1994). F1 values for /u/, /a/, and /i/ improved towards normative values based on TBI02's gender and age. The participant's F1 averages for /u/ and /i/ decreased towards the normative averages immediately post and were maintained at six months following treatment, while his F1 average for /a/ increased towards the normative average only immediately post-treatment. The participant's F2 averages for /u/ immediately post-treatment and /a/ six months following treatment approximated the normative averages. His F2 average for /i/ was approximate to the normative average at baseline, with a decrease below the normative value post- and six months following treatment. Table 6 illustrates quantitative changes in F1 and F2 across pre-, post-, and follow-up evaluation session for /u/, /a/, and /i/.

Table 6. Quantitative changes in F1and F2 for /u/, /a/, and /i/

	/u/		**/a/**		**/i/**	
	F1	**F2**	**F1**	**F2**	**F1**	**F2**
Pre Avg. (SD)	418.0 (23.1)	1064.0 (77.6)	712.5 (33.9)	1257.5 (57.9)	372.8 (11.2)	2347.3 (56.0)
Post Avg. (SD)	395.3 (17.9)	1003.8 (102.0)	738.5 (60.2)	1178.8 (29.2)	352.3 (8.5)	2228.8 (143.5)
FU Avg. (SD)	398.5 (26.7)	1102.5 (81.8)	825.8 (14.1)	1268.0 (29.4)	352.3 (12.9)	2274.0 (9.4)

3.4 *Vocal dB SPL*

Visual inspection of mean vocal dB SPL data for sustained vowel phonation and speech tasks (e.g. reading of sentences and paragraphs, picture and task description) indicated stability across pre-, post-, and follow-up evaluation sessions. Appendices C and D present visual depictions of pre-post and pre-follow-up mean vocal dB SPL data for sustained vowel phonation and speech tasks, respectively. The slopes of dB SPL data for pre-, post-, and follow-up treatment fluctuated for each evaluation session with overlapping values for each speech task. Pre-post and pre-follow-up t-tests were not statistically significant for any speech tasks ($p< 0.05$) and the effect size was small for sustained vowel phonation, reading of paragraphs, and task description and medium for reading of sentences and picture description. The pre-follow-up effect size was small to medium for sustained vowel phonation, reading of paragraphs, picture description, and task description and medium for reading of sentences. A summary of quantitative changes in vocal dB SPL from pre-, post-, and follow-up evaluations is displayed in Table 7.

Table 7. Quantitative changes in vocal dB SPL

	Pre dB SPL Avg. (SD)	Post dB SPL Avg. (SD)	FU dB SPL Avg. (SD)	Pre-Post T-Test	Effect Size	Pre-FU T-Test	Effect Size
Ah Loud	83.87 (2.56)	84.55 (3.18)	85.80 (1.57)	0.76	0.12	0.30	0.41
Sentence	78.97 (1.58)	80.10 (1.79)	81.45 (1.97)	0.53	0.32	0.21	0.57
Paragraph	81.21 (2.36)	81.45 (1.20)	82.75 (0.93)	0.88	0.06	0.39	0.39
Picture Description	79.39 (2.64)	80.95 (1.52)	81.35 (0.76)	0.48	0.34	0.33	0.45
Task Description	77.66 (2.90)	77.70 (0.61)	75.80 (1.99)	0.98	0.01	0.30	0.35

*Note: All dB SPL measurements were made at a mouth to SLM distance of 40 cm.

Visual inspection of mean duration of vowel prolongation indicated a significant increase from pre- to post-treatment evaluations, which was maintained at follow-up. Vowel prolongation increased from a pre-treatment mean of 4.43 seconds (SD=1.01) to a post-treatment mean of 11.96 seconds (SD=1.50), revealing a 7.53 second increase. The follow-up treatment mean was 11.63 seconds (SD=2.30), indicating maintenance of vowel prolongation duration six months following treatment. The pre-post t-test was 0.00, which was statistically significant ($p<0.05$), with a large effect size at 0.95. The pre-follow-up t-test was 0.01, which was also statistically significant ($p<0.05$), with a large effect size at 0.90. Figure 3 illustrates pre- and post- treatment vowel prolongation duration and Figure 4 illustrates pre- and follow-up treatment vowel prolongation.

Figure 3. Mean duration of vowel prolongation pre- and post-treatment

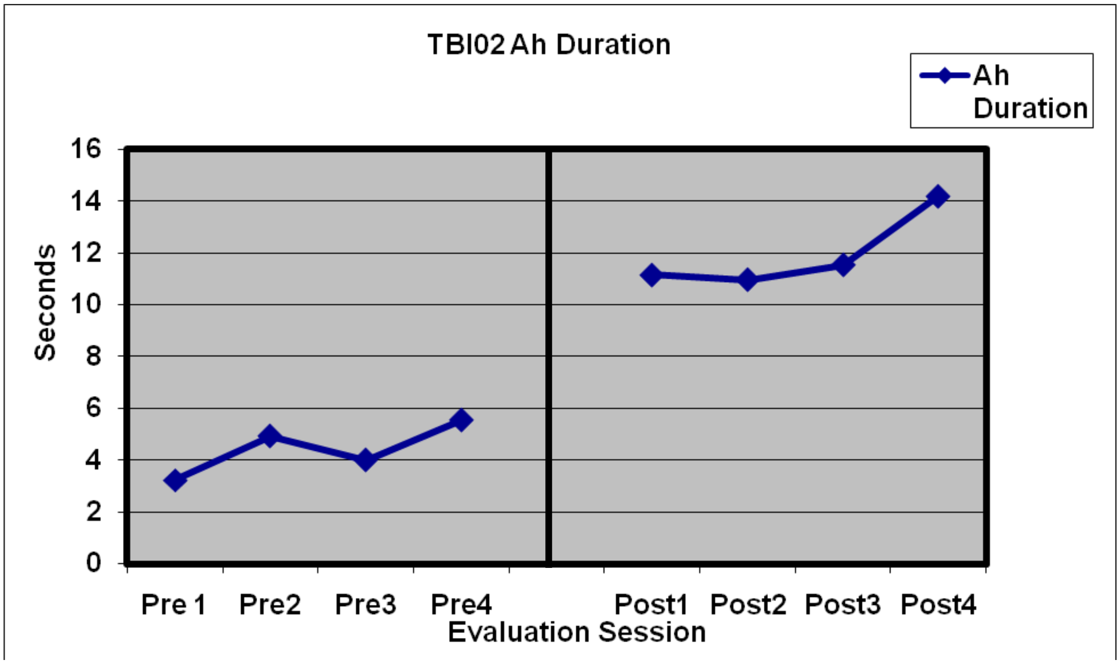
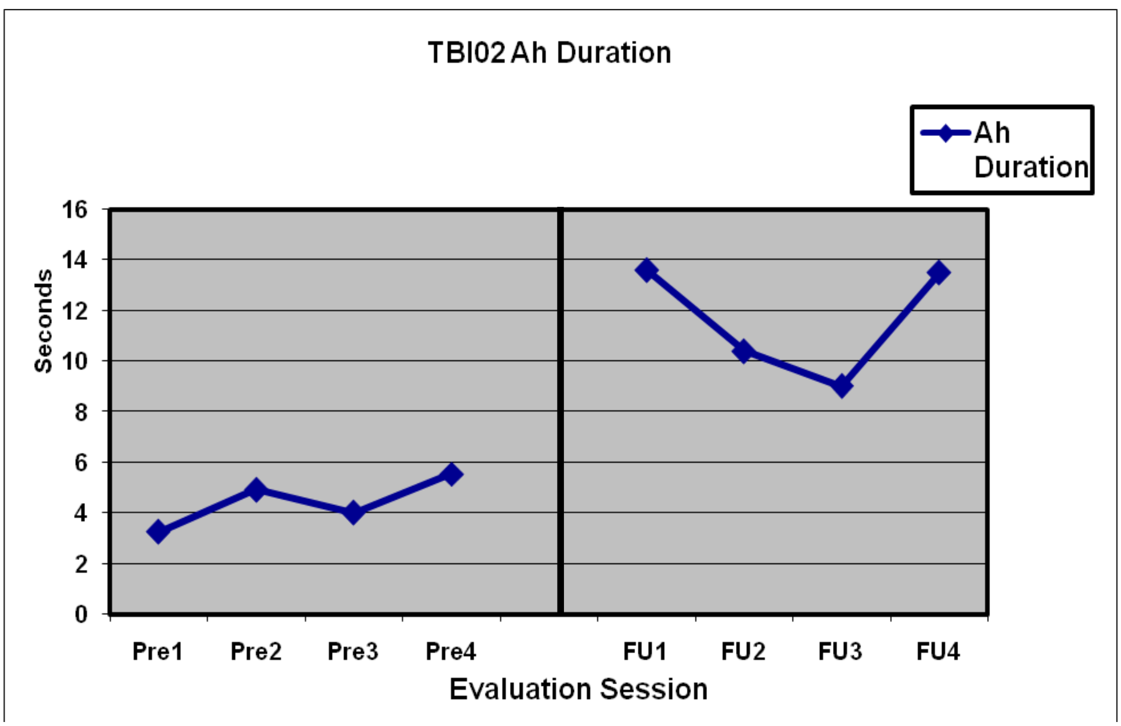


Figure 4. Mean duration of vowel prolongation post- and follow-up treatment



3.5 *Phonatory Stability*

The pre-post t-tests for relative average perturbation (RAP), pitch perturbation quotient (PPQ), and noise-to-harmonics ratio (NHR) revealed no statistically significant changes ($p<0.05$) in phonatory stability, with a small effect size for RAP and PPQ and a medium to large effect size for NHR. The pre-follow-up t-tests for RAP and PPQ were not statistically significant ($p<0.05$), with small effect sizes. However, the pre-follow-up t-test for NHR was 0.02 and was statistically significant ($p<0.05$), with a large effect size at 0.89. The RAP and PPQ pre-, post-, and follow-up treatment means were within the normative range for the participant's gender and age. The NHR pre-treatment mean was slightly above the normative range, but fell within the normative range for both post-treatment and six months following treatment. Quantitative changes in MDVP values during vowel prolongation are displayed in Table 8.

Table 8. Quantitative changes in MDVP values during vowel prolongation

Measure	Pre Avg. (SD)	Post Avg. (SD)	FU Avg. (SD)	Norm Avg. (SD)	Pre-Post T-Test	Effect Size	Pre-FU T-Test	Effect Size
RAP%	0.43 (0.15)	0.46 (0.05)	0.47 (0.03)	0.345 (0.333)	0.81	0.18	0.63	0.12
PPQ%	0.42 (0.14)	0.44 (0.04)	0.46 (0.03)	0.414 (0.290)	0.75	0.14	0.64	0.27
NHR	0.13 (0.00)	0.12 (0.00)	0.11 (0.00)	0.114 (0.014)	0.24	0.69	0.02	0.89

3.6 *Lip and Lingual Pressure Exerted*

The pre-post t-test for lip pressure exerted was 0.04 and was statistically significant ($p<0.05$), with a large effect size at 0.85. However, the pre-follow-up t-test was not statistically significant ($p<0.05$), with a medium effect size at 0.54. The pre-post and pre-follow-up t-tests for lingual pressure exerted were not statistically significant ($p<0.05$), with a medium effect sizes of 0.47 and 0.48, respectively. Quantitative changes in lip and lingual pressure exerted kPa values are displayed in Table 9. Figures 5 and 6 illustrate mean lip and lingual pressure exerted pre-post treatment and pre-follow-up treatment, respectively.

Table 9. Quantitative changes in lip and lingual pressure exerted

kPa	Pre Avg. (SD)	Post Avg. (SD)	FU Avg. (SD)	Pre-Post T-Test	Effect Size	Pre-FU T-Test	Effect Size
Lip	27.68 (6.03)	45.08 (4.55)	34.65 (4.82)	0.04	0.85	0.19	0.54
Lingual	47.66 (18.71)	61.75 (2.75)	62.10 (1.93)	0.23	0.47	0.20	0.48

Figure 5. Mean lip and lingual pressure exerted pre- and post-treatment

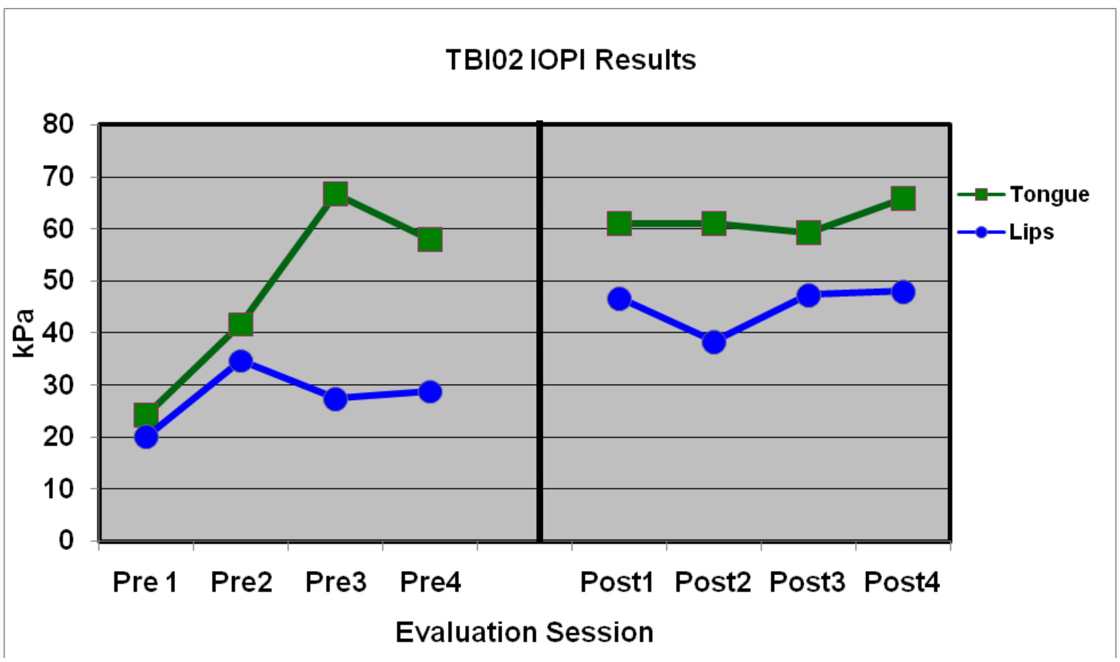
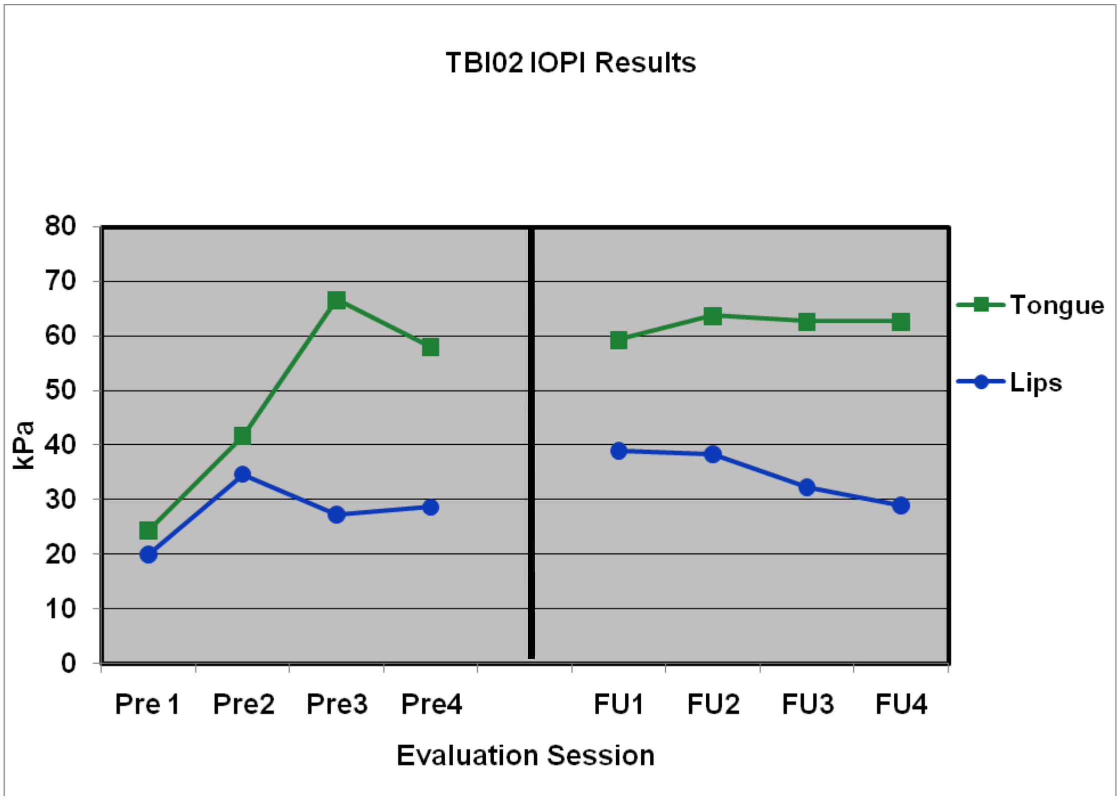


Figure 6. Mean lip and lingual pressure exerted pre- and follow-up treatment



CHAPTER FOUR

4.0 Discussion

This study examined the impact of an intensive articulation treatment based on the principles of motor learning on perceptual and acoustic aspects of speech intelligibility in an individual with chronic spastic dysarthria acquired from TBI. The results of this research study demonstrated that an individual with chronic, nonprogressive dysarthria responded positively to an intensive articulation treatment. The research participant demonstrated clinically significant improvements in single word intelligibility, vowel space area, vowel prolongation, phonatory stability, and lip and lingual pressure exerted immediately following treatment, which facilitated functional communication and improved quality of life. The treatment, which included traditional articulation tasks, had a positive impact on speech intelligibility and comprehensibility when treatment incorporated principles of motor learning, including intensity, salience, and complexity of practice. These results were consistent with the results of the Wenke, Theodoros, & Cornwell (2008) study, which revealed that individuals with nonprogressive dysarthria acquired from TBI can improve speech intelligibility following intensive treatment. Clinically significant improvements were evident with tasks that were directly trained within each treatment session with little generalization to stimuli not directly trained. The first hypothesis that this individual would improve single word intelligibility was supported by the data immediately following treatment, but not at the six-month evaluation. TBI02 had hip replacement surgery performed three weeks following post-treatment evaluations. Lack of maintenance of statistically significant improvements in single word intelligibility may have been related to TBI02's shift in focus from clear speech for functional communication to physical mobility. The second hypothesis that there would be an increase in vowel space area was supported immediately following treatment and at the six month evaluation, with the most significant increase occurring at follow-up. This increase in vowel space area was related to improvements in F1 across /u/, /a/, and /i/ towards normative values, which was indicative of increased lingual height. However, this increase in lingual movement did not have an impact on single word intelligibility six months following treatment.

4.1 *Listener Intelligibility and Perception Tasks*

A four-week intensive articulation program appeared to be a feasible intervention with a large treatment effect size for single word intelligibility for the participant in this study. However, improvements in single word intelligibility were not maintained six months following treatment, with percent accuracy declining approximately to baseline. Lack of maintenance of increased intelligibility at the word level may be related to the participant's complex cognitive-linguistic deficits acquired from his TBI, his hip replacement surgery, and lack of consistent completion of homework exercises. He continued to require external cues on untrained single words and conversation outside of the treatment room. Listener perceptual studies using sentence pairs demonstrated little to no carryover of improvement in speech intelligibility at the sentence level across pre-, post-, and follow-up evaluations. Listeners preferred treated sentence pairs 51.7% of the time immediately post-treatment and 48.2% of the time six months following treatment, which suggested a lack of generalization to sentences that were not directly targeted during treatment.

This was expected due to the increased cognitive-linguistic demands associated with a more complex speech task, as well as, the participant's habitual use of telegraphic speech.

Improvements in single word intelligibility had a functional impact on TBI02's daily communication and social participation due to his chronic use of single words and short phrases during conversation. His caregivers, family members, and graduate speech-language pathology clinicians reported increased comprehensibility and reduced communicative breakdowns during conversation immediately post-treatment. In addition, his caregivers continued to report increased intelligibility and comprehensibility during functional communication six months following treatment. These qualitative reports from various communicative partners demonstrated the clinical significance of the treatment study because the clear speech techniques learned within the treatment room facilitated functional communication and communicative success. Improved intelligibility at the word level was not maintained at the six month follow-up, but family reports illustrated maintenance of increased comprehensibility. Improved comprehensibility may have been related to TBI02's continued stimulability for increased intelligibility at the word and sentence levels when provided the single motor organizing cue to "speak clearly." However, his cognitive and language deficits may have limited generalization of clear speech to more cognitively demanding speech tasks, including sentences and conversation used with friends and family outside of treatment. This lack of generalization illustrates the importance of training with salient material that is individualized to the participant based on an assessment of cognitive and linguistic ability.

Interpreting the results of listener perceptual ratings of speech and intelligibility highlights the challenges of intelligibility studies and listener perceptual studies. The results indicated an increase in single word intelligibility, while improvements in listener perceptions of treated speech did not improve. Other perceptual factors, such as naturalness, nasality, and vocal quality may influence how listeners perceive speech. A dynamic interaction between multiple aspects of voice and speech makes listener perceptual studies complex and difficult to administer reliably. The literature does not define a hallmark method of scaling for perceptual studies (Walshe et al., 2008). Therefore, the rating continuum used in this research study may not have been sensitive enough to capture changes in speech perception.

4.2 *Vowel Space Area*

Acoustic analysis of vowel space area was completed to determine acoustic-articulatory changes associated with increased single word intelligibility. The magnitude of treatment effect on vowel space area was small to medium immediately post-treatment and medium to large six months following treatment. The change in vowel space area was not statistically significant immediately post or six months following treatment. However, the increase in vowel space area illustrated changes in F1 and F2 values towards the normative range, which was indicative of increased lingual height and advancement (Hillenbrand et al., 1994). An inverse relationship occurs with F1 values and tongue height (e.g., high-low), while a direct relationship occurs with F2 values and tongue advancement (e.g., front-back). For example, F1 is lower in frequency when tongue position is higher in the mouth and F2 is higher in frequency when the tongue is more anterior in the mouth (Liu et al., 2005). A larger vowel space area following treatment was primarily dependent on improvements in F1 values across /u/, /a/, and /i/, which demonstrated critical changes in tongue height.

It may be that the external cue to "speak clearly" prompted TBI02 to use greater articulatory effort, which resulted in improvements in vowel space area (Kim, Hasegawa-Johnson, & Perlman, 2010). This improvement towards normative values for vowel space may have impacted significant single word intelligibility changes post-treatment. However, this acoustic-perceptual relationship between improved vowel space and single word intelligibility was not present six months following treatment. Vowel space area continued to approximate normative values six months following treatment, which demonstrated generalization of increased articulatory movements during speech outside of treatment. These results illustrated that TBI02 had the most significant improvements with F1 values, which was indicative of increased tongue height during sentence production. Changes in tongue height may have been related to intensive practice of high lingual positioning with /t/ and /d/ minimal pairs and lingual pressure exerted exercises on the alveolar ridge in treatment.

4.3 *Vocal dB SPL*

The intensive articulation treatment had no statistically significant effect on vocal dB SPL for all speech tasks immediately post and six months following treatment. This finding was expected because increased loudness was not directly trained during treatment since TBI02 presented with loudness levels within normal limits pre-treatment, which was consistent with his diagnosis of spastic dysarthria. His spastic vocal quality was a significant contributor to his overall reduced speech intelligibility related to dysarthria. Changes in vocal dB SPL were not expected to occur due to his average normal loudness at baseline and lack of training, which further emphasized the motor learning principles of salience and specificity. These results indicated that improved speech intelligibility was not correlated with increased vocal loudness.

A significant treatment effect was demonstrated for vowel prolongation immediately post-treatment, with significant maintenance of skills six months following treatment. Individuals with spastic dysarthria may have impaired respiration and phonation secondary to increased muscle tone and muscle weakness. Respiratory training was not indicated for TBI02 because his breath support was adequate for speech across pre-treatment speech tasks and lack of an underlying respiratory disorder. Speech is a submaximal task that does not require maximal respiratory capacity. However, better coordination of respiration, phonation, and articulation may improve the intricate balance of these subsystems and have a positive impact on speech and voice characteristics. Therefore, increased duration of vowel prolongation may have been indicative of improvement in the coordination of respiration and phonation. Sustained vowel prolongation, a speech task with very limited cognitive load, was sensitive enough to capture the improved relationship between respiration and phonation.

4.4 *Phonatory Stability*

Phonatory stability parameters were selected to determine the impact of the intensive articulation treatment on laryngeal valving patterns and vocal tract shaping due to the effects of vocal tract size and configuration on the resonant properties of phonemes. Laryngeal valving and vibration affects overall vocal tract length and corresponding resonant characteristics, resulting in formant frequencies, which are measured through acoustic analysis. Therefore, any changes in vocal fold vibrations may affect formant frequencies, which are correlated with improved speech intelligibility. TBI02's phonatory stability parameters of RAP and PPQ were within the normative range for an individual of his gender and age, despite presence of spastic vocal quality. Therefore, little to no treatment effect on RAP and PPQ values post-treatment and follow-up treatment was expected. NHR was the only perturbation parameter outside of the normative range, so improvements in this variable were critical. The magnitude of treatment effect on NHR was medium to large post-treatment and large six months following treatment. NHR values continued to decrease six months following treatment, which was indicative of improved regularity of vocal fold vibration with strong generalization outside of treatment. This suggests that an intensive articulation treatment had a spreading of effects to the phonatory subsystem.

4.5 *Lip and Lingual Pressure Exerted*

A large treatment effect was evident for lip pressure exerted immediately post-treatment. However, this treatment effect was not maintained six months following treatment, with results decreasing to a medium treatment effect. These results indicated that some improvements in lip pressure exerted were maintained six months following treatment. Improvements in lip pressure exerted were related to direct training through labial tasks using the IOPI that were completed at the start of each session across four weeks. Increased pressure exerted was related to improved awareness of labial movement during speech production. These improvements in lip pressure exerted were especially critical in improvements of vowel space area and particularly F2 values of /u/ post-treatment, which were related to increased speech intelligibility. The corner vowel /u/ is a high-back, rounded vowel, which means the tongue is in a high, back position in the oral cavity and the lips are protruded during production. Lip rounding is a vowel space dimension that is independent of high-low and front-back tongue positioning and has an impact on formant frequencies. Specifically, lip rounding results in lower F2 values because the lips elongate the oral tract resonator. Improvements in lip pressure exerted were consistent with a decrease in TBI02's F2 value for /u/ towards normative values immediately post-treatment. The reduction in treatment effect for lip pressure exerted six months following treatment may have contributed to reduced meaningful improvements for F2 of /u/ during follow-up.

A medium magnitude of treatment effect was present on lingual pressure exerted immediately post-treatment and was maintained six months following treatment, illustrating maintenance of increased lingual pressure exerted. The post- and follow-up treatment means increased due to specificity of practice during treatment sessions. In addition, the standard deviation for lingual pressure exerted was significantly reduced compared to pre-treatment, which illustrated stabilization of pressure exerted. Improvements in lingual pressure exerted were consistent with stable progress in accuracy of minimal contrast pairs that were addressed throughout the four weeks of treatment. The alveolar ridge was the target articulatory placement for both lingual pressure exerted exercises and /t/ and /d/ minimal pairs, indicating the relationship between accuracy of /t/ and /d/ minimal pairs and lingual pressure exerted.

CHAPTER FIVE

5.0 Conclusion

TBI, one of the leading causes of disability in the United States, frequently results in acquired complex cognitive-linguistic deficits and motor speech disorders. Individuals with TBI are often diagnosed with dysarthria, a motor speech disorder characterized by deficits in strength, range of motion, coordination, and speed of the articulators. Dysarthria can, potentially, limit functional communication, social interactions, and reduce quality of life, particularly when it is chronic in individuals with TBI. Type and severity of dysarthria in individuals with TBI is heterogeneous due to the difference in site and extent of lesion patterns. Therefore, group treatment studies of dysarthria acquired from TBI are rare and a specific treatment approach designed for specific dysarthria types is rare in the literature. This preliminary study aimed to determine the impact of an intensive articulation treatment based on the principles of motor learning on perceptual and acoustic measures of speech intelligibility in an individual with spastic dysarthria acquired from TBI. These results indicated that the participant in this study with spastic dysarthria secondary to TBI improved speech intelligibility at the single word level and increased vowel space area following an intensive articulation treatment that incorporated principles of motor learning.

Implementation of a single-subject design was appropriate to capture the impact of treatment on multiple dependent variables in one individual with spastic dysarthria acquired from TBI. Treatment outcomes were specific to the research participant’s individual characteristics, including level of cognitive and linguist abilities and time post-accident. The research treatment was implemented 20 years post TBI02's motor vehicle accident. His treatment outcomes may have been affected by his age at the time of the accident, as well as, the amount of time between his accident and participation in the research study. TBI02 was 18 years-old at the time of his accident and continued maturation post-accident may have been limited. Therefore, it is critical to thoroughly evaluate a patient's level of cognitive-linguistic abilities to determine whether an intensive articulation treatment is an appropriate treatment option. TBI02's cognitive-linguistic abilities appeared to be more severe post-treatment through informal observations due to increased speech intelligibility and comprehensibility. For example, TBI02 demonstrated more severe deficits in orientation and memory when he inaccurately answered a simple question (e.g., "What day is tomorrow?") using his clear speech techniques. This suggested that additional speech exercise may have been warranted to facilitate generalization of clear speech outside of the treatment environment. It is critical that treatment be structured based on the participant's physiology motor speech deficits, as well as, cognitive-linguistic and language abilities. In addition, TBI02's strained-strangled vocal quality associated with spasticity dysarthria may have had a great impact on listener perception. It is recommended that future studies evaluate the effectiveness of an intensive articulation treatment based on principles of motor learning with other types of dysarthria, such as flaccid dysarthria, which is associated with a less distracting vocal quality.

The post-treatment evaluation results indicated significant improvements in single word intelligibility for this individual. However, improvements in single word intelligibility were not maintained six months following treatment, illustrating reduced treatment effect over time and little maintenance of the targeted communicative behavior. This may have been due to the complex cognitive-linguistic deficits associated with TBI02's brain injury. Therefore, it is recommended that future research studies investigate the feasibility and response to treatment of an intensive speech treatment based on the motor learning literature with increased treatment duration. Duration of treatment should increase to four times per week for six weeks to accommodate cognitive-linguistic deficits associated with TBI. People with nonprogressive dysarthria may need to establish new motor programs for speech motor control and it is possible that a longer treatment duration might facilitate internalization of the cue to speak clearly and reduce reliance on external feedback for greater generalization during functional communication and social participation. The current study was a single subject case study, so the findings cannot be generalized to the population of people who have dysarthria secondary to a TBI. Future studies should include more participants and follow-up evaluations at one and three months to determine whether increased duration of treatment facilitates generalization of improved intelligibility across speech tasks over time and the point in which a decline in intelligibility may begin due to cognitive-linguistic deficits and/or lack of consistent completion of homework tasks. The improvements measured immediately post- and six months following treatment cannot be generalized to all individuals with dysarthria secondary to TBI, but his positive response to treatment indicated that individuals with chronic dysarthria can improve speech intelligibility, even 20 years post injury. Therefore, further studies should be completed to determine whether similar improvements in speech intelligibility and comprehensibility are made with additional individuals with chronic dysarthria acquired from TBI.

APPENDIX A

Task	Instrumentation	Measurement	Dur. (mins.)	Purpose/Rationale
Lip Exercises	IOPI	kPa	5	Emphasize labial, speech positions and high effort training for clear speech
Tongue Exercises	IOPI	kPa	5	Emphasize lingual, speech positions and high effort training for clear speech
Sustain Vowel Prolongation	Sound Level Meter	dB SPL	5	Increase vocal loudness for clear speech
Counting to 15	Sound Level Meter	dB SPL	5	Incorporate high effort training of articulation and vocal loudness during an automatic task with low cognitive load
Minimal Pairs	N/A	# of speech errors	5	Use high effort training to address specific speech errors in single words
Functional Phrases	Sound Level Meter	dB SPL	20	Increase intelligibility of phrases that are functional and salient
Structured Dialogue, Conversation	Sound Level Meter	dB SPL	15	Incorporate clear speech techniques during salient and meaningful speech tasks based on functional situations and interests

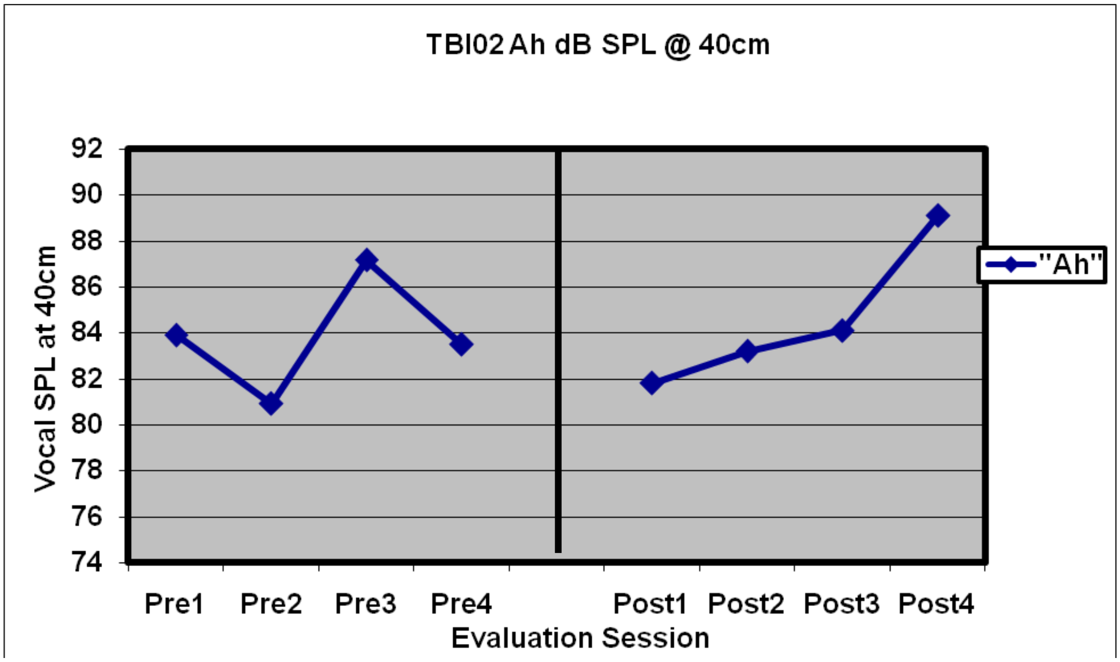
APPENDIX B

TBI02 Minimal Pair Word List Final /t/ and /d/		
1.	Ant	And
2.	Mat	Mad
3.	Bet	Bed
4.	Kit	Kid
5.	Beat	Bead
6.	Set	Said
7.	Let	Led
8.	Rot	Rod
9.	Rat	Rad
10.	Cart	Card
11.	Heart	Hard
12.	Sent	Send

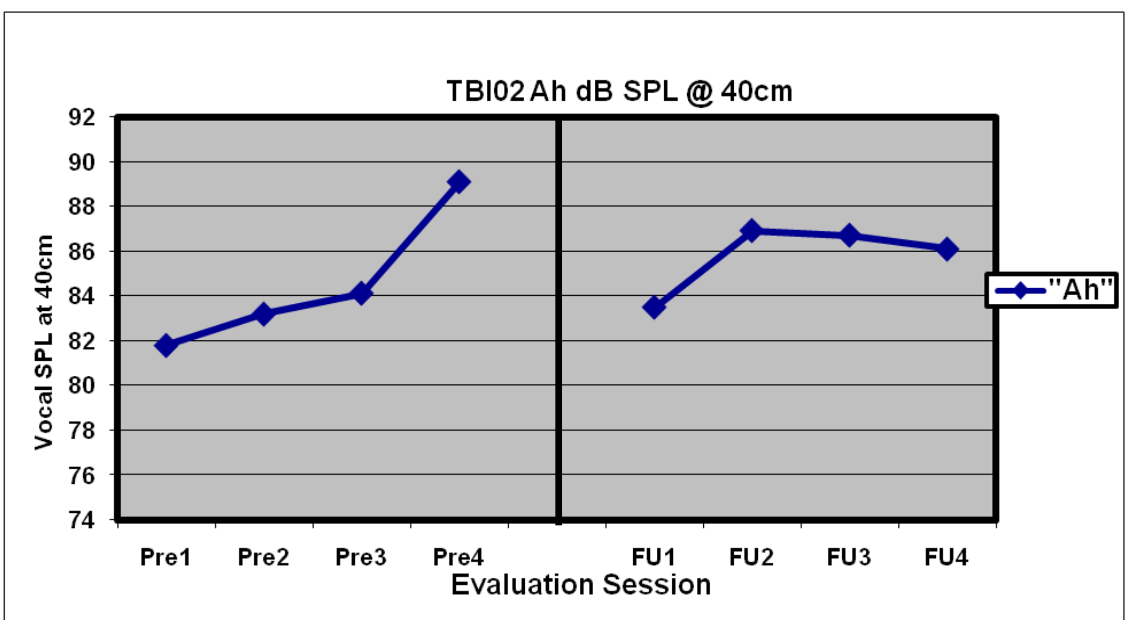
TBI02 Minimal Pair Word List Final /g/ and /k/		
1.	Bag	Back
2.	Jog	Jock
3.	League	Leak
4.	Sag	Sack
5.	Tug	Tuck
6.	Peg	Peck
7.	Wag	Wack
8.	Tag	Tack
9.	Log	Lock
10.	Lag	Lack
11.	Rag	Rack
12.	Pig	Pick

APPENDIX C

Pre-Post Mean Vocal dB SPL for Sustained Phonation

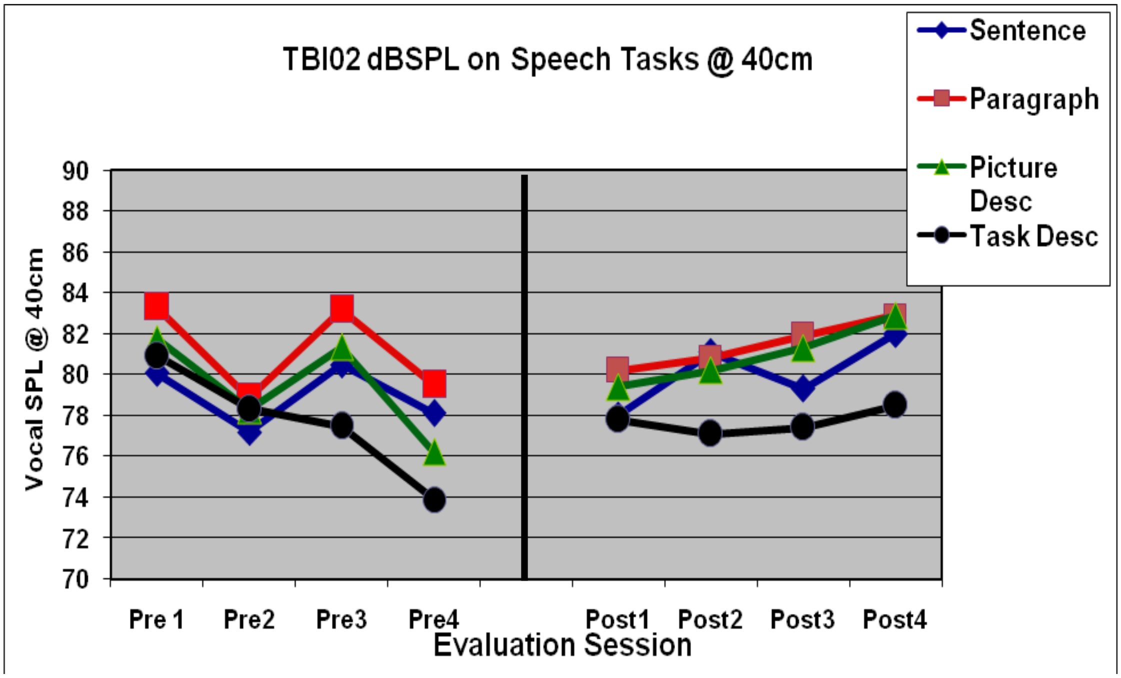


Pre-Follow-up Mean Vocal dB SPL for Sustained Phonation

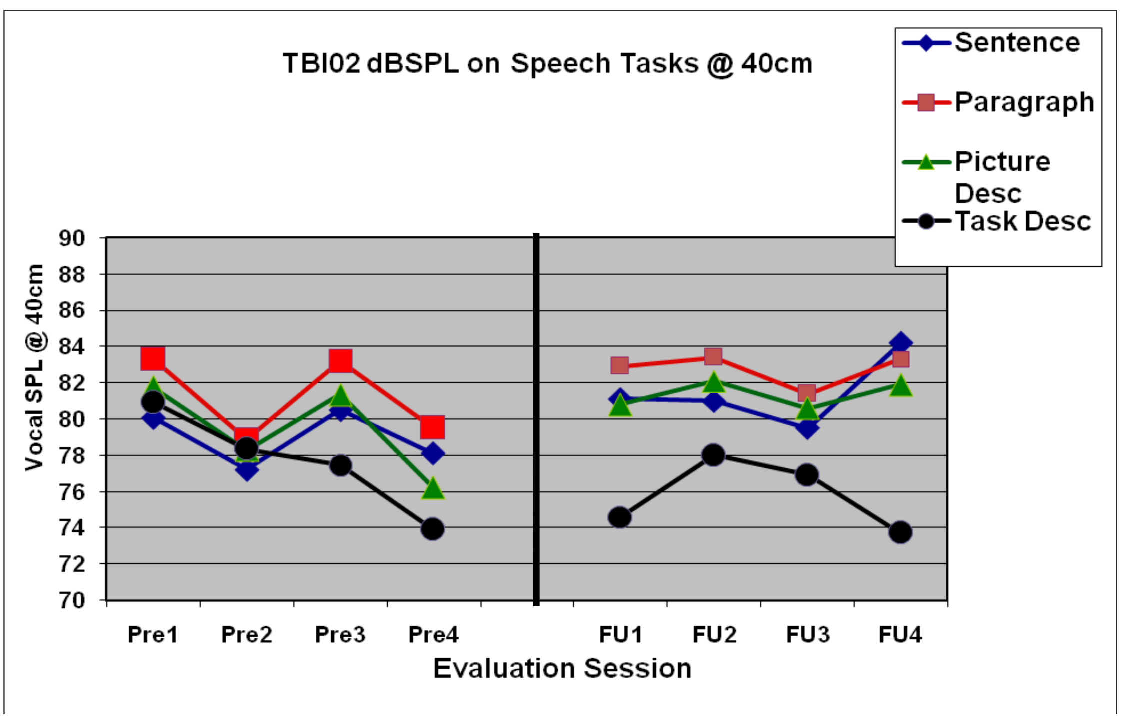


APPENDIX D

Pre-Post Mean Vocal dB SPL across Speech Tasks



Pre-Follow-up Mean Vocal dB SPL across Speech Tasks



BIBLIOGRAPHY

Axelrod, B. N., Fichtenberg, N. L., Liethen, P. C., Czarnota, M. A., & Stucky, K. (2001). Performance characteristics of postacute traumatic brain injury patients on the WAIS-III and WMS-III. *The Clinical Neuropsychologist*, *15*(4), 516–520.

Beeson, P., & Robey, R.R. (2006). Evaluating single-subject treatment research: Lessons learned from the aphasia literature. *Neuropsychological Review*, 16, 161-169.

Brady, M.C., Clark, A.M., Dickson, S., Paton, G., & Barbour, R.S. (2011). The impact of stroke-related dysarthria on social participation and implications for rehabilitation. *Disability and Rehabilitation*, 33(3), 178-186.

Brain Injury Association of America. (2013). *What is the difference between an acquired brain injury and a traumatic brain injury?* Retrieved from http://www.biausa.org/FAQRetrieve.aspx?ID=43913&A=SearchResult&SearchID=5986227&ObjectID=43913&ObjectType=9 on January 8, 2013.

Bunton, K., Leddy, M., & Miller, J. (2007). Phonetic intelligibility testing in adults with Down syndrome. *Down Syndrome Research & Practice: The Journal of the Sarah Duffen Centre/University of Portsmouth*, 12, 230–239.

Carone, Burns, Gold, & Mittenberg. (2004, February). A comparison of three cognitive screening tests in a traumatic brain injury sample. In *Poster session presented at the 32nd meeting of the international neuropsychological society*.

Center for Disease Control and Prevention. (2012). *Injury Prevention & Control: Traumatic Brain Injury*. Retrieved from http://www.cdc.gov/TraumaticBrainInjury/ on January 8, 2013.

Collins, M. (1984). Integrating perceptual and instrumental procedures in dysarthria assessment. *Journal of Communication Disorders*, 5, 159-170.

Duffy, J.R. (2013). Motor speech disorders: Substrates, differential diagnosis, and management. (3rd ed.). St. Louis, Missouri: Elsevier Mosby. (pp. 405-433).

Dromey, C. (2000). Articulatory kinematics in patients with Parkinson disease using different speech treatment approaches. *Journal of Medical Speech-Language Pathology*, 8, 155–161.

Garcia, J.M., & Cannito, M.P. (1996). Influence of verbal and nonverbal contexts on the sentence intelligibility of a speaker with dysarthria. *Journal of Speech and Hearing Research*, 39, 750-760.

Goberman, A. M., & Elmer, L. W. (2005). Acoustic analysis of clear versus conversational speech in individuals with Parkinson disease. *Journal of Communication Disorders*, 38, 215–230.

Hustad, K.C. (2008). The relationship between listener comprehension and intelligibility scores for speakers with dysarthria. *American Speech-Language-Hearing Association*. 51, 562-573.

Hillenbrand, J., Getty, L.A., Clark, M.J., and Wheeler, K. (1994). Acoustic characteristics of American English vowels. *Journal of Acoustic Society of America*. 97, 5, 3099-3111.

Kent, R.D., Weismer, G., & Kent, J.F. (1989). Toward phonetic intelligibility testing in dysarthria. *Journal of Speech and Hearing Disorders*, 54, 482-499.

Kent, R. D., Weismer, G., Kent, J. F., Vorperian, H. K., & Duffy, J. R. (1999). Acoustic studies of dysarthric speech: Methods, progress and potential. *Journal of Communication Disorders, 32*, 141–186.

Kent, R.D., Vorperian, H., Kent, J.F., & Duffy, J. (2003). Voice dysfunction in dysarthria; application of the Multi-dimensional Voice Program. *Journal of Communication Disorders, 34*, 281-306.

Kim, H., Hasegawa-Johnson, M., & Perlman, A. (2010). Vowel contrast and speech intelligibility in dysarthria. *Folia Phoniatr Logop*, 63, 187-194.

Kertesz, A. (1982). *Western Aphasia Battery*. Psychological Corporation.

Lam, J., Tjaden, K., & Wilding, G. (2012). Acoustics of clear speech effect of instruction. *Journal of Speech, Language, and Hearing Research*, 55, 1807-1821.

Liu, H., Tsao, F., & Kuhl, P. K. (2005). The effect of reduced vowel working space on speech intelligibility in Mandarin speaking young adults with cerebral palsy. *Journal of the Acoustical Society of America,* 117, 3879–3889.

Ludlow, C.L., Hoit, J., Kent, R., Ramig, L.O., Shrivastav, R., Strand, E., Yorkston, K., & Sapienza, C.M. (2008). Translating principles of neural plasticity into research on speech motor control recovery and rehabilitation. *Journal of Speech, Language, and Hearing Research*, 51, S240-S258.

Mackenzie, C., & Lowit, A. (2007). Behavioural intervention effects in dysarthria following stroke: Communication effectiveness, intelligibility, and dysarthria impact. *International Journal of Language & Communication Disorders*. (4), 2, 131-153

Mahler, L., & Jones, H.N. (2012). Intensive treatment of dysarthria in two adults with Down syndrome. *Developmental Neurorehabilitation*, 15, 44-53

Matos, C. (2005). SPL Extractor. Developed by Carlos Matos, MS Electrical Engineering, Salvador, Brazil.

McAuliffe, M., Carpenter, S., & Moran, C. (2010). Speech intelligibility and perceptions of communication effectiveness by speakers with dysarthria following traumatic brain injury and their communication partners. *Brain Injury*, 24(12), 1408-1415.

McKay, C., Casey, J.E., Wertheimer, J., & Fichtenberg, N.L. (2006). Reliability and validity of the RBANS in a traumatic brain injured sample. *Archives of Clinical Neuropsychology*, 22, 91-98.

Milenkovic, P. (2001). Time-frequency analysis for 32-bit Windows [computer software] Madison, WI: Department of Electrical Engineering, University of Wisconsin-Madison.

Pannbacker, M. (1998). Voice treatment techniques: A review and recommendations for outcome studies. *American Journal of Speech-Language Pathology*. 7(3) 49-65.

Parsonson, B.S. & Baer, D.M. (1992). The visual analysis of data and current research into the stimuli controlling it. In T.R. Kratochwill & R.R. Levin (Eds), *Single-case research design and analysis: New directions for psychology and education*, (pp. 15-40). Mahwah, NJ: Erlbaum.

Picheny, M. A., Durlach, N. I., & Braida, L. D. (1986). Speaking clearly for the hard of hearing II: Acoustic characteristics of clear and conversational speech. *Journal of Speech and Hearing Research*, 29, 434–445.

Ramig, L., Countryman, S., Thompson, L. & Horii, Y. (1995). Comparison of two forms of intensive speech treatment for Parkinson. *Journal of Speech and Hearing Research*, 38, 1232–1251.

Ramig, L., Sapir, S., Countryman S., Pawlas, A., O'Brien, C., Hoehn, M., & Thompson, L. (2001a). Intensive voice treatment (LSVT LOUD) for individuals with Parkinson disease: A two-year-follow-up. *Journal of Neurology, Neurosurgery, and Psychiatry,* 71, 493-498.

Robey, R.R. (2004). A five-phase model for clinical-outcome research. *Journal of Communication Disorders*, 37, 401-411.

Roy, N., Leeper, H.A., Blomgren, M., & Cameron, R.M. (2001). A description of phonetic, acoustic, and physiological changes associated with improved intelligibility in a speaker with spastic dysarthria. *American Journal of Speech-Language Pathology*, 10, 274-290.

Sellars, C., Hughes, T., & Langhorne, P. (2005). Speech and language therapy for dysarthria due to non-progressive brain damage. Cochrane Database Systematic Review, CD002088.

Shewan, C.M., & Kertesz, A. (1980). Reliability and validity characteristics of the Western Aphasia Battery. *Journal of Speech and Hearing Disorders*, 45, 208-324

Svec, J., Popolo, P., & Titze, I. (2003). Measurement of vocal doses in speech: Experimental procedure and signal processing. *Journal of Logopedic and Phoniatrics,* 28, 181-192.

Trail, M., Fox, C., Ramig, L.O., Sapir, S., Howard, J., & Lai, E.C. (2005) Speech treatment for Parkinson's disease. *NeuroRehabilitation*, 20, 205-221.

Yorkston, K.M. (1996). Treatment efficacy: Dysarthria. *Journal of Speech and Hearing Research*, (39), S46-S57

Walshe, M., Miller, N., Leahy, M., & Murray, A. (2008). Intelligibility of dysarthric speech: Perceptions of speakers and listeners. *International Journal of Language & Communication Disorders*, (43), 6, 633-648.

Wenke, R.J., Theodoros, D., & Cornwell, P. (2008). The short- and long-term effectiveness of the LSVT for dysarthria following TBI and stroke. *Brain Injury*. 22(4), 339-352.