

2015

Effects of Intensive Speech Treatment for an Individual with Spastic Dysarthria Secondary to Stroke

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EFFECTS OF INTENSIVE SPEECH TREATMENT FOR AN
INDIVIDUAL WITH SPASTIC DYSARTHRIA

SECONDARY TO STROKE

BY

CHARLOTTE PURCELL

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

SPEECH-LANGUAGE PATHOLOGY

UNIVERSITY OF RHODE ISLAND

2015

MASTER OF SCIENCE THESIS

OF

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2015

ABSTRACT

Objective: This study investigated the impact of an intensive speech treatment on listener-rated communication success and functional outcome measures of communication for an individual with spastic dysarthria secondary to stroke.

Method: A single-subject A-B-A-A experimental design was used to measure the effects of an intensive speech treatment that incorporated principles of motor learning to drive activity-dependent changes in neural plasticity. The primary dependent variables were listener-rated communication success (comprehensibility transcription in two conditions and listener perceptual ratings of speech and voice), and functional outcome measures as rated by the participant and his spouse. Secondary dependent variables included acoustic factors: vowel space area, phonatory stability, and vocal dB SPL during speech tasks.

Results: Multiple comparisons with t-tests were used to determine statistically significant changes in primary and secondary dependent variables. Statistically significant changes ($p < 0.05$) were present immediately post-treatment in listener perceptual ratings for speech naturalness in sentences ($p = 0.00$), but demonstrated a preference for pre-treatment sustained vowel phonation ($p = 0.04$). All functional outcome measures reflected the participant's perception of increased communicative effectiveness, decreased psychosocial impacts of dysarthria, and increased social participation. There were statistically significant changes in secondary variables at post-treatment including phonatory stability in amplitude perturbation quotient ($p = 0.02$), and vocal dB SPL during sustained vowel phonation ($p = 0.01$), and sentence reading ($p = 0.03$). Vowel space area increased by 13% at post-treatment. Three months

following treatment, there were statistically significant changes in listener comprehensibility at the single word length ($p=0.02$) and sentence length ($p=0.03$), and listener perceptual ratings of speech naturalness ($p=0.02$). All functional outcome measures displayed maintained post-treatment effect. Vowel space area increased by 25% compared to pre-treatment. There were no statistically significant changes in phonatory stability or vocal dB SPL three months following treatment.

Conclusions: Treatment outcomes were specific to the research participant's individual characteristics. The improvements measured immediately post- and three months following treatment cannot be generalized beyond this individual with dysarthria secondary to stroke. However, the positive treatment effects for STR03 indicated that individuals in the chronic stages of recovery with dysarthria can improve and maintain speech comprehensibility as well as increase communication effectiveness and reduce some of the negative emotional and social components of chronic dysarthria, even four years post-onset, warranting further investigation.

ACKNOWLEDGMENTS

I would like to acknowledge my wonderful mentor, Dr. Leslie Mahler, and my committee, Dr. Dana Kovarsky, Dr. Susan Roush, and Dr. Ingrid Lofgren for their encouragement, suggestions, and enthusiasm. I would also like to acknowledge and thank STR03 and his wife for their participation in the research treatment. I would like to recognize the Sue Oppenheim for all her positivity and the students in the Department of Communicative Disorders for their assistance with listener tasks and their support, particularly Paige Clarkin, Tori Seites-Rundlett, and Carlene McGuigan for all their help with evaluations. In addition, I am grateful to my family and friends for all the love and support I could ever ask for.

PREFACE

Manuscript format is used. This article is prepared for submission to the journal Stroke.

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**“Effects of Intensive Speech Treatment for an Individual with Spastic Dysarthria
Secondary to Stroke”**

by

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is prepared for submission to the journal Stroke

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CHAPTER 1.

INTRODUCTION

This thesis reports the results of a treatment effectiveness study. The study examined the impact of an intensive behavioral speech treatment that targeted clear speech with an adult who had spastic dysarthria secondary to a stroke. This first chapter of the thesis presents the background of the study, specifies the problem of the study, describes its significance and presents an overview of the methodology used.

1.1 Background

It is reported that approximately 795,000 individuals experience a new or recurrent stroke each year, but the fatality rate is in decline (Go et al., 2014). Therefore, stroke is one of the leading causes of long-term disability in the United States. An estimate of the incidence of dysarthria post-stroke is around 40% (Flowers, 2013). Dysarthria is the collective term for a neurological speech disorder resulting from changes in strength, speed, range, steadiness, tone, or accuracy of speech movements. Dysarthria is further categorized and defined by the location of damage to the nervous system. Spastic dysarthria results from bilateral damage to the direct and indirect activation pathways in the central nervous system, which can result in changes to speech components including respiration, resonance, articulation, phonation, and prosodic variation (Duffy, 2012).

Very few studies have documented the efficacy of specific treatment approaches for individuals with dysarthria secondary to stroke (Sellars et al., 2005;

Mackenzie, 2011). Even fewer studies describe specific treatment approaches for individuals over nine months post-onset (Palmer and Enderby, 2007). Many of the studies available emphasize the effects of treatment on acoustic factors of speech such as decibel sound pressure level (dB SPL), voice parameters, and vowel space area or the effects of treatment on listener intelligibility. A complete look at the effects of treatment should also include measurements of communication success and patient and/or family reported functional outcomes to determine the overall impact of treatment on activities of daily living.

1.2 Significance

Individuals with dysarthria secondary to stroke have reported feelings of marginalization and stigmatization, as well as emotional and social changes including changes in self-identity and relationships (Walshe et al., 2009). Social and emotional effects of dysarthria may be disproportionate to the severity of the communication disorder (Dickson et al., 2008) and can contribute to the negative impact of dysarthria on quality of life. Given the lack of research in this area and the significant social and emotional consequences associated with dysarthria after stroke, the purpose of this study was to determine the effect of a well-defined and intensive speech treatment for an individual with dysarthria secondary to stroke in the chronic stage of recovery with the goal of improving comprehensibility, and increasing participation in functional communication.

1.3 Methodology Overview

This Phase I study utilized a single-subject A-B-A-A experimental design (Robey, 2004). This design was selected because it was appropriate for making initial observations about the impact of an intensive speech treatment on an individual with spastic dysarthria secondary to stroke. The primary aim of the study was to determine the effect of treatment on listener-rated communication success and functional outcome measures. Changes in communication success from pre- to post-treatment and pre- to 3-months following treatment were assessed using listener comprehensibility ratings of the participant's speech in two conditions: 1) using the acoustic signal alone and 2) using the acoustic signal plus visual information as the participant spoke. Listeners also rated voice quality and speech to assess perceptual characteristics of voice and speech. The impact of treatment on functional outcome measures including participation in functional communication and communicative effectiveness were assessed using two patient and spouse-reported outcome measures, the Communicative Effectiveness Index-Modified (CETI-M; Yorkston et al., 1999), and the Dysarthria Impact Profile (DIP; Walshe et al., 2009). Additional qualitative input was obtained from the participant's and spouse's interviews pre-, post-, and 3-months following treatment, and field notes taken during treatment. The following were the study hypotheses:

Listener-rated Communication Success:

- 1) Listener comprehensibility ratings will increase following treatment using the acoustic signal alone.

- 2) Listener comprehensibility ratings will increase to a greater extent following treatment using the acoustic signal plus visual information.
- 3) Listeners will rate perceptual characteristics of voice and speech better following treatment when compared to pre-treatment.

Functional Outcome Measures

- 4) The participant and his spouse will rate communicative effectiveness higher following treatment.
- 5) The participant will rate psychosocial impacts of dysarthria lower following treatment.
- 6) The participant and his spouse will describe overall increases in social participation following treatment.

A secondary aim of the study was to evaluate the impact of treatment on acoustic variables of speech including the first two formants (F1 and F2) of the corner vowels /i/, /u/, and /a/, measures of phonatory stability, and vocal dB SPL during speaking tasks.

CHAPTER 2.

METHODOLOGY

The methods section of this thesis provides a study overview, information about the participant, protocol for the specific treatment approach, a rationale for the dependent variables of the study, explanation of assessment procedures, description of data analyses and statistical analyses, and a discussion about reliability in this study.

2.1 Study Overview

This study examined the administration of an intensive behavioral speech treatment that incorporates principles of motor learning to drive activity-dependent changes in neural plasticity that can contribute to our understanding of how motor learning theory applies to treatment of dysarthria and how we can administer effective treatment efficiently. The primary dependent variables of interest were speech comprehensibility in two conditions, listener perceptual ratings of voice and speech, and changes in communicative effectiveness, the psychosocial impact of dysarthria, and social participation based on questionnaire responses and interviews.

Speech comprehensibility was measured by listener transcriptions of phonetically balanced single word and sentence length materials (Kent et al. 1989; Nilsson 1994) using an audio recording of the participant alone, and using audio and video recordings of the participant. Perceptual voice quality and speech naturalness were measured with listener ratings of sustained vowel phonation and sentence

reading samples comparing pre- and post-treatment and pre- and 3-month follow-up (FU).

Communicative effectiveness was measured using the CETI-M. The participant and his spouse rated communicative effectiveness in 10 different scenarios. The participant and his spouse's responses were used to determine the participant's overall success with communication in different situations. Psychosocial impacts of dysarthria were measured using the DIP. Psychosocial factors reported in the DIP provide an indication of the effects of dysarthria on daily living and self-concept. Social participation is a related construct to communicative effectiveness and psychosocial factors of dysarthria. Self-perception of changes in social participation was assessed during participant interviews. This construct is related to the amount and quality of communication the participant pursues or participates in. All together, these aspects of personal experience provide an understanding of the impact of treatment on the participant's functional communication. Secondary dependent variables of interest included vowel space area, measures of phonatory stability, and sound pressure level measured in dB SPL.

2.2 Participant

The participant (STR03) was a 44 year-old male who was 3.5 years post-onset of stroke at the time of treatment. He experienced a pontine hemorrhagic stroke secondary to arteriovenous malformation (AVM) in July 2011. STR03 had reduced visual acuity characterized by diplopia that interfered with reading and spastic quadriplegia that interfered with ambulation. He used a wheelchair for mobility. His

speech characteristics were consistent with a diagnosis of spastic dysarthria based on the results of an oral mechanism examination completed by a speech-language pathologist (LM) experienced in the diagnosis of individuals with dysarthria. His speech was characterized by imprecise articulation, slow rate, increased loudness, strained-strangled voice quality, reduced prosodic variation, and decreased respiratory-phonatory coordination.

STR03 was selected based on a confirmed diagnosis of dysarthria secondary to stroke. He demonstrated minimal language and cognitive-linguistic deficits secondary to his stroke. Further evaluations were completed during pre-treatment evaluations to assess language and cognitive-linguistic abilities. STR03's aphasia quotient of 77.7 on the Western Aphasia Battery (WAB; Kertesz, 2006) indicated relatively well-preserved language in the context of severe spastic dysarthria. Further assessment of cognitive-linguistic deficits using the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS-R; Randolph, 2012) was not completed due to the assessment's limitations for individuals with gross motor and visual impairments. However, observations of STR03 during the patient interview and pre-treatment evaluations confirmed relatively well-preserved cognitive status. Assessment of phonological errors using the Goldman Fristoe Test of Articulation-2 (GFTA; Goldman & Fristoe, 2000) demonstrated significant and consistent phonological errors, particularly highlighting patterns of vowel distortion, voicing errors, and deletion errors.

2.3 Treatment

Treatment sessions were completed at the University of Rhode Island's Speech and Hearing Center by a graduate speech-language pathology student (CP) under the supervision of a speech-language pathologist certified by the American Speech-Language and Hearing Association (LM). The schedule of evaluations and treatment sessions are listed in Appendix A. TST protocol tasks are listed in Appendix B.

Total Speech Treatment (TST) targets clear speech to improve comprehensibility for individuals with dysarthria. The treatment protocol used in this study utilized principles of motor learning to drive activity-dependent changes in neural plasticity for carryover and generalization of increased comprehensibility to functional communication. The term neural plasticity relates to the adaptive capability of the central nervous system. Neuroscience research has demonstrated that brain cells have an ability to change structure and function in response to new learning and training (Doyon and Benali, 2005). An individual stores past experiences and learns new behaviors through a process of neural plasticity. Neural plasticity has also been identified as the mechanism by which an individual rehabilitates and relearns processes following brain injury (Kleim & Jones, 2008). There are ten principles of experience-dependent neural plasticity defined by Kleim and Jones, 2008. These principles include, "use it or lose it", "use it and improve it", "specificity", "repetition matters", "intensity matters", "time matters", "salience matters", "age matters", "transference", and "interference". These principles were translated to serve as guidelines for behavioral treatment of motor systems, defined as principles of motor learning. Mass et al. 2008 demonstrated how principles of motor learning might be

incorporated into treatment of motor speech disorders. Neural plasticity, as identified in the literature, was the foundational principle of the intervention in this study, with TST the specific intervention.

Intensity was targeted through multiple repetitions of TST exercises during individual treatment sessions and through intensive treatment dosage (four times per week for six weeks). Salience was achieved through the use of functional phrases and activities related to the individual's routine and interests such as hierarchy reading of words and phrases used during activities of daily living and structured dialogues related to interests. Salience was also achieved by using real speech tasks related to the subject's communication goals. Specificity of practice was targeted through actual speech tasks and with exercises designed to direct effort toward the lips and tongue. Implicit learning (if you are using a cue, why are you calling this "implicit learning" when you are explicitly highlighting clear speech?) was utilized through the use of a single cue for "clear speech" throughout the treatment, which minimized the cognitive load for the individual while allowing the clinician to change the way this is modeled based on the client's specific speech patterns. Augmented feedback was provided based on the needs of the client and decreased systematically throughout the treatment course to support generalization and increased independence (Duffy, 2012; Maas et al., 2008; Kleim & Jones, 2008).

Increasing intelligibility and naturalness are common goals of speech treatment for individuals with dysarthria. Providing cues for loudness, reducing rate of speech, and cueing for clear speech have been studied as ways to improve intelligibility for neurologically normal individuals as well as individuals with dysarthria secondary to

multiple sclerosis and Parkinson's disease (Smijanac & Bradlow, 2009; Uchanski, 2005; Tjaden, 2014). Tjaden et al. (2014) established that speaker' intelligibility ratings increased with cues for either increased loudness or clear speech. A cue for clear speech may be a more effective cue for individuals with spastic dysarthria who may not benefit from a cue to "speak loud" or "slow down" speech due to the speech components and patterns that these individuals present with. Despite this evidence, there are very few studies reporting on the impact of a clear speech treatment protocol for individuals with dysarthria, or more specifically spastic dysarthria.

Cueing and modeling were important components of the treatment process. Direct modeling can provide the participant with an understanding of what is meant by the cue for "clear speech". Cueing during non-speech tasks emphasized increasing or maintaining effort level. Appropriate cueing for non-speech tasks with the Iowa Oral Performance Instrument (IOPI) are "Push, push, push!" or "Go, go, go". Examples of appropriate cueing during speech tasks include "Remember to use your clear speech" and "Speak clearly". The participant received positive reinforcement following speech tasks such as "Great clear speech" and "That's the speech that people will understand". Cueing and modeling were decreased throughout the course of treatment to promote independence and increase carry-over outside of the clinic setting.

Data were collected during each session including kPa (pressure measurement) during lip and tongue IOPI exercises, duration of sustained vowel phonation, percentage of accurate articulation in minimal pair repetition, and the loudness of sustained vowel phonation, salient sentence reading, and the hierarchy reading task. The consistent speech sound errors noted during pre-treatment evaluations included

voicing errors, deletion errors, and vowel errors. STR03's speech sound errors were targeted through minimal pair tasks (i.e., pairs of words which differ by only one phoneme; e.g. bad and pad). Particular emphasis during the minimal pair task was placed on voicing errors due to their frequency in STR03's speech. The frequency of voiced/voiceless cognates in typical speech interfered with STR03's communication success in the pre-treatment evaluation. A list of minimal pair sets used during treatment is displayed in Appendix C. Homework consisting of treatment tasks and a carryover task (e.g. using clear speech to order movie tickets) were assigned each day to increase treatment intensity and promote generalization of clear speech to activities of daily living.

2.4 Dependent Variables

Primary Aim, Hypotheses 1-3: Listener-rated Communication Success

Listener-rated communication success was measured using listener transcriptions of comprehensibility at the single word and sentence level in two conditions and using listener perceptual ratings of speech and voice. The goal of speech treatment is to increase communication success in functional conversation so outcome variables need to capture these functional changes.

Comprehensibility is differentiated from intelligibility because the listener is provided with the communication context of the utterance (Barefoot et al., 1993). Measuring comprehensibility entails providing the listener with information other than the acoustic signal. This information may be in the form of semantic, syntactic, or physical context (Yorkston et al., 1996). Lindblom (1991) suggests that speech and

listener perceptions of speech are adaptive to the needs of the situation. Therefore, speech perception is not always simply signal-dependent. Listener perception may require background knowledge or shared context when speech is disordered or distorted. Comprehensibility was selected as a primary variable because it provides the listener with some context for determining whether the participant was successful in conveying his message.

We compared how providing the listener with visual information through video and audio input impacts listener transcriptions of single word and sentence length material compared with audio input alone. Several other studies have used both audio and audio and video listener conditions for transcriptions (Keintz et al., 2007; Hunter et al., 1991; Garcia and Cannito, 1996). The listeners in both conditions are prompted to write down what they perceive the speaker's message to be. Audio input alone provides the listeners with contextual information about the participant's speech patterns including articulatory precision, prosody, voice quality, and loudness. Visual information provides the listeners with additional physical context such as oral movements in the formation of speech sounds as well as facial expressions, eye contact, and gestures (when applicable). Evaluating comprehensibility in two different conditions allowed a comparison of these methods for measuring treatment outcomes. A comparison of results in each listener condition also allowed for analysis of the specific treatment effects in this study.

Listener-rated communication success was also evaluated using perceptual ratings comparing speech and voice samples from each evaluation. Samples of sustained vowel phonation and sentence readings were compared at pre- and post-

treatment and at pre- and follow up-treatment (FU). A preference for post- or FU treatment evaluation samples over pre-treatment samples would indicate a positive treatment effect on listener perception of voice quality and/or speech naturalness. These data combined with the measurement of the participant's perceptions of communication and analyses of acoustic variables provide valuable insights about treatment outcomes.

Primary Aim, Hypotheses 4-6: Functional Outcome Measures

Functional outcome measures included communicative effectiveness, psychosocial impacts of dysarthria, and social participation. The International Classification of Functioning, Disability and Health (ICF; World Health Organization (WHO) 2001) is a classification system of health and health-related conditions, which looks at the functioning of the individual. This system provides a framework with which to define a disorder and determine individual treatment needs. One of the effects of the *ICF* has been to encourage clinicians to look at the individual client and his/her everyday life and social participation in the context of treatment (Walshe et al., 2009). This has encouraged more clinical research with increased attention to the effects of the *ICF* constructs on quality of life and attention to the role of personal factors in the rehabilitation process. It has also informed clinicians about the different aspects of functioning and disability (Threats, 2012).

Addressing the concerns of the individual receiving treatment is an essential component of the treatment process. Qualitative measurement of the participant's personal experience is critical for evaluating a treatment (Kovarsky, 2008). The

participants' perceptions of treatment outcomes are particularly important due to the impact of acquired dysarthria on social participation and psychosocial factors (Dickson et al., 2008).

Communicative effectiveness is measured using the Communicative Effectiveness Index-Modified (CETI-M) in this study. Lomas et al. (1989) introduced the CETI as a measure of functional communication for adults with aphasia. The authors of the CETI demonstrated the measure's internal reliability (Split-half $r=0.90$), inter-rater reliability ($r=0.73$), test-retest reliability ($r=0.94$), and construct validity using an n of 22 (Lomas et al., 1989). A modified version of the CETI (CETI-M) has since been used with individuals with dysarthria (Ball et al., 2004; Clark, 2012). Ball et al. (2004) demonstrated the instrument's face validity and content validity as a participation measurement for a group of individuals with dysarthria secondary to amyotrophic lateral sclerosis. Psychosocial aspects of dysarthria are addressed using the DIP. The authors of the DIP demonstrated high internal consistency (greater than $r=0.80$), intra-rater reliability, and convergent validity using an n of 31 (Walshe et al., 2009). Informal and formal interview questions were open-ended and used to determine overall impressions of treatment effects on social participation, if any and collect a record of personal experience narratives.

Secondary Aim: Acoustic Factors

Acoustic measurements in this study included vowel space area, phonatory stability, and vocal dB SPL. The selected acoustic measurements were analyzed for the purpose of understanding potential factors contributing to changes in listener

comprehensibility ratings. There is no direct correlation between perceptual features and acoustic variables but acoustic analysis can be informative and supportive of perceptual findings (Kent et al., 1999).

Vowel formants are important measurements in the analysis of speech production as they have been linked to articulatory precision. Vowel space area was determined by measurement of the first and second formants (F1 and F2) of three corner vowels: /a/, /i/, and /u/ in the sentence “The boot on top is packed to keep”. These three corner vowels are selected because of their representation of extreme articulatory movements of the tongue. Kim et al. (2011) demonstrated that lower intelligibility ratings were associated with greater overlap among vowel formants, relating to “reduced articulatory working space” (192). Vowel space area analysis will help to determine the impacts of treatment on articulatory precision in speech production.

Kent et al. (2003) validated the use of the Multidimensional Voice Profile (MDVP Advanced; CSL 4500) to assess voice data collected from individuals with dysarthria secondary to hemispheric and brainstem stroke. This study identified several potentially deviating acoustic measurements associated with this population such as variation in fundamental frequency (vf0), smoothed pitch perturbation quotient (sPPQ), absolute shimmer (ShdB), relative shimmer (Shim), smoothed amplitude perturbation quotient (sAPQ), peak amplitude variation (vAm), and amplitude perturbation quotient (APQ). All of these acoustic measurements fall into categories of either frequency perturbation or amplitude parameters and are considered measures of phonatory stability.

Vocal loudness is determined by the intensity of the sound signal, which is measured in dB SPL. The speaker's vocal loudness impacts the listener's understanding of the message.

2.5 Assessment Procedures

Dependent variables were assessed three times during the study. Each of the three evaluations included four consecutive days of testing. Initial data collection took place immediately prior to treatment (Pre), the second occurred during the week immediately following completion of treatment (Post), and the third was a follow-up evaluation, which took place three months following treatment (FU).

Each evaluation 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 placed on the participant at a distance of 8 cm from the mouth and even with the participant's mouth. A Type I sound level meter (SLM; Bruel & Kjaer Type 2239) was placed at a distance of 40 cm from the participant's mouth to record sound pressure level during speech tasks. The head-mounted microphone and SLM signal were digitized and sent directly to the computer (Toshiba Qosmio). Speech was sampled at 44 kHz using Goldwave software. Each evaluation session was recorded using a Cannon FS400 camcorder. Additionally, biweekly probe tasks assessed the dependent variables of the study during the course of treatment. Data collected during biweekly probes were used to identify an evolution of changes and to promote generalization of strategies for clear speech outside the context of specific treatment tasks. Biweekly probe tasks included a picture description, a sentence-reading task,

sustained vowel phonation, and conversation. The picture description task and sentence reading task were used respectively to incorporate high effort clear speech into a minute-length monologue and into phonetically balanced sentence length speech. Conversations about topics of interest (such as movies and sports) were used to incorporate high effort clear speech into functional communication with additional conversation partners including unfamiliar and familiar listeners. The sustained vowel phonation task was used to measure any changes made throughout treatment on phonatory stability variables measured by MDVP. Audio recording was completed using a Roland R-05 Wave/MP3 recorder, and video recording was completed using a Cannon FS400 camcorder during biweekly probes. Evaluation protocol included speech and non-speech tasks. Details of the evaluation tasks are provided in Appendix D.

2.6 Data Analyses

Primary Aim, Hypotheses 1-3: Listener-rated Communication Success

A total of sixty listeners with normal hearing and no history of neurological disorder or head injury assessed comprehensibility by transcribing single word and sentence length materials. One group of thirty listeners transcribed words and sentences from audio input only, and one group of thirty listeners transcribed using both audio and visual input to measure and compare comprehensibility conditions. Ten listeners from each group transcribed pre-treatment samples, ten listeners from each group transcribed post-treatment samples, and ten listeners from each group transcribed FU-treatment samples.

Samples of sentence repetition and single word reading were extracted from the video recordings of the evaluations. The visual information in the video was unsaturated for the audio-only condition, so that the listeners heard only the acoustic information without visual input. The listener conditions were presented in a controlled environment (IAC sound-treated booth). The listeners were provided with a single prompt to write down what they thought the participant was saying in each sample.

Transcription of single words and sentences was analyzed for percent accuracy. Percent accuracy was defined as the number of words correctly identified in single word and sentence length transcriptions divided by the total number of words on the list and multiplied by 100. The mean and standard deviation of percent accuracy for all listeners was calculated, and these values were compared at pre- to post-treatment and pre- to FU-treatment.

A total of ten listeners with normal hearing and no history of neurological disorder or head injury rated voice quality based on magnitude of preference for one sample over another. Five listeners heard comparison samples of pre-post evaluations and five listeners heard comparison samples of pre-FU evaluations. Listener preference was determined for samples of sustained vowel phonation and for samples of sentence reading (“The boot on top is packed to keep”). These listeners were presented with two different samples from comparison conditions. Each listener heard a series of 25 pairs of sustained vowel phonation samples and 25 pairs of sentence reading samples and was instructed to select the preferred sample and rate it on a scale from 0 to 50, indicating the magnitude of preference for the sample. Five samples out

of the group were selected to have the same condition (ex. pre- to pre- comparison) and five samples out of the group were randomly selected as repeated measures for determination of intra-rater reliability.

Primary Aim, Hypotheses 4-6: Functional Outcome Measures

The impact of treatment on the functional outcomes was measured in three ways. The CETI-M was used to provide a quantitative measure of change in the level of communicative effectiveness in daily living situations over the treatment course (Lomas et al. 1999; Yorkston et al., 1999). The DIP was used to determine the psychological and social impacts of acquired dysarthria on the participant (Walshe et al., 2009). A positive change in the CETI-M or DIP demonstrates increased communicative effectiveness and/or psychosocial components aligned with communication. An interview format was used to capture qualitative ratings of communication changes reported by the participant or his spouse. The participant's ratings were compared from pre- to post-treatment and pre- to FU-treatment evaluations.

Secondary Aim: Acoustic Factors

Vowel space area was calculated based on the articulation of corner vowels, /i/, /u/, /a/ in the sentence, "The boot on top is packed to keep" during evaluation. This sentence was read five times during each evaluation session. The average formant frequency was taken from the duration of the vowel. Wideband spectrograph

interpretation and formant frequency analysis was completed using PRAAT, an acoustic analysis software (Boersma & Weenink, 2015).

Voice dysfunction and targeted acoustic parameters of voice were assessed using acoustic software, MDVP. MDVP was used to analyze phonatory stability measures during sustained vowel phonations. Vocal sound pressure level (dB SPL) during speech tasks was collected throughout the evaluation sessions. Vocal sound pressure level was also measured during each treatment session using an SLM.

2.7 Statistical Analyses

Multiple comparisons with t-tests determined the significance of any changes to the dependent variables following treatment at Post or FU evaluations. Effect size using Cohen's d determined the magnitude of treatment effect. Average percentage and standard deviation of listener ratings for sustained vowel phonation and sentence reading were calculated to determine overall listener preference and the magnitude of preference for samples. The means of F1, F2, and vowel duration from 20 corner vowels repeated in "The boot on top is packed to keep" were used to create pre-, post-, and 3-month follow-up mean vowel space area, calculate vowel space area change, and determine changes in vowel duration.

2.8 Measurement Reliability

The clinician who administered the treatment (CP) did not participate in evaluations to limit potential bias. Intra-rater reliability was calculated using percent agreement for vowel space area analysis on 25% of the data at 2-4 months following

the initial analysis. There is typical agreement in the literature that percent agreement above 70% is acceptable (Stemler, 2004). Intra-rater reliability for vowel space area using PRAAT formant analysis was 87.5%, calculated based on differences in formant data over 50 Hz during the second analysis. Intra-rater reliability for vowel duration using PRAAT was 75%, calculated based on differences in duration data over 50 ms during the second analysis.

Listener studies were conducted in the IAC treated sound booth. Participants listened to samples at a consistent volume. A random number generator was used to randomize HINT sentences repeated during evaluation tasks and presented to listeners during the transcription task. Individual rater variability for each component of the listener transcription task is displayed in Appendix E. Any individual listener percentage that was two standard deviations below or above the mean was extracted from the data set to reduce the effects of inter-rater variability.

Listeners participating in the perceptual rating task evaluated a randomized selection of 20 pairs of sustained vowel phonations and 20 pairs of sentence repetitions (“The boot on top is packed to keep”) collected during evaluations. Twenty percent of sentence pair and sustained vowel phonation combinations were randomly selected and repeated to determine intra-rater reliability with this task. Intra-rater and inter-rater reliability for the listener preference study was calculated using ReCal 0.1 Alpha, a statistics application on the Internet (Freelon 2010; Freelon 2013), which performed a calculation of average pairwise percent agreement and Cohen’s Kappa (Dewey 1983). Cohen’s Kappa was designed as a reliability measurement to eliminate the amount that raters may agree by chance alone. Landis and Koch (1977) suggested

that Cohen's Kappa coefficients between 0.41-0.60 represent moderate agreement, and coefficients above 0.60 represent substantial agreement. However, other studies suggest greater stringency when interpreting inter-rater and intra-rater reliability coefficients.

Listener intra-rater reliability for the sustained vowel phonation listener preference task was 74%, with an average pairwise Cohen's Kappa of $r=0.61$. Listener intra-rater reliability for the sentence reading listener preference task was 74%, with an average pairwise Cohen's Kappa of $r=0.53$. Listener inter-rater reliability for sustained vowel phonation preference at pre-post and pre-FU was 60.5% and Cohen's Kappa was $r=0.40$. Listener inter-rater reliability for sentence reading preference at pre-post and pre-FU was 74.8% and Cohen's Kappa was $r=0.54$.

STR03 did not receive any co-occurring speech treatment during the treatment phase of this study. However, he received speech, physical therapy, and occupational therapy 2 days/week for two months following treatment (between post-treatment and 3-month follow-up evaluations).

CHAPTER 3.

RESULTS

The results of this study are presented in five categories: treatment data, biweekly probe data, listener-rated communication success (comprehensibility in audio-only and audio+visual conditions and listener perceptual ratings), functional outcome measures (CETI-M, DIP, and interview), and acoustic variables of speech and voice (vowel space area, phonatory stability, and vocal dB SPL).

3.1 Treatment Data

The data collected during each treatment session for vocal dB SPL and lip and tongue pressure in kPa were compiled for an average per week to determine trend changes from week 1 to week 6. Lip pressure increased by an average of 0.6 kPa. Tongue pressure decreased by an average of 0.3 kPa. Sustained vowel phonation loudness increased 2.4 dB SPL. Sustained vowel phonation duration decreased by 0.8 seconds. There were decreases in vocal loudness during speech tasks including automatic speech (3.5 dB SPL), sentence reading (1.4 dB SPL) and hierarchy tasks (4.2 dB SPL). Summary data for treatment tasks are displayed in Table 1. Changes in treatment variables are displayed graphically in graphs 1-3 in Appendix F.

Table 1: Summary data for treatment tasks by treatment week

Treatment Week	1	2	3	4	5	6
Lips (kPa)	54.5	60.4	55.5	54.3	54.4	55.1
Tongue (kPa)	59.0	59.3	63.0	62.6	60.8	58.7
Sustained Vowel Loudness (dB SPL)*	89.6	89.3	86.2	89.7	91.5	92.0
Sustained Vowel Duration (sec)	6.3	6.7	6.4	6.6	5.6	5.5
Automatic Speech 1-10 (dB SPL)	81.2	79.8	80.3	77.6	79.9	77.7
Sentence Reading (dB SPL)*	78.6	79.5	79.6	77.2	78.8	77.2
Hierarchy Task (dB SPL)*	80.6	79.2	79.5	75.9	77.8	76.4

*dB SPL measured at 40cm from mouth to SLM

3.2 Biweekly Probe Data

Vocal dB SPL data were taken during the sentence reading task and the picture description task and compared to the pre-treatment evaluation data for these tasks. These data demonstrate an overall decrease in vocal dB SPL during the biweekly probes as compared to the pre-treatment evaluation. The summary vocal dB SPL data for biweekly probes during sentence reading and picture description is displayed in Table 2.

Table 2. Vocal dB SPL data collected during biweekly probes and difference from data collected pre-treatment to probe data

	Pre-Treatment	Probe 1: Tx 8	Probe 2: Tx 12	Probe 3: Tx 20	Pre-Probe 1, Diff.	Pre-Probe 2, Diff.	Pre-Probe 3, Diff.
Sentence Reading (dB SPL)	84.6	80.0	77.4	79.8	-4.6	-7.2	-4.8
Picture Description (dB SPL)	85.6	80.4	77.3	75.8	-5.2	-8.3	-9.8

Sustained vowel phonation from the biweekly probes was analyzed through MDVP and compared to the pre-treatment evaluation data. The data collected at the biweekly probes displayed considerable variability. Few patterns emerged from this data, aside from a considerable decrease in vAM displayed at all three probes.

Summary MDVP data from biweekly probes is displayed in Table 3.

Table 3. MDVP data collected during biweekly probes

	Pre-Treatment	Probe 1: Tx 8	Probe 2: Tx 12	Probe 3: Tx 20	Pre-Probe 1, Diff.	Pre-Probe 2, Diff.	Pre-Probe 3, Diff.
vF0 (%)	3.83 (1.32)	2.50 (0.62)	3.04 (1.07)	7.93 (8.95)	-1.33	-0.79	+4.1
sPPQ (%)	1.76 (0.70)	1.40 (0.40)	1.39 (0.10)	2.59 (1.94)	-0.36	-0.37	+0.83
ShdB (dB)	0.36 (0.08)	0.58 (0.23)	0.37 (0.08)	0.43 (0.32)	+0.22	+0.01	+0.07
Shim (%)	3.80 (0.88)	5.89 (2.24)	3.76 (0.77)	4.53 (3.50)	+2.09	-0.04	+0.73
APQ (%)	3.92 (0.72)	4.83 (1.39)	3.93 (0.45)	3.66 (2.11)	+0.91	+0.01	-0.26
sAPQ (%)	9.86 (3.41)	8.41 (1.60)	9.69 (1.64)	9.70 (1.54)	-1.45	-0.17	-0.16
vAM (%)	28.49 (7.34)	19.73 (4.17)	18.30 (2.56)	18.39 (2.29)	-8.76	-10.19	-10.1

3.3 Primary Aim: Listener-rated Communication Success

Hypothesis 1: Audio-Only Condition- Single Word Comprehensibility

There was not a statistically significant difference between single word comprehensibility measured during the audio-only condition from pre- to post-treatment ($p=0.22$). Single word comprehensibility, however, increased significantly from pre- to FU-treatment ($p=0.02$) with a medium effect size ($r=0.58$). Quantitative changes of single word percent comprehensibility in the audio-only condition from pre-, post-, and follow-up-treatment evaluations are displayed in Table 4.

Table 4. Quantitative changes in single word percent comprehensibility (audio-only condition)

Listeners	1	2	3	4	5	6	7	8	9	10	Average (SD)
Pre-Tx (%)	37	27	39	54	37	36	31	37	29	20	32.5% (4.4%)
Post-Tx (%)	31	37	37	24	33	21	33	31	39	39	32.6% (5.9%)
FU-Tx (%)	43	36	33	40	40	46	31	44	41	37	39.1% (4.8%)

*Listeners were not the same at pre-, post-, and FU-treatment evaluations

Hypothesis 1: Audio-Only Condition- Sentence Comprehensibility

Sentence comprehensibility measured in the audio-only condition increased from pre- to post-treatment, but the change was not statistically significant ($p=0.22$). Sentence comprehensibility in this condition increased significantly from pre- to FU-treatment ($p=0.03$) with a medium effect size ($r=0.42$). Quantitative changes in sentence percent comprehensibility in the audio-only condition from pre-, post-, and follow-up treatment evaluations are displayed in Table 5.

Table 5. Quantitative changes in sentence percent comprehensibility (audio-only condition)

Listeners	1	2	3	4	5	6	7	8	9	10	Avg. (SD)
Pre-Tx (%)	80	67	79	82	81	73	71	80	41	56	74.3% (10.0%)
Post-Tx (%)	74	86	81	78	82	82	66	82	86	82	79.9% (10.1%)
FU-Tx (%)	89	80	84	84	83	84	81	74	84	83	82.6% (7.9%)

Hypothesis 2: Audio+Visual Condition- Single Word Comprehensibility

There was not a statistically significant difference between single word comprehensibility in the video condition from pre- to post-treatment ($p=0.32$). The difference between pre- and FU-treatment evaluations was also not statistically significant during this condition ($p=0.38$). Quantitative changes of single word percent comprehensibility in the video condition from pre-, post-, and follow-up treatment evaluations are displayed in Table 6.

Table 6. Quantitative changes in single word percent comprehensibility (audio+visual condition)

Listeners	1	2	3	4	5	6	7	8	9	10	Avg. (SD)
Pre-Tx (%)	37	47	53	31	47	44	49	43	43	39	43.3% (6.4%)
Post-Tx (%)	41	41	46	43	31	39	37	40	41	36	40.0% (3.0%)
FU-Tx (%)	44	39	37	41	44	43	47	36	43	37	41.1% (3.8%)

Hypothesis 2: Audio+Visual Condition- Sentence Comprehensibility

There was no statistically significant difference between sentence comprehensibility in the video condition from pre- to post-treatment ($p=0.25$). The difference between pre- and FU-treatment evaluations was also not statistically significant during this condition ($p=0.25$). Quantitative changes in sentence percent comprehensibility in the video condition from pre-, post-, and FU-treatment evaluations are displayed in Table 7.

Table 7. Quantitative changes in sentence percent comprehensibility (audio+visual condition)

Listeners	1	2	3	4	5	6	7	8	9	10	Avg. (SD)
Pre-Tx (%)	81	68	84	87	82	77	87	81	71	78	79.5% (8.3%)
Post-Tx (%)	79	83	84	84	86	88	78	83	86	77	82.7% (5.7%)
FU-Tx (%)	85	82	80	81	78	90	91	71	89	86	83.2% (8.3%)

Hypothesis 3: Perceptual Rating Tasks

There was a statistically significant preference for pre-treatment sustained vowel phonation compared with post-treatment sustained vowel phonation ($p=0.04$) with a large effect size ($r=0.80$). Table 8 illustrates the individual listener preference ratings including the frequency and magnitude of preference for the pre-treatment sustained vowel phonations.

Table 8. Quantitative changes in pre-post listener ratings of sustained vowel phonations

	L1	L2	L3	L4	L5	Average (SD)
Frequency Pre-Tx Preferred	47%	47%	40%	67%	53%	50.7 (10.1%)
Magnitude Pre-Tx Preferred	23.3%	44.7%	33.7%	25.1%	35.8%	32.5% (8.68%)

There was a statistically significant preference for post-treatment sentence reading compared with pre-treatment sentence repetitions ($p=0.00$) with a large effect size of ($r=0.98$). Table 8 illustrates the individual listener preference ratings for post-treatment sentences.

Table 9. Quantitative changes in pre-post listener ratings of sentences

	L1	L2	L3	L4	L5	Average (SD)
Frequency Post-Tx Preferred	87%	73%	87%	80%	93%	84.0% (7.6%)
Magnitude Post-Tx Preferred	34.5%	41.3%	59.8%	27.4%	35.7%	37.7% (8.4%)

The listeners who compared pre-FU sustained vowel samples preferred FU-treatment voicing 41.7% of the time at a magnitude of 37.0%. There was greater preference for FU sustained vowel phonation; however, the difference was not statistically significant ($p=0.36$). Table 10 illustrates the individual listener preference ratings for FU-treatment samples of sustained vowel phonations.

Table 10. Quantitative changes in pre-FU listener ratings of sustained vowel phonations

	L1	L2	L3	L4	L5	Average (SD)
Frequency FU-Tx Preferred	60%	67%	40%	27%	33%	41.7% (17.3%)
Magnitude FU-Tx Preferred	30.2%	35.6%	53.4%	33.5%	32.2%	37.0% (9.4%)

There was a statistically significant preference for sentence reading at FU-treatment ($p=0.02$) with a large effect size ($r=0.86$). Table 11 shows the individual listener preference ratings for FU-treatment samples of sentence repetitions.

Table 11. Quantitative changes in pre-FU listener ratings of sentences

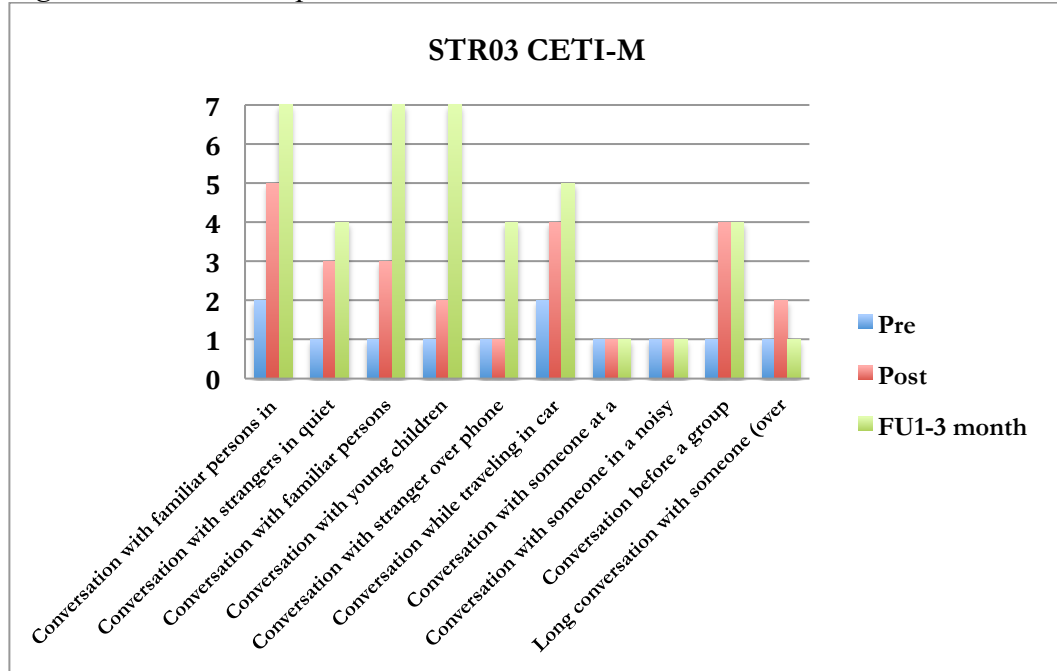
	L1	L2	L3	L4	L5	Average (SD)
Frequency FU-Tx Preferred	100%	93%	60%	60%	60%	74.7% (20.2%)
Magnitude FU-Tx Preferred	40.8%	38.8%	77.6%	37.2%	57.7%	50.4% (17.3%)

3.4 Primary Aim: Functional Outcome Measures

Hypothesis 4: Communication Effectiveness Index-Modified

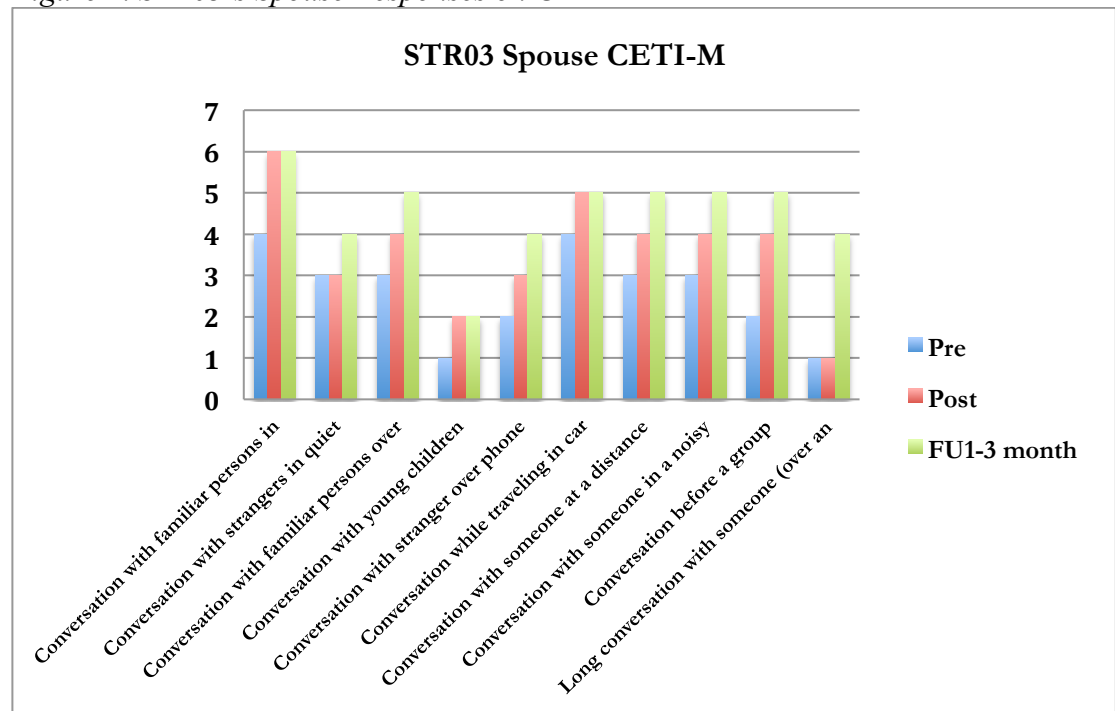
STR03 listed increases in 7/10 of the communication situations on the CETI-M during his post-evaluation, four of which were increases of two points or higher on the CETI-M scale (1: “not at all effective”- 7 “very effective”). Functional outcomes continued to increase in the 3-month follow-up evaluation, in which STR03 wrote that he was very effective (7) in 3/10 of the communication situations. Figure 1 displays STR03’s responses on the questionnaire at pre-, post-, and FU-treatment evaluations.

Figure 1. STR03's Responses on CETI-M



STR03's spouse reported that he was more effective in 8/10 of the situations listed on the CETI-M during the post-treatment evaluations. Her responses indicated that he had continued to increase communicative effectiveness in 7/10 situations at the 3-month follow-up. Figure 2 displays STR03's responses on the questionnaire at pre-, post-, and FU-treatment evaluations.

Figure 2. STR03's Spouse Responses on CETI-M



Hypothesis 5: Dysarthria Impact Profile

STR03 displayed an increase in positive responses on the DIP during the post-treatment evaluation and the 3-month follow-up evaluation. His overall DIP score increased from 122 at pre-treatment, to 132 at post-, and 136 at FU. The greatest increases in positive responses were noted at the post-evaluation in response to the section titled “How I feel others react to my speech”. The greatest increases in positive responses at the 3-month follow-up were in the section “The effect of dysarthria on me as a person”. STR03 also recorded notable changes to the section of the DIP titled “Dysarthria relative to other worries and concerns”, in which he is asked to rank his dysarthria within four other personal and health related concerns. STR03 reported that speech was a primary concern during pre- and post-treatment evaluations, but that the

dysarthria was secondary to concerns about eyesight, physical mobility, and independence during the FU-treatment evaluation.

Hypothesis 6: Interviews

The participant and his spouse discussed progress and treatment goals with the primary clinician (CP) and the supervisor of the study (LM) throughout the course of treatment and during evaluations. Information was collected during formal and informal interviews about any specific changes noted by the participant or spouse during or following treatment. Formal interviews included a specific set of questions, which were collected and recorded. Formal interviews with STR03 were collected and audio and video recorded during pre-, post-, and FU-treatment evaluations by the supervisor (LM). Interviews with STR03's spouse at post- and FU-treatment evaluations were collected and audio recorded at FU by the treating clinician (CP). Field notes were collected based on informal interviews about homework, family and friend reactions to speech, and any additional observations made during the treatment and evaluation periods. STR03's spouse provided informal input about baseline communication and participation at pre-treatment. Several communication changes were repeatedly presented during the interviews and during conversations about changes in communication and speech throughout treatment course. The themes that emerged from the interviews and field notes included an increase in frequency of conversation initiation and quantity of information, an increase in comprehensibility reported by familiar listeners, and a decrease in effort necessary for speech.

Both STR03 and his spouse reported an increase in frequency of conversation initiation and quantity of information during conversational turns. STR03's spouse stated that he was commenting more often during daily activities and inserting humor into his daily routine. Several examples were provided during conversations with STR03's spouse. She described a room in their house with saloon-like doors. As they entered the room one day during the second week of treatment, he said, "I'll have a sarsaparilla." She stated that he continued joking with her whenever they opened the door throughout treatment. A similar pattern with initiation of conversation and humor was present in treatment. STR03 began talking with the clinic administrator and students in the hallways on his way to the treatment room. He developed recurring jokes with the clinician about treatment materials. STR03's spouse stated during a conversation that the increase in daily commentary was having a positive effect on their daily routine and their relationship. STR03's spouse talked about some of the changes in the quality of social interaction during the 3-month follow-up; "Obviously we sit and have conversations now, which is nice...you know because the dogs don't talk back to me. So socially maybe, we've added a little more social activities because he's way more open to it."

STR03 and his wife reported comments made by friends and family about his speech. Familiar listeners noted increases in his clarity of speech. Required homework for the treatment often related to speaking with others using the clear speech practiced during the sessions. STR03 often spoke with his parents via video chat on an iPad. A personal goal was set at the beginning of treatment to increase his speech intelligibility during these conversations. STR03 stated that in a conversation during the third week

of treatment, he spoke with his parents independently and they asked for minimal repetition. STR03 reported on a second personal goal achieved during the fourth week of treatment: calling his dog over to him. He stated that his dog came over to him for the first time following his stroke while he was practicing his functional phrase, “Come here, Cookie.” STR03’s spouse stated that people continued to comment on his speech 3 months following treatment; “Everyone that we see comments on how good his speech is. I think the times people don’t understand him it’s when he says something out of the blue so there’s no context around what he’s getting at... or sometimes there are some people that don’t pay attention.”

Throughout the treatment, STR03 reported that he required a high level of effort to speak. Discussion about this throughout treatment indicated that he felt as though he would speak more frequently if it didn’t require so much effort. His wife also commented during the FU evaluation that the effort level for speaking was STR03’s biggest complaint for the three years following his stroke. STR03 temporally located a substantial change in the amount of effort required during his FU evaluation: “the effort has gone away...since we finished.”

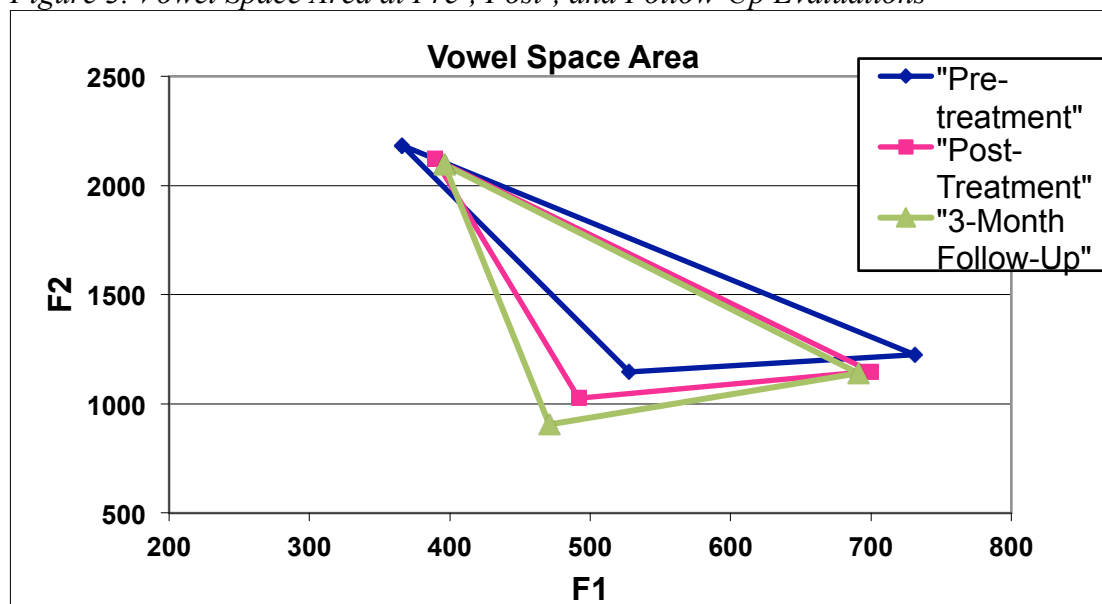
3.5 Secondary Aim: Acoustic Variables

Vowel Space Analysis

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 111,645 Hz² and 120,150 Hz² at post-treatment, indicating an increase of 8,505 Hz² (13%). Vowel space area continued to increase at the 3-month follow-up

evaluation, to 139,933 Hz², indicating an increase of 28,288 Hz² (25%) from pre-treatment. Figure 1 is a visual depiction of pre, post-, and follow-up evaluation visual space areas.

Figure 3. Vowel Space Area at Pre-, Post-, and Follow-Up Evaluations



There were statistically significant changes in F1 and F2 values during the post- and FU evaluations. All values for F1 and F2 /u, a, i/ changed significantly at FU. Quantitative changes in F1 and F2 for /u/, /a/, and /i/ are illustrated in Table 12.

Table 12. Quantitative changes in F1 and F2 for /u/, /a/, and /i/

Hz		Pre	Post	FU-1	Pre-Post T-Test	Effect Size	Pre-FU T- test	Effect Size
/u/	F1	528 (61.2)	492 (28.7)	472 (18.3)	0.05	0.352	0.00	0.527
	F2	1146 (110.9)	1023 (145.8)	910 (73.8)	0.03	0.429	0.00	0.781
/a/	F1	731 (35.9)	700 (49.1)	691 (34.9)	0.03	0.339	0.01	0.492
	F2	1224 (74.6)	1150 (74.0)	1140 (54.5)	0.00	0.446	0.00	0.541
/i/	F1	366 (46.5)	389 (17.8)	396 (36.3)	0.07	0.310	0.02	-0.338
	F2	2182 (66.1)	2122 (73.6)	2097 (133.9)	0.06	0.394	0.05	0.373

Vowel duration for all three corner vowels decreased with statistical significance and large effect sizes during the post-treatment evaluation. Vowel duration also demonstrated a statistically significant decrease at FU compared to the pre-treatment evaluation. Quantitative changes in vowel duration for /u/, /a/, and /i/ are illustrated in Table 13.

Table 13. Quantitative changes in vowel duration for /u/, /a/, and /i/

ms	Pre	Post	FU-1	Pre-Post T-Test	Effect Size	Pre-FU T-test	Effect Size
/u/ duration	646 (47.5)	445 (42.4)	520 (44.9)	0.00	0.913	0.00	0.807
/a/ duration	686 (79.6)	482 (73.0)	534 (83.8)	0.00	0.800	0.00	0.704
/i/ duration	558 (49.9)	281 (37.5)	361 (42.2)	0.00	0.952	0.00	0.905

Phonatory Stability

The pre-to post- and pre- to FU- t-tests for *vf0*, *sPPQ*, *ShdB*, *Shim*, *sAPQ*, *vAm* revealed no statistically significant changes. STR03 demonstrated a statistically significant increase in amplitude perturbation quotient (APQ) from 3.81 to 3.01 ($p=0.02$) with a medium effect size ($r=0.40$). The comparison from pre- to FU-treatment for APQ was not statistically significant. Quantitative changes in these measures are displayed in Table 14.

Table 14. Quantitative changes in phonatory stability

	Pre	Post	FU-1	Pre-Post T-Test	Effect Size	Pre-FU T-test	Effect Size
vF0	3.83 (1.32)	3.73 (1.33)	4.30 (1.64)	0.97	0.038	0.48	0.156
sPPQ	1.76 (0.70)	1.98 (1.86)	2.05 (0.68)	0.40	0.157	0.06	0.420
ShdB	0.36 (0.08)	0.29 (0.05)	0.42 (0.11)	0.09	0.464	0.16	0.298
Shim	3.60 (0.88)	3.12 (0.65)	4.23 (0.95)	0.10	0.296	0.23	0.688
APQ	3.92 (0.73)	3.22 (0.81)	4.76 (1.12)	0.02	0.413	0.10	0.406
sAPQ	9.86 (3.41)	9.20 (2.19)	12.34 (3.76)	0.38	0.114	0.23	0.327
vAM	28.5 (7.34)	21.7 (5.73)	23.97 (7.36)	0.05	0.459	0.05	0.294

Vocal dB SPL

Data collected during pre- and post-treatment evaluations indicated significant increases in dB SPL during sustained vowel and sentence length speech tasks. The effect sizes for the changes in dB SPL from pre- to post-treatment were large. The 3-month follow-up evaluation data indicated that dB SPL during sustained vowel phonation and speech tasks were not significantly different from the pre-treatment

vocal dB SPL data. Table 15 demonstrates the quantitative changes in dB SPL during evaluation tasks at pre-, post-, and follow-up evaluations.

Table 15. Quantitative changes in vocal dB SPL

dB SPL measured @ 40cm	Pre	Post	FU-1	Pre-Post T-Test	Effect Size	Pre-FU T-test	Effect Size
Ah (dB SPL)	91.2 (1.75)	96.3 (0.51)	90.6 (1.63)	0.01	0.89	0.82	0.175
Read Sentences (dB SPL)	84.7 (0.14)	87.8 (1.01)	83.6 (2.24)	0.01	0.91	0.39	0.327
Paragraph (dB SPL)	84.9 (0.65)	87.6 (1.57)	84.4 (1.58)	0.10	0.75	0.63	0.183
Repeated Sentences (dB SPL)	84.9 (1.05)	88.9 (1.76)	85.3 (0.92)	0.03	0.81	0.56	0.222
Task Description (dB SPL)	84.6 (0.84)	88.8 (1.05)	85.2 (1.04)	0.12	0.910	0.65	0.289

CHAPTER 4.

DISCUSSION

The purpose of this study was to examine the impact of an intensive clear speech treatment on listener-rated communication success and functional outcome measures for an individual with spastic dysarthria secondary to stroke. The results of this study demonstrated that the participant responded positively to the intensive treatment. There were statistically significant increases in listener ratings of communication in sentence and single word comprehensibility and listener preference for naturalness in speech samples. Listeners continued to display a preference for speech samples from the follow-up evaluation compared to the pre-treatment evaluations. The participant rated his communication as more effective and reported a decrease in the negative impact of dysarthria on daily life following treatment. These changes were maintained at the 3-month follow-up evaluation.

The first hypothesis that the participant's listener comprehensibility ratings would increase following treatment was supported by the data collected immediately following treatment and at follow-up for sentence and single word comprehensibility collected in the audio-only condition. A statistically significant increase in single word comprehensibility was documented at the 3-month follow-up for the audio-only condition. The second hypothesis that the participant's listener comprehensibility ratings on the audio+visual condition would increase following treatment was not supported at a statistically significant level by the data collected at post- or FU-treatment. Single word comprehensibility decreased at the post- and FU-treatment

compared with the pre-treatment percentage, but not at a statistically significant level. Listener sentence length comprehensibility transcriptions during the audio-only condition increased at the sentence level by 5.6% versus an increase of 3.2% in comprehensibility post-treatment during the audio+visual condition. Therefore, the audio+visual condition did not yield the greater increase in comprehensibility following treatment. The third hypothesis that listener perceptual ratings would display a preference for post- and FU-treatment voice and speech samples was supported for speech samples only. There was not a statistically significant preference for voice samples taken during the evaluations following treatment.

The hypotheses related to functional outcome measures were all supported by the data collected at the post-treatment evaluation and were maintained at the 3-month follow-up. The fourth hypothesis was supported because the participant and his spouse rated communicative effectiveness higher on multiple components of the CETI-M. Reported increases were maintained and, in some cases, continued to increase at follow-up on this questionnaire. The fifth hypothesis was supported because STR03 rated psychosocial impacts of dysarthria lower following treatment, and lower still at the 3-month follow-up. The sixth hypothesis was supported because the participant and his spouse described overall increases in social participation following treatment during the interviews in post- and FU-treatment evaluations.

Statistically significant increases in vowel space area, phonatory stability, and vocal dB SPL were measured in the post-treatment evaluation. Vowel space area increased further at the follow-up evaluation. Increased vowel space area may have

contributed to increases in comprehensibility and communicative effectiveness measurements taken at post- and FU-treatment.

4.1 Primary Aim, Hypotheses 1-3: Listener-rated communication success

The six-week intensive treatment appeared to be a feasible intervention for increasing listener-rated communication success for the individual in this study. There were increases in the audio-only comprehensibility condition with sentences and single words at post-treatment, but the changes were not statistically significant. The increase in comprehensibility was supported by the listener perceptual study at post-treatment, which revealed a statistically significant preference for post-treatment sentences. However, both sentence length and single word comprehensibility significantly increased from the pre-treatment level to the 3-month follow-up. This demonstrated that the participant continued to make progress following treatment. This finding was supported by the listener perceptual study, which revealed a statistically significant preference for the FU-treatment sentences. Preference for post- and FU-treatment sentences demonstrated that there was a listener perception of increased speech naturalness. Increased speech naturalness would support the listener's use of contextual cues during sentence transcription even in the absence of visual information. Improvements in sentence length comprehensibility had a functional impact on STR03's daily communication and social participation. His wife, family members, and other members of his community reported increased comprehensibility on the phone, and in conversations during and following the treatment. His wife stated that communication partners understood STR03 most of the

time, with minimal repetitions when context was provided during the later weeks of treatment and following treatment.

Listeners in the audio+visual condition transcribed a higher overall percentage of single words and sentences when compared to the listeners in the audio-only condition. Visual information supported listener understanding of the participant's message more than acoustic information alone. However, comprehensibility at the sentence level increased at a lesser magnitude in the audio+visual condition than the audio-only condition. Comprehensibility measured in the audio+visual condition was initially higher by approximately 5% for sentences and 11% for single words during the pre-treatment evaluations. These comprehensibility percentages did not increase in each evaluation in the same pattern as the audio-only condition. An increase in sentence length comprehensibility was documented during the audio+visual condition; but, the listeners rated an overall decrease in single word comprehensibility at post- and FU-treatment.

An increase in comprehensibility in the audio+visual condition similar or greater than the increase in the audio-only condition would have indicated that nonverbal components of communication improved during treatment for this individual. The findings indicated that there was no clear evidence of spreading effects of treatment to nonverbal communication components. This measurement may have been better suited for a treatment that directly or indirectly treated non-verbal aspects of communication to increase listener comprehension. The higher comprehensibility percentage in this condition may also have made it more difficult to measure a statistically significant improvement. Therefore, the measurement of

comprehensibility using visual information plus audio information was a less sensitive measurement of treatment effectiveness than the audio-only condition for this study at the sentence level.

The single word comprehensibility measurement taken at follow-up from the audio+visual condition was 2% greater than that taken during the audio-only condition. Comprehensibility measured during sentence length materials in the audio+visual condition was approximately 0.6% greater at FU than the audio-only condition. Therefore, the treatment had a clinically meaningful effect of increasing understandability using acoustic information alone to a level consistent with communication supported by visual information. This could have a meaningful effect on functional communication and conversation with others, in which visual information is not consistently available such as conversation while driving in a car, conversation on the phone, or conversation while walking/pushing a wheelchair.

Listener perceptual ratings identified significant preference for post- and FU-treatment speech samples when compared to pre-treatment. This indicated that the participant's speech was perceived as more natural following treatment, which was reflected in the increase in listener comprehensibility ratings. However, listener preference for voice quality during sustained phonation was greater at pre-treatment when compared to post-treatment. Due to STR03's baseline increased vocal loudness, it is possible that listener preference ratings for voice quality were related to the statistically significant increases in loudness recorded during post-treatment evaluations. The subsequent decrease in vocal loudness from post- to FU-treatment coincided with the preference for vocal quality in FU sustained vowel phonation, and

an increase in comprehensibility ratings at FU-treatment. Intra-rater and inter-rater reliability for listener perceptual rating tasks were challenges in this study. Listeners demonstrated moderate-substantial intra-rater reliability for perception of voice in sustained vowel phonation and speech naturalness in sentences. Listeners demonstrated weak-moderate inter-rater reliability for perceptual ratings of voice and speech, respectively. The listener perceptual rating task was subjective, and listeners demonstrated poorer reliability with rating voice quality in sustained vowel phonations than rating speech naturalness in sentence reading. These challenges with reliability highlight the difficulty with using perceptual measures as treatment effectiveness variables.

4.2 Primary Aim, Hypotheses 4-6: Functional Outcome Measures

The participant and his spouse reported increases in communicative effectiveness and decreases in the psychosocial impacts associated with dysarthria following treatment. STR03 and his wife reported increases in the quantity of information he provided in conversation, and the frequency with which he contributed. The six-week intensive treatment appeared to provide social stimulation, practice with specific speech tasks, and a decreased level of effort necessary for speech, which likely contributed to the greater interest in and pursuance of social interaction in new environments reported on functional outcome measures and during interviews.

An argument can be made that the participant and his spouse's responses reflected their desire for treatment changes in these areas. However, the themes that emerged during interviews and on the questionnaires were consistent with

observations made by the primary clinician (CP) and the supervisor (LM).

Furthermore, the responses on the follow-up evaluation questionnaires and interviews reflected the same changes on these measures as in the post-treatment evaluation. The consistency and further increases on these measures reflected that the perceptions that were shared in post-treatment were maintained at follow-up.

Particular increases on the CETI-M were noted at post-treatment on social situations practiced during treatment, including “Conversation with familiar persons in a quiet environment” and “Conversation before a group”. STR03 reported increases of three scale points (scale from 1-7) in both of these areas, and his spouse reported an increase of two scale points. The six-week treatment included 1:1 conversation with the clinician in a quiet environment for one hour, four times per week. The biweekly probes provided some practice with a group conversation environment. Several conversation partners spoke with STR03 for 5-10 minutes during each probe. STR03 also spoke to a class during his treatment, providing additional practice for communication in a group. Further changes reflected on the CETI-M were related to carryover homework assignments, in which STR03 was asked to communicate with individuals he did not know, or speak on the phone with familiar persons. The changes reflected on the CETI-M demonstrated greater comfort and confidence with the types of communication environments practiced during treatment.

STR03 reported the greatest increases during the post-treatment evaluation on the DIP section “How I feel others react to my speech”. He participated in frequent interactions with other graduate students in the clinic, the clinic administrator, and the primary clinician and supervisor throughout the six-week treatment. He received

frequent positive feedback about his speech during treatment. The increase on this construct of psychosocial impacts of dysarthria was likely related to his interactions in the speech and hearing clinic, and based on the positive feedback he received from friends and relatives during the process. The follow-up evaluation and responses on the DIP reflected a shift from post-treatment. The greatest increases from pre-treatment to follow-up were in the section “The effect of dysarthria on me as a person”, and the section, “Dysarthria relative to other worries and concerns”. His responses at post-treatment demonstrated that he felt others responded more positively to his speech; whereas, his responses at FU demonstrated that he felt more positively about his speech.

Emergent themes during participant and spouse interviews included an increase in conversation initiation and quantity of information provided during conversation, family and friend reports of greater intelligibility and comprehensibility, and a decrease in the level of effort required for speech. The increase in conversation initiation and quantity of information provided during conversation was supported by a post-hoc analysis revealing statistically significant increases in mean length of utterance during evaluation tasks. Family and friend reports of greater intelligibility and comprehensibility related to the specific treatment task of improving and increasing “clear speech”. This was an expected treatment effect. The extreme decrease in the level of effort required for speech was an unexpected, but positive treatment outcome. Effort in the oral articulators was emphasized during treatment, which may have lead to an overall decrease in the effort exerted at the level of the

larynx. Decreased laryngeal effort may have reduced STR03's laryngeal tension, promoting the participant's perception of significantly reduced effort overall.

4.3 Secondary Aim: Acoustic factors

4.3a Vowel Space Area

Acoustic analysis of vowel space area was completed to determine the acoustic-articulatory changes associated with increased comprehensibility. The overall vowel space area increased, reflecting a greater articulatory working space at post- and FU-treatments. The cue for clear speech likely prompted STR03 to employ greater articulatory effort, resulting in the increase in vowel space area (Kim, Hasegawa-Johnson, & Perlman, 2011). There was increased comprehensibility at the sentence level during post-treatment evaluations. This result may be linked to the changes in vowel space area. The difference in vowel space area was greater at pre- to FU treatment, and coincided with increased comprehensibility at both the single word and sentence length level. The increase in articulatory working space area may have increased the amount of distinction between phonemes, allowing for greater listener understanding, particularly when aided by context.

Vowel duration exhibited a statistically significant decrease during post-treatment, which was maintained at FU. Vowel durational changes reflected large treatment effect sizes. This temporal-acoustic component relates to the overall rate of speech. The statistically significant decrease in vowel duration reflected an overall increase in speech rate at post-treatment and FU. Given STR03's slow rate of speech

due to spastic dysarthria, this finding may be related to the listener preference ratings of greater speech naturalness in sentence reading at post-treatment and FU.

4.3b Phonatory Stability

Phonatory stability parameters were selected based on Kent et al. (2003), in which the use of several frequency perturbation and amplitude parameters were validated as potentially deviating measurements associated with the people who have experienced stroke. These measures were used to determine the impact of the treatment on resonant properties of the vocal tract. Resonant characteristics are related to formant frequencies, which were measured to determine vowel space area. STR03 displayed multiple deviant phonatory stability parameters, but the only parameter to move significantly toward the normative value was the Amplitude Perturbation Quotient (APQ). This is a measurement of perturbation in vocal intensity. There was a medium effect size for this change. However, it was not maintained at FU. This result suggested that there was a transient spread of treatment effects to the phonatory subsystem for speech.

4.3c Vocal dB SPL

The treatment had a statistically significant effect of increasing vocal dB SPL for speech tasks including sentence reading and sustained vowel phonation. These increases displayed large effect sizes. This finding was unexpected because increased loudness was not directly trained during treatment. STR03 presented with loudness levels greater than normal limits at pre-treatment, which was consistent with his

diagnosis of spastic dysarthria. Decreased loudness and easy-onset of phonation during treatment tasks was modeled, but not directly stated throughout treatment to preserve the singular cue for “clear speech”.

STR03 presented with laryngeal tension, and severe strain-strangled voice quality, which likely contributed to greater loudness during speech tasks. He received cues to bring the effort to his lips and tongue, and away from his throat during treatment tasks. He frequently produced several utterances following cueing with reduced vocal loudness, but did not achieve independence from this cue during the treatment course. The increased vocal dB SPL level during the post-treatment is consistent with continued dependence on cues for decreased loudness in the presence of the high effort training necessary for clear speech.

The decreased loudness at the 3-month FU back to baseline level suggests that STR03 successfully incorporated the cue for reducing effort at the level of the larynx into his typical speech pattern. Combined with the other evident effects of treatment maintained at the FU, this likely contributed to greater overall intelligibility and comprehensibility and continued reports of clear speech with familiar listeners.

4.4 Limitations

There are inherent limitations related to single-subject research designs. Findings are specific to the individual, and therefore, cannot be further generalized to other individuals with the same disorder. However, positive treatment results can provide a rationale for future investigatory research. Inherent small sample sizes in data collection for a single-subject design relate to challenges with internal validity.

Only the greatest changes reflected in the data are likely to display statistical significance, and changes that do not display statistical significance may be related to sampling error. Additionally, the number of multiple t-test comparisons of data was a limitation of the study because this type of statistical investigation increases the likelihood of type I errors. For these reasons, effect size results were important for demonstrating the strength of treatment effect phenomena.

At STR03's chronic stage of recovery at approximately 4 years post-onset, he had not pursued speech treatment for at least one year prior to beginning TST. STR03's spouse had reported relatively stable speech and reduced social participation during the time between outpatient speech treatment and beginning TST. The treatment that was provided following the post-evaluation represented a possible confounding variable. The two treatments provided to STR03 differed in use of principles of motor learning including intensity of practice and repetition of exercise, specificity of practice, and implicit learning. The treatments also differed in primary focus. TST utilizes cues for clear speech to explicitly address articulatory precision and implicitly address additional characteristics of speech through modeling. STR03's treatment following TST appeared to have multiple targets including breathing/relaxation, emphatic stress (LOOK out vs. look OUT), and repetition of consonant-vowel (CV) pair sounds. The speech exercises STR03 practiced outside of TST certainly may have impacted the findings at the three-month follow-up evaluation. However, the most significant improvements in listener-rated communication success and the improvements in the functional outcome measures were largely related to specific speech tasks practiced during TST. One of the most

salient findings of the study was the continued improvement at FU. Regardless of the limitations of this study, these findings displayed the potential for an individual in the chronic stages of recovery from dysarthria secondary to stroke to improve on the selected outcome measures.

CHAPTER 5.

CONCLUSION

Stroke is one of the leading causes of disability in the United States. There is a high incidence of dysarthria secondary to stroke. This motor speech disorder is characterized by deficits in strength, coordination of movement, range of motion, and speed of articulation. The social and emotional changes associated with dysarthria can contribute to a reduced quality of life and considerable impact on activities of daily living. Very few studies have documented efficacy of specific treatment approaches for this population. Even fewer studies demonstrate the effects of treatment for individuals in the chronic stages of dysarthria secondary to stroke. This preliminary study aimed to determine the impact of an intensive speech treatment based on the principles of motor learning on listener-rated communication success and participant-rated functional communication for an individual with chronic spastic dysarthria secondary to stroke. The results indicated that the participant in the study improved speech comprehensibility at the single word and sentence level, increased self-reported communication effectiveness, and reduced psychosocial impacts of dysarthria following intensive treatment. The results also suggested that a presentation of audio-only information might be a more sensitive measurement of comprehensibility when compared to audio plus visual information. Additional evaluation measures revealed increases in vowel space area and decreases in vowel duration. These measures were maintained and/or continued to improve at three months following treatment.

Treatment outcomes were specific to the research participant's individual characteristics, including the area of damage secondary to his stroke and the time post-onset of stroke. Therefore, the improvements measured immediately post- and three months following treatment cannot be generalized to all individuals with dysarthria secondary to stroke. However, the positive treatment effects for STR03 indicated that individuals in the chronic stages of recovery with dysarthria can improve and maintain speech comprehensibility as well as increase communication effectiveness and reduce some of the negative emotional and social components of chronic dysarthria, even four years post-onset.

The single-subject design was appropriate to capture a comprehensive view of treatment effects in the areas of listener-rated communication success, participant reported outcomes on functional communication, and acoustic factors in one individual with spastic dysarthria secondary to stroke. The maintenance and continued improvements at three months following treatment demonstrate that a treatment adhering to the principles of motor learning can be appropriate for stimulating increases in speech comprehensibility and communication effectiveness in the chronic stages of recovery for a person with dysarthria secondary to stroke. This preliminary study demonstrates that further study with a greater number of participants with dysarthria secondary to stroke is warranted.

CHAPTER 6

FUTURE DIRECTIONS

The results of this study demonstrate that this treatment can be effective for an individual with chronic dysarthria secondary to stroke. Future projects are warranted to determine the generalizability of the findings by studying the treatment effects for additional participants and include multiple follow-up evaluation points. This study examined multiple ways to calculate comprehensibility and highlighted the complexity of measuring treatment outcomes. The two comprehensibility measurement conditions displayed different results in the context of this treatment effectiveness study. There are many different ways to measure treatment effectiveness. A comparison study of methods for calculating percent intelligibility and percent comprehensibility would help researchers determine the method most appropriate for each study. This type of study may support research in treatment effectiveness by setting standards for measurement and improving reproducibility for research studies.

APPENDIX A

Schedule of Evaluations and TST Treatment Sessions

Participant: STR03

Week 1	Weeks 2-7	Week 8	3 Months	6 Months
4 Pre-Treatment Evaluations (1 hour) over 4 days	Treatment 4 one-hour sessions each week	4 Post-Treatment Evaluations (1 hour) over 4 days	4 Follow-Up Evaluations (1 hour) over 4 days	4 Follow-Up Evaluations (1 hour) over 4 days

APPENDIX B

Treatment Protocol						
Task	Instrumentation	Measurement	Repetitions	Duration (min)	Task Description	Purpose/Rationale
Lip Exercises	IOPI	kPa	10	5	Iowa Oral Performance Instrument (IOPI) bulb is placed in the participant's mouth in between the cheek and teeth, participant instructed to purse lips and press bulb against the cheek for 6 seconds using lip strength	Emphasize labial speech positions and high effort training for clear speech
Tongue Exercises	IOPI	kPa	10	5	IOPI bulb is placed against the participant's hard palate posterior to the alveolar ridge, participant instructed to press the bulb against the roof of his mouth for 6 seconds using only his tongue	Emphasize lingual speech positions and high effort training for clear speech
Sustain Vowel Phonation	SLM	dB SPL	5	5	Participant is asked to sustain the vowel "ah" five times for as long as possible	Increase vocal loudness for clear speech
Counting to 15	SLM	dB SPL	5	5	Participant will count from one to fifteen using "clear speech"	Incorporate high effort training of articulation and vocal loudness during an automatic task with low cognitive load
Minimal Pairs	N/A	# of speech errors	2/set, 2 sets	5	Target sounds are determined based on the participant's pattern of errors on the GFTA-2 and during the initial evaluation, participant reads through two sets	Use high effort training to address specific speech errors in single words

					of 10 minimal pairs using “clear speech” twice during the session	
Functional Phrases	SLM	dB SPL	3	20	Participant reads a list of 12-15 sentences that he says everyday (e.g. “I’m ready for bed”)	Increase intelligibility of phrases that are functional and salient
Structured Dialogue, Conversation	SLM	dB SPL	Variable	15	Participant uses reading materials which reflect his interests, reading materials increase in length and complexity from week-to-week	Incorporate clear speech techniques during salient and meaningful speech tasks based on functional situations and interests
Homework	N/A	N/A	2 sets	15-20	Participant completes 6 repetitions of IOPI lip and tongue exercises using bulb, 5 sustained vowel phonations, 5 repetitions of counting exercise, 1 repetition of salient sentences, 1 repetition of reading material assigned for week, and a carryover assignment involving speaking clearly outside of treatment.	Increase repetition of exercises and intensity of practice

APPENDIX C

Minimal Pair Sets

Final /t/ and /d/

1. Spend – Spent
2. Plate – Played
3. Sent – Send
4. Set – Said
5. Sat – Sad
6. Hat – Had
7. Write – Ride
8. Cute – Queued
9. Bet – Bed
10. Neat – Need

Initial /s/ and /z/

1. Sip – Zip
2. Sink – Zinc
3. Sap – Zap
4. Suit – Zoot
5. Ice – Eyes
6. Bus – Buzz
7. Rice – Rise
8. Fussy – Fuzzy
9. Lacy – Lazy
10. Prices – Prizes

Initial /p/ and /pl/

1. Pay – Play
2. Peas – Please
3. Pace – Place
4. Pug – Plug
5. Pie – Ply
6. Pow – Plow
7. Paid – Played
8. Pan – Plan
9. Pot – Plot
10. Pane – Plane

/l/ and /r/ in initial and medial position

1. Alive – Arrive
2. Free – Flee
3. Blue – Brew
4. Fly – Fry
5. Lane – Rain
6. Clash – Crash
7. Lamp – Ramp
8. Lead – Read
9. Lip – Rip
10. Late – Rate

Initial position /b/ and /br/

1. Bat – Brat
2. Bake – Brake
3. Bag – Brag
4. Beach – Breach
5. Bow – Brow
6. Bed – Bread
7. Bunch – Brunch
8. Book – Brook
9. Bought – Brought
10. Ban – Bran

Initial position /k/ and /g/

1. Came – Game
2. Class – Glass
3. Cold – Gold
4. Could – Good
5. Curly – Girly
6. Clam – Glam
7. Crab – Grab
8. Cut – Gut
9. Clue – Glue
10. Kale – Gale

APPENDIX D

Evaluation Protocol			
Evaluation Task		Description	Dependent Variable(s) Assessed
Speech Tasks	Sentence Reading	Five repetitions of “The boot on top is packed to keep.”	Vowel Space Analysis
	Paragraph Reading	Participant will read through the Farm Passage, (Crystal & House, 1982)	Loudness data and specific sound errors
	Picture Descriptions	Participant will describe the picnic scene from the Western Aphasia Battery (WAB), (Kertesz, 1982)	
	Task Description	Patient will describe how to do a stated task (e.g. “Describe how to make a peanut butter and jelly sandwich”)	
	Hearing in noise test	Participant will repeat a series of sentences (Nilsson, 1994)	Sentence-level speaker intelligibility and comprehensibility
	Single word reading	Participant will read through a series of 70 single words (Kent et al., 1989) *Completed only at Pre4, Post1, and FU1 evaluation sessions	Single word-level speaker intelligibility and comprehensibility
	Sustained Vowel Phonation	Participant will repeat vowel “ah” for maximum duration	Loudness data
Non-speech tasks	Sustained Vowel Phonation	Participant will repeat 5 sustained “ahs” in the IAC sound-treated booth	Loudness data

		Participant will repeat 6 sustained “ahs” using the Multi-Dimensional Voice Program Model 5105 (MDVP; Computerized Speech Lab 4500, Kay Elemetrics Corp., 1999)	Voice acoustic parameters
	IOPI bulb lip and tongue exercises	Measurements of tongue and lip strength will be collected using the Iowa Oral Pressure Instrument (IOPI)	Tongue and lip strength
	Respiratory Pressure	Measurement of inspiratory and expiratory pressure will be collected using a respiratory pressure meter (RPM01, Micro Direct; Lewiston, ME)	Inspiratory and expiratory pressure
	Psychosocial impacts and Communicative Effectiveness Scales	Participant will rate communication and psychosocial impacts using two scales; CETI-M and DIP during Pre4, Post1, FU Spouse will rate communicative effectiveness using CETI-M	Psychosocial impacts and Communicative Effectiveness
	Grip Strength Measurement	Participant will grip the dynamometer and exerts pressure using his dominant hand	Grip Strength; <i>Control Variable</i>
Biweekly Probe			
Speech Tasks	Hearing in noise test	Participant will repeat a series of sentences (Nilsson, 1994)	Sentence-level speaker intelligibility and comprehensibility

	Picture Description	Participant will describe the Cookie Theft Picture (Boston Diagnostic Aphasia Examination, 2000)	Loudness data and specific sound errors
	Conversation	Participant will converse with individual other than clinician during treatment.	Loudness data and specific sound errors Provides information about social participation and communication effectiveness
Non-Speech Tasks	Sustained Vowel Phonation	Participant will repeat 6 sustained “ahs” using the Multi-Dimensional Voice Program Model 5105 (MDVP; Computerized Speech Lab 4500, Kay Elemetrics Corp., 1999)	Voice acoustic parameters
	IOPI bulb lip and tongue exercises	Measurements of tongue and lip strength will be collected using the Iowa Oral Pressure Instrument (IOPI)	Tongue and lip strength
	Grip Strength Measurement	Participant will grip the dynamometer and exerts pressure using his dominant hand	Grip Strength; <i>Control Variable</i>

APPENDIX E

Individual Listener Variability in Transcription

Figure 4. Individual listener variability during pre-treatment single word comprehensibility (audio) condition

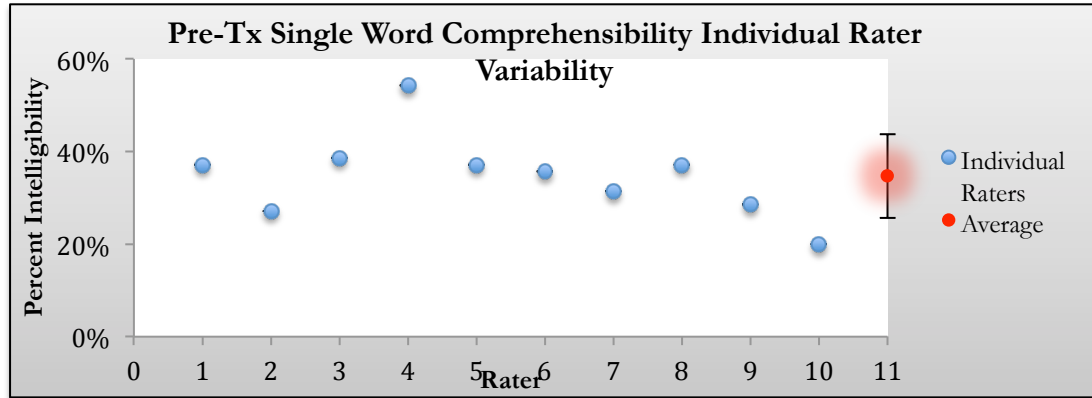


Figure 5. Individual listener variability during pre-treatment sentence comprehensibility (audio) condition

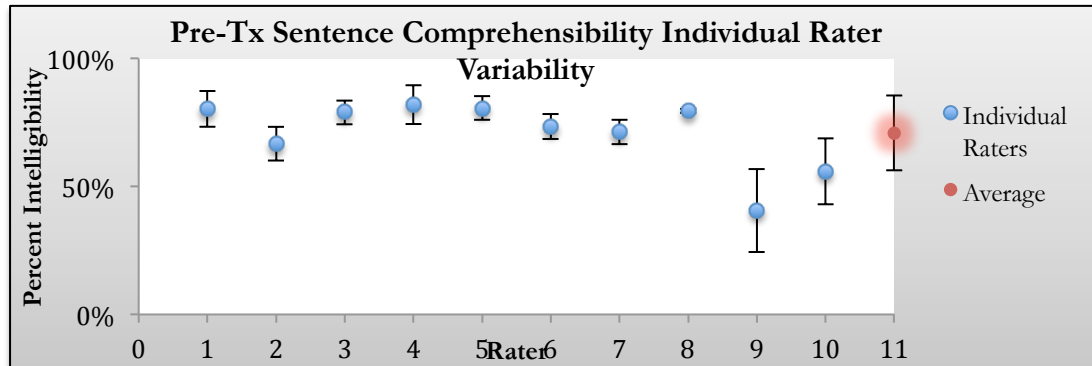


Figure 6. Individual listener variability during post-treatment single word comprehensibility (audio) condition

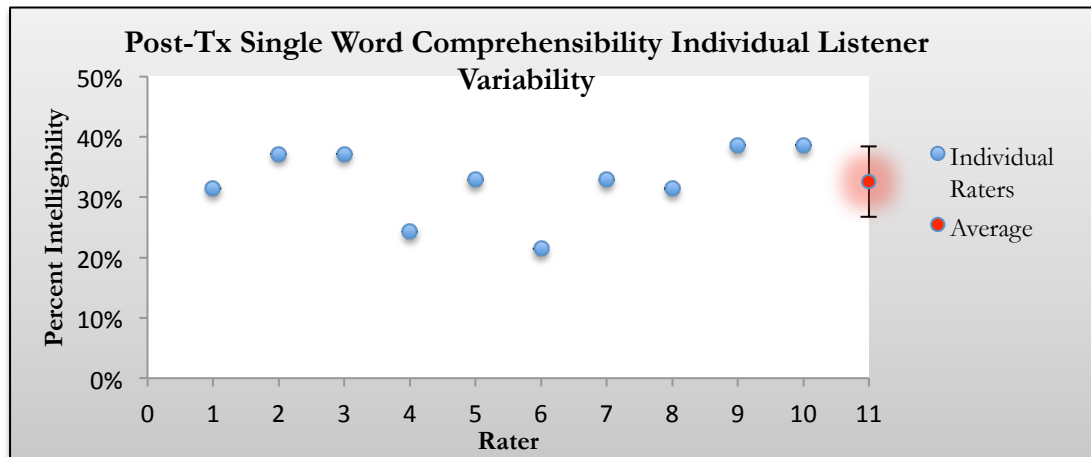


Figure 7. Individual listener variability during post-treatment sentence comprehensibility (audio) condition

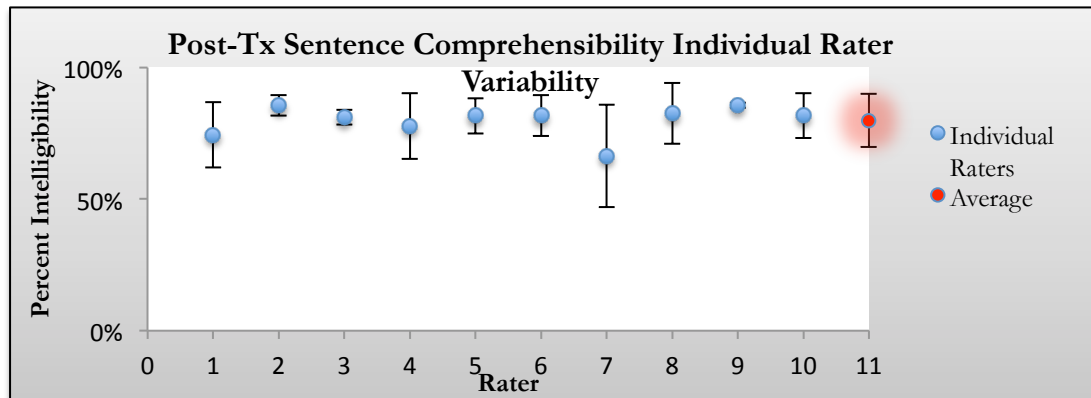


Figure 8. Individual listener variability FU-treatment single word comprehensibility (audio) condition

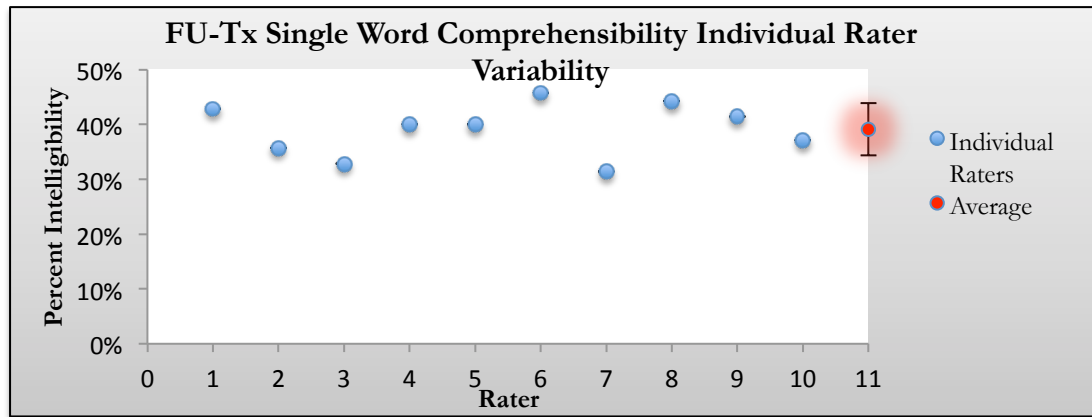


Figure 9. Individual listener variability during FU-treatment sentence comprehensibility (audio) condition

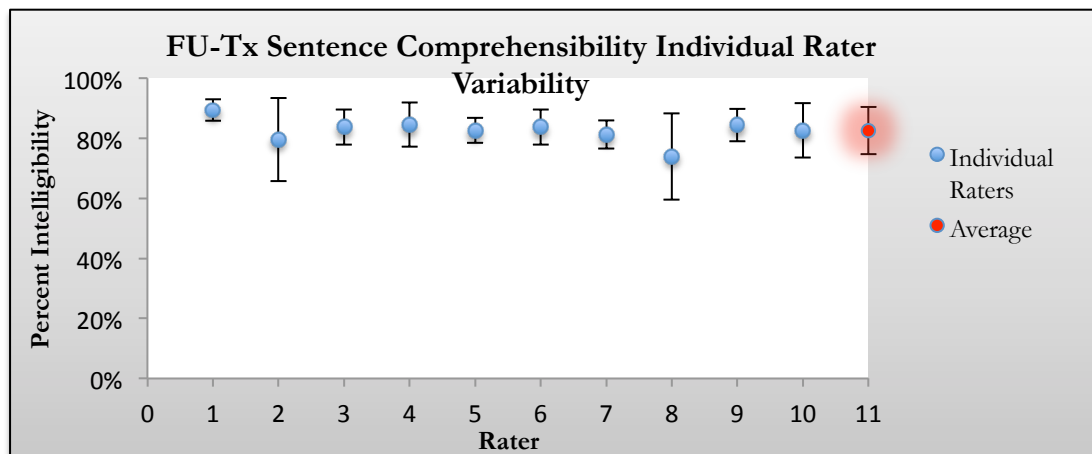


Figure 10. Individual listener variability during pre-treatment single word comprehensibility (audio+visual) condition

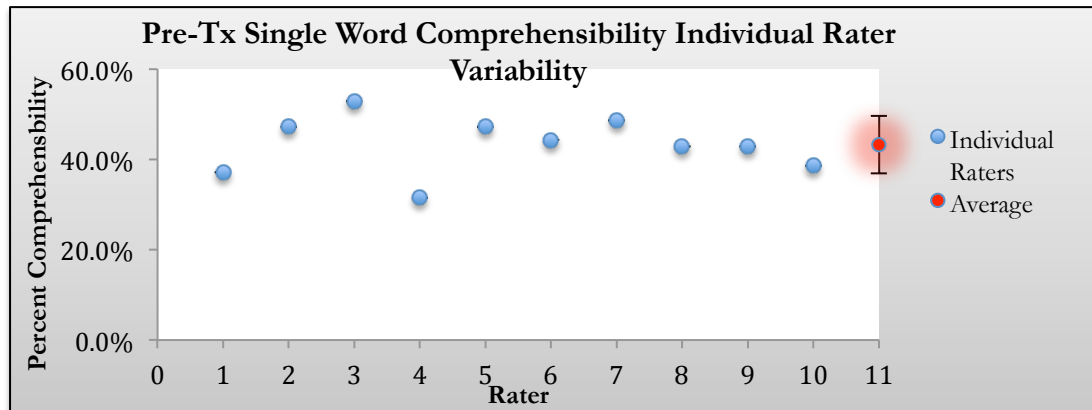


Figure 11. Individual listener variability during pre-treatment sentence comprehensibility (audio+visual) condition

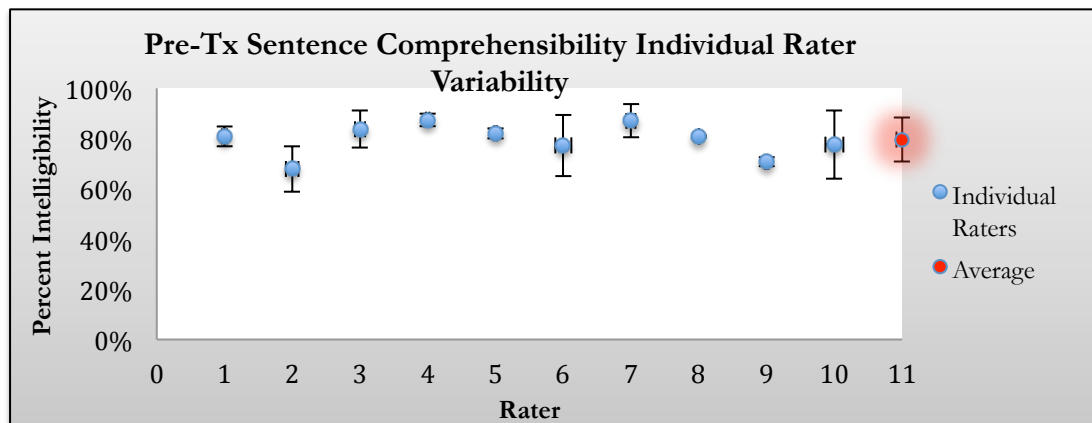


Figure 12. Individual listener variability during post-treatment single word comprehensibility (audio+visual) condition

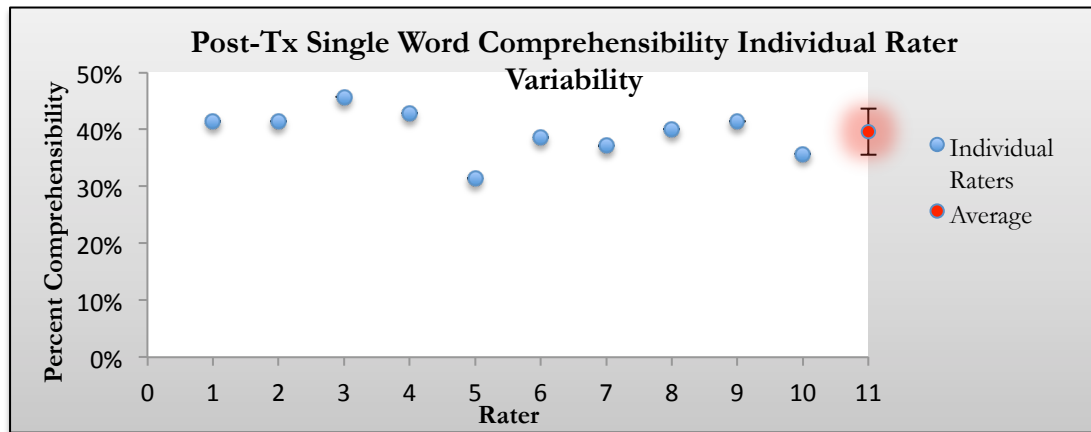


Figure 13. Individual listener variability during post-treatment sentence comprehensibility (audio+visual) condition

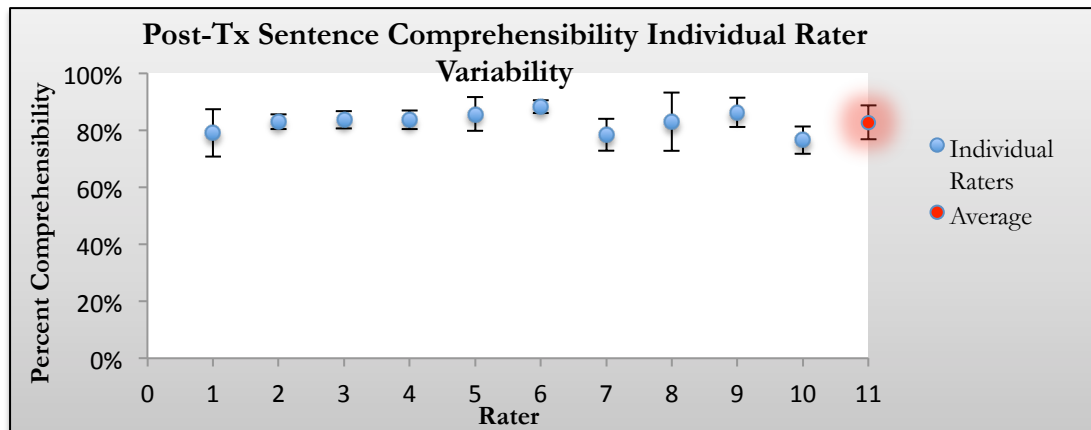


Figure 14. Individual listener variability FU-treatment single word comprehensibility
(audio+visual) condition

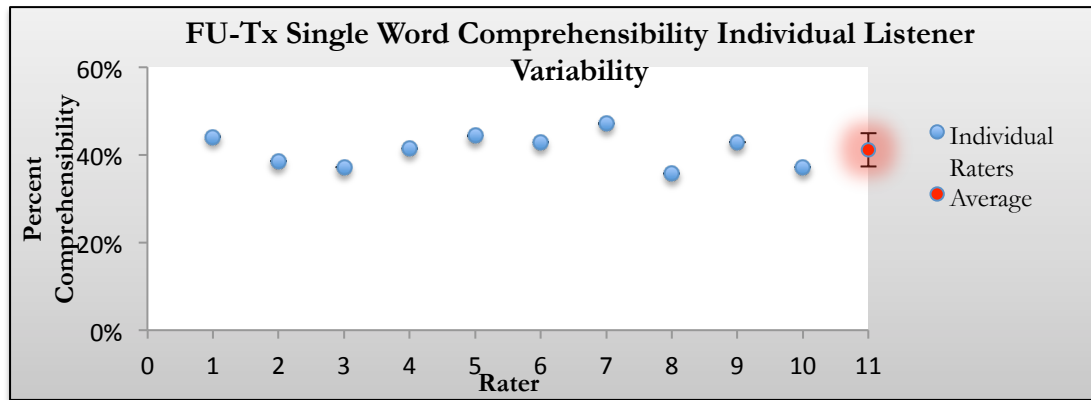
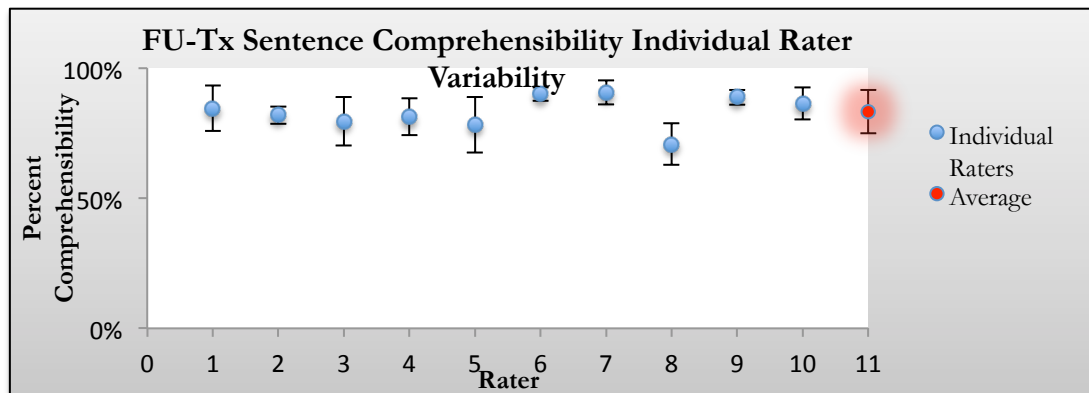


Figure 15. Individual listener variability FU-treatment sentence comprehensibility
(audio+visual) condition



APPENDIX F

Treatment Summary Data

Figure 16. Summary Treatment Data: Vocal dB SPL during treatment tasks

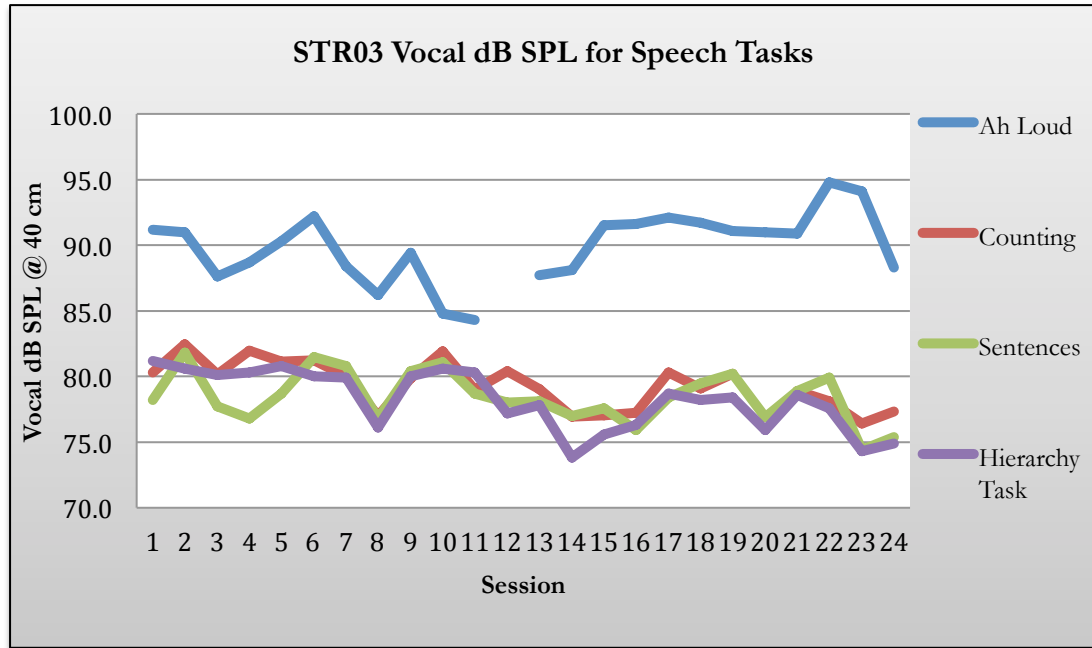


Figure 17. Summary Treatment Data: Duration (ms) of sustained vowel phonation

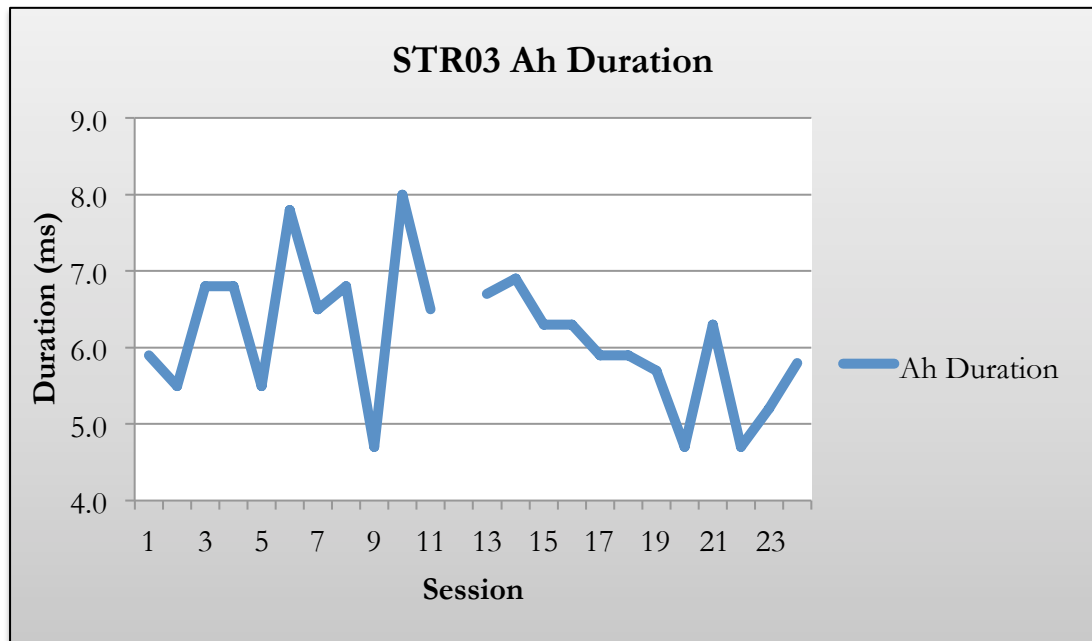
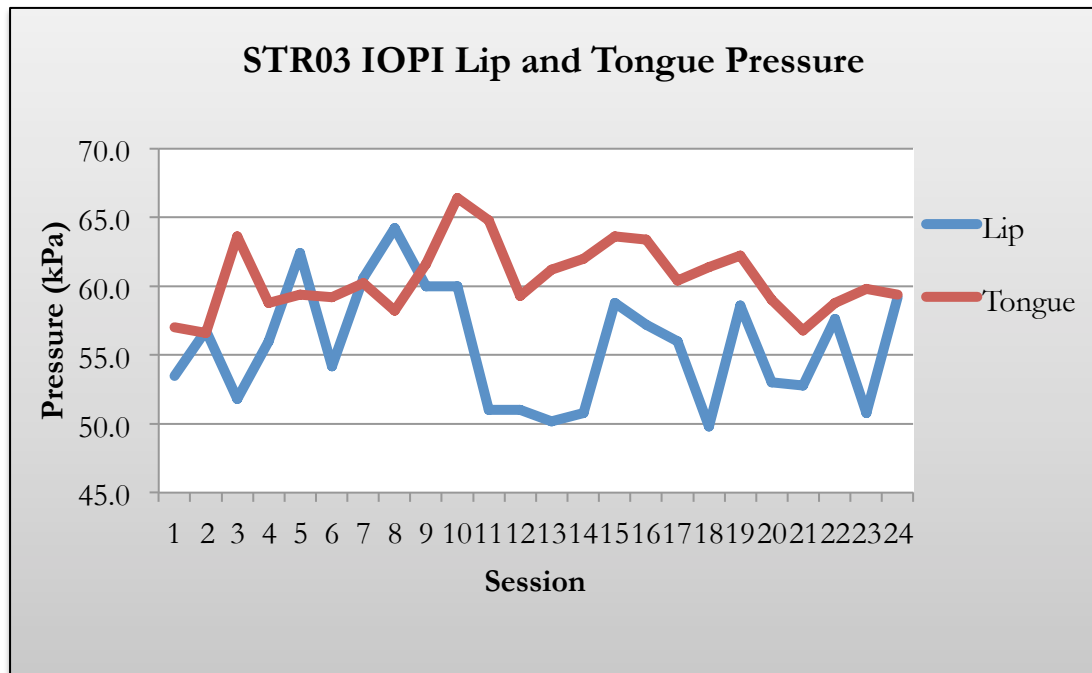


Figure 18. Summary Treatment Data: IOPI Lip and Tongue Pressure (kPa)



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