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Victoria Anne Lovett
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Voice Features of Sjögren's Syndrome: Examination of

Relative Fundamental Frequency (RFF)

During Connected Speech

Victoria A. B. Lovett

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

Kristine Tanner, Chair
Shawn L. Nissen
Ron Channell

Department of Communication Disorders

Brigham Young University

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ABSTRACT

Voice Features of Sjögren's Syndrome: Examination of
Relative Fundamental Frequency (RFF)
During Connected Speech

Victoria A. B. Lovett
Department of Communication Disorders, BYU
Master of Science

The purpose of this study was to examine the effectiveness of relative fundamental frequency (RFF) in quantifying voice disorder severity and possible change with treatment in individuals with Primary Sjögren's Syndrome (SS). Participants completed twice-daily audio recordings during an ABAB within-subjects experimental study investigating the effects of nebulized saline on voice production in this population. Voice samples of the Rainbow Passage from seven of the eight individuals with Primary SS involved in a larger investigation met inclusion criteria for analysis, for a total of 555 tokens. The results indicated that RFF values for this sample were similar to previously reported RFF values for individuals with voice disorders. RFF values improved with nebulized saline treatment but did not fall within the normal range for typical speakers. These findings were similar to other populations of voice disorders who experienced improvement, but not complete normalization, of RFF with treatment. Patient-based factors, such as age and diagnosis as well as measurement and methodological factors, might affect RFF values. The results from this study indicate that RFF is a potentially useful measure in quantifying voice production and disorder severity in individuals with Primary SS.

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I would like to express my sincere appreciation and gratitude to all those who supported and encouraged me throughout the process of completing this thesis. Above all, I would like to thank Dr. Kristine Tanner, my thesis chair, who guided me through each step of the project. I also want to thank Dr. Nissen and Dr. Channell for their expertise and support as committee members. Lastly, but certainly not least, I am also sincerely grateful for the support and encouragement of my family, particularly that of my husband, Kendall. Thank you all for your constant love and support.

TABLE OF CONTENTS

LIST OF TABLES

Table   Page

LIST OF FIGURES

LIST OF APPENDICES

DESCRIPTION OF STRUCTURE AND CONTENT

The body of this thesis is written as a manuscript suitable for submission to a peer-reviewed journal in speech-language pathology. This thesis is part of a larger collaborative project, portions of which may be submitted for publication, with the thesis author being one of multiple co-authors. The participant consent and authorization form, the experimental protocol, and the annotated bibliography are presented as noted in the List of Appendices.

Introduction

Sjögren's Syndrome (SS) is an autoimmune disease characterized by *sicca* or dryness symptoms affecting the eyes and mouth (Sjögren's Syndrome Foundation, 2013). These symptoms result from exocrine gland deficiencies and can cause dryness in many areas of the body, including the throat, intestines, lower airway, and vagina (Chambers, 2004). There are two recognized forms of SS: Primary SS and Secondary SS. Primary SS exists in the absence of another autoimmune disease, while Secondary SS is the result of another more common autoimmune disease, such as rheumatoid arthritis or lupus (Chambers, 2004; Kassan & Moutsopoulos, 2004). Nearly four million individuals in the US alone have SS, most of whom have Secondary SS. Primary SS is less prevalent, with incidence rates estimated at four in 100,000 (Kruzka & O'Brian, 2009; Pillemer et al., 2001). SS occurs most often in females after menopause, although men may also acquire SS (Skalova, Minxova, & Slezak, 2008). Although the exact etiology remains unknown, genetic and environmental factors may play a significant role (Rojas & Kraus, 2002).

Research indicates that individuals with SS may experience disorders that require speech-language pathology care (Heller et al., 2014; Kassan & Moutsopoulos, 2004; Ogut et al., 2005). One of the most common symptoms in SS is difficulty swallowing; nearly three-quarters of patients with SS have reported symptoms of dysphagia (Sheehan, 2008). Although esophageal peristalsis may also be affected, patients often complain of severe oropharyngeal swallowing problems (Leonard & Kendall, 2013). Often, professionals have ascribed swallowing problems solely to xerostomia or severe mouth dryness. However, decreased esophageal motility can be an additional causal factor of severe dysphagia (Anselmino et al., 1997). Further, reduced lubrication can cause prolongation of pharyngeal transit time, which can impair mastication

(Bailey, Chapin, Licht, & Reynolds, 1998) and acid-clearance capacity of the esophagus (Volter, Fain, Mathieu, & Thomas, 2004). Individuals with SS may also be predisposed to laryngopharyngeal reflux, which causes a backflow of gastric contents into the upper aerodigestive tract. The acidic backflow can also be attributed to problems with dysphonia, chronic cough, throat pain, and reactive airway disease (Belafsky & Postma, 2003).

Individuals with SS have also been reported to be at risk for developing voice problems (Heller et al., 2014; Kassan & Moutsopoulos, 2004; Ogut et al., 2005). Voice characteristics reported in individuals with SS include vocal strain, breathiness, and hoarseness (Allec et al., 2011; Heller et al., 2014; Ogut et al., 2005; Wheaton, 2007), as well as vocal fatigue and increased vocal effort (Tanner et al., 2013). Additionally, statistically significant differences in voice quality—including differences in jitter, pitch period perturbation quotient, and shimmer—between patients with SS and controls have been reported in the literature (Ogut et al., 2005). Similarly, laryngostroboscopic studies have documented vocal fold vibratory abnormalities such as reduced glottal closure, amplitude of vibration, mucosal wave, and phase symmetry (Allec et al., 2011; Ogut et al., 2005). Allec et al. (2011) also confirmed the presence of at least one or more laryngeal alterations present in all observed patients with SS. Other studies have also found that vocal fold lesions, specifically bamboo nodes, are often the first reported voice-related symptoms in patients with SS (Mahoney & Spiegel, 2003). However, because bamboo nodules are also associated with rheumatoid arthritis (Hilgert, Toleti, Kruger, & Nejedlo, 2008), and patients with SS often have these symptoms secondary to the arthritis, it is somewhat difficult to determine causality. Collectively, studies indicate that individuals with SS are susceptible to voice problems. However few studies exist to quantify voice problems, particularly in Primary SS.

Voice problems in SS are related, in part, to the extreme laryngeal dryness associated with the disease (Allec et al., 2011; Heller et al., 2014; Kassan & Moutsopoulos, 2004; Ogut et al., 2005). Vocal fold vibration is reliant on the condition of the vocal fold mucosa, which is responsive to the hydration levels of the tissue (Hemler, Wieneke, & Dejonchere, 1997; Verdolini-Marston, Titze, & Druker, 1990; Verdolini-Marston, Titze, & Fennell, 1994). Oral breathing, particularly of dry air, dehydrates the vocal fold mucosa and negatively affects voice production (Sivasankar & Erickson, 2009; Sivasankar & Erickson-Levendoski, 2012; Sivasankar, Erickson, Schneider, & Hawes, 2008; Sivasankar & Fisher 2002; 2003; 2007). Vocal fold surface hydration is maintained, in part, by water and ion fluxes across the vocal fold epithelia (Leydon, Sivasankar, Falciglia, Atkins, & Fisher, 2009; Sivasankar & Fisher, 2007). Historically, increased water consumption and ambient humidity are recommended to alleviate voice symptoms by presumably increasing the availability of extracellular water to the vocal fold tissues. However, in persons with normal renal function, the body retains little excess water outside of its immediate needs (Fisher, Ligon, Sobecks, & Roxe, 2001). Current intervention strategies focus on enhancing both systemic and surface tissue hydration to increase vocal fold hydration and alleviate adverse vocal symptoms (Sivasankar & Leydon, 2010; Tanner et al., 2010).

Phonation threshold pressure (PTP), the minimum subglottal pressure required to initiate and sustain vocal fold oscillation (Titze, 1994), has been the primary measure used to estimate changes in voice production related to vocal fold hydration. Previous research suggests that systemic or surface tissue dehydration elevates PTP by increasing the viscosity of fluid within or on the surface of the vocal folds (Finkelhor, Titze, & Durham, 1988; Hemler, Wieneke, LeBacq, & Dejonckere, 2001; Jiang, Verdolini, Ng, & Hanson, 2000; Verdolini, Titze, & Fennell, 1994).

Using PTP as the primary outcome measure, Roy (2003) observed modest, fairly transient effects of a nebulized laryngeal lubricant (i.e., liquid Mannitol) to ostensibly decrease viscosity of the vocal fold surface fluid. Subsequently, Tanner, Roy, Merrill, and Elstad (2007) used PTP to quantify effects of 3 mL of nebulized hypertonic saline (7% Na^+Cl^-), nebulized isotonic saline (0.9% Na^+Cl^-), and nebulized sterile water after a laryngeal desiccation challenge. PTP has also been used to examine the effects of vocal fold dehydration and hydration treatments in classical singers (Tanner et al., 2010), as well as the effects of other medications and irritants that might influence the vocal fold epithelia (Erickson & Sivasankar, 2010; Erickson-Levendoski & Sivasankar, 2011).

Recently, additional research has been undertaken to develop new treatments for individuals who experience chronic vocal and laryngeal dryness. Tanner et al. (2013) examined self-perceived phonation effort (PPE) and PTP, as well as self-perceived mouth and throat dryness after laryngeal desiccation treatments in patients with Primary SS. It was found that patients experienced significantly increased incidences of mouth dryness, throat dryness, and vocal effort after the desiccation challenge. PTP also increased significantly after the desiccation challenge. Further, the Voice Handicap Index (VHI; Jacobsen et al., 1997) showed a positive correlation in dryness and vocal effort measures at baseline. Following the nebulized saline treatment, improvement in both throat dryness and PTP were noted. Thus, it was determined that nebulized isotonic saline may counter the adverse effects of the laryngeal desiccation treatments in patients with Primary SS.

Although PTP has been in numerous studies to assess and quantify laryngeal hydration, it is a somewhat variable measure that lacks practicality in assessing hydration in patients at home over long periods of time. Recent research has discussed the importance of evaluating laryngeal

hydration under more realistic conditions or during more realistic activities of daily living (Sivasankar & Erickson-Levendoski, 2012). Further, in the above studies, participants were first desiccated to test hydration treatments. That is, the effects of nebulized saline on voice production in the absence of a prior desiccation challenge remain unknown. This is particularly important in individuals who may have health conditions that cause chronic laryngeal dryness, such as SS. The current study seeks to assess dryness in patients with SS under such conditions; that is, in the absence of an experimental laryngeal desiccation challenge and over a longer period of time. Relative fundamental frequency (RFF) will be used to examine voice production under different experimental conditions in a group of individuals with Primary SS.

RFF is a promising new acoustic measure for evaluating voice problems in the mild to moderate range (Goberman & Blomgren, 2008; Hanson, 2009; Ohde, 1984; Robb & Smith, 2002; Stepp, Merchant, Heaton, & Hillman, 2011; Watson, 1998). Operationally defined, RFF is the fundamental frequency (F_0) of the cycles immediately preceeding and subsequent to production of voiceless consonants. The "steady state" of fundamental frequencies as a speaker transitions from voicing into and out of a voiceless consonant allows comparison across individuals with diverse resting fundamental frequencies (Stepp, et al., 2011). Previous studies have shown that the vocal cycles immediately after voiceless consonant production show a consistent pattern in healthy speakers (Goberman & Blomgren, 2008; Ohde, 1984; Robb & Smith, 2002; Watson, 1998). Prior to devoicing, younger healthy speakers have reliably stable RFF across 10 cycles, while older speakers tend to show a slight decrease in RFF (Watson, 1998). Robb and Smith (2002) found no significant difference among individuals at 4, 8, and 21 years of age; additionally, they consistently found a slight decrease in RFF across the 10 cycles prior to devoicing. Recent research has also found that the RFF pattern seen in healthy voices

differs from that found in disordered voices (Goberman & Blomgren, 2008; Stepp, Hillman, & Heaton, 2010; Stepp, Merchant, Hillman, & Heaton, 2011).

Physiological behaviors preceding, during, and immediately following voiceless consonant production—such as tension near voiceless consonants (Löfqvist, Baer, McGarr, & Story, 1989; Stevens, 1977), vocal fold abduction (Fukui & Hirose, 1983), and minimum airflow and peak increase (Löfqvist, Koenig, & McGowan, 1995; Löfqvist & McGowan, 1992)—have been hypothesized to influence the production of vowels near voiceless consonants. Thus, an increase in both offset and onset RFF may be observed. The influence of these physiological effects is compatible with the findings regarding lowered RFF in individuals with Parkinson's Disease during both vocal offset and onset compared to age-matched controls (Goberman & Blomgren, 2008). The hypothesis that decreased RFF is the result of increased laryngeal muscle tension in individuals with Parkinson's Disease impedes their ability to use tension as a devoicing strategy (Goberman & Blomgren, 2008) and is supported by a recent study regarding lowered RFF after treatment for laryngeal muscle tension (Stepp, Hillman, & Heaton, 2010). More recently, Stepp, Marchant, Heaton, and Hillman (2011) showed an increase in RFF from pre- to post-therapy. That is, successful therapy increased RFF measures toward patterns seen in individuals with typical voices. Thus, RFF is a sensitive measure in detecting subtle changes in onset and offset of voicing, including at-risk populations for voice problems.

The primary purpose of this overarching investigation was to examine the effects of nebulized hydration treatments in individuals with Primary SS. The current study will attempt to quantify voice severity with and without the administration of a topical hydration treatment in these individuals. Nebulized hydration treatments, historically, have only been tested on individuals with normal and healthy voices. However, the treatment may be of benefit to

individuals with dehydration or other dryness-related voice problems, particularly those who are on the mild to mild-to-moderate severity spectrum. The present investigation will evaluate the effects of nebulized isotonic saline in Primary SS to answer the following research questions:

1. What are the RFF characteristics of individuals with Primary SS?

2. Does RFF change after laryngeal hydration treatment in Primary SS?

Method

Participants

Eight individuals with Primary SS (8 females; age range 36 to 74 years; mean age 57 years) participated in the study. All participants resided in the intermountain region, including Utah and Idaho and were recruited at the University of Utah Division of Rheumatology. All participants voluntarily consented to the eight-week study. All informed consent and study-related procedures were approved by the University of Utah and Brigham Young University Institutional Review Boards (IRB_00061835). The informed consent and authorization document is provided in Appendix A.

Participants completed patient-based SS and voice severity scales prior to initiation of the study; patient-based scales used to quantify SS severity scales included the EULAR Sjögren's Syndrome Patient Reported Index (ESSPRI; Seror et al., 2012) and the Sicca Symptoms Inventory (SSI; Bowman, Booth, Platts, Field, & Rostron, 2003). The ESSPRI includes three subscales—dryness, pain, and fatigue—using a 1 to 10 point equal appearing interval scale, with 10 being most severe and 1 being not a problem. The SSI quantifies the patient-perceived severity of somatic and mental fatigue as well as general discomfort and pain. The SSI includes four domains—ocular, oral, vaginal, and cutaneous—including five, three, and one-item facets, respectively. The SSI scale ranges from 0 to 7 for each item, with 7 being an extreme problem

and 0 being no problem; the final score is the sum of the four domains. The SSI is presented in Appendix B. In addition to completing the SS severity scales, participants completed the Voice Handicap Index (VHI; Jacobsen et al., 1997). The VHI is a 30 question patient-based measure of voice impairment. Scores on the VHI can range from 0 to 120, with 0 being no impairment and 120 being maximum impairment. The VHI is presented in Appendix C. The average Primary SS diagnosis length in participants was 11 years (range 2 to 32 years) while the average number of years with sicca symptoms was 13 (range 3 to 30 years). Medical history questionnaire and select medical history factors are reported in Appendix D and Appendix E, respectively.

Study Design and Procedure

This prospective study involved an ABAB withdrawal within-subjects experimental design. The eight-week study included four phases: a two-week baseline phase, a two-week treatment phase, another two-week baseline and treatment withdrawal phase, and a final two-week treatment phase. An experimental protocol and overview of the study are provided in Appendix F and Appendix G, respectively. During the eight-week study period, participants recorded speech and voice samples twice daily at approximately the same time each day. Audio recordings included the first paragraph of the Rainbow Passage (Fairbanks, 1960), as well as three sentences from the Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V; Zraick et al., 2011), word lists, and sustained vowels not included in the current study. Recordings were acquired using the Zoom digital audio recorder (model H1) and an Audio Technica head-mounted microphone (model ATM75-SP-NP), sampled at 96,000 kHz, quantization of 32 bits, and stored as .wav files on a 32GB MicroSD card (Sandisk, Inc.). Participants received written instructions, including photographs regarding recording procedures, correct microphone placement, and monitoring the volume unit meter to prevent peak-clipping. Recording

instructions are presented in Appendix H. Following each morning and evening speech and voice recording, participants were instructed to rate their self-perceived level of vocal effort, mouth dryness, and throat dryness using three 10 cm visual analog scales (VASs). The extreme left of the scale represented no vocal effort or dryness while the extreme right represented extreme vocal effort or dryness. The VASs used in the present investigation are provided in Appendix I and Appendix J. Participants again completed the ESSPRI, SSI, and VHI at the conclusion of each two-week study phase.

During weeks one and two (i.e., baseline), participants completed audio recordings and VAS ratings of vocal effort and dryness twice daily as described above. During weeks three and four, a nebulized saline treatment was introduced. This treatment included 9 mL of isotonic saline (Simply Saline,™ 0.9% Na⁺Cl⁻) administered with the Omron Micro Air™ vibrating mesh nebulizer (model NE-U22V). Participants nebulized only after completing the audio recordings in the morning and evening. This was done in order to prevent solitarily detecting the short-lived effects of the nebulized saline solution on vocal fold dryness and voice production (Tanner et al., 2013). During weeks five and six of the study (i.e., second baseline/treatment withdrawal), twice-daily audio recordings and VAS ratings were continued. Lastly, during weeks seven and eight participants continued voice recordings, and resumed twice-daily nebulized treatments.

RFF Analysis

Original .wav files were imported via a micro USB cable to an iMac desktop computer. These included 112 possible audio recordings for each of the eight participants (i.e., twice-daily recordings for 8 weeks). Samples were imported into Adobe Audition (v. 5, Adobe, Inc.), trimmed, down-sampled (44.1 kHz, 16 bits), and resaved as coded .wav files. One vowel-

voiceless consonant-vowel combination was selected from the audio recordings for acoustic analysis. The "ever finds" (i.e., "er" and "fi") token was extracted from the first paragraph of the Rainbow Passage, as this token has been shown to produce reliable RFF measurements in previous studies (Lien, Gattuccio, & Stepp, 2014; Lien & Stepp, 2013; Stepp et al., 2011).

RFF analysis was accomplished using previously established methodological procedures reported in the literature (Stepp et al., 2010; 2011). Tokens were analyzed using the PRAAT® acoustic analysis software (v. 5.2.17). Using the pulse function, RFF was calculated for the 10 periods of vibration prior to (i.e., voicing offset) and after (i.e., voicing onset) the voiceless consonant. Per established operational procedures (Lien et al., 2013; Lien & Stepp, 2013; Stepp et al., 2010; 2011) sample tokens were excluded if they (a) included vocal fry, (b) included voice breaks, (c) contained fewer than 10 pulses, (d) if the participant took a breath during the token, or (e) the participant made an articulatory error during production of the token. Therefore, of the 896 possible tokens (i.e., 8 participants x 56 days x 2 recordings per day), 555 met inclusion criteria. Excluded samples included 322 tokens based on the above criteria and 19 recordings not completed by participants.

Statistical Analysis

Descriptive summary statistics were used to examine voice production in participants at baseline and treatment phases of the study. Treatment effects over time were examined using the Friedman nonparametric analysis of variance. Intrajudge reliability was calculated for 15% of repeated analyses for the two student examiners who performed all RFF measurement procedures. A Spearman correlation of .85 (p < .000) and an average absolute difference of .26 semitones demonstrated acceptable levels of measurement reliability.

Results

Daily RFF values were averaged within each two-week phase (i.e., Baseline, Treatment Phase 1, Withdrawal, and Treatment Phase 2) for AM and PM recordings, respectively. RFF means and standard deviations (SDs) for each two-week phase are provided in Table 1. For AM recordings, RFF Offset Cycle 10 increased by .39 and RFF Onset Cycle 1 increased by .20 from pre- to post-treatment. For PM recordings, RFF Offset Cycle 10 increased by .44 and RFF Onset Cycle 1 decreased by .62 from pre- to post-treatment. Only increases in AM RFF Onset Cycle 1 were statistically significant based on Freidman tests for related samples and a .05 alpha level (see Table 1).

Table 1

Relative Fundamental Frequency Values

Cycle	Baseline	Treatment	Withdrawal	Treatment	*p* value
Offset Cycle 10 (AM)					
Mean	-1.61	-1.30	-1.73	-1.22	.104
SD	2.27	2.17	1.97	2.05	
Offset Cycle 10 (PM)					
Mean	-1.65	-1.74	-1.86	-1.21	.204
SD	2.51	2.78	2.27	2.79	
Onset Cycle 1 (AM)					
Mean	1.84	1.31	0.95	2.04	.007*
SD	1.81	1.84	3.04	1.63	
Onset Cycle 1 (PM)					
Mean	1.77	1.84	1.82	1.15	.304
SD	1.98	2.57	2.19	2.14	

Note: Average Relative Fundamental Frequency (RFF) in Semitones (ST) for Offset Cycle 10 and Onset Cycle 1 during AM and PM voice recordings, including mean and standard deviation (SD) for each two-week study phase. *statistically significant at alpha < .05

For each two-week phase, RFF means and standard errors during phonation Offset and

Onset Cycles 1 through 10 are provided in Figures 1 through 4. Figures 1 and 2 include

phonation Offset and Onset for AM recordings. Figures 3 and 4 include phonation Offset and

Onset for PM recordings.
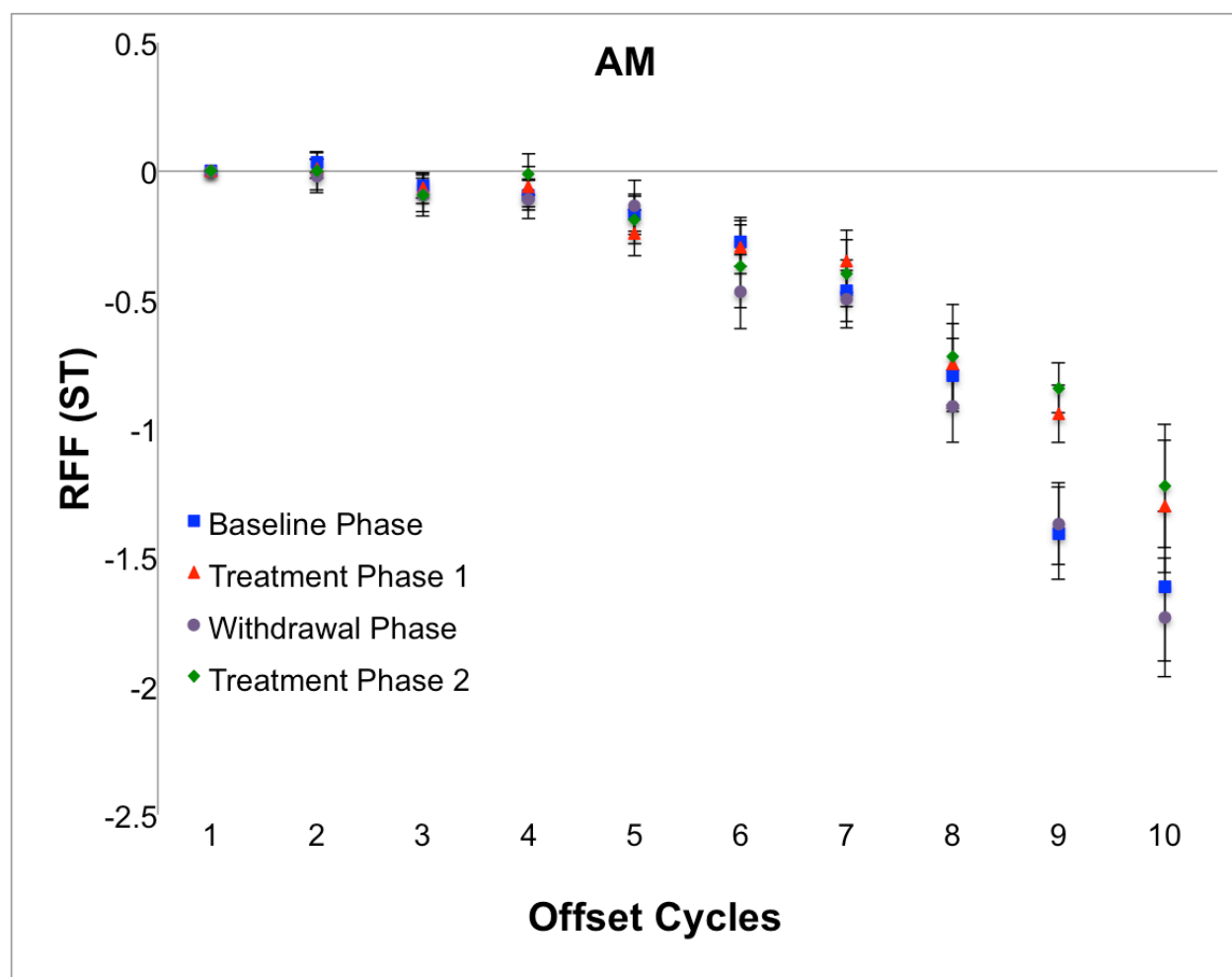
Figure 1. Average Relative Fundamental Frequency (RFF) Offset Cycles 1 through 10 in
Semitones (ST) with standard errors across each of the four study phases for morning (AM)
recordings.
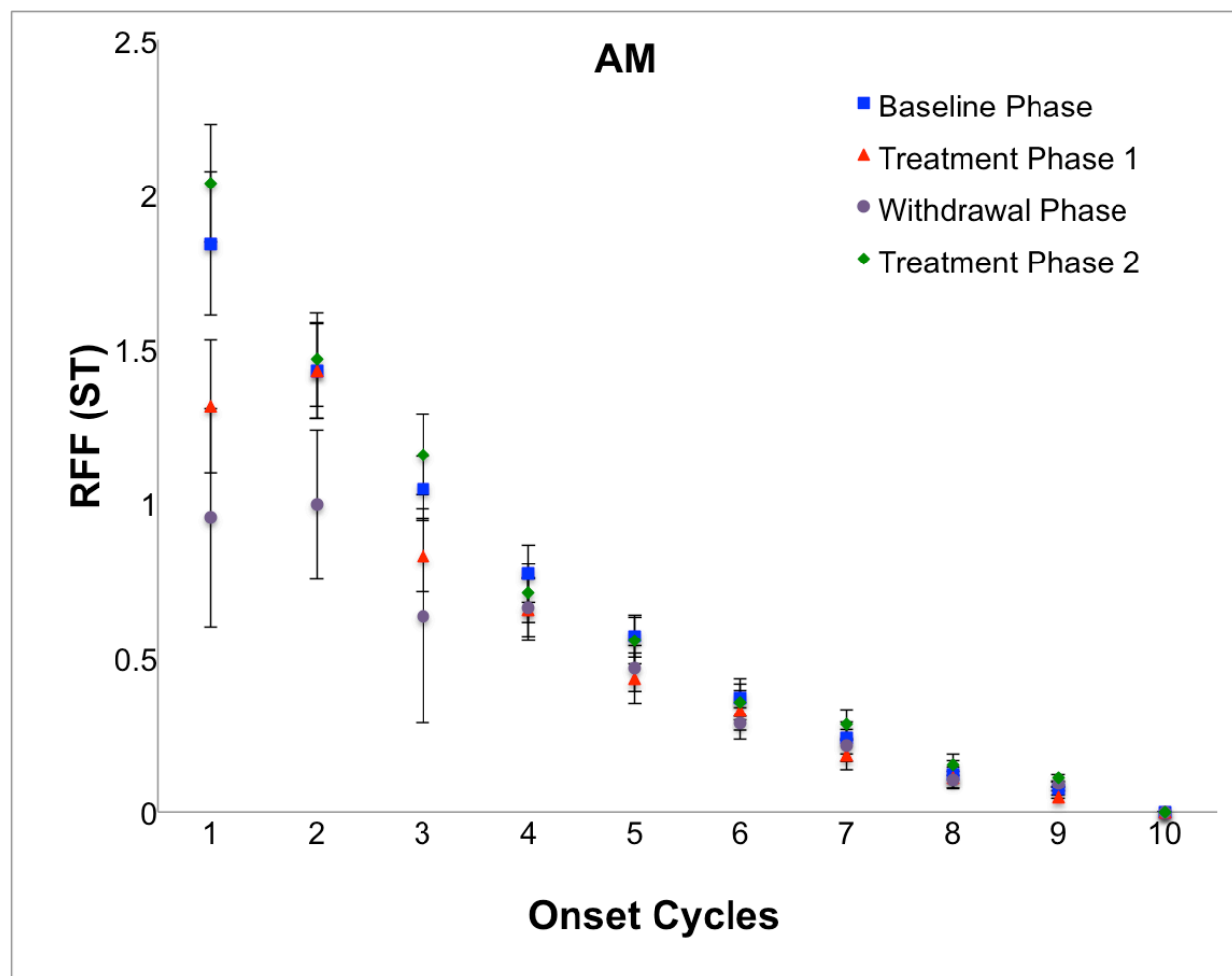
Figure 2. Average Relative Fundamental Frequency (RFF) Onset Cycles 1 through 10 in Semitones (ST) with standard errors across each of the four study phases for morning (AM) recordings.
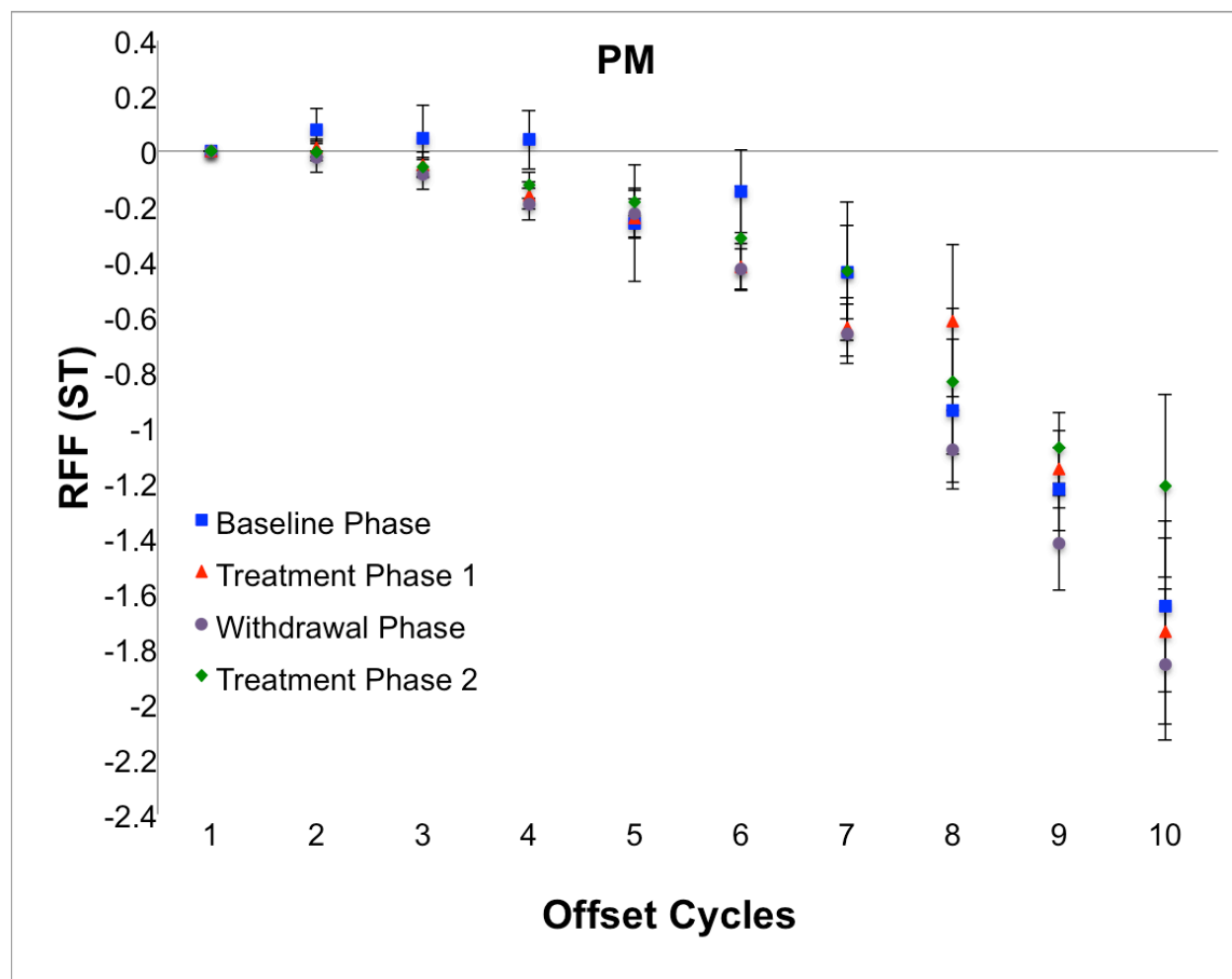
Figure 3. Average Relative Fundamental Frequency (RFF) Offset Cycles 1 through 10 in Semitones (ST) with standard errors across each of the four study phases for evening (PM) recordings.
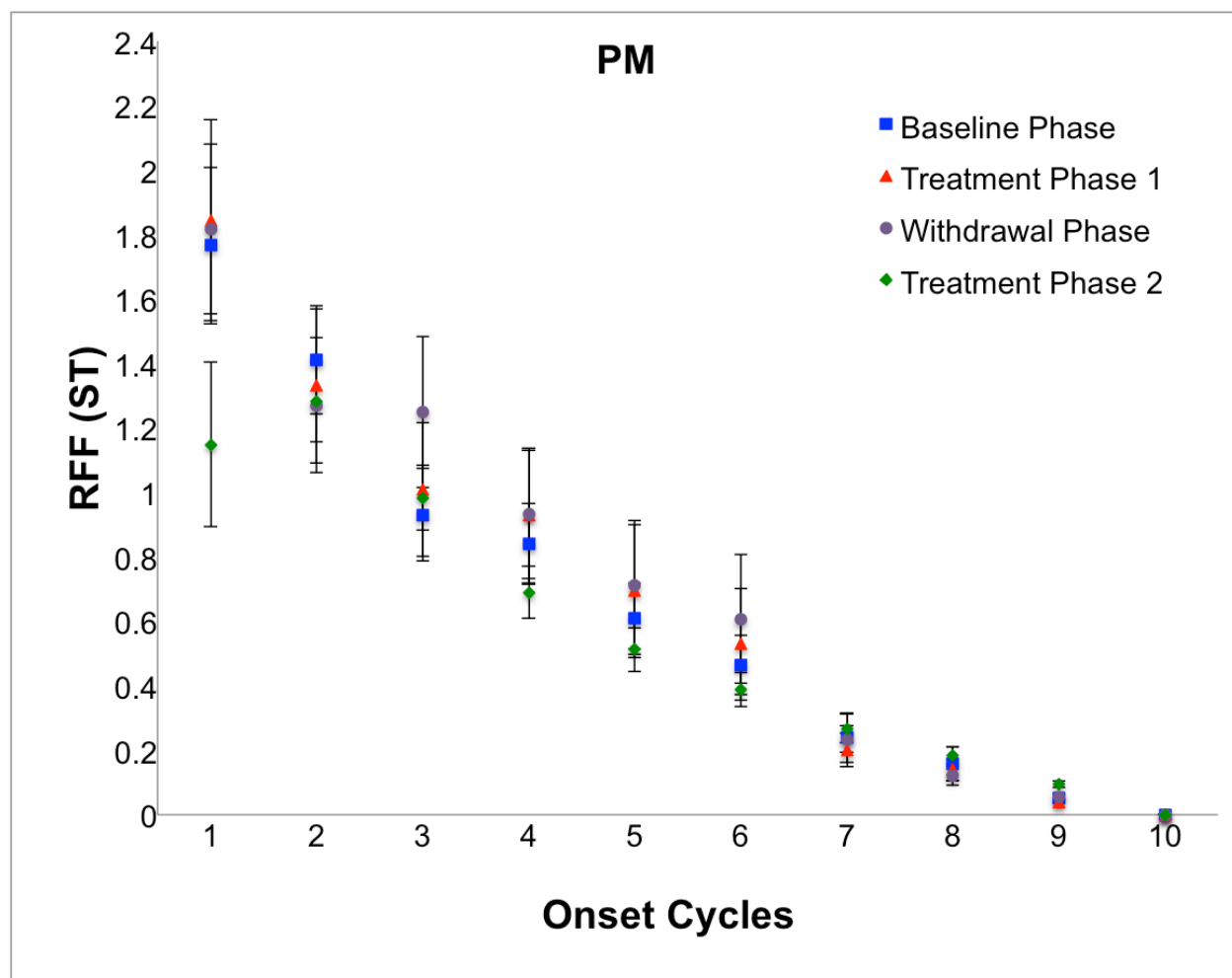
Figure 4. Average Relative Fundamental Frequency (RFF) Onset Cycles 1 through 10 in Semitones (ST) with standard errors across each of the four study phases for evening (PM) recordings.

Discussion

The present study evaluated acoustic changes in voice production before and after nebulized hydration treatments in individuals with Primary SS. During the study, patients received nebulized saline treatments twice daily using an ABAB eight-week experimental design. This study was part of a larger investigation examining the effects of long-term nebulized saline treatment on several acoustic and patient-based measures in individuals with Primary SS.

Other acoustic and patient-based measures from the larger investigation indicated that the participants experienced improvements in voice production, vocal effort, and mouth and throat dryness symptoms with nebulized saline treatment (Miner, 2014).

The purpose of this investigation was to (a) quantify voice disorder severity at baseline and (b) determine what change, if any, occurred with treatment as measured using RFF. It was hypothesized that RFF would increase or improve with increases in vocal fold hydration via ultrasonic nebulized saline. Analysis of the results indicated that baseline RFF values were in the voice-disordered range based on recent studies involving speakers with typical versus disordered voices (Lien et al., 2013; Stepp et al., 2010; 2011). Additionally, average RFF values improved following nebulized saline treatment during AM and PM Offset Cycle 10 and AM Onset Cycle 1 tokens; these improvements were statistically significant at the .05 alpha level for the AM Onset Cycle 1 tokens. In general, these results indicate that RFF may be a sensitive measure for voice severity in the Primary SS population; RFF might also be sensitive to functional changes in voice production with vocal fold hydration treatment. Given the preliminary nature of the current study, some caution is warranted when interpreting these results. However, the primary findings of the current study, in the context of recent literature involving RFF quantification of voice production, are discussed below.

When examining the RFF values reported in Table 1, it is useful to consider RFF values among typical and voice disorder populations previously reported in the literature. Stepp et al. (2010) examined RFF values for individuals with vocal nodules, muscle tension dysphonia, and healthy controls, as well as pre-surgical versus post-surgical RFF values for individuals with vocal fold polyps. For individuals with voice disorders, average Offset Cycle 10 values ranged from -1.017 ST to -1.61 ST and average Onset Cycle 1 values ranging from 2.12 ST to 2.48 ST.

Changes in RFF for the polyp group were approximately .20 ST for Offset Cycle 10 and .40 ST for Cycle 1, and were not statistically significant. Healthy controls with typical voices averaged Offset Cycle 10 values of -.33 ST and Onset Cycle 1 values of 3.82 ST. Therefore, RFF values were observed to be generally greater for typical versus disordered voices. Similar findings were observed by Stepp et al. (2011) in individuals with vocal hyperfunction, including vocal nodules and muscle tension dysphonia varieties. Pre-therapy average Offset Cycle 10 values were -.80 ST and Onset Cycle 1 values were 1.90 ST; post-therapy Offset Cycle 10 values were -.30 ST and Onset Cycle 1 values were 2.71 ST.

The methodology from the current study attempted to follow precisely the methodology reported by Stepp et al. (2010, 2011; Lien et al., 2014); therefore, it was anticipated that the RFF values in this study would fall within the range of those reported previously. In general, the baseline values in the current study are similar to the disorder Offset values previously reported in Stepp et al. (2010) and are more severe than those reported in Stepp et al. (2011); Onset values were slightly more severe than those reported in both studies. Although RFF generally improved with nebulized saline in the current study, post-treatment Offset and Onset values remained in the voice disorders range. Interestingly, the magnitude of RFF change in the current study (i.e., approximately .40 ST) was similar to that reported for the vocal fold polyp treatment group in Stepp et al. (2010), but less than the improvement reported for the vocal fold hyperfunction participants in Stepp et al. (2011). Therefore, it is not surprising that the RFF change with nebulized saline treatment was not statistically significant. Stepp et al. (2011) theorized that RFF might be more sensitive to functional, versus structural, voice change with treatment and factors such as age, treatment efficacy, and measurement variability might account for some of the

variance in RFF values. Nevertheless, it is reassuring that the RFF values observed in this study are within the range of those previously reported in the literature.

Previous research indicates that several factors likely account for voice disorders in individuals with Primary SS. The presence of vocal fold lesions, neuropathy, dryness, viscous secretions, age-related changes, and muscle tension dysphonia has been observed in this population (Allec et al., 2011; Heller et al., 2014; Ogut et al., 2005). Although the individuals in the current study did not undergo videolaryngostroboscopic evaluation, patient-based and other acoustic analysis as part of the larger investigation indicated the presence of mild to mild-to-moderate voice disorders in this group (Miner, 2014). The RFF values in the current study are slightly more severe than those reported for mild-to-moderate vocal hyperfunction based on the CAPE-V (Stepp et al., 2011), and are similar to those from Stepp et al. (2010), wherein voice severity was not reported. These RFF magnitude differences might reflect differences in voice disorder causality (i.e., more structural than functional) or methodological differences related to sample inclusion or exclusion criteria, pulse selection, or number of tokens analyzed from each voice recording. These differences notwithstanding, RFF analysis does seem to be sensitive to voice disorders present during connected speech in individuals with Primary SS. In a similar vein, RFF improved with nebulized treatment, but did not fall within the normal range based on samples from typical speakers (Stepp et al., 2010). Indeed, RFF values were more similar to post-treatment values observed in vocal hyperfunction (Stepp et al., 2011). Perhaps this relates to the heterogeneous causative factors associated with voice disorders in Primary SS and that hydration treatments might only address one of these factors in promoting voice improvement (Heller et al., 2014).

When interpreting findings from the current study, it is important to consider several factors that might have influenced the results. One of the largest factors may be the sample inclusion and exclusion criteria. Due to the nature of how RFF is calculated, the analysis will not tolerate certain acoustic parameters, which are relatively common in disordered voices. These might include sample tokens with vocal fry, voice breaks, or were spoken quickly and therefore did not contain 10 pulses prior to and following the voiceless consonant. Any time samples are excluded based on criteria that potentially discriminate voices based on level of severity, the external validity of the analysis procedures should be considered. Similarly, the reliability estimates in the present study, though high, were not as high as those reported by Stepp and colleagues (2010, 2011). This suggests that additional training might be required to ensure that analyses are being performed correctly, or possibly that strict inclusion and exclusion criteria might influence the reliability of the results. Nevertheless, the reliability estimates in the current study were strong and indicated confidence that the analyses were accomplished following standard operational procedures.

One possibility for reducing the influence of these factors in future studies might be to select additional tokens from each connected speech sample, which might also reduce the variability seen in RFF values. Similarly, determining how much RFF varies from day to day in typical versus atypical speakers would be useful. Although the Rainbow Passage is often used in clinical voice sampling, it is possible that a standardized protocol geared toward RFF analysis might ensure an adequate number of pulses prior to and following the voiceless consonant. And lastly, making the RFF analysis procedure more automatic might improve clinical utility in addition to the benefits of standardization and reliability.

Conclusion

This study sought to examine the effectiveness of RFF in quantifying voice disorder severity. Possible voice production changes with nebulized saline treatment were also identified in individuals with Primary SS. The results indicated that RFF values for this sample were similar to previously reported RFF values in individuals with voice disorders. Additionally, RFF values were shown to improve with the nebulized saline treatment. However, RFF values still did not fall within the normal range for typical speakers. These findings were similar to other populations of voice disorders who experienced improvement, but not complete normalization, of RFF with treatment. Patient-based factors, such as age and diagnosis as well as measurement and methodological factors, might affect RFF values. The results indicate that RFF may be a sensitive measure for voice severity in the Primary SS population and may be used clinically for treatment criterion. Additionally, RFF might also be sensitive to functional changes in voice production with vocal fold hydration treatment.

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Appendix A: Informed Consent and Authorization

BACKGROUND
You are being asked to take part in a research study. People with Sjögren's Syndrome may be more likely to experience voice problems and throat dryness. The University of Utah Health Care Voice Disorders Center is studying the effects of throat dryness and hydration in individuals with Sjögren's.
Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with friends and relatives if you wish. Ask the research doctor or staff if there is anything that is not clear or if you would like more information. Take time to decide whether or not to volunteer to take part in this research study.

STUDY PROCEDURES
This research study will examine the effects of a hydration treatment on the voice and throat dryness. All participants will be individuals with Sjögren's. If you agree to participate in this study, you will participate in an 8-week home program including the hydration treatment, research paperwork, and audio recordings. You will do all research tasks in your own home, and will not need to travel to participate. The hydration treatment is inhaled saline mist. The mist is similar to fluid in the cells in your body.

The study is divided into 4, 2-week phases. The first 2 weeks will be the baseline phase. You will complete daily ratings of your voice and dryness, and recordings of your voice using the portable recorder we send you. The next 2 weeks will be the first treatment phase. You will continue all the ratings you did during the first phase, but will add the daily hydration treatment in the morning and evening. The treatment involves breathing saline using a personal nebulizer. The treatment is 9 mL, and takes approximately 15 minutes to administer.

The next phase of the research study involves withdrawing the nebulized treatment. During this 2-week phase, you will not receive the hydration treatment, but will continue completing daily ratings and audio recordings. The final phase includes 2-weeks of the hydration treatment, ratings, and recordings. You will mail ratings in a prepaid envelope at the end of each 2-week phase. When the study is completed, you will return the audio equipment in a prepaid envelope.

Your participation is outlined in the table below:

Study Phase	Participation
Phase 1 = Baseline 2 weeks	Daily ratings of voice and dryness; Daily recording of voice
Phase 2 = Treatment 2 weeks	Daily ratings of voice and dryness; Daily recordings of voice; Twice-daily nebulized treatment
Phase 3 = Baseline 2 weeks	Daily ratings of voice and dryness; Daily recording of voice
Phase 4 = Treatment 2 weeks	Daily ratings of voice and dryness; Daily recordings of voice; Twice-daily nebulized treatment

You will receive detailed instructions on how to perform the ratings and recordings. The study coordinator will call you before you begin the study to review the instructions with you and answer questions. Also, the study coordinator will be available by telephone to answer any questions you might have.

RISKS

It is possible that you may experience occasional coughing associated with the inhaled mist. This coughing should be infrequent, and should not continue after the treatment is completed. The nebulizers used in this study have been used to treat asthma and have not been reported to be uncomfortable.

REPRODUCTIVE RISKS

If you are pregnant or think you might be pregnant, you should not participate in the study. The inhaled mist is not believed to have adverse effects in pregnancy. However, changes to the voice during pregnancy could influence the research study outcomes. Therefore pregnant women are not being included in this study.

BENEFITS

There are no direct benefits to you from your taking part in this study. The information we get from this study may help us provide better recommendations to address throat dryness in people with Sjögren's.

ALTERNATIVE PROCEDURES

There are no similar alternative treatments to the inhaled treatments being studied in this research.

CONFIDENTIALITY

The results of this study will be stored on a password-protected computer on a University of Utah network drive with restricted access. Only the investigators and research assistants will have access to the results and confidentiality and privacy will be maintained. You will be assigned a code number and your name will not appear on any written or computer documents. All identifying information will be stored separately, preventing any link between you and the results. The results of this study may be published for scientific purposes. By Federal Law, the information gathered in this study may be reviewed by the United States Food and Drug Administration. We will do everything we can to keep your records private, but cannot guarantee this.

PERSON TO CONTACT

If you have questions, complaints or concerns about this study, you can contact Dr. Kristine Tanner at (801) 633-7471. If you think you may have been injured from being in this study, please call Dr. Mark Elstad, MD or Dr. Kathy Kendall, MD at (801) 587-8368. The doctors can be reached at this number during the hours of 8:30 am to 4:30 pm.

Institutional Review Board: Contact the Institutional Review Board (IRB) if you have questions regarding your rights as a research participant. Also, contact the IRB if you have questions, complaints or concerns which you do not feel you can discuss with the investigator. The University of Utah IRB may be reached by phone at (801) 581-3655 or by e-mail at irb@hsc.utah.edu.

Research Participant Advocate: You may also contact the Research Participant Advocate (RPA) by phone at (801) 581-3803 or by email at participant.advocate@hsc.utah.edu.

RESEARCH-RELATED INJURY

If you are injured from being in this study, medical care is available to you at the University of Utah, as it is to all sick or injured people. The University of has not set aside any money to pay the costs for such care. The University will work with you to address costs from injuries. Costs would be charged to you or your insurance company (if you have insurance), to the study sponsor or other third party (if applicable), to the extent those parties are responsible for paying for medical care you receive. Since this is a research study, some health insurance plans may not pay for the costs. By signing this consent form you are not giving up your right to pursue legal action against any parties involved with this research.

The University of Utah is a part of the government. If you are injured in this study, and want to sue the University or the doctors, nurses, students, or other people who work for the University, special laws may apply. The Governmental Immunity Act of Utah is a law that controls when a person needs to bring a claim against the government, and limits the amount of money a person may recover. See sections 63G - 7-101 to -904 of the Utah Code.

VOLUNTARY PARTICIPATION
It is up to you to decide whether or not to take part in this study. If you decide to take part you are still free to withdraw at any time and without giving a reason. Refusal to participate or the decision to withdraw from this study will involve no penalty or loss of benefits to which you are otherwise entitled. If you don't take part, you can still receive all standard care that is available to you. This will not affect the relationship you have with your doctor or other staff, nor decrease the standard of care that you receive as a patient.

UNFORESEEABLE RISKS
In addition to the risks listed above, you may experience a previously unknown risk or side effect.

COSTS AND COMPENSATION TO PARTICIPANTS
There is no cost associated with your participation in this study. You will be compensated in the amount of $160 after completing the study. A check will be mailed after you have completed the 8-week program and have returned the ratings and recording equipment. Compensation is not available to participants who do not complete the study. Brigham Young University, Provo, Utah is funding this study, and will retain your name and citizenship status for accounting purposes. If you prefer not to have your information retained by Brigham Young University, you may still participate in the study and can choose not to receive compensation.

NUMBER OF PARTICIPANTS
We expect to enroll 15 individuals with Sjögren's in this study at The University of Utah.

AUTHORIZATION FOR USE OF YOUR PROTECTED HEALTH INFORMATION
Signing this document means you allow us , the researchers in this study, and others working with us to use information about your health for this research study. You can choose whether or not you will participate in this research study. However, in order to participate you have to sign this consent and authorization form.
This is the information we will use:

- Name

- Address

- Telephone number

- Participant's prior medical history (self-report)

- Sjögren's Syndrome diagnosis medical records

- Vocal measures and throat dryness ratings that will be performed in the study

Others who will have access to your information for this research project are the University's Institutional Review Board (the committee that oversees research studying people) and authorized members of The University of Utah Health Sciences Center who need the information to perform their duties (for example: to provide treatment, to ensure integrity of the research, and for accounting or billing matters).

If we share your information with anyone outside The University of Utah Health Sciences Center you will not be identified by name, social security number, address, telephone number, or any other information that would directly identify you, unless required by law.

You may revoke this authorization. This must be done in writing. You must either give your revocation in person to the Principal Investigator or the Principal Investigator's staff, or mail it to Kristine Tanner, Ph.D., Voice Disorders Center, 729 Arapeen Dr., Salt Lake City, UT, 84108. If you revoke this authorization, we will not be able to collect new information about you, and you will be withdrawn from the research study. However, we can continue to use information we have already started to use in our research, as needed to maintain the integrity of the research.

You have a right to information used to make decisions about your health care. However, your information from this study will not be available during the study; it will be available after the study is finished.

This authorization does not have an expiration date.

CONSENT
I confirm that I have read this consent and authorization document and have had the opportunity to ask questions. I will be given a signed copy of the consent and authorization form to keep.

I agree to take part in this research study and authorize you to use and disclose health information about me for this study, as you have explained in this document.

_____
Participant's Name

_____   _____
Participant's Signature   Date

_____
Name of Person Obtaining Authorization and Consent

_____   _____
Signature of Person Obtaining Authorization and Consent   Date

Would you like to receive information on future studies involving Sjögren's Syndrome?

Yes _____ (we will retain your name, telephone number, and mailing address to provide information)

No _____

Appendix B: Sjögren's Symptom Severity Scale Questionnaires

Instructions: Please complete the following questions.

Participant # ____
Date: ____

Please consider the past 2 weeks when rating the following:

Sore Eyes

      0   1   2   3   4   5   6   7

0=No problem at all   7=As bad as imaginable

Eye Irritation

      0   1   2   3   4   5   6   7

0=No problem at all   7=As bad as imaginable

Poor Vision

      0   1   2   3   4   5   6   7

0=No problem at all   7=As bad as imaginable

Difficulty Eating

      0   1   2   3   4   5   6   7

0=No problem at all   7=As bad as imaginable

Dry Throat/Bad Breath

      0   1   2   3   4   5   6   7

0=No problem at all   7=As bad as imaginable

(Difficulty) Wetting Mouth (e.g., needing to drink fluid often)

      0   1   2   3   4   5   6   7

0=No problem at all   7=As bad as imaginable

Oral Problems (e.g., ulcers, swollen salivary glands, taste altered)

      0   1   2   3   4   5   6   7

0=No problem at all   7=As bad as imaginable

Vaginal Dryness (females only)

      0   1   2   3   4   5   6   7

0=No problem at all   7=As bad as imaginable

Skin Dryness

      0   1   2   3   4   5   6   7

0=No problem at all   7=As bad as imaginable

Systemic Discomfort/Arthralgia (joint pain)

      0   1   2   3   4   5   6   7

0=No problem at all   7=As bad as imaginable

Sjögren's Questionnaire 2

Please rate the items below, where 0=no dryness and 10=maximum dryness.

Dryness

0   1   2   3   4   5   6   7   8   9   10

Limb Pain

0   1   2   3   4   5   6   7   8   9   10

Fatigue

0   1   2   3   4   5   6   7   8   9   10

Appendix C: Voice Handicap Index

NAME_____   Date_____

Voice Handicap Index (VHI)

Instructions: These are statements that many people have used to describe their voices and the effects of their voices on their lives. Check the response that indicates how frequently you have the same experience. (Never=0 points, Almost Never=1 point, Sometimes=2 points, Almost Always=3 points, Always=4 points)

		Never	Almost Never	Sometimes	Almost Always	Always
F1	My voice makes it difficult for people to hear me					
P2	I run out of air when I talk					
F3	People have difficulty understanding me in a noisy room					
P4	The sound of my voice varies throughout the day					
F5	My family has difficulty hearing me when I call them					
F6	I use the phone less often than I would like					
E7	I'm tense when talking with others because of my voice					
F8	I tend to avoid groups of people because of my voice					
E9	People seem irritated with my voice					
P10	People ask, "What's wrong with your voice?"					
F11	I speak with friends, neighbors or relatives less often because					
F12	People ask me to repeat myself when speaking face-to-face					
P13	My voice sounds creaky and dry					
P14	I feel as though I have to strain to produce voice					
E15	I find other people don't understand my voice problem					
F16	My voice difficulties restrict my personal and social life					
P17	The clarity of my voice is unpredictable					
P18	I try to change my voice to sound different					
F19	I feel left out of conversations because of my voice					
P20	I use a great deal of effort to speak					
P21	My voice is worse in the evening					
F22	My voice problem causes me to lose income					
E23	My voice problem upsets me					
E24	I am less out-going because of my voice problem					
E25	My voice problem makes me feel handicapped					
P26	My voice "gives out" on my in the middle of speaking					
E27	I feel annoyed when people ask me to repeat					
E28	I feel embarrassed when people ask me to repeat					
E29	My voice makes me feel incompetent					
E30	I'm ashamed of my voice problem					

***Please circle the word that matches how you feel your voice is today: No Problem   Mild Problem   Moderate Problem Severe Problem

On a scale of 1-10, with 1 being least talkative and 10 being most talkative, how would your rate yourself?

On a scale of 1-10, with 1 being most soft and 10 being most loud, how would you rate yourself?

For Clinician Use Only:

P Scale _____F Scale_____ E Scale_____ Total_____

Jacobson, Johnson, Grywalski, Silbergleit, Jacobson, Benninger, & Newman (1997). The Voice Handicap Index (VHI). *American Journal of Speech Language Pathology, 6*, 66-70.

Appendix D: Medical History

Instructions: Please complete the following questions on the <u>first day of week 1.</u>

Participant # _____
Date: _____

Medical History

1. How long have you had Sjögren's <u>symptoms</u> (# years)?

2. How long have you been <u>diagnosed</u> with Sjögren's (# years)?

3. Please list all treatments tried for Sjögren's, if they helped, and if you are still using this treatment:

4. Please list other health conditions:

5. Do you have asthma or other pulmonary disease (if yes, please describe and list meds/inhalers/oxygen use/CPAP)?

6. Do you smoke, or have you ever smoked (if yes, frequency, # years)?

7. Date of your last menstrual period (possible effect on voice quality):

8. Do you have acid reflux/heartburn (if yes, # years)?

9. Do you have seasonal allergies (if yes, please list, including medications taken for allergies)?

10. What (other) medications do you take, and why?

11. Have you had voice training (if yes, number of years, type of training)?

Appendix E: Select Medical History Factors

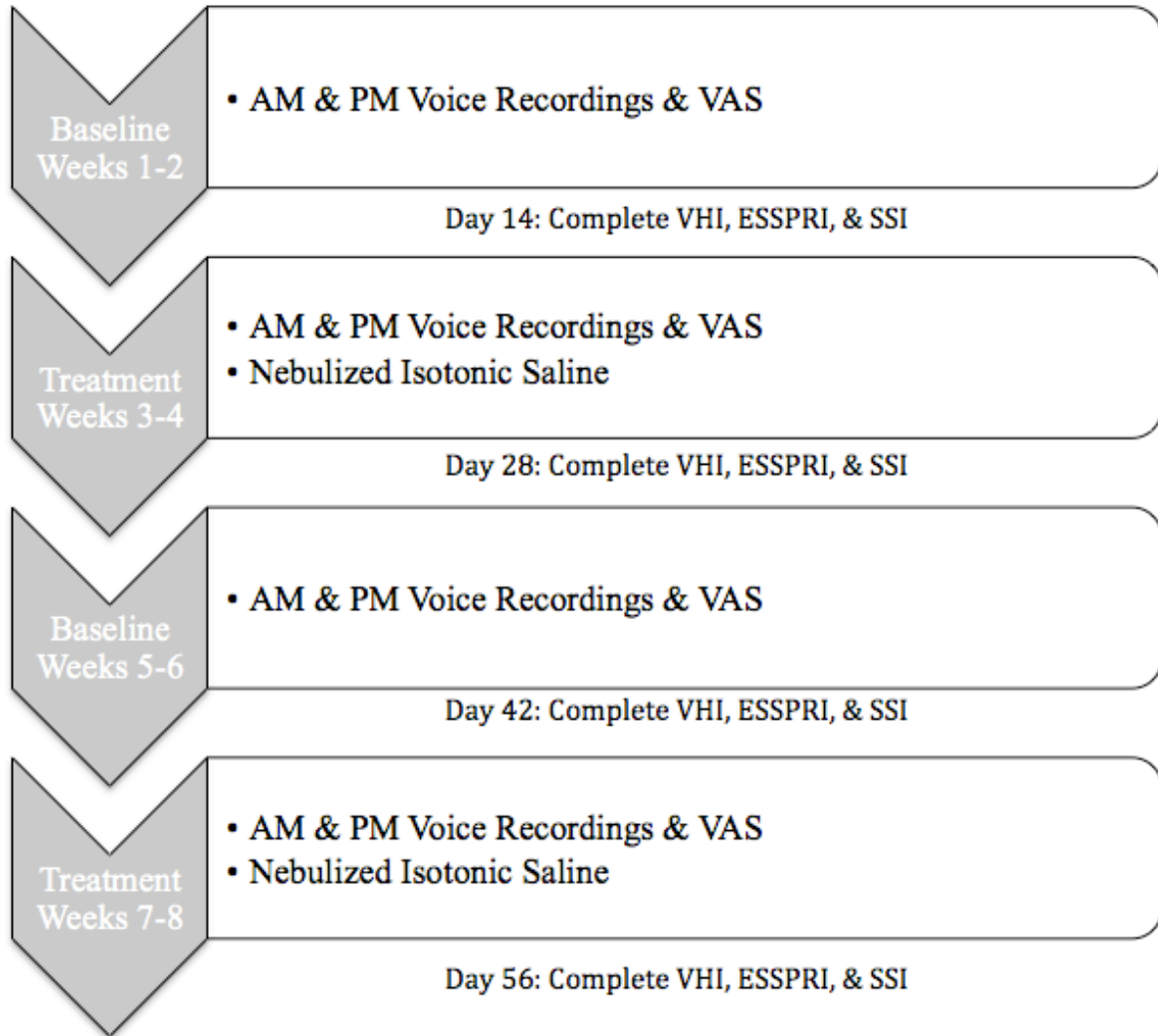| Factor		Participant							
		1	2	3	4	5	6	7	8
Sex									
	Male								
	Female	x	x	x	x	x	x	x	x
Age									
	36 to 45		x		x		x		
	46 to 55								
	56 to 65	x							
	66 to 75			x		x		x	x
Sicca Symptoms (years since onset)									
	0 to 5		x						
	6 to 10	x			x		x		
	11 to 20			x		x			x
	21+							x	
SS (years diagnosed)									
	0 to 5		x		x				
	6 to 10	x					x		
	11 to 20			x		x			x
	21+							x	
SS related medications									
	Hydroxychloroquine	x	x	x	x	x	x		
	Pilocarpine	x	x	x	x	x		x	
	Evoxac		x				x		
	Retuxan		x						
	Anucort				x				
	Prednisone					x			
	Imuran					x			
Other Sicca treatments									
	Restatis				x			x	
	Nasal spray				x				
	Humidifier				x				
	Preservative-free eye drops				x				
	Biotene products						x		
	Gum						x	x	x
	Refresh eye drops							x	
	Sugar-free lemon drops							x	
	Mouth spray								x
	Water								x
Other Health Care conditions									
	Hypothyroidism	x				x	x		
	Peripheral neuropathy	x							
	Juvenile rheumatoid arthritis		x						
	Dry eyes/mouth			x					
	Arthritis			x					
	Osteoporosis			x					
	Raynaud's				x				
	Rheumatoid arthritis			x				x	x
	Heart stent							x	
	Lymphoma							x	
	Interstitial lung disease								x
	Sleep apnea								x
Asthma/Pulminary Disease		x				x			x
Wears O2								x	x
Smokes						x			
Acid Reflux/heatburn		x	x			x		x	x
Seasonal Allergies		x	x	x	x	x		x	
Voice Training			x						

Appendix F: Experimental Protocol

Thank you for participating in this study! We have outlined the steps you will perform during the next **8 weeks** below. Please contact Dr. Kristine Tanner at (801) 633-7471 with questions at any time during your participation.

1. Complete Voice Handicap Index, Sjögren's Questionnaires, and Medical History the day before you begin the study.

2. Read Zoom instruction manual. Watch Omron nebulizer instructional DVD.

3. <u>Weeks 1-2</u>: Complete baseline audio recordings and ratings <u>every morning and evening at similar times of day</u>. Track completion on the <u>Participant Log (Note: track any additional information, protocol deviations, and illnesses/colds on the participant log throughout the study)</u>. Purchase distilled water and white vinegar. Clean nebulizer following manufacturer instructions.

4. Complete the Voice Handicap Index and Sjögren's Questionnaires again on the last day of Week 2.

5. <u>Weeks 3-4</u>: Complete audio recordings and ratings prior to nebulizing. <u>Nebulize 9 mL of saline TWICE daily, immediately following recording and ratings</u>. (Note: Spray saline into medicine cup and fill to black 9mL line. Pour into nebulizer per manufacturer instructions. The nebulizer holds about 6 mL, so you will need to pour saline in 2 stages to reach 9 mL. It should take 15-20 min to breathe the saline. **It is essential that you breathe in and out continuously with your lips around the nebulizer mouthpiece. Don't remove the nebulizer during exhalation like the woman does in the DVD! You should breathe continuously, in and out, at your normal respiration rate.** Stop nebulizing when the mist runs out.). Track completion on the Participant Log. Clean nebulizer daily per manufacturer instructions.

6. Complete Voice Handicap Index and Sjögren's Questionnaires again on the last day of Week 4.

7. <u>Weeks 5-6</u>: Complete baseline audio recordings and ratings. Track completion on the Participant Log. **Do not use the nebulizer during these weeks.**

8. Complete Voice Handicap Index and Sjögren's Questionnaires again on the last day of Week 6.

9. <u>Weeks 7-8</u>: Complete audio recordings and ratings prior to nebulizing. <u>Nebulize 9 mL of saline TWICE daily, immediately following recording and ratings</u>. Track completion on the Participant Log. Clean nebulizer daily per manufacturer instructions.

10. Complete Voice Handicap Index and Sjögren's Questionnaires on the last day of Week 8.

11. Return the portable recorder, head-mounted microphone, and all study forms in the pre-addressed, postage-paid box. Please use bubble wrap from the original shipment to protect the equipment. <u>You will need to ship this package from the Post Office counter.</u> Please keep the nebulizer as this is a personal medical device and cannot be reused.

Appendix G: Overview of Study

Study Onset: Complete Medical History, VHI, ESSPRI, & SSI

Baseline Weeks 1-2	• AM & PM Voice Recordings & VAS

Day 14: Complete VHI, ESSPRI, & SSI

Treatment Weeks 3-4	• AM & PM Voice Recordings & VAS • Nebulized Isotonic Saline

Day 28: Complete VHI, ESSPRI, & SSI

Baseline Weeks 5-6	• AM & PM Voice Recordings & VAS

Day 42: Complete VHI, ESSPRI, & SSI

Treatment Weeks 7-8	• AM & PM Voice Recordings & VAS • Nebulized Isotonic Saline

Day 56: Complete VHI, ESSPRI, & SSI

Appendix H: Recording Instructions

Recordings will be performed twice daily, at similar times of day, for 8 weeks. You will read a paragraph, sentences, a list of words (3 times) and sustain "ah" (3 times for 5 seconds each), during each recording. It is very important that recordings are made under similar conditions, with the same mouth-to-microphone distance, and in quiet environments. Recordings are made with you speaking at comfortable pitch and loudness.

Please read the Zoom H1 instruction manual prior to performing recordings. Recording steps have been summarized here:

1. Put on the headset microphone with the pads over the temples. The silver microphone should be facing your lips, approximately 3 inches away, like the photos enclosed. The microphone puff should be covering the mic (see photo 2).
2. Be sure the mic is plugged into the mic/line in slot on the recorder (see diagram #1).
3. Turn on the recorder by holding the power lever to the left for 2 seconds (see diagram #2). The LCD screen will say "Hi" (see diagram #3).
4. Check the battery level on the upper right of the LCD screen. If the battery is low, replace with another AA battery (enclosed).
5. Test the record level by reading the first sentence of the reading passage (below), watching the moving bars on the left side of the LCD screen (see diagram #4). They should range between 50-75% of the scale. If you are "too loud", a red light will flash (see diagram #5). If this happens, adjust the mic slightly away from your lips (don't just get softer; keep the comfortable pitch and loudness and adjust the mic instead).
6. When you are ready, press the "record" button (see diagram #6).

At the beginning of each recording, say your participant number, day of the week, date and time.

Then read: "WHEN THE SUNLIGHT STRIKES RAINDROPS IN THE AIR THEY ACT LIKE A PRISM AND FORM A RAINBOW. THE RAINBOW IS A DIVISION OF WHITE LIGHT INTO MANY BEAUTIFUL COLORS. THESE TAKE THE SHAPE OF A LONG ROUND ARCH WITH ITS PATH HIGH ABOVE, AND ITS TWO ENDS APPARENTLY BEYOND THE HORIZON. THERE IS, ACCORDING TO LEGEND, A BOILING POT OF GOLD AT ONE END. PEOPLE LOOK, BUT NO ONE EVER FINDS IT. WHEN A MAN LOOKS FOR SOMETHING BEYOND HIS REACH, HIS FRIENDS SAY HE IS LOOKING FOR THE POT OF GOLD AT THE END OF THE RAINBOW."

"The blue spot is on the key again." (pause briefly)
We were away a year ago. (pause briefly)
We eat eggs every Easter." (pause briefly)

Read the 3 lists of words at normal rate:

List 1	List 2	List 3
"Bye"	"Boy"	"Bay"
"Heat"	"Hoot"	"Hat"
"Bow" (like "go")	"Bay"	"Bow" (go)
"Hat"	"Hot"	"Hot"
"Bough" (like "cow")	"Bough" (cow)	"Bye"
"Hot"	"Hat"	"Hoot"
"Bay"	"Bow" (go)	"Bough" (cow)
"Hoot"	"Heat"	"Heat"
"Boy"	"Bye"	"Boy"
"Hut"	"Hut"	"Hut"

Say and hold "ah" for at least 5 seconds at a comfortable pitch and loudness. <u>Do this 3 times, pausing in between.</u>

7. Press the "record" button again to stop recording. Remaining record time available will be indicated on the LCD screen.
8. Turn off the recorder by holding the power lever to the left for 2 seconds. The LCD screen will say "bye".

Appendix I: Patient-based Rating (Weeks 1, 2, 5, and 6)

RATINGS

Participant #: _____
WEEK 1 (Baseline)

Instructions: Please rate your level of vocal effort, mouth dryness, and throat dryness **every morning and evening** using the rating scales below. You may refer to previous ratings.

For vocal effort, please rate the amount required during the recorded reading task by placing a <u>vertical line</u> on the scale. The extreme left of the scale represents "no effort" and the extreme right represents "extreme effort".

For mouth and throat dryness, please rate your current level of dryness by placing a <u>vertical line</u> on the scale below. The extreme left of the scale represents "no dryness" and the extreme right represents "extreme dryness".
(*note: lines not to scale)

Date: _____   AM

No Vocal Effort _____ Extreme Vocal Effort

No Mouth Dryness _____ Extreme Mouth Dryness

No Throat Dryness _____ Extreme Throat Dryness

PM

No Vocal Effort _____ Extreme Vocal Effort

No Mouth Dryness _____ Extreme Mouth Dryness

No Throat Dryness _____ Extreme Throat Dryness

Date: _____   **AM**

No Vocal Effort _____ Extreme Vocal Effort

No Mouth Dryness _____ Extreme Mouth Dryness

No Throat Dryness_____ Extreme Throat Dryness

PM

No Vocal Effort _____ Extreme Vocal Effort

No Mouth Dryness_____ Extreme Mouth Dryness

No Throat Dryness_____ Extreme Throat Dryness

Date: _____   **AM**

No Vocal Effort _____ Extreme Vocal Effort

No Mouth Dryness _____ Extreme Mouth Dryness

No Throat Dryness_____ Extreme Throat Dryness

PM

No Vocal Effort _____ Extreme Vocal Effort

No Mouth Dryness_____ Extreme Mouth Dryness

No Throat Dryness_____ Extreme Throat Dryness

Date: _____   **AM**

No Vocal Effort _____ Extreme Vocal Effort

No Mouth Dryness _____ Extreme Mouth Dryness

No Throat Dryness_____ Extreme Throat Dryness

PM

No Vocal Effort _____ Extreme Vocal Effort

No Mouth Dryness_____ Extreme Mouth Dryness

No Throat Dryness_____ Extreme Throat Dryness

Date: ____ **AM**

No Vocal Effort _____ Extreme Vocal Effort

No Mouth Dryness _____ Extreme Mouth Dryness

No Throat Dryness_____ Extreme Throat Dryness

PM

No Vocal Effort _____ Extreme Vocal Effort

No Mouth Dryness_____ Extreme Mouth Dryness

No Throat Dryness_____ Extreme Throat Dryness

Date: ____ **AM**

No Vocal Effort _____ Extreme Vocal Effort

No Mouth Dryness _____ Extreme Mouth Dryness

No Throat Dryness_____ Extreme Throat Dryness

PM

No Vocal Effort _____ Extreme Vocal Effort

No Mouth Dryness_____ Extreme Mouth Dryness

No Throat Dryness_____ Extreme Throat Dryness

Date: ____ **AM**

No Vocal Effort _____ Extreme Vocal Effort

No Mouth Dryness _____ Extreme Mouth Dryness

No Throat Dryness_____ Extreme Throat Dryness

PM

No Vocal Effort _____ Extreme Vocal Effort

No Mouth Dryness_____ Extreme Mouth Dryness

No Throat Dryness_____ Extreme Throat Dryness

Appendix J: Patient-based Rating (Weeks 3, 4, 7, and 8)

RATINGS

Participant #: _____
WEEK 3 (Treatment)

Instructions: Please rate your level of vocal effort, mouth dryness, and throat dryness **every morning and evening** using the rating scales below. You may refer to previous ratings.

For vocal effort, please rate the amount required during the recorded reading task by placing a <u>vertical line</u> on the scale. The extreme left of the scale represents "no effort" and the extreme right represents "extreme effort".

For mouth and throat dryness, please rate your current level of dryness by placing a <u>vertical line</u> on the scale below. The extreme left of the scale represents "no dryness" and the extreme right represents "extreme dryness".
(*note: lines not to scale)

<u>Please complete all ratings BEFORE nebulizing.</u>

Date: ___   AM

No Vocal Effort _____ Extreme Vocal Effort

No Mouth Dryness _____ Extreme Mouth Dryness

No Throat Dryness _____ Extreme Throat Dryness

          PM

No Vocal Effort _____ Extreme Vocal Effort

No Mouth Dryness _____ Extreme Mouth Dryness

No Throat Dryness _____ Extreme Throat Dryness

Date: ____   AM

No Vocal Effort _____ Extreme Vocal Effort

No Mouth Dryness _____ Extreme Mouth Dryness

No Throat Dryness _____ Extreme Throat Dryness

PM

No Vocal Effort _____ Extreme Vocal Effort

No Mouth Dryness _____ Extreme Mouth Dryness

No Throat Dryness _____ Extreme Throat Dryness

Date: ____   AM

No Vocal Effort _____ Extreme Vocal Effort

No Mouth Dryness _____ Extreme Mouth Dryness

No Throat Dryness _____ Extreme Throat Dryness

PM

No Vocal Effort _____ Extreme Vocal Effort

No Mouth Dryness _____ Extreme Mouth Dryness

No Throat Dryness _____ Extreme Throat Dryness

Date: ____   AM

No Vocal Effort _____ Extreme Vocal Effort

No Mouth Dryness _____ Extreme Mouth Dryness

No Throat Dryness _____ Extreme Throat Dryness

PM

No Vocal Effort _____ Extreme Vocal Effort

No Mouth Dryness _____ Extreme Mouth Dryness

No Throat Dryness _____ Extreme Throat Dryness

Date: _____ **AM**

  No Vocal Effort _____ Extreme Vocal Effort

  No Mouth Dryness _____ Extreme Mouth Dryness

  No Throat Dryness_____ Extreme Throat Dryness

      PM

  No Vocal Effort _____ Extreme Vocal Effort

  No Mouth Dryness_____ Extreme Mouth Dryness

  No Throat Dryness_____ Extreme Throat Dryness

Date: _____ **AM**

  No Vocal Effort _____ Extreme Vocal Effort

  No Mouth Dryness _____ Extreme Mouth Dryness

  No Throat Dryness_____ Extreme Throat Dryness

      PM

  No Vocal Effort _____ Extreme Vocal Effort

  No Mouth Dryness_____ Extreme Mouth Dryness

  No Throat Dryness_____ Extreme Throat Dryness

Date: _____ **AM**

  No Vocal Effort _____ Extreme Vocal Effort

  No Mouth Dryness _____ Extreme Mouth Dryness

  No Throat Dryness_____ Extreme Throat Dryness

      PM

  No Vocal Effort _____ Extreme Vocal Effort

  No Mouth Dryness_____ Extreme Mouth Dryness

  No Throat Dryness_____ Extreme Throat Dryness

Appendix K: Participant Tracking Sheet

Participant # _____   **PARTICIPANT LOG**

On the day before beginning the study, complete:
___ Voice Handicap Index
___ Sjogren's Symptom Severity Scales
___ Medical History

Week 1 (Baseline)

Date:_____	Date:_____	Date:_____	Date:_____	Date:_____	Date:_____	Date:_____
__AM Recording __AM Ratings __PM Recording __PM Ratings	__AM Recording __AM Ratings __PM Recording __PM Ratings	__AM Recording __AM Ratings __PM Recording __PM Ratings	__AM Recording __AM Ratings __PM Recording __PM Ratings	__AM Recording __AM Ratings __PM Recording __PM Ratings	__AM Recording __AM Ratings __PM Recording __PM Ratings	__AM Recording __AM Ratings __PM Recording __PM Ratings

Week 2 (Baseline)

Date:_____	Date:_____	Date:_____	Date:_____	Date:_____	Date:_____	Date:_____
__AM Recording __AM Ratings __PM Recording __PM Ratings	__AM Recording __AM Ratings __PM Recording __PM Ratings	__AM Recording __AM Ratings __PM Recording __PM Ratings	__AM Recording __AM Ratings __PM Recording __PM Ratings	__AM Recording __AM Ratings __PM Recording __PM Ratings	__AM Recording __AM Ratings __PM Recording __PM Ratings	__AM Recording __AM Ratings __PM Recording __PM Ratings

On the last day of week 2, complete:
___ Voice Handicap Index
___ Sjogren's Symptom Severity Scales

Week 3 (Treatment)

Date:_____	Date:_____	Date:_____	Date:_____	Date:_____	Date:_____	Date:_____
__AM Recording __AM Ratings __AM Treatment __PM Recording __PM Ratings __PM Treatment	__AM Recording __AM Ratings __AM Treatment __PM Recording __PM Ratings __PM Treatment	__AM Recording __AM Ratings __AM Treatment __PM Recording __PM Ratings __PM Treatment	__AM Recording __AM Ratings __AM Treatment __PM Recording __PM Ratings __PM Treatment	__AM Recording __AM Ratings __AM Treatment __PM Recording __PM Ratings __PM Treatment	__AM Recording __AM Ratings __AM Treatment __PM Recording __PM Ratings __PM Treatment	__AM Recording __AM Ratings __AM Treatment __PM Recording __PM Ratings __PM Treatment

Week 4 (Treatment)

Date:___	Date:___	Date:___	Date:___	Date:___	Date:___	Date:___
__AM Recording	__AM Recording	__AM Recording	__AM Recording	__AM Recording	__AM Recording	__AM Recording
__AM Ratings	__AM Ratings	__AM Ratings	__AM Ratings	__AM Ratings	__AM Ratings	__AM Ratings
__AM Treatment	__AM Treatment	__AM Treatment	__AM Treatment	__AM Treatment	__AM Treatment	__AM Treatment
__PM Recording	__PM Recording	__PM Recording	__PM Recording	__PM Recording	__PM Recording	__PM Recording
__PM Ratings	__PM Ratings	__PM Ratings	__PM Ratings	__PM Ratings	__PM Ratings	__PM Ratings
__PM Treatment	__PM Treatment	__PM Treatment	__PM Treatment	__PM Treatment	__PM Treatment	__PM Treatment

On the last day of week 4, complete:
___ Voice Handicap Index
___ Sjogren's Symptom Severity Scales

Week 5 (Baseline)

Date:___	Date:___	Date:___	Date:___	Date:___	Date:___	Date:___
__AM Recording	__AM Recording	__AM Recording	__AM Recording	__AM Recording	__AM Recording	__AM Recording
__AM Ratings	__AM Ratings	__AM Ratings	__AM Ratings	__AM Ratings	__AM Ratings	__AM Ratings
__PM Recording	__PM Recording	__PM Recording	__PM Recording	__PM Recording	__PM Recording	__PM Recording
__PM Ratings	__PM Ratings	__PM Ratings	__PM Ratings	__PM Ratings	__PM Ratings	__PM Ratings

Week 6 (Baseline)

Date:___	Date:___	Date:___	Date:___	Date:___	Date:___	Date:___
__AM Recording	__AM Recording	__AM Recording	__AM Recording	__AM Recording	__AM Recording	__AM Recording
__AM Ratings	__AM Ratings	__AM Ratings	__AM Ratings	__AM Ratings	__AM Ratings	__AM Ratings
__PM Recording	__PM Recording	__PM Recording	__PM Recording	__PM Recording	__PM Recording	__PM Recording
__PM Ratings	__PM Ratings	__PM Ratings	__PM Ratings	__PM Ratings	__PM Ratings	__PM Ratings

On the last day of week 6, complete:
___ Voice Handicap Index
___ Sjogren's Symptom Severity Scales

Week 7 (Treatment)

Date:___	Date:___	Date:___	Date:___	Date:___	Date:___	Date:___
__AM Recording	__AM Recording	__AM Recording	__AM Recording	__AM Recording	__AM Recording	__AM Recording
__AM Ratings	__AM Ratings	__AM Ratings	__AM Ratings	__AM Ratings	__AM Ratings	__AM Ratings
__AM Treatment	__AM Treatment	__AM Treatment	__AM Treatment	__AM Treatment	__AM Treatment	__AM Treatment
__PM Recording	__PM Recording	__PM Recording	__PM Recording	__PM Recording	__PM Recording	__PM Recording
__PM Ratings	__PM Ratings	__PM Ratings	__PM Ratings	__PM Ratings	__PM Ratings	__PM Ratings
__PM Treatment	__PM Treatment	__PM Treatment	__PM Treatment	__PM Treatment	__PM Treatment	__PM Treatment

Week 8 (Treatment)

Date:___	Date:___	Date:___	Date:___	Date:___	Date:___	Date:___
__AM Recording	__AM Recording	__AM Recording	__AM Recording	__AM Recording	__AM Recording	__AM Recording
__AM Ratings	__AM Ratings	__AM Ratings	__AM Ratings	__AM Ratings	__AM Ratings	__AM Ratings
__AM Treatment	__AM Treatment	__AM Treatment	__AM Treatment	__AM Treatment	__AM Treatment	__AM Treatment
__PM Recording	__PM Recording	__PM Recording	__PM Recording	__PM Recording	__PM Recording	__PM Recording
__PM Ratings	__PM Ratings	__PM Ratings	__PM Ratings	__PM Ratings	__PM Ratings	__PM Ratings
__PM Treatment	__PM Treatment	__PM Treatment	__PM Treatment	__PM Treatment	__PM Treatment	__PM Treatment

On the last day of week 8, complete:
___ Voice Handicap Index
___ Sjogren's Symptom Severity Scales

Appendix L: Annotated Bibliography

Allec, L. D. R., Lopez, X. H., Porras, J. B. A. P., Ramos, R. V., del Valle, J. C. P., & Garcia, A. P. (2011). Alterations in voice, speech and swallowing in patients with Sjögren's Syndrome. *Acta Otorrinolaringológica Española, 62*(4), 255-264. doi: 10.1016/j.otorri.2010.12.011

> *Purpose:* This study sought to identify objective and specific impairments to describe voice, speech, and swallowing in patients with SS. *Method:* Thirty-one participants, including four Primary and 26 Secondary, with a confirmed diagnosis of SS and no history of vocal alterations or vocal pathologies that could be distinguishable from SS were interviewed and physically examined using nasolaryngeal endoscopy and videolaryngostroboscopy. Computerized voice spectrographic analysis using PRAAT® software and a fiberoptic endoscopic evaluation of swallowing was performed on all participants. *Results:* Dysphagia was found to be the most common problem in participants. Mild dysphonia was seen in most cases and did not interfere with speech intelligibility. Abnormalities were found principally in: one or more cranial nerves, nasopharyngolaryngeal mucosa, and in mucosal wave formation of vocal folds. *Conclusions:* Patients with SS have significant voice, speech, and swallowing abnormalities. These abnormalities are hypothesized to be associated with xerosis and possible secondary neurological abnormalities in SS. *Relevance to the current work:* Patients with SS were included in the current study. This article confirms that SS patients have high rates of voice abnormalities, particularly in mucosal wave vibration. Further research on how dryness may be a component of this abnormality is needed.

Bowman, S. J., Booth, D. A., Platts, R. G., Field, A., Rostron, J., & the UK Sjögren's Interest Group. (2003). Validation of the Sicca Symptoms Inventory for clinical studies of Sjögren's Syndrome. *Journal of Rheumatology, 30*(6), 1259-1266.

> *Purpose:* The purpose of this study was to construct a new measure of mucosal surface *sicca* or dryness symptoms for evaluating patients with Primary SS. *Method:* Female Caucasian groups of patients clinically diagnosed with SS, systematic lupus erythematous, and rheumatoid arthritis, as well as healthy controls, were assessed for saliva and tear production. Participants also completed a symptoms-profiling inventory, which consisted of both SS patients' self-reported items and construct-validated items. *Results:* From the surveys returned, approximately 70 in total, the domains of long-term and short-term versions showed strong correlations. *Conclusions:* The long-and-short form questionnaires correlate closely; this suggests the short-form is indeed a valid tool. Preliminary data further suggests that an even briefer questionnaire is feasible for this population. *Relevance to the current work:* The short form of the SSI assessment was used to rate participants' symptoms as a valuable tool to assess changes due to hydration treatment.

Erickson, E., & Sivasankar, M. (2010). Evidence for adverse phonatory change following an inhaled combination treatment. *Journal of Speech, Language, and Hearing Research, 53,* 75-83. doi:10.1044/1092-4388(2009/09-0024)

Purpose: The purpose of this study was to investigate whether inhaled combination treatments are detrimental to phonation through PTP and perceived phonatory effort. Inhaled combination treatments combine a corticosteroids and long-acting beta agonist in order to manage multiple respiratory symptoms— such as asthma and emphysema— simultaneously. *Method:* Fourteen healthy adults participated in a repeated-measures design. Participants were subjected to both inhaled combination treatments and sham treatments at approximately the same time on two consecutive days. The treatments were administered in a counterbalanced order among participants. PTP and self-perceived phonatory effort were measured prior to treatments, immediately after treatments, one hour post-treatment, and two hours post-treatment. *Results:* Inhaled combination treatments increased PTP; the increase in PTP was maintained for a two-hour period following administration. Sham treatments did not increase PTP. Further, perceived phonatory effort ratings were not significantly correlated with PTP. *Conclusions:* Inhaled combination treatments may have an acute adverse effect on phonation. Because inhaled combination treatments are increasingly prescribed across the lifespan, more research must be done to develop treatments that effectively control respiratory disease while minimizing an adverse effect on phonation. *Relevance to the current work:* The current thesis will explore the effects of a hydration treatment to alleviate adverse effects of chronic dryness in the nose, throat, and larynx. The hydration treatment may be generalized to many populations in need of vocal relief.

Erickson-Levendoski, E., & Sivasankar, M. (2011). Investigating the effects of caffeine on phonation. *Journal of Voice, 25,* 5.

Purpose: This study investigated the effects of caffeine and vocal loading on voice production in which two main objectives were examined. The first objective was to evaluate if caffeine can adversely affect vocal production and the second was to evaluate if caffeine aggravates the adverse phonatory effects of vocal loading, such as speaking for prolonged periods of time with background noise. *Method:* Sixteen healthy participants were divided into two groups for the study. Participants then consumed either a caffeine concentrate of 480 mg or the sham caffeine concentrate of 24 mg and were then asked to complete the vocal loading task while voice measures were obtained. *Results:* It was found that caffeine consumption did not adversely affect voice production. Additionally, neither caffeine nor sham consumption worsened the effects of vocal loading. *Conclusions:* The authors thus postulate that recommendations to eliminate caffeine, as a component of a vocal hygiene program, should be appraised on an individual basis. *Relevance to the current work:* Previous studies of vocal production in relation to measures of vocal effort show the need for more knowledge regarding vocal production.

Fisher, K. V., Ligon, J., Sobecks, J. L., & Roxe, D. M. (2001). Phonatory effects of body fluid removal. *Journal of Speech, Language, and Hearing Research, 44,* 354-367. doi:10.1044/1092-4388(2001/029)

Purpose: The purpose of this study was to explore the effects of body fluid reduction, without dehydration, on PTP as well as patient-perceived increases in phonatory effort and worsening voice quality. *Method:* Six women and two men

participated in the study. Seven of the subjects were in the end stage of renal disease, and one male subject was in full health. All participants presented normal speech and denied voice symptoms other than occasional and temporary hoarseness following a dialysis session. PTP, vocal effort rating, and voice quality were measured before, during, and after fluid removal. Fluid removal was calculated by taking the difference between ultrafiltered fluid and the fluids administered. Fluid removal was additionally validated against the difference between pre- and post-dialysis body weight. *Results:* Group data for participants who underwent body fluid removal revealed a statistically significant treatment effect for PTP. The effects observed for treatment were reversed by fluid replacement. *Conclusions:* Results indicate that depletion of substantial extracellular volume without body dehydration causes voice symptoms. However, the effect may possibly be mediated by autonomic nervous control. It is proposed that intrinsic mechanisms in the vocal folds may regulate water flux in response to hydration challenges. *Relevance to the current work:* The current study acknowledges that systemic hydration is important and will explore the effects of a superficial hydration treatment.

Goberman, A. M., & Blomgren, M. (2008). Fundamental frequency change during offset and onset of voicing in individuals with Parkinson disease. *Journal of Voice, 22,* 546-553.

> *Purpose:* This article examined short-term phonatory behavior in individuals with Idiopathic Parkinson Disease (PD). Specifically, F_0 was measured at the offset and onset of phonation before and after a voiceless consonant. *Method:* Nine individuals with PD, including six males and three females, between the ages of 57 and 84, participated in the study. Eight control participants were closely matched in age and gender. All participants produced speech samples that were digitally-examined to identify RFF differences in participants. Two sessions were conducted over two separate days, in which participants withdrew from medications for at least eight hours prior to the session. One data collection session took place 30 minutes before the participant took their usual morning medication, such that participants were not in a medication state. The second data collection occurred on the second day, approximately one hour after the participant took their morning medication. *Results:* Analysis of the data indicated that all participating groups used some laryngeal tension in initiation of voicing. Tension was lowest in individuals who were in their off-medication state, while the highest tension was found in age-matched control participants in their on-medication state. *Conclusions:* This study provides quantitative data to support perceptual voice fluctuations in response to levodopa medication in PD patients. *Relevance to the current work:* This study exemplifies that examining RFF can provide quantitative data to analyze mild voice changes. The current study will utilize RFF to determine vocal characteristics in the SS population.

Hanson, H. M. (2009). Effects of obstruent consonants on fundamental frequency at vowel onset in English. *The Journal of the Acoustical Society of America, 125,* 425-441.

> *Purpose:* This study sought to examine the influence of a voiced consonant on the F_0 of a vowel. *Method:* Vowels /i/ and /a/ were paired with stops, fricatives, and the nasal /m/ to form CVm syllables. The target syllables were then embedded in a sentence. Five

male and five female speakers read each sentence with intonation varied to produce each syllable in either a high, low, or neutral pitch environment. Using PRAAT® software, the F_0 contours were evaluated in each of the F_0 environments. *Results:* In a high-pitch environment, the F_0 following voiceless obstruents significantly increased relative to the baseline /m/. However, F_0 stayed close to the baseline following voiced obstruents. In a low-pitch environment, F_0 increased very slightly following all obstruents, voiced and unvoiced. The results were found to be consistent among both males and females, and in both stop and fricative consonants. *Conclusions:* It is suggested that the spreading of vocal energy that occurs during voiceless consonants in certain contexts in English may aid the resolution of gestural conflicts, including different acoustic manifestations in different pitch environments. It is hypothesized that voiceless consonants allow the weakening of a defining segmental gesture to occur without losing perceptual salience. *Relevance to the current work:* The current thesis will use the RFF before and after a voiceless consonant to determine the effects of a hydration treatment.

Hemler, R. J., Wieneke, G. H., & Dejonchere, P. H. (1997). The effect of relative humidity of inhaled air on acoustic parameters of voice in normal subjects. *Journal of Voice, 11,* 292-300. doi:10.1016/S0892-1997(97)80007-0

Purpose: The purpose of this study was to demonstrate if relative air humidity affects the voice. Specifically, this study sought to examine if there would be measurable effects with short-term changes in the humidity of the environmental air. *Method:* Eight healthy subjects, four men and four women, were included in this study. The participants inhaled three separate air conditions—dry, standard room, and humidified air—for 10 minutes each. After each inhalation, participants repeatedly produced sustained /a/ with controlled pitch and loudness. The voice recordings were analyzed for perturbation and noise-to-harmonic parameters. *Results:* Perturbation measures were found to increase after inhalation of dry air; however, no significant differences existed between standard air and humidified air. *Conclusions:* It is concluded that the human voice is sensitive to decreases in relative humidity of inhaled air. This is evidenced because even after a relatively short exposure to dry air, a significant increase in perturbation occurred. *Relevance to the current work:* The present study will explore the effects of nebulized saline solution, similar to humidified air conditions, on severely dry voices. It will explore the effects of this hydration treatment on severely dry voices. This study outlines the need for further investigation of hydration challenges.

Kassan, S. S., & Moutsopoulos, H. M. (2004). Clinical manifestations and early diagnosis of Sjögren's Syndrome. *Archives of Internal Medicine, 164*(12), 1275-1284. doi:10.1001/archinte.164.12.1275

Purpose: This work sought to give increased understanding of the autoimmune disease SS in both primary and secondary varieties. *Summary:* SS was found to be a systemic disease that can occur independently or in connection with other autoimmune diseases, such as rheumatoid arthritis or lupus. The disease is often under-diagnosed. Additionally, many patients are treated at the individual symptom level. Therefore, diagnosis time is frequently very long. Females are much more likely to have SS, and

approximately one million have a diagnosis; though many individuals who may have SS go undiagnosed. Often women attribute symptoms to menopause. Other problems can include dermatological problems, fatigue, joint problems, as well as gastroenterologic, neurologic, oncologic, and renal involvement. Symptoms are outlined in this work. *Conclusion:* SS is often under-diagnosed. Refined criteria assessments are assisting in properly diagnosing SS. Most treatments assist with symptom relief rather than recovery. SS is not a life threatening disease, but it can have a significant effect on quality of life. *Relevance to the Current Work:* Xerostomia, a common symptom in SS, can produce dryness in the nose, throat, and trachea. Treatments for dryness are needed for the improved and sustained quality of life in individuals with SS.

Lien, Y. A., & Stepp, C. E. (2013). Automated estimation of relative fundamental frequency. *Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Japan, 2013,* 2136-2139. doi:10.1109/EMBC.2013.6609956

>   *Purpose:* The purpose of this study was to develop a method to automate RFF estimation and to test the algorithm on recordings of 12 healthy participants and 12 participants with PD. *Method:* An automation algorithm was developed by using an algorithm similar to the "gold standard" which was developed using two trained technicians. *Results:* The mean squared error for the automated estimated of RFF were compared to the "gold standard" RFF estimates, and found to be similar. *Conclusions:* In comparison to the "gold standard" the means and 95% confidence intervals of the automated RFF estimates were similar. Automated RFF estimation is valuable clinically because it enables clinicians to use RFF analysis to quantify voice changes. Further work will focus on improving vocal cycle detection as well as estimating RFF in instances of continuous speech. *Relevance to the current work:* The current study will utilize similar methodology in analyzing voice samples; specifically the algorithm developed in this study to estimate RFF in participants will be used in the present study.

Lien, Y. A., Gattuccio, C. L., & Stepp, C. (2014). Effects of phonetic context on relative fundamental frequency. *Journal of Speech, Language, and Hearing Research,* 1-9. doi:10.1044/2014_JSLHR-S-13-0158.

>   *Purpose:* This study sought to examine the effect of phonetic context on RFF. This information would assist in the development of sets of stimuli with minimal within-speaker variability for future clinical protocols that utilize RFF-based assessments. *Method:* Sixteen healthy speakers produced uniform utterances, which consisted of three repetitions of the same stimuli. The stimuli were loaded with speech sequences using multiple phonemes, and consisted of the following three stimuli types: uniformed voiced sonorant-voiceless consonant-voiced sonorant speech sequences, moderately variable sentences which contained speech sequences with a single voiceless phoneme, and highly variable sentences. RFF means and standard deviations were identified for both the stimulus type and phoneme identity. *Results:* As expected, stimulus type was significant for RFF mean and standard deviation; additionally, the interaction of vocal cycle and stimulus type was also significant. However, both had only small effect sizes. Phoneme

identity and the interaction of vocal cycle and phoneme identity on RFF for both mean and standard deviation was also significant with small-to-medium effect sizes. *Conclusions*: For speakers with healthy voices, uniform utterances with /f/ and /sh/ are recommended for RFF-based assessments because they had the lowest standard deviations. *Relevance to current work:* The current thesis took stimuli type and phonetic context into consideration while choosing the token to analyze for RFF analysis.

Löfqvist, A., & McGowan, R. S. (1992). Influence of consonantal environment on voice source aerodynamics. *Journal of Phonetics, 20,* 93-110.

    Purpose: The purpose of this study was to report detailed measurements of voice source aerodynamics during transitions between consonants and vowels as well as between vowels and consonants. *Method:* Airflow, oral air pressure, and glottal opening were recorded from two subjects producing reiterate speech with the vowel /a/ with voiced and voiceless consonants. To estimate the glottal pulse, the flow signal was inverse-filtered. *Results:* A considerable influence on the source was found both before the end of the proceeding vowel and after the onset of the following vowel. Voiceless consonants, where the source is breathy at both vowel offset and onset, produced the most marked influence between vowel and consonant. *Conclusions:* It was observed that source variations can be rationalized with reference to aerodynamic and myodynamic factors during both vowel offset and onset. *Relevance to the current work:* This article also exemplifies the early findings which show RFF sensitivity in acoustic analysis. The current study will analyze the RFF in the onset and offset of voiceless vowel production in connected speech by analyzing the influence of consonantal environment before and after voiceless vowel production.

Ogut, F., Midilli, R., Oder, G., Engin, E. Z., Bulent, K., & Kabasakal, Y. (2005). Laryngeal findings and voice quality in Sjögren's Syndrome. *Auris Nasus Larynx, 32,* 375-380. doi:10.1016/j.anl.2005.05.016

    Purpose: The objective of this study was to examine the effects of SS on objective voice quality and the perceptual ratings of laryngeal findings. *Method:* Seventy-seven patients with SS and 77 healthy controls were examined using the Reflux Finding Score (RFS) and the Reflux Symptom Index (RSI) as well as jitter, an objective voice quality measurement. Additionally, Pitch Period Perturbation Quotient, Shimmer, Amplitude Perturbation Quotient, and Noise-to-Harmonic Ratio were examined. *Results:* The difference between patients with SS and the control sample in RSI and RFS scores were statistically significant. The voice quality measures for SS individuals and the control group were also significantly different. *Conclusions:* Through this study, it was found that laryngeal pathologies are more common in those with SS than in those without. The cause of increased frequency of reflux is hypothesized to be due to the lack of esophageal pressure and saliva production. *Relevance to the current work:* This article addresses potential variances in voice quality as well as laryngeal differences seen in patients with SS.

Robb, M. P., & Smith, A. B. (2002). Fundamental Frequency onset and offset behavior: A comparative study of children and adults. *Journal of Speech, Language, and Hearing Research, 45,* 446-456. doi:1092-4388/02/4503-0446

Purpose: This study sought to determine if age-related differences existed in the short-term changes of vowel fundamental frequency immediately preceding and subsequent to a voiceless obstruent. *Method:* Three groups consisting of 4-year-olds, 8-year-olds, and 21-year-olds participated in the study. There were 10 participants in each age group; none of whom had a suspected speech, language, or hearing disorder. Each participant audio-recorded four sentences, which varied in location of stress boundaries. F_0 onset and F_0 offset were measured, normalized, and then analyzed separately. *Results:* F_0 was significantly lower at vowel offset across all age groups; there was no significant differences noted between groups. F_0 onset, however, was high and significantly decreased, and age-related differences were found. *Conclusions:* Because there were no significant differences noted between age groups, it is hypothesized that F_0 offset is merely an acoustic consequence of producing a voiceless obstruent preceding a vowel. It was determined that laryngeal adjustment requirements for articulatory events do not undergo developmental changes. However, age-related differences found in F_0 behaviors appear to be influenced by sex. *Relevance to the current work:* This study outlines the use of RFF to detect subtle voice changes during connected speech, and further evidences the usefulness of RFF in a clinical setting.

Roy, N., Tanner, K., Gray, S. D., Blomgren, M., & Fisher, K. V. (2003). An evaluation of the effects of three laryngeal lubricants on phonation threshold pressure (PTP). *Journal of Voice, 17*(3)*, 331-342. doi:10.1067/S0892-1997(03)00078-X

Purpose: The purpose of this study was to evaluate the relative effects of three potential laryngeal lubricants on phonatory function. This article also gives a summary of superficial and systemic studies of note. *Method:* Eighteen vocally normal, healthy female participants were used in the study. PTP was measured twice to accumulate baseline data, and sequentially measured four times after 2 mL of each substance, including water, Mannitol, and Entertainer's Secret Throat Relief, was nebulized. Participants were tested three times over a three-week period with one-week intervals. Each time tested, participants were given a different nebulized treatment. PTP for both high fundamental frequency and comfortable productions were measured using an oral-pressure flow system. *Results:* No significant trends were noted at the comfortable pitch level. At the high pitch level, Mannitol immediately lowered PTP after administration. However, the effects only lasted approximately 20 minutes. The other substances—water and Entertainer's Secret Throat Relief—did not produce any significant effect on PTP after administration. *Conclusions:* Although Mannitol a produced statistically significant change, the effects only lasted for a brief period of time. Additional studies should be conducted to study the observed effects of Mannitol. *Relevance to the current work:* This study looks at vocal fold hydration using nebulized saline treatments and demonstrated the effects of nebulized treatments to decrease dryness in females with no voice complaints, and without a laryngeal desiccation challenge. Therefore, the study

demonstrates the fact that effects may be observed without including a laryngeal desiccation challenge in the experimental design.

Sivasankar, M., & Erickson, E. (2009). Short-duration accelerated breathing challenges affect phonation. *The Laryngoscope, 119*, 1658-1663. doi:10.1002/lary.20530

Purpose: The current study sought to investigate the effects of accelerated oral breathing challenges on phonation. A secondary objective sought to determine whether smokers who have an increased risk for developing voice problems have more adverse phonatory effects after an accelerated breathing challenge than nonsmoking controls. *Method*: Twenty-four females, 12 smokers and 12 non-smoking controls, participated in the study. The study took place over two separate days, differing in ambient humidity. Respiratory measures were collected during the short-term accelerated breathing and the habitual breathing challenges. PTP measures were collected before and after both breathing challenges. *Results*: PTP was significantly increased following short-term accelerated breathing, and was transient and not significantly influenced by breathing route, ambient humidity, or smoking status. Respiratory measures were not affected by breathing route, ambient humidity, or smoking status either. *Conclusions*: Accelerated breathing challenges increase PTP in smokers and in nonsmoking controls. Dehydration in female speakers has a detrimental effect on phonation. *Relevance to current study:* The effects of oral breathing and dehydration are also observed in the current thesis work.

Sivasankar, M. P., & Erickson-Levendoski, E. (2012). Influence of obligatory mouth breathing, during realistic activities, on voice measures. *Journal of Voice, 26,* 813e9-813.e13. doi:10.1016/j.voice.2012.03.007

Purpose: This study examined mouth breathing during exercise and during loud reading at different levels of environmental humidity. The different levels of humidity are thought to lead to vocal fold dryness and, therefore, increase effort in vocal production. *Method:* Sixty-three participants participated in mouth breathing, loud reading, and exercise with oral breathing. PTP and PPE were measured before and after each oral breathing challenge. Humidity was controlled with participants in the category of either low or high conditions. *Results:* There were no significant effects shown in PPE measurements. However, PTP was found to be significantly affected by the vocal behavioral and environmental challenges at both low and high humidity. There was no marked difference between the two groups in any of the challenges. *Conclusions:* This study showed that both exercise and loud reading increased PTP, but did not conclude if the same underlying mechanisms are responsible for this increase. Also, it is hypothesized that longer durations of mouth breathing may be necessary to show a difference between the two groups of participants. The lack of significant findings related to PPE offered additional information regarding relationships between this and other measures, as well as the value of including multiple measures. *Relevance to the current work:* This study provides evidence for the relationship between vocal fold dehydration and patient-perceived vocal effort ratings. Similar rating scales are incorporated as a primary outcome measure in the present investigation.

Sivasankar, M., Erickson, E., Schneider, S., & Hawes, A. (2008). Phonatory effects of airway dehydration: Preliminary evidence for impaired compensation to oral breathing in individuals with a history of vocal fatigue. *Journal of Speech, Language, and Hearing Research, 51,* 1494-1506. doi:10.1044/1092-4388(2008/07-0181)

> *Purpose*: This study researched the presence of adverse phonatory effects of dehydration in speakers who self-report vocal fatigue. *Method*: A repeated measures design with both a control group and test group of 16 female participants with a history of vocal fatigue was used. Voice measurements were taken before and after oral and nasal breathing challenges. Measurement of respiratory frequency were taken during the dehydration challenge. *Results*: At both low and moderate humidity levels, PTP was shown to increase in individuals reporting a history of vocal fatigue as compared to controls following oral breathing. However, PTP was not shown to increase after oral breathing in a humid environment in either participant group. *Conclusions*: Dryness challenges might be unfavorable to voice production in individuals with a history of vocal fatigue when conducted at low and moderate ambient humidity levels. This is not the case in high humidity levels. Due to the phonatory effects of dehydration, it is suggested that individuals reporting vocal fatigue may demonstrate impaired compensation to airway drying induced by short-term oral breathing. *Relevance to current study:* The current study extends these results to participants with chronic dryness.

Sivasankar, M., & Fisher, K. V. (2002). Oral breathing increases Pth and vocal effort by superficial drying of vocal fold mucosa. *Journal of Voice, 16,* 172-181. doi:10.1016/S0892-1997(02)00087-5

> *Purpose:* This study examined oral and nasal breathing and their respective effects on vocal effort and PTP, referred to in this study as P_{th}. *Method:* Twenty female participants were instructed to breathe orally and then breathe nasally for 15 minutes before P_{th} and perceived vocal effort were measured at three different pitches. *Results:* As hypothesized, short-term oral breathing increased P_{th} while short-term nasal breathing did not. Overall, perceived vocal effort increased following the oral breathing task and decreased following the nasal breathing task, though four subjects reported a decrease or no change in effort following oral breathing and three nasal breathers reported no change in effort. *Conclusions:* The authors postulate that oral breathing places healthy subjects at risk for symptoms of increased vocal effort. As demonstrated in previous studies, oral breathing for short periods of time superficially dehydrates the human airway. This is because the depth of the sol layer is decreased in oral breathing. Conversely, nasal breathing increases the depth of the sol layer, and can increase the humidity of the air inspired. *Relevance to the current work*: This study provides support for the previous assumption that vocal fold hydration responds to humidity of inhaled air. Not only is this important during singing and physical exercise, but also for individuals with chronic dryness conditions, such as SS.

Sivasankar, M., & Fisher, K. V. (2003). Oral breathing challenge in participants with vocal attrition. *Journal of Speech, Language, and Hearing Research, 46*, 1416-1427. doi:1092-4388/03/4606-1416(2003/110)

> *Purpose*: The current study sought to determine whether or not oral breathing is more detrimental to phonation in healthy participants with a history of temporary vocal attrition. *Method*: Forty healthy females with normal voices participated in this study. Twenty participants had experienced vocal attrition prior to the study, and 20 participants served as controls. Participants were randomized in to the following groups: oral breathing and nasal breathing. Participants were directed to sustain a 15-minute oral or nasal breathing challenge as indicated by PTP. Perceived expiratory vocal effort were compared for participants reporting symptoms of vocal attrition and normal controls. *Results*: Pre versus post-challenge changes in PTP and effort showed that oral breathing increased PTP at comfortable low and high pitches. In participants with vocal attrition, the difference in PTP was significantly greater than in the normal control group. Nasal breathing was shown to reduce PTP for all controls but not for all participants who reported vocal attrition. *Conclusion*: It can be speculated that greater increases in PTP in participants reporting vocal attrition may result from delayed or inadequate compensatory response to superficial dehydration throughout the larynx. Obligatory oral breathing may place voice users at risk for exacerbating vocal attrition. PTP and increased vocal effort from obligatory breathing provide support for maintaining superficial hydration to ensure ease of phonation. *Relevance to current work:* Oral breathing has been shown to dry the vocal folds and the dehydration of vocal folds can affect phonation. The current thesis attempted to demonstrate improved phonation with vocal fold hydration.

Sivasankar, M. & Fisher, K. (2007). Vocal fold epithelial response to luminal osmotic perturbation. *Journal of Speech, Language, and Hearing Research, 50*, 886-898. doi:10.1044/1092-4388(2007/063)

> *Purpose:* The purpose of this study was to examine the extent to which de-innervated, viable vocal fold epithelium responds to osmotic perturbations of fluid on the luminal surface. It was hypothesized that vocal fold epithelium would generate a water flux to reduce an osmotic challenge on the lumen. *Method:* Thirty-six ovine focal folds were exposed to either isosmotic or luminal hyperosmotic perturbations. Water fluxes and vocal fold viability were measured at baseline and for 30 minutes after the osmotic challenge. *Results:* It was demonstrated that the electrophysiological capability of ovine vocal fold epithelium was maintained despite osmotic perturbation in the luminal surface fluid. Luminal osmotic exposure increased luminally directed transepithelial water fluxes in approximately 60% of the vocal folds. However, the increase was of short duration and did not negate the osmotic gradient. *Conclusions:* Homeostatic regulation of vocal fold surface fluid may highly involve the ability to detect and respond to osmotic perturbations in the luminal surface. *Relevance to the current study:* This study demonstrates how healthy vocal folds should regulate changes in superficial vocal fold hydration. This study is foundational in showing that manipulation of surface vocal fold hydration is possible through topically administered treatments. The present study will explore the potential long-term effects of surface hydration to the vocal folds.

Stepp, C. E., Hillman, R. E., & Heaton, J. T. (2010). The impact of vocal hyperfunction on relative fundamental frequency during voicing offset and onset. *Journal of Speech, Language, and Hearing Research, 53,* 1200-1226. doi:10.1044/1092-4388(2011/10-0274)

> *Purpose:* This study sought to determine if RFF surrounding a voiceless consonant would decrease in individuals with vocal fold hyperfunction. *Method:* The retrospective study used two clinical databases of speech samples from 82 participants with hyperfunction-related voice disorders; including muscle tension dysphonia, vocal fold nodules, and vocal fold polyps. Using the PRAAT® program, three voiced-voiceless-voiced combinations were analyzed. *Results:* Individuals with vocal hyperfunction showed significant lowering of offset and onset RFF compared to controls. In the surgical group, offset and onset RFF was not significantly changed by the removal of vocal fold lesion; that is, voicing onset and offset RFF were not significantly changed by the removal of vocal fold lesions. *Conclusions:* Heightened levels of laryngeal muscle tension can cause an altered offset and onset RFF in patients with hyperfunction-related voice disorders. It is concluded that RFF has the potential to be used as a noninvasive, simple measure of vocal hyperfunction. *Relevance to the current work:* This study affirmed that RFF is a useful acoustic measure that is sensitive in detecting small changes in vocal hyperfunction. The current thesis used RFF to analyze changes before and after hydration treatment in a population.

Stepp, C. E., Merchant, G. R., Heaton, J. T., & Hillman, R. E. (2011). Effects of voice therapy on relative fundamental frequency during voicing offset and onset in patients with vocal hyperfunction. *Journal of Speech, Language, and Hearing Research, 54*, 1260-1266. doi:10.1044/1092-4388

> *Purpose:* This study utilized RFF to determine if patients with hyperfunctionality voice disorders could normalize after receiving voice therapy to reduce laryngeal muscle tension, thereby showing an objective measurement for vocal hyperfunction. *Method:* Sixteen females between the ages of 18 and 58 with either muscle tension dysphonia or bilateral vocal fold nodules, and no other known speech, language, or hearing disorder participated in the study. Measurements of participants' RFF were measured before voice therapy and after successful completion of voice therapy treatment. Analyses included acoustic and aerodynamic measurements as well as perceptual ratings by the speech pathologist and the participant. *Results:* Post-therapy RFF measurements of participants proved to be a statistically significant increase from pre-therapy RFF. That is, successful therapy increased RFF measures toward patterns seen in individuals with typical voices. *Conclusions:* Results signify the future adoption of RFF measures to assess clinical progress in voice therapy. *Relevance to the current work:* RFF has been shown to be a useful, objective measure of vocal dysfunction. This study laid the foundation for future work in assessing changes in RFF to determine within-speaker voice changes.

Tanner, K., Roy, N., Merrill, R. M., & Elstad, M. (2007). The effects of three nebulized osmotic agents in the dry larynx. *Journal of Speech, Language, and Hearing Research, 50,* 635-646. doi:1092-4388/07/5003-0635

    Purpose: The purpose of this study was to examine the effects of three nebulized treatments with differing osmotic properties on voice production in participants after a laryngeal desiccation challenge. *Method:* Sixty women with no previous history of voice-related problems or complaints participated in the study. A double-blind, randomized group design assigned participants to one of four groups, including three treatment groups with varying concentrations of nebulized saline and a control group. PTP and PPE served as dependent variables. *Results:* The low correlation between PTP and PPE demonstrated that these measures might not be as closely correlated as previously assumed. Though there was a worsening in PTP values following treatment, there was also a delayed worsening in the isotonic and saline solution groups compared to the control group. This suggests that isotonic saline might offset the negative effects associated with vocal fold dehydration. *Relevance to the current work:* This study provided treatment selection data for the current study involving patients with Primary SS. Additionally, this study gives a foundation for further studies by showing that significant results showed PTP increases following laryngeal desiccation.

Tanner, K., Roy, N., Merrill, R. M., Kendall, K., Miller, K. L., Clegg, D. O., …Elstad, M. (2013). Comparing nebulized water versus saline after laryngeal desiccation challenge in Sjögren's Syndrome. *The Laryngoscope, 123*, 2787-2792. doi:10.1002/lary.24148

    Purpose: This study examined PTP, PPE, as well as self-perceived mouth and throat dryness after a laryngeal desiccation treatment in patients with Primary SS. *Method:* Using a double-blind study, researchers examined the effects of vocal effort and throat dryness. Eleven participants with SS went through a 15-minute desiccation challenge followed by either nebulized isotonic saline or nebulized water treatments for two weeks. *Results:* Statistically significant increases in PTP, PPE, and mouth and throat dryness were found after the laryngeal desiccation challenge. Nebulized saline produced greater, although not statistically significant, treatment effects than water. PTP was correlated more with throat dryness than vocal effort. *Conclusions:* Nebulized isotonic saline was hypothesized to counteract changes following dry air exposure in patients with chronic airway dryness. It was suggested that future research explore alternative nebulized treatments, voice change, self-perceived throat dryness, and dose-response relationships among dry air exposure. *Relevance to current work:* The current study was largely based on this work. The study demonstrated the effects of dryness as well the potential benefits of nebulized treatments in individuals with SS. It established a basis for future dosage, frequency, concentration, and types of nebulized treatments. Similar participants and experimental questions were incorporated in the current work.

Watson, B. C. (1998). Fundamental frequency during phonetically governed devoicing in normal young and aged speakers. *Journal of the Acoustical Society of America, 103,* 3642-3647.

Purpose: This study utilized measures of F_0 to determine the differences between young and aged voices. *Method:* Ten aged and ten young speakers produced a short sentence that contained an intervocalic voiceless obstruent. The F_0 was measured for the ten cycles before voice offset and the ten cycles after voice onset. In order to minimize effects of inter-subject and intra-subject variability in the intonation contour, F_0 values were converted to semitones relative to the reference cycle to normalize values within individual tokens. *Results:* Young speakers showed a consistent, yet small, increase in F_0 during devoicing. Aged speakers showed a decrease in F_0 during devoicing, and significantly greater within-group variability for most vocal cycles. *Conclusions:* Differences between young and aged speakers were found. Specifically, to achieve voicing, aged speakers seem to rely more on strict vocal fold abduction rather than using a combination of tension and abduction. *Relevance to the current work:* In essence, this study used RFF to determine subtle changes in vocal fold abduction between young and aged speakers. The current thesis will also utilize RFF to explore the effects of a hydration treatment within speakers.