2015-03-01

Monophthongal Vowel Production in Females with Primary Sjögren's Syndrome Following a Hydration Treatment of Nebulized Saline

Kara Rytting
Brigham Young University - Provo

Monophthongal Vowel Production in Females with Primary Sjögren's Syndrome Following a Hydration Treatment of Nebulized Saline

Kara N. Rytting

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

Master of Science

Shawn L. Nissen, Chair
Kristine Marie Tanner
Ron W. Channell

Department of Communication Disorders

Brigham Young University

March 2015

ABSTRACT

Monophthongal Vowel Production in Females with Primary Sjögren's Syndrome following a Hydration Treatment of Nebulized Saline

Kara N. Rytting
Department of Communication Disorders, BYU
Master of Science

Sjögren's Syndrome (SS) is an autoimmune disease that causes extreme dryness, or *sicca*, of the eyes and mouth, as well as other potential drying of the throat and intestines. Speech, voice, and swallowing problems are common in individuals with SS. Therefore, this study examined the possible changes in acoustic characteristics of monophthongs **(**/i, æ, ɑ, u, ʌ/**)** in eight females with SS following laryngeal hydration treatments. An ABAB experimental design was implemented. Treatment consisted of nebulized isotonic saline immediately following completion of audio-recordings. Using acoustic analysis software the duration, formant frequencies, and vowel space area (VSA) was calculated for the participant's vowel productions. Overall the mean duration of the participant's vowel productions increased slightly from baseline measurements through the last treatment phase. Minimal deviations were observed in first and second formant frequency values throughout the study. Only minor differences were found in the participant's VSA from baseline phase of data collection through the final treatment phase, with most of these differences due to a change in the first formant of the /æ/ vowel. Despite the need for future research, the findings of this study increase understanding into how SS impacts speech production.

Keywords: monophthongs, Sjögren's Syndrome, laryngeal hydration, saline treatments

ACKNOWLEDGMENTS

I would first like to thank the members of my committee. Drs. Ron Channell, Kristine Tanner, and specifically my chair Dr. Nissen dedicated many hours in both mentoring and in all aspects of this thesis. I would also like to thank my husband and children for all of their love, support, and encouragement throughout my master's program and thesis work.

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

LIST OF APPENDICES

DESCRIPTION OF STRUCTURE AND CONTENT

This thesis was part of a larger collaborative project, portions of which may be submitted for publication, with the thesis author being one of multiple contributing coauthors. The body of this thesis was written as a manuscript suitable for submission to a peer-reviewed journal in speech-language pathology. The analyses conducted in this study were based on a set of recordings originally collected by Tanner (2014). The participant consent form, materials related to the study, and an annotated bibliography are presented as noted in the List of Appendices.

Introduction

A condition known as Sjögren's Syndrome (SS) is an autoimmune disease that causes extreme dryness or *sicca* of the eyes and mouth, as well as the potential drying of the throat, intestines, and vagina (Tanner et al., 2013). Most occurrences of SS systematically cause a drying of the mucosal tissue throughout the body. When this drying occurs in the presence of another autoimmune disease, individuals are generally diagnosed with secondary SS. When sicca symptoms present independently, in the absence of another autoimmune condition, the condition is considered to be primary SS (Kassan & Moutsopoulos, 2004). Primary SS occurs in approximately 4 in 100,000 individuals, whereas Secondary SS is more common, occurring in approximately four million individuals in the US (Kruszka & O'Brian, 2009; Pillemer et al., 2001). The difference in occurrence between primary and secondary SS is largely due to the higher prevalence of autoimmune conditions present in the general population, such as rheumatoid arthritis and lupus.

People with SS are at higher risk for sinus symptoms, sensorineural hearing loss, pulmonary symptoms, neurological symptoms, and throat dryness (Freeman, Sheehan, Thorpe, & Rutka, 2005; Stojan, Baer, & Danoff, 2013; Wheaton, 2007). There are also notable correlations between laryngeal pathologies and SS like granuloma, posterior commissure hypertrophy, pseudosulcus vocalis, bamboo nodules, thick mucus (Mahoney & Spiegel, 2003; Ogut et al., 2005), reflux, partial or complete ventricular obliteration, arytenoid erythema or hyperemia (Ogut et al., 2005), and dysphagia due to dryness and reduced esophageal motility. Individuals with SS also commonly experience difficulties with their voice and speech function, including conditions such as dysphonia and associated difficulties with speech articulation (Allec

et al., 2011). These difficulties are due in part to changes in the layers of mucosal fluid in the respiratory and vocal tracts, a reduction in saliva, and an increase in oral breathing.

A thin blanket of mucus, consisting of water and gel layers, lines the surface of the airway. This layer defends surface cells against potential irritants (Proetz, 1953; Rogers, 1994). These layers also hydrate the vocal folds and facilitate mucociliary clearance (Labiris & Dolovich, 2003; Sivasankar, Carroll, Kosinski, & Rosen, 2013; Widdicombe, 1997). The sicca commonly associated with SS, as well as changes in environmental humidity, can impair the function of these mucosal layers (Yeates, 1991), resulting in increased vocal effort during speech production (Chan & Titze, 1998; Finkelhor, Titze, & Durham, 1988; Hemler, Wieneke, & Dejonckere, 1997; Titze, 1988; 1994; Verdolini et al., 2002; Verdolini-Marston, Titze, & Druker, 1990).

Ogut et al. (2005) explain that saliva is not produced spontaneously in individuals with SS. This is problematic because saliva is a mechanism through which the body denaturalizes and expels the acidic reflux advancing from the stomach. Reflux can become an irritant to the dry laryngeal mucosa, especially without the necessary amount of saliva, possibly resulting in chronic coughing. An increase in reflux combined with a chronic cough can have a significant effect on an individual's voice function (Ogut et al., 2005), resulting in characteristics such as breathiness, vocal strain, increased vocal effort, and hoarseness (Allec et al., 2011; Tanner et al., 2013).

Individuals with SS may also encounter difficulty with their speech and voice due in part to an increase in oral or mouth breathing. A pattern of breathing with a higher ratio of mouth breathing has been shown to have several effects on human subjects, such as increases in the viscosity of surface fluid, reduction of mucociliary clearance, and causing a cough. An

accumulation of mucus on the airway surface may occur due to increases in the adhesiveness and viscosity of respiratory mucus causing a reduction in the ease of vocal fold separation, compelling greater phonation threshold pressure (PTP) (Sivasankar, Erickson, Schneider, & Hawes, 2008; Sivasankar & Fisher, 2002). Previous research has also found that oral breathing increases self-perceived vocal effort and PTP even in healthy participants, with some individuals exhibiting an increase in PTP in as little as 15 minutes (Sivasankar & Fisher, 2002; 2003).

Considering the possible impact sicca symptoms associated with SS have on speech and voice functioning it is important that individuals with SS pursue a program of proper hydration. Vocal fold hydration involves both systemic and surface tissue hydration mechanisms to regulate fluid inside the vocal folds and on the vocal fold surface. Systemic and surface fluid mechanisms maintain vocal fold hydration (Verdolini et al., 2002). Systemic hydration is managed by the renal system and is affected by drinking fluids. Ionic transport and lubrication from the mucus-secreting glands maintain surface fluid hydration. Both systemic and surface fluid are necessary for balancing the depth and viscosity of vocal fold and respiratory airway surface fluid.

The ability to rehydrate the vocal folds using nebulized substances has been empirically examined by measuring the PTP and self-perceived vocal effort before and after treatment. Roy, Tanner, Gray, Blomgren, and Fisher (2003) conducted a study involving 18 healthy females, where the effects of Mannitol (an osmotic agent), water, and Entertainer's Secret Throat Relief™ (a glycerin-based product) nebulized agents were measured. In the end, Mannitol was the only substance to significantly decrease PTP following administration. However it is important to note that the effects of the Mannitol remained for only 20 minutes. Tanner, Roy, Merrill, and Elstad (2007) examined the effects of treating 60 vocally healthy females with a nebulized

hypertonic saline, isotonic saline, and hypotonic water. The researchers found that although the desiccation task regularly heightened the PTP, none of the saline concentrations examined were successful in significantly lowering the PTP of the women following the desiccation task. Tanner et al. (2007) determined that the data from this study indicated that self-perceived vocal effort was not correlated to PTP. Subsequently, Tanner et al. (2013) compared isotonic saline to nebulized water treatments. Their findings revealed that isotonic saline was successful in decreasing the effects of the desiccation task, although the findings were not statistically significant. One area not addressed by the previous studies was that treatments were only applied once and not followed over time to verify long-term effects.

Abnormalities in speech articulation may be due to problems in the vocal mechanism, which could be linked to pathological conditions. Speech depends upon the coordinated functioning of both the vocal folds as a source and the associated movements of the articulators. Occasionally, disorders that affect one part of the speech chain might also affect another area. For instance, Dromey, Nissen, Roy, and Merrill (2008) studied the production of the diphthong vowels /eI/ and /aI/, before and after manual circumlaryngeal treatment (MCT) in a population of people with muscle tension dysphonia (MTD). Significant post treatment measurements were observed including significant speech acoustic changes as well as improved perceptual voice quality judgments when compared to pretreatment recordings. Both diphthongs produced an increase in the slope of the second formant (F2) and following treatment the sample durations were overall decreased. The researchers concluded that successful treatment targeting the larynx produced positive changes in both articulatory and phonatory behavior in individuals with MTD.

The study by Dromey et al. (2008) examined the participant's ability to produce vowels in terms of mean formant frequencies. Historically, these types of acoustic measures have been

used to examine vowel production due to the relatively close relationship between the F1 and F2 frequencies and the movement of the tongue, in terms of its relative height and advancement. Vowel phonemes occupy a particular acoustic and perceptual space (depending on individual speakers) and when an individual produces a vowel outside of that space, the vowel becomes less intelligible (Roy, Nissen, Dromey, & Sapir, 2009). The formant frequencies for vowel productions are modified in three basic ways, changing the overall length of the vocal tract, the degree of constriction, and the location of that constriction along the length of the vocal tract. Peterson and Barney (1952) found that formant frequencies depend on the length of an individual's vocal tract, with a strong negative correlation between tongue height and the F1 frequency, as well as a positive correlation between the length of the anterior resonating cavity and the F2 frequency. In other words, a higher tongue position results in a lower F1 frequency and a more fronted tongue position results in a higher F2 frequency (Ferrand, 2007).

An individual's vowel production can also be examined by measuring their Vowel Speech Area (VSA) during speech. VSA is used to indirectly assess the normalcy of vowel articulation and is a commonly used acoustic index in clinical research (Kent & Kim, 2003; Kuhl et al., 1997, Vorperian & Kent, 2007). VSA is calculation of the Euclidean distances between the F1 and F2 coordinates of the corner vowels. When evaluating English vowel productions, one method of VSA measurement computes the triangular area of only three corner vowels (e.g., /i/, /u/, and /ɑ/), whereas other VSA measures calculate the quadrilateral English vowel space using all four corner vowels (i.e., /i/, /u/, /ɑ/, /æ/) (Blomgren, Robb, & Chen, 1998; Jacewicz, Fox, & Salmons, 2007; Kent & Kim, 2003; Liu, Tsao, & Kuhl, 2005; Vorperian & Kent, 2007). A speaker's VSA has been found to change as a function of the nature of his/her speech. When speaking faster it is expected that the VSA will be somewhat lower as a result of vowel

centralization, however with hyperarticulation of vowels or clear speech, individuals often increase their VSA when speaking (Ferguson & Kewley-Port, 2007; Smiljanic & Bradlow, 2005).

VSA appears to be sensitive to changes in articulatory function caused by a number of disorders that may affect an individual's ability to communicate. Several different studies have reported a correlation between VSA and speech intelligibility (Higgins & Hodge, 2002; Liu et al., 2005; Weismer, Jeng, Laures, Kent, & Kent, 2001). If a speaker is unable to extend their tongue to the peripheral position necessary for a corner vowel, characterized by a smaller VSA, the resulting vowel productions may acoustically and perceptually overlap or merge into a neighboring vowel category. This condition has been exhibited by individuals with dysarthria and amyotrophic lateral sclerosis.

Some research has indicated that VSA may be overly sensitive to the inherent amount of inter and intra-speaker variability present in typical speech patterns. Several studies have been conducted in which the VSA has failed to differentiate between speakers even though these individuals were judged perceptually to have abnormal articulation or poor speech intelligibility (Ansel & Kent, 1992; Bunton & Weismer, 2001; Roy et al., 2009; Sapir, Spielman, Ramig, Story, & Fox, 2007).

A study by Roy et al. (2009) used formant frequency (F1 and F2) and VSA measures to examine monophthong vowel production (pre and post treatment) produced by speakers diagnosed with MTD. Similar to the researchers previous study (Dromey et al., 2008) participants were treated with MCT. The formant patterns and VSA dimensions of the participants' vowel productions were found to be closer to typical production patterns following the MCT treatment. Their study provided some evidence that conditions that lead to a decrease

in functioning with the vocal folds might also lead to a decrease in function with the articulators. However the association between dysfunction of the vocal folds and movement of the speech articulators has yet to be fully understood for many conditions that affect speech communication.

It is well established that SS is a disease that results in symptoms that can have a negative effect on the functioning of the vocal folds (Freeman et al., 2005; Tanner et al., 2013), however the degree and nature of its effect on the articulation of speech is less clear. Thus the purpose of this investigation was to examine the impact of SS on speaker's ability to articulate monopthongal vowels and the effectiveness of laryngeal hydration in alleviating any decrease in speech function as measured by the acoustic measures of formant frequencies and VSA.

Method

This thesis examines one aspect of a more extensive research project on nebulized hydration for individuals with Primary SS. As such, the procedure and study design described below is similar to other studies within the project.

Participants

Eight female individuals with Primary SS ranging in age from 36 to 74 years, with a mean age of 57 years, participated in the study. A chart review identifying potential study participants, including the review of sicca symptom clinical presentation, antinuclear antibody testing, and/or lip biopsy was conducted by The University of Utah Division of Rheumatology. Relevant factors of each participant's medical history are detailed in Appendix B. The average duration of time that the participants were diagnosed with sicca symptoms was 14 years (range 3 to 30 years) and duration of time diagnosed with SS was 11 years (range 2 to 32 years). The participants reported no upper respiratory symptoms at the time of study. The participants' average total score on the Voice Handicap Index (Jacobson et al., 1997) at the beginning of the

study was 32.5 (range 12 to 62). To assess the disease severity immediately prior to data collection participants also completed the EULAR (European League Against Rheumatism) Sjögren's Syndrome Patient Reported Index (Seror et al., 2012) and the Sicca Symptoms Inventory (Bowman, Booth, Platts, Field, & Rostron, 2003). This study was approved by the Institutional Review Boards at the University of Utah and Brigham Young University (IRB_00061835).

Procedures

This study applied a within-subjects repeated-measures ABAB experimental design. Each phase was two weeks in duration. The first phase of data collection (baseline) involved audio-recordings of each participant completed in the morning and evening at approximately the same time of day. During the second phase (Tx_1), participants continued twice-daily audio-recordings followed by the nebulized saline treatment. This treatment consisted of 9 mL of nebulized isotonic saline ($Na^{+}Cl$) using the Omron MicroAir Nebulizer (Model NE-U22V) immediately following completion of audio-recordings. Audio-recordings were collected immediately prior to the application of the nebulized saline to avoid detecting only short-term effects of nebulized saline on voice production in SS (Tanner et al., 2013). Phase three (withdrawal) included withdrawal of the nebulized treatment while the participants continued to complete twice-daily audio-recordings and VAS ratings. During phase four (Tx_2), the nebulized treatment was resumed in a manner similar to the Tx_1 phase of data collection.

Audio Recordings

Each participant was instructed to record their speech production before, during, and after a home program of laryngeal hydration of nebulized saline. The vowel productions examined in this study (/u, ɑ, i, æ, ʌ/) were embedded in a series of real words, (i.e., *hoot, hot, heat, hat, hut*).

In order to prevent possible list effects, each set of target words was randomized and produced three times (see Appendix C). Vowel tokens were recorded twice daily in the morning and the evening over the course of eight weeks. Audio recordings immediately preceded treatment during the treatment phases of the study. Audio-recordings also included segments of speech that were not part of this study, including the first paragraph of the Rainbow Passage (Fairbanks, 1960), three Consensus Auditory-Perceptual Evaluation of Voice (Kempster, Gerratt, Abbott, Barkmeier-Kraemer, & Hillman, 2009) sentences and three sustained vowels. Participants recorded these speech and voice samples using the Zoom Handy Recorder (Model H1) and a head-mounted Audio-Technica cardioid condenser microphone (ATM75-SP-NP). Recordings were sampled at a rate of 96 kHz, with a quantization of 32 bits, and saved on a SanDisk 32 GB microSD card. Written and photographic instructions were provided to each participant concerning how to correctly record their speech, microphone placement, and treatment procedures (see Appendix C). After each audio-recording participants also completed patient-based VAS ratings of vocal effort, mouth dryness and throat dryness (see Appendix D).

Acoustic Analysis

Similar to the methodology used in previous research (Dromey et al., 2008; Perry, 2014; Roy et al., 2009), PRAAT® acoustic analysis software, version 5.2.17 (Boersma & Weenink, 2004), was used to extract F1 and F2 measurements from each monophthongal vowel target. The analysis software used a linear predictive coding (LPC) based tracking algorithm (Burg method, 11 coefficients) to determine formant values for the vocalic segments of each vowel production at approximately 5 millisecond (ms) intervals. The LPC analysis also used a 25 ms Hamming window with 50% overlap and 98% pre-emphasis. Each vowel token was visually and auditorily monitored during the formant extraction process to help prevent the erroneous

inclusion of surrounding speech sounds in the analyzed segment. The extracted formant values and associated time points for each vowel target were then saved as a separate text file. Custom-designed MATLAB software was used to detect halving or doubling in the extracted formant tracks. The reliability of the acoustic measures was examined by randomly selecting 10% of the original formant tracks and conducting a reanalysis by a second judge. The latter set of values was then correlated to the values of the originally extracted formant tracks.

The mean F1 and F2 frequencies were calculated at eight different equidistant measurement points through each vowel's overall duration (t1-t8) from the values of the extracted formant tracks. The relative steady-state of the monophthongal vowel targets were calculated by averaging the values of F1 and F2 extracted from analysis windows t3 through t6 or middle 50% of each vowel's overall duration. It was inferred that the middle portion of the vowel was less influenced by the surrounding consonantal context. Average duration measures were also calculated using a MATLAB program which calculated the duration based on initial and final segmentation points of the vowel track.

Following the methodology of Jacewicz et al. (2007), the mean F1 and F2 frequencies were used to compute VSA measures. Specifically, two sets of three vowels /i, u, ɑ / and /æ, u, i/ from each speaker were used to calculate the vowel area of the triangles by using the average F1 and F2 measurements. The subsequent equation was used to compute the area using Heron's method (Jacewicz et al., 2007).

$$Area = \sqrt{s(s-a)(s-b)(s-c)} \quad \text{where} \quad s = \frac{a+b+c}{2}$$

The lengths of the three sides of each vowel space triangle were characterized by a, b, and c. The areas of these two triangles were then combined to estimate the overall VSA.

Results

Descriptive statistics were used to report the acoustic characteristics of the participants' monophthongal vowel productions. An overall mean and standard deviation were calculated for the duration, F1, F2, and VSA of each vowel type as a function of the phase of data collection (baseline, Tx_1, withdrawal, Tx_2) by collapsing the data across the individual participants, treatment week, treatment day, time of day, and repetition. Tables 1 through 5 provide a detailed listing of the duration and formant values for each monophthongal vowel type.

Vowel Duration

As shown in Figure 1, the durational mean values were relatively similar across all five monophthongal vowels. Overall, an increase in duration was observed for each monophthong from baseline to the conclusion of the study at Tx_2 with the largest increase of 14 ms and the smallest increase of 7 ms respectively. An increase in duration of at least 2 ms was observed across all vowels from baseline to Tx_1.

Table 1

Duration and Formant Values for /æ/

Treatment Phase	Duration[a]		F1[b]		F2[c]	
	M	*SD*	*M*	*SD*	*M*	*SD*
Baseline	262	70	933	158	1826	189
Tx_1	273	60	847	203	1784	257
Withdrawal	263	70	894	161	1815	176
Tx_2	269	60	923	155	1802	165

Note. [a]Values reported in milliseconds. [b]F1 frequency reported in hertz. [c]F2 frequency reported in hertz.

Table 2

Duration and Formant Values for /a/

Treatment Phase	Duration[a]		F1[b]		F2[c]	
	M	*SD*	*M*	*SD*	*M*	*SD*
Baseline	242	60	836	123	1287	136
Tx_1	244	50	839	127	1273	125
Withdrawal	260	50	810	126	1304	129
Tx_2	256	50	810	144	1299	131

Note. [a]Values reported in milliseconds. [b]F1 frequency reported in hertz. [c]F2 frequency reported in hertz.

Table 3

Duration and Formant Values for /i/

Treatment Phase	Duration[a]		F1[b]		F2[c]	
	M	*SD*	*M*	*SD*	*M*	*SD*
Baseline	232	60	357	32	2832	229
Tx_1	246	60	364	33	2862	261
Withdrawal	240	60	361	31	2787	303
Tx_2	244	60	352	40	2795	306

Note. [a]Values reported in milliseconds. [b]F1 frequency reported in hertz. [c]F2 frequency reported in hertz.

Table 4

Duration and Formant Values for /u/

Treatment Phase	Duration[a]		F1[b]		F2[c]	
	M	*SD*	*M*	*SD*	*M*	*SD*
Baseline	227	50	400	58	1343	237
Tx_1	230	50	413	105	1361	199
Withdrawal	244	60	424	92	1422	195
Tx_2	234	60	420	101	1364	245

Note. [a]Values reported in milliseconds. [b]F1 frequency reported in hertz. [c]F2 frequency reported in hertz.

Table 5

Duration and Formant Values for /ʌ/

Treatment Phase	Duration[a]		F1[b]		F2[c]	
	M	*SD*	*M*	*SD*	*M*	*SD*
Baseline	148	40	813	95	1641	157
Tx_1	155	40	778	121	1618	184
Withdrawal	175	50	775	106	1656	153
Tx_2	155	40	799	120	1655	129

Note. [a]Values reported in milliseconds. [b]F1 frequency reported in hertz. [c]F2 frequency reported in hertz.

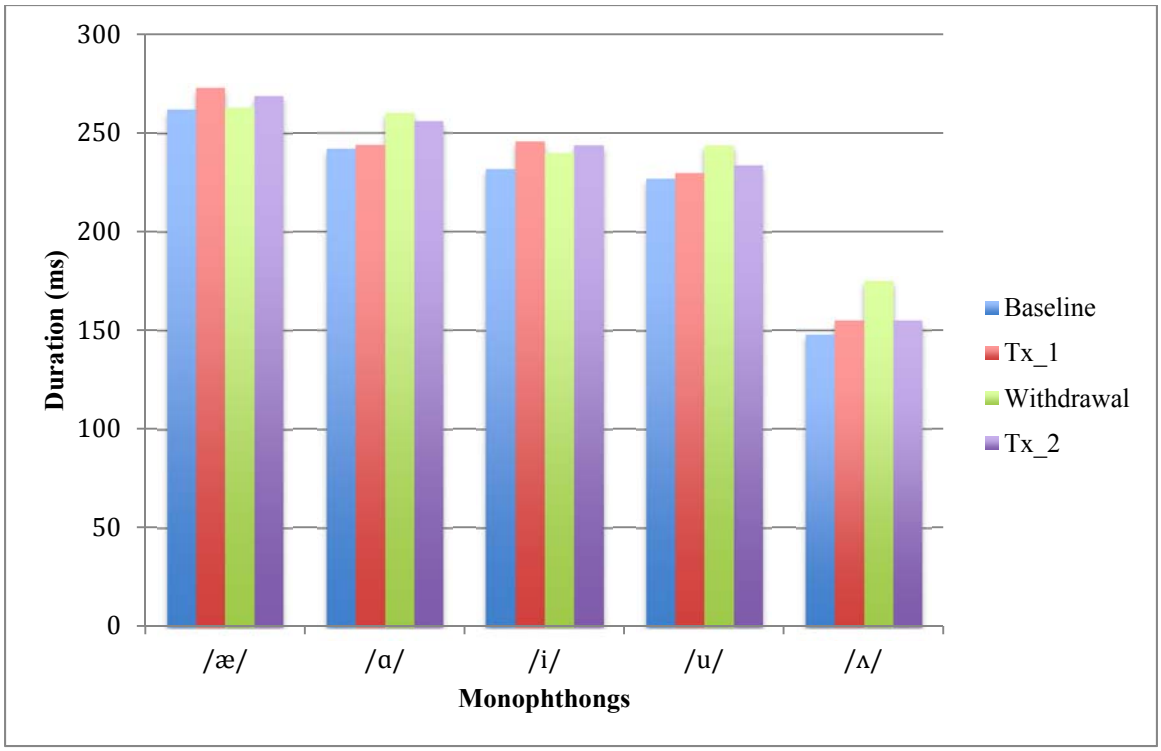

Figure 1. Duration means for the monophthongs from the participants with Sjögren's at Baseline, Treatment 1, Withdrawal, and Treatment 2.

Duration measures from Tx_1 to withdrawal differed between the vowels where an increase of at least 14 ms was observed for /ɑ, u, and ʌ/ and a decrease of at least 20 ms was noted for /æ and i/ followed by a decrease of vowels /ɑ, u, and ʌ/ and increase of vowels /æ and i/ from withdrawal to Tx_2. Across the study the shortest mean duration was found for /ʌ/ at 148 ms with the longest mean duration found for /æ/ at 273 ms.

F1 and F2 Frequencies

As can be seen in Figure 2 the F1 and F2, values of the five monophthong vowels did not deviate greatly across the four phases of data collection. The mean F1 values, which correspond to tongue height, differed by no more than 85 Hz. The largest shifts in F1 were found for the participant's productions of the /æ/ vowel. A decrease of 86 Hz was observed from baseline to

Tx_1, an increase of 47 Hz at withdrawal, and an increase of 29 Hz at Tx_2 was observed which brought the Tx_2 measures back to near baseline values. When comparing the mean F2 values, which correspond to tongue advancement, a mean decrease of 41 Hz was found during the Tx_1 phase of data collection for the F2 /æ/ vowel. A mean increase of 75 Hz was found during the withdrawal phase for the /i/ vowel. During the Tx_2 phase a mean decrease of 58 Hz was found for the F2 /u/ vowel.

Vowel Space Area

Using the mean F1 and F2 frequencies of the four corner vowels (/i u ɑ æ/) the VSA was calculated for each phase of data collection, as shown in Figure 3. When collapsed across all participants, the VSA was highest in the baseline condition at 527 kHz^2. The VSA decreased slightly for the Tx_1 and withdrawal phases of data collection with areas of 445 kHz^2 and 437 kHz^2 , respectively. In the Tx_2 phase of data collection the mean VSA increased to a value closer to that of the baseline condition at 476 kHz^2. Overall, the differences in VSA across the four phases of data collection were primarily the result of F1 fluctuations of the /æ/ vowel.

Discussion

The acoustic characteristics of the participants' monophthongal vowel productions were found to exhibit minor differences across the course of the nebulized saline treatment in terms of duration, formant frequencies, and VSA. A minimal increase in overall duration from baseline to Tx_2 was observed for all monophthongs bringing duration values at the conclusion of the study close to baseline measurements. Although the formant frequency values of the five monophthongal vowels did not deviate greatly across the phases of data collection, the largest differences in F1 and F2 were observed for the vowel /æ/. When comparing F2 values, the greatest shift from baseline to Tx_1 was observed on the vowel /æ/, with the greatest shifts being

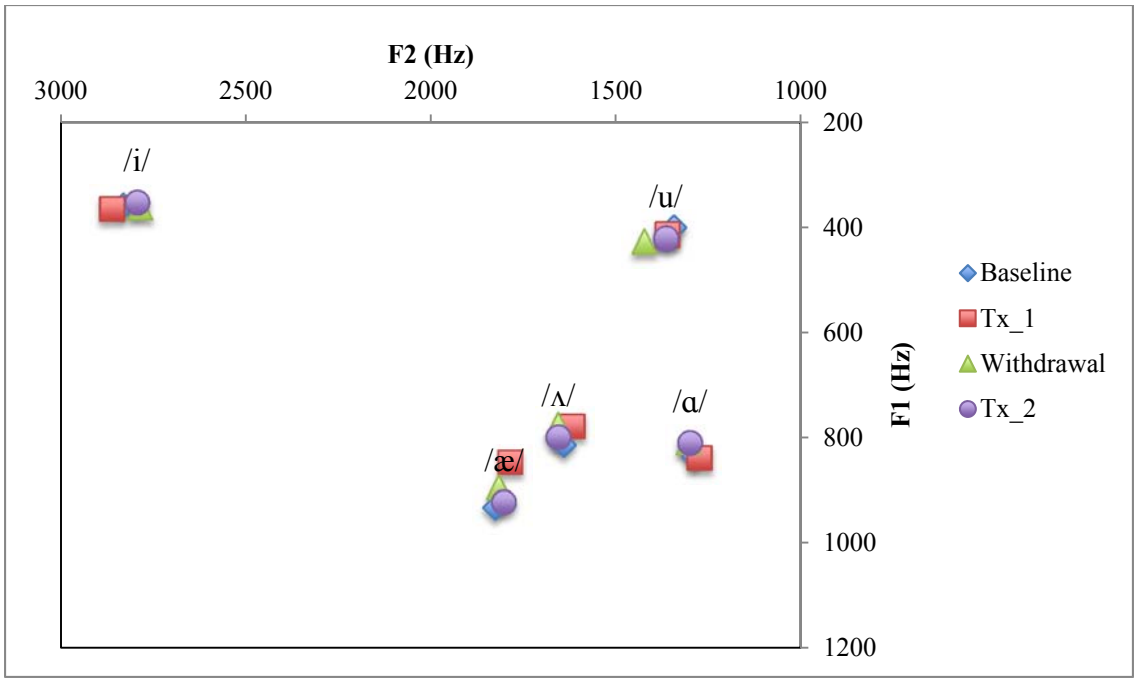

Figure 2. Formant frequency monophthong values from all four data collection phases.

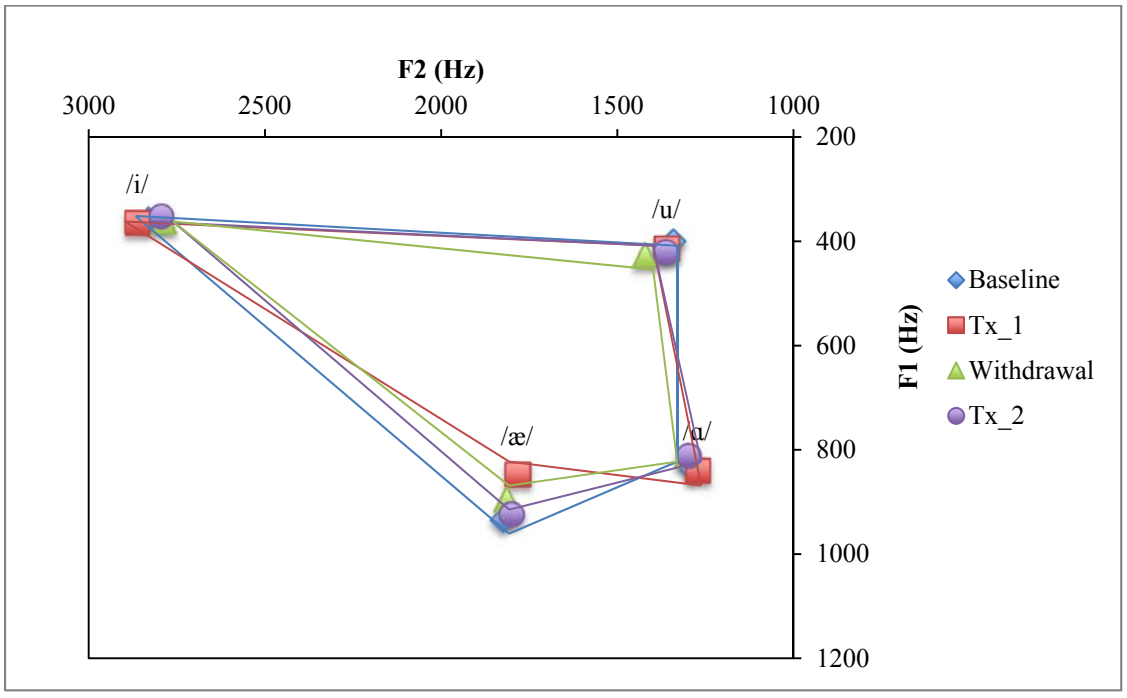

Figure 3. Vowel space area calculations for monophthongal vowel productions across all four phases of data collection

observed on the vowel /i/ from Tx_1 to withdrawal, and the vowel /u/ from withdrawal to Tx_2. Minimal decreases or centralizations were noted in the participant's VSA from baseline to Tx_2. The differences in VSA are primarily a result of F1 fluctuations of the /æ/ vowel.

The minimal acoustic differences from baseline through the Tx_2 phase of the study could be due to the probability that the SS participants' baseline vowel measures may initially be similar to that of typical speakers, thus the participants would not be expected to change significantly as a function of treatment. Figure 4 shows a comparison of the baseline data of this study with normative data collected in previous studies. A report by Kent and Read (2002) calculated mean values from eight different studies on monophthongal vowels (i.e., Assmann & Katz, 2000; Childers, & Wu, 1991; Hagiwara, 1995; Hillenbrand, Getty, Clark, & Wheeler, 1995; Lee, Potamianos, & Narayanan, 1999; Peterson & Barney, 1952; Yang, 1996; Zahorian & Jagharghi, 1993). The mean values from Kent and Read were collected from speakers with a regional dialect that was somewhat different than the region and dialect of the SS participants in this study. However there are also some normative vowel production data from the same geographic region as that of the SS participants available in an unpublished thesis by Reeves (2009). The formant frequency data that was collected throughout the course of the current thesis study fell within one standard deviation of the normative mean values from Kent and Read (2002) for all vowels and treatment phases with one exception. F2 values for the vowel /æ/ were slightly less than the normative data during all phases of data collection. The F1 and F2 values for the remaining vowel tokens (/i, u, ʌ, and ɑ/) were found to be similar to the normative data reported by Kent and Read (2002).

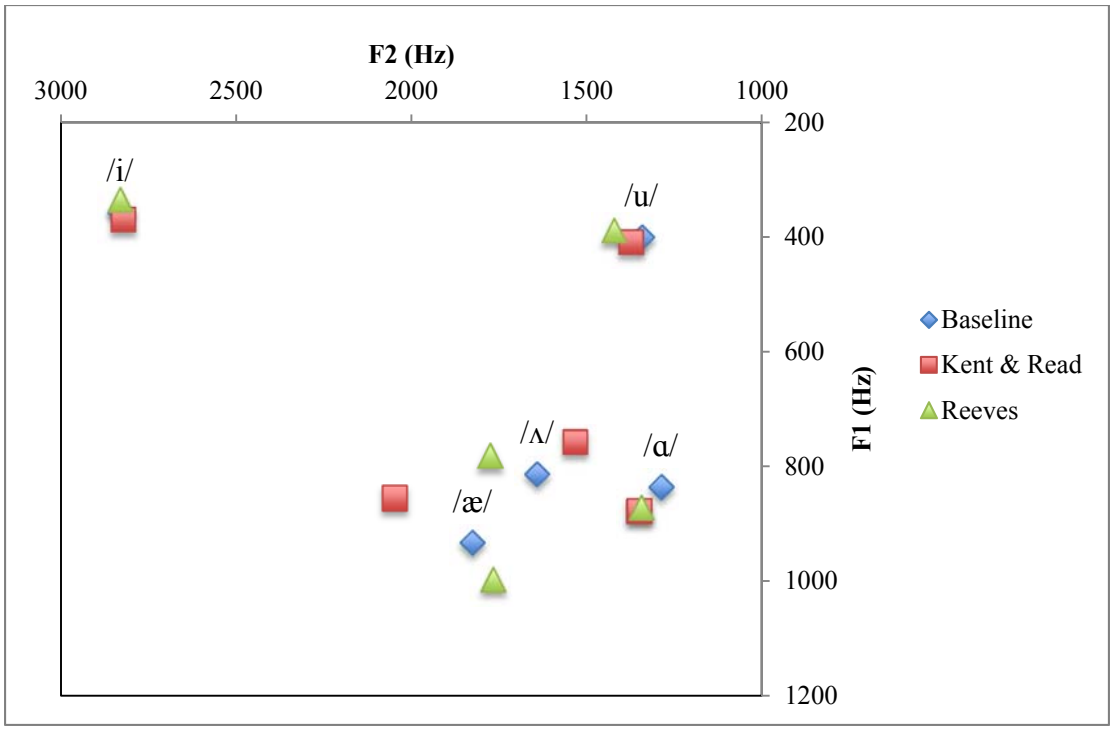

Figure 4. Mean monophthong F1 and F2 values for baseline compared to values reported by Kent and Read (2002) and Reeves (2009).

When comparing the fundamental frequency measures collected in the current study to data collected by Reeves (2009) it was found that all of the vowels except /æ/ fell within one *SD* of the mean. However, the baseline mean formant frequencies for /æ/ were 3 Hz less than the mean data found by Reeves and 43 Hz less than the Kent and Read data.

Acoustic differences in females with MTD following MCT were also analyzed by Roy et al. (2009). These findings suggested that individuals with MTD showed significant vowel space expansion in VSA following treatment. A possible reason for the difference in treatment effect between the study by Roy et al. and the current study may be due to the participants' voice disorder. The SS participants in the current study differed from the MTD participants in that the voice disorders from the SS participants was due to tissue dryness as opposed to muscle tension.

Another possible explanation for not finding a large treatment effect may be the level or severity of impairment of the current study's participants. The SS participants in this study were mildly impaired. A greater effect of the hydration treatment on monophthongs could possibly be seen with clients who have moderate to severe SS's.

It is also likely that although the SS participant's speech and voice have been perceptually rated as disordered, the perceived impairment in the participants' speech may not be due to the misarticulation of the monophthongal vowel segments. The perceptual abnormalities produced by the participants may be the result of difficulties in producing other types of speech sounds, such as dynamic vowels (diphthongs) or consonant segments that rely on fine-tuned motor movements. Considering the quantal nature of speech (Stevens & Keyser, 2010), very slight movements in certain speech sounds can produce a large acoustic consequence. However, for other sounds slight movements of the articulators may not perceptually alter the speech sound to the same degree.

It is important to also discuss some of the possible limitations of the current study, which could be addressed in future research within the SS population. The participants' vowel productions were described only using acoustic measures, thus we do not know the perceptual consequences of the study. It may be of value to perceptually rate the audio recordings throughout the different treatment phases to assess for perceptual changes with treatment. Collecting a running speech sample could also be beneficial, as the participants would be producing a more naturalistic sample of their speech. Also, the current audio samples were recorded in a quiet room environment, but considering that formant frequency extraction is highly sensitive to background noise, future studies could control for that factor by recording in a sound attenuated booth to produce more exact formant frequency measures. Lastly, the current

study's participants had mild SS whose baseline acoustic measurements closely resembled that of typical speakers, thus it would be useful to also study clients who have moderate to severe SS.

Despite these limitations, this study leads to a greater understanding of the clinical treatment and description of Primary SS. The symptoms of Primary SS can have a noticeable negative effect on the quality of life for individuals living with the disease. People with SS as well as their families and friends experience difficulties in communication and activities of daily living. The information from this study may assist future research and understanding regarding the speech characteristics of individuals with SS.

References

Allec, L. D. R., Hernández López, X., Arreguín Porras, J. B., Velasco Ramos, R., Pacheco del Valle, J. C., & Pérez García, Á. I. (2011). Alterations in voice, speech, and swallowing in patients with Sjögren's syndrome. *Acta Otorrinolaringologica (English Edition)*, *62*, 255-264. doi:10.1016/j.otoeng.2010.12.005

Ansel, B. M., & Kent, R. D. (1992). Acoustic-phonetic contrasts and intelligibility in the dysarthria associated with mixed cerebral palsy. *Journal of Speech, Language, and Hearing Research*, *35*, 296-308. doi:10.1044/jshr.3502.296

Assmann, P. F., & Katz, W. F. (2000). Time-varying spectral change in the vowels of children and adults. *The Journal of the Acoustical Society of America*, *108*, 1856-1866. http://dx.doi.org/10.1121/1.1289363

Blomgren, M., Robb, M., & Chen, Y. (1998). A note on vowel centralization in stuttering and nonstuttering individuals. *Journal of Speech, Language, and Hearing Research*, *41*, 1042-1051. doi:10.1044/jslhr.4105.1042

Boersma, P., & Weenink, D. (2004). Praat signal processing [Computer Software]. Retrieved www.fon.hum.uva.nl/praat/.

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

Bunton, K., & Weismer, G. (2001). The relationship between perception and acoustics for a high-low vowel contrast produced by speakers with dysarthria. *Journal of Speech, Language, and Hearing Research*, *44*, 1215-1228 doi:10.1044/1092-4388(2001/095)

Chan, R. W., & Titze, I. R. (1998). Viscosities of implantable biomaterials in vocal fold augmentation surgery. *The Laryngoscope*, *108*, 725-731. doi:10.1097/00005537-199805000-00019

Childers, D. G., & Wu, K. (1991). Gender recognition from speech. Part II: Fine analysis. *The Journal of the Acoustical Society of America*, *90*, 1841-1856. http://dx.doi.org/10.1121/1.401664

Dromey, C., Nissen, S. L., Roy, N., & Merrill, R. M. (2008). Articulatory changes following treatment of muscle tension dysphonia: Preliminary acoustic evidence. *Journal of Speech, Language, and Hearing Research*, *51*, 196-208. doi:10.1044/1092-4388(2008/015)

Fairbanks, G. (1960). *Voice and articulation drillbook* (p. 127). New York, NY: Harper.

Finkelhor, B. K., Titze, I. R., & Durham, P. L. (1988). The effect of viscosity changes in the vocal folds on the range of oscillation. *Journal of Voice*, *1*, 320-325. http://www.sciencedirect.com.erl.lib.byu.edu/science/article/pii/S0892199788800055

Ferguson, S. H., & Kewley-Port, D. (2007). Talker differences in clear and conversational speech: Acoustic characteristics of vowels. *Journal of Speech, Language, and Hearing Research*, *50*, 1241-1255. doi:10.1044/1092-4388(2007/087)

Ferrand, C. T. (2007). *Speech science: An integrated approach to theory and clinical practice* (2nd ed.). Boston, MA: Pearson Education, Inc.

Freeman, S. R., Sheehan, P. Z., Thorpe, M. A., & Rutka, J. A. (2005). Ear, nose, and throat manifestations of Sjögren's Syndrome: Retrospective review of a multidisciplinary clinic. *Journal of Otolaryngology*, *34*, 20-24. http://search.proquest.com/docview/85383273

Hagiwara, R. (1995). Acoustic realizations of American /r/ as produced by women and men (Vol. 90). *Phonetics Laboratory, Dept. of Linguistics, UCLA*.

Hillenbrand, J., Getty, L. A., Clark, M. J., & Wheeler, K. (1995). Acoustic characteristics of American English vowels. *Journal of the Acoustical Society of America, 97,* 3099-3111. doi:10.1121/1.411872

Hemler, R. J., Wieneke, G. H., & Dejonckere, P. H. (1997). The effect of relative humidity of inhaled air on acoustic parameters of voice in normal subjects. *Journal of Voice*, *11*, 295-300. doi:10.1016/S0892-1997(97)80007-0

Higgins, C. M., & Hodge, M. M. (2002). Vowel area and intelligibility in children with and without dysarthria. *Journal of Medical Speech-Language Pathology*, *10*, 271-277.

Jacewicz, E., Fox, R. A., & Salmons, J. (2007). Vowel space areas across dialects and gender. *Proceedings of the XVIth International. Congress of Phonetic Sciences*, 1465-1468.

Jacobson, B. H., Johnson, A., Grywalski, C., Silbergleit, A., Jacobson, G., Benninger, M. S., & Newman, C. W. (1997). The voice handicap index (VHI): Development and validation. *American Journal of Speech-Language Pathology, 6,* 66. http://search.proquest.com.erl.lib.byu.edu/comdisdome/docview/85292723/D6D069333B1B4159PQ/1?accountid=4488

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

Kempster, G. B., Gerratt, B. R., Abbott, K. V., Barkmeier-Kraemer, J., & Hillman, R. E. (2009). Consensus auditory-perceptual evaluation of voice: Development of a standardized clinical protocol. *American Journal of Speech-Language Pathology, 18*, 124-132. doi: 1058-0360/09/1802-0124

Kent, R. D., & Kim, Y. J. (2003). Toward an acoustic typology of motor speech disorders. *Clinical Linguistics & Phonetics*, *17*, 427-445. doi:10.1080/0269920031000086248

Kent, R. D., & Read, C. (2002). *Acoustic analysis of speech.* San Diego, CA: Singular Publishing Group. doi:10.1080/0269920031000086248

Kruszka, P., & O'Brian, R. J. (2009). Diagnosis and management of Sjögren syndrome. *American Family Physician, 79,* 465-470.

Kuhl, P. K., Andruski, J. E., Chistovich, I. A., Chistovich, L. A., Kozhevnikova, E. V., Ryskina, V. L., ... & Lacerda, F. (1997). Cross-language analysis of phonetic units in language addressed to infants. *Science*, *277*, 684-686. doi:10.1126/science.277.5326.684

Labiris, N. R., & Dolovich, M. B. (2003). Pulmonary drug delivery. Part I: Physiological factors affecting therapeutic effectiveness of aerosolized medications. *British Journal of Clinical Pharmacology*, *56*, 588-599. doi:10.1046/j.1365-2125.2003.01892.x

Lee, S., Potamianos, A., & Narayanan, S. (1999). Acoustics of children's speech: Developmental changes of temporal and spectral parameters. *The Journal of the Acoustical Society of America*, *105*, 1455-1468. http://dx.doi.org/10.1121/1.1289363

Liu, H. M., Tsao, F. M., & Kuhl, P. K. (2005). The effect of reduced vowel working space on speech intelligibility in Mandarin-speaking young adults with cerebral palsy. *The Journal of the Acoustical Society of America*, *117*, 3879-3889. doi:10.1121/1.1898623

Mahoney, E. J., & Spiegel, J. H. (2003). Sjögren's disease. *Otolaryngologic Clinics of North America, 36*, 733-745. doi**:**10.1016/S0030-6665(03)00024-0

Ogut, F., Midilli, R., Oder, G., Engin, E. Z., Karci, B., & 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

Perry, K. N. (2014). *The effects of nebulized saline treatments on diphthongal vowel production on female subjects with Sjögren's Syndrome* (Unpublished master's thesis). Brigham Young University, Provo, UT.

Peterson, G. E., & Barney, H. L. (1952). Control methods used in a study of the vowels. *The Journal of the Acoustical Society of America*, *24*, 175-184. doi:10.1121/1.1906875

Pillemer, S. R., Matteson, E. L., Jacobsson, L. T., Martens, P. B., Melton III, L. J., O'Fallon, W. M., & Fox, P. C. (2001). Incidence of physician-diagnosed primary Sjögren Syndrome in residents of Olmsted County, Minnesota. *Mayo Clinic Proceedings, 76,* 593-599. doi:10.4065/76.6.593

Proetz, A. W. (1953). Applied physiology of the nose. *Annals*, St. Louis, IL. doi:10.1007/978-3-0348-3_12

Reeves, L. H. (2009). *Patterns of vowel production in speakers of American English from the state of Utah.* (Unpublished master's thesis). Brigham Young University, Provo, UT.

Rogers, D. F. (1994). Influence of respiratory tract fluid on airway caliber. *Airways Smooth Muscle: Development, and Regulation of Contractility* (pp. 375-409). Birkhäuser Basel. doi:10.1007/978-3-0348-7408-3_12

Roy, N., Nissen, S. L., Dromey, C., & Sapir, S. (2009). Articulatory changes in muscle tension dysphonia: Evidence of vowel space expansion following manual circumlaryngeal therapy. *Journal of Communication Disorders*, *42*, 124-135. doi:10.1016/j.jcomdis.2008.10.001

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*, 331-342. doi:10.1067/S0892-1997(03)00078-X

Sapir, S., Spielman, J. L., Ramig, L. O., Story, B. H., & Fox, C. (2007). Effects of intensive voice treatment (the Lee Silverman Voice Treatment [LSVT]) on vowel articulation in dysarthric individuals with idiopathic Parkinson disease: Acoustic and perceptual findings. *Journal of Speech, Language, and Hearing Research*, *50*, 899-912. doi:10.1044/1092-4388(2007/064)

Seror, R., Bootsma, H., Bowman, S. J., Dörner, T., Gottenberg, J. E., Mariette, X., … & Vitali, C. (2012). Outcome measures for primary Sjögren's Syndrome. *Journal of Autoimmunity. 39*, 97-102. doi:10.1016/j.jaut.2012.01.013

Sivasankar, M. P., Carroll, T. L., Kosinski, A. M., & Rosen, C. A. (2013). Quantifying the effects of altering ambient humidity on ionic composition of vocal fold surface fluid. *The Laryngoscope, 123,* 1725-1728. doi:10.1002/lary.23924

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)

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

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:10.1044/1092-4388(2003/110)

Smiljanić, R., & Bradlow, A. R. (2005). Production and perception of clear speech in Croatian and English. *The Journal of the Acoustical Society of America*, *118*, 1677-1688. doi:10.1121/1.2000788

Stevens, K. N., & Keyser, S. J. (2010). Quantal theory, enhancement and overlap. *Journal of Phonetics, 38*, 10-19. http://ocw.raf.edu.rs/courses/linguistics-and-philosophy/24-941j-the-lexicon-and-its-features-spring-2007/readings/stevens_keyser07.pdf

Stojan, G., Baer, A. N., & Danoff, S. K. (2013). Pulmonary Manifestations of Sjögren's Syndrome. *Current allergy and asthma reports*, *13*, 354-360. doi:10.1007/s11882-013-0357-9

Tanner, K. (2014). *Speech and voice production data from patients with primary Sjogren's Syndrome*. Provo, UT: Brigham Young University.

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:10.1044/1092-4388(2007/045)

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

Titze, I. R. (1988). The physics of small-amplitude oscillation of the vocal folds. *The Journal of the Acoustical Society of America, 83*, 1536–1552. https://camtools.cam.ac.uk/access/content/group/d4fe6800-4ce2-4bad-8041-957510e5aaed/Public/3G2/Lab/Titze1988.pdf

Titze, I. R. (1994). *Principles of voice production*. Englewood Cliffs, NJ: Prentice Hall. doi:10.1121/1.395910

Verdolini, K., Min, Y., Titze, I. R., Lemke, J., Brown, K., Jiang, J., & Fisher, K. (2002). Biological mechanisms underlying voice changes due to dehydration. *Journal of Speech, Language, and Hearing Research*, *45*, 268-281. doi:10.1044/1092-4388(2002/021)

Verdolini-Marston, K., Titze, I. R., & Druker, D. G. (1990). Changes in phonation threshold pressure with induced conditions of hydration. *Journal of Voice*, *4*, 142-151. doi:10.1016/S0892-1997(05)80139-0

Vorperian, H. K., & Kent, R. D. (2007). Vowel acoustic space development in children: A synthesis of acoustic and anatomic data. *Journal of Speech, Language, and Hearing Research*, *50*, 1510-1545. doi:10.1044/1092-4388(2007/104)

Weismer, G., Jeng, J. Y., Laures, J. S., Kent, R. D., & Kent, J. F. (2001). Acoustic and intelligibility characteristics of sentence production in neurogenic speech disorders. *Folia Phoniatrica et Logopaedica*, *53*, 1-18. doi:10.1159/000052649

Wheaton, F. (2007) *Medifocus guide book on: Sjogren's Syndrome.* CreateSpace Independent Publishing Platform. Retrieved from http://www.medifocus.com

Widdicombe, J. G. (1997). Airway surface liquid: Concepts and measurements. In D. F. Rogers & M. Letham (Eds.), *Airway mucus: Basic mechanisms and clinical perspectives* (pp. 1-17). Basel, Switzerland: Birkhäuser Verlag. doi:10.1007/978-3-0348-8874-5_1

Yang, B. (1996). A comparative study of American English and Korean vowels produced by male and female speakers. *Journal of Phonetics*, *24*, 245-261. doi:10.1006/jpho.1996.0013

Yeates, D. B. (1991). Mucus rheology. In J. B. West (Ed.), *The lung: Scientific foundations* (pp. 197-203). New York, NY: Raven.

Zahorian, S. A., & Jagharghi, A. J. (1993). Spectral-shape features versus formants as acoustic correlates for vowels. *Journal of Phonetics, 94,* 1966-1982. http://dx.doi.org/10.1121/1.407520

Appendix A: Consent and Authorization Document

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: 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/Pulmonary Disease	x				x			x
Wears O2							x	x
Smokes					x			
Acid Reflux/heartburn	x	x			x		x	x
Seasonal Allergies	x	x	x	x	x		x	
Voice Training		x						

Appendix C: 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. Do this 3 times, pausing in between.

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 D: 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 vertical line 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 vertical line 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 E: 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 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 2 (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 2, complete:

___ Voice Handicap Index
___ Sjogren's Symptom Severity Scales

Week 3 (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 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 F: Annotated Bibliography

Allec, L. D. R., Lopez, X. H., Porras, J. B. A., Ramos, R. V., Pacheco del Valle, J. C., & Garcia, A. I. P. (2011). Alterations in voice, speech, and swallowing in patients with Sjögren's Syndrome. *Acta Otorrinolaringologica (English Edition), 62,* 255-264. doi:10.1016/j.otoeng.2010.12.005

Objective: The purpose of this study was to determine speech, voice, and swallowing problems in participants with SS. *Method:* There were 31 participants in this study who presented with a confirmed diagnosis of SS and who denied a history of phoniatric alterations or vocal pathologies that could be distinguishable from SS. Participants were interviewed and nasolaryngeal endoscopy and video laryngeal stroboscopy were used to examine them. Computerized voice spectrographic analysis (PRAAT® software) of voice and speech were performed as well as fiberoptic endoscopic evaluation of swallowing. *Results:* Anomalies were identified generally in: one or more of the following cranial nerves (V, VII, IX, X, XII), mucosal wave of vocal cords, nasopharyngolaryngeal mucosa, spectrogram of the vowels /e/ and /i/, and rhythm of the trisyllable *pa-ta-ka* and in the swallowing mechanism. *Conclusion:* Substantial swallowing anomalies, speech, and voice problems were found in patients with SS. It was hypothesized that these abnormalities were to be related with xerosis and possibly secondary neurological abnormalities in SS. *Relevance to the current work:* The participants in the current thesis work have SS. This study confirms that SS patients have high rates of voice, speech, and swallowing abnormalities.

Bowman, S. J., Booth, D. A., Platts, R. G., Field, A., Rostron, J., and the UK Sjögren's Interest Group. (2003). Validation of the Sicca Symptoms Inventory for clinical studies of Sjögren's Syndrome. *The Journal of Rheumatology,* 30, 1259-1266. Online ISSN 1462-0332

Objective: The purpose of this study was to generate a new way of measuring mucosal surface (sicca) symptoms for evaluating patients living with primary SS. *Method:* The participants in this group were Caucasian female patients who were diagnosed clinically with systematic lupus erythematous, SS, and rheumatoid arthritis, as well as healthy controls.

Saliva and tear production were analyzed and participants completed a symptoms-profiling inventory of SS patients' self-reported and construct-validated items. *Results:* Information was gathered from the 70 surveys that were returned. Strong relationships were shown in both the long and short-term forms. *Conclusions:* The long and short form PROFAD-SSI questionnaires show a close correlation. This leads us to believe that the short form is a valid tool to use. Preliminary evidence further suggests that even a briefer questionnaire may be feasible. *Relevance to the current work:* The SSI assessment, short form was used to rate the participants' symptoms in the current thesis work.

Clopper, C. G., & Paolillo, J. C. (2006). North American English vowels: A factor-analytic perspective. *Literary and Linguistic Computing*, *21*, 445-462. doi: I0.1093/llc/fql039

Objective: The purpose of this study was to analyze linguistic aspects of vowels (found from vowel space measures) derived from various groups of speakers who speak different dialects. *Method*: Participants were selected from the six different dialect areas of the US. A total of 48 speakers participated and were evenly divided within the six dialectal regions and in gender. They were recorded speaking /i,ɪ,ɑ,æ,u,ʊ,o,ʌ,ɛ/ in h_d words. CVC combinations were also collected as the participants recorded /ɔ, ɑy, oy, ɑw/. The affiliation of five acoustic measures was one factor that was analyzed. The affiliation among production and dialect and individual speakers is what the second analysis examined. *Results*: Vowel space area for vowels appeared typical. F1 and F2 measures produced a larger fluctuation in female participants. The primary elements in a body of speakers that fluctuate in dialect and measures of vowel production and gender are vowel duration, gender, back vowel fronting, minimum F1 and F2, and the NCCS. *Discussion*: The F1 and F2 measurements are vital to analyzing the uniqueness of a vowel. A primary element in vowel variation in North American English vowels is gender. *Relevance to current study*: The researchers identified a few of the aspects of vowel production that influence speech perception.

Dromey, C., Heaton, E., & Hopkin, J. A. (2011). The acoustic effects of vowel equalization training in singers. *Journal of Voice, 25,* 678-682. doi:10.1016/j.jvoice.2010.09.003

Objective: The objective of this study was to analyze the formant frequencies of singers following the effects of one lesson on vowel equalization. *Method*: There were 16 participants who were amateur singers that sang at least one hour a day in this study. They were individually recorded singing *Somewhere Over the Rainbow*, and then their vowels were recorded in isolation. The singers were trained in the vowel equalization technique for 15 minutes. The singers were asked to re-record the song three times following training and coaching, as well as their vowels in isolation. *Results*: *Praat* was used to analyze the results. The first and second formant frequencies of /ɑ/ decreased after training in the singing passage with /e/ and /i/ also experiencing more neutral placement. Neutralization of vowels in isolation was also noted after equalization training. The second formant frequency for /e/ and /i/ decreased while /u/ increased. *Discussion*: There were positive findings that singers may be able to benefit from training in their attempts to neutralize their vowels and balance between brightness and warmth. A limitation of the study is that tongue height was not analyzed as extensively as tongue advancement. *Relevance to current study*: Vowel productions were affected by oral and pharyngeal space.

Dromey, C., Nissen, S. L., Roy, N., & Merrill, R. M. (2008). Articulatory changes following treatment of muscle tension dysphonia: Preliminary acoustic evidence. *Journal of Speech, Language, and Hearing Research*, *51*, 196-208. doi: 10.1044/1092-4388(2008/015)

Objective: The purpose of this study was to determine whether or not acoustic evidence exists for articulatory changes (particularly the diphthongs /eI/ and /aI/) following successful management of Muscle Tension Dysphonia (MTD). *Method*: Pre and post treatment speech samples were collected from 111 females with MTD and were analyzed for acoustic evidence of vocal tract changes associated with improvement of the voice. This was confirmed by perceptual assessment of dysphonia severity. The slopes of the first and second formants in diphthongs and comprehensive measures of speech timing were collected. To allow for comparisons in performance, there were also two samples taken from 20 younger women with typical voices. *Results*: When comparing the control group and the MTD group it was found that diphthong second formant transitions increased in slope and timing measures showed increases in speech stability. *Discussion*: Following successful treatment

that targets the larynx, the findings suggest that individuals with MTD encountered shifts in both articulatory and phonatory behavior. *Relevance to current work*: The analysis of the data in this study was conducted in a like style to that which was used in the current thesis work.

Finkelhor, B. K., Titze, I. R., & Durham, P. L. (1988). The effect of viscosity changes in the vocal folds on the range of oscillation. *Journal of Voice, 1,* 320-325. http://www.sciencedirect.com.erl.lib.byu.edu/science/article/pii/S0892199788800055

Objective: The purpose of this research was to study the internal vocal folds in four canine larynges as directly affected by viscosity changes. It was one of the first in vitro model studies to be conducted. *Method:* The larynx was exposed to various osmotic solutions and fluid transport. Measurements of these solutions both into and out of the larynx of the canine were collected. *Results:* The oscillation threshold pressure shifted in each hydration condition. *Discussion:* Decreased hydration caused an increase in viscosity of vocal fold tissue which resulted in an increased threshold of oscillation. Likewise an increase in hydration resulted in a reduction in the viscosity of vocal fold tissue. Therefore, the threshold oscillation was also reduced. *Relevance to the current work:* This research can be considered a pilot study as it was one of the first of its kind in understanding dehydration of the vocal folds and the disorders regarding it.

Hemler, R. J., Wieneke, G. H., & Dejonckere, P. H. (1997). The effect of relative humidity of inhaled air on acoustic parameters of voice in normal subjects. *Journal of Voice*, *11*, 295-300. doi: 10.1016/S0892-1997(97)80007-0

Objective: The purpose of this study was to determine whether or not it could be demonstrated that relative humidity (RH) can affect the voice. *Method*: Eight healthy participants inhaled three distinct substances: humidified air, standard room air, and dry air. Then at controlled pitch and loudness the participants repeatedly recorded a continuous /a/. Those recordings were then analyzed for perturbation and noise to harmonic guidelines. *Results*: After dry air was inhaled, perturbation increased. No significant differences between standard and humidified air were observed in regards to the noise-to-harmonic ratio. *Discussion*: After a short period of time inhaling dry air, significant increases were found in

perturbation. It was determined that the voice is very susceptible to declines in RH of inspired air. *Relevance to current study*: In the current thesis research the effects of RH on voice and laryngeal hydration was discussed.

Hillenbrand, J., Getty, L. A., Clark, M. J., & Wheeler, K. (1995). Acoustic characteristics of American English vowels. *The Journal of the Acoustical Society of America, 97*, 3099-3111. doi:00001-4966/95/97(5)/3099/13/$6.00

Objective: The purpose of the study was to broaden the research previously conducted by Peterson and Barney (1952) regarding vowel acoustics. *Method*: The participants consisted of 45 men, 48 women, and 46 children who ranged in age from 10-12 (19 girls, 27 boys). The greater part of the participants population grew up in Michigan and all of the speakers went through a set of pre-screenings and a dialect assessment. They spoke and recorded 12 vowels (i, I, e, eh, ae, a, c, o, uu, u, v, er) in an h-V-d context. The duration and *steady-state* times of the vowels were recorded as well as the calculations of the F1, F2, F3, and F4. *Results*: In comparing the duration measurement data with the research of Black (1949), this study produced findings that were 2/3 longer in duration than the duration measures analyzed during connected speech. However, durations similarly correlated with the connected speech data. When comparing men's, women's, and children's vowel durations it was found that the men's duration measurements were significantly reduced when related to the groups of women and children. The position of the tongue in this study gravitated more to the front and lower when compared with Peterson and Barney (1952). *Discussion*: Hillenbrand et al. and Peterson and Barney have like conclusions even though there are many contrasts between the two studies. Those differences could likely be due to the use of LPC by Hillenbrand et al. instead of using another spectrum analysis method. Assuming that acoustic measurements were similar in both studies, it could also be said that the speakers of the two groups pronounced vowels differently. *Relevance to current study*: The findings of this study were used as normative data in the current thesis project.

Neel, A. (2008). Vowel space characteristics and vowel identification accuracy. *Journal of Speech, Language, & Hearing Research, 51,* 574-585. doi: 10.1044/1092-4388(2008/041)

Objective: The purpose of this study was to determine whether or not vowel intelligibility in adults relies on certain characteristics to produce those vowels. *Method*: Ten vowels from the Hillenbrand study were analyzed. Two vowel measurement methods were implemented (converting to Bark units and mean Euclidean distances) to determine vowel space area. *Results*: Vowel space areas, fundamental frequency ranges, mean distance through vowels, and F1 and F2 distances were larger in women than in men. Mean measurements of vowel identification were 95.6% for men with a standard deviation of 4.0% and 96.8% for women with a standard deviation of 2.6. Vowel space and F1 measurement correlations were $r = .80$, $p < .01$ for women and $r = .49$, $p < .01$ for men. F2 and vowel space correlations were $r = .52$, $p < .01$ for women and $r = .48$, $p < .01$ for men. The correlation between VSA and the dispersion measure was $r = .79$, $p < .01$ for men and $r = .83$, $p < .01$ for women. *Discussion*: It was determined that the following vowel characteristics: duration, formant frequency, and mean fundamental frequency did not have much to do with the discrimination of vowels. VSA has a smaller impact than vowel distinctiveness among bordering vowels when identifying vowels. *Relevance to current work:* The current thesis study aimed to compare vowels measurements including VSA and compare them to normal speech measurements.

Ogut, F., Midilli, R., Oder, G., Engin, E. Z., Karci, B., & 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

Objective: The objective was to investigate the effect that Sjögren's Syndrome (SS) has on objective voice quality and perceptual ratings of the laryngeal findings. *Method*: A control group and an SS group participated in this study. The following measurements were used during this study: Reflux Finding Score for laryngeal findings, The Reflux Symptom Index, outcomes instrument for symptom assessment, and the laryngoscopic-based scale. Voice samples were analyzed using the Multi Dimensional Voice Program and a t-test was also used to measure comparisons in the results. *Results*: Significant discrepancies were noted for The Reflux Symptom Index and the Reflux Finding Score between the two groups. There were also significant differences between the two groups in the voice quality measures. *Discussion*: The lack of saliva and esophageal pressure is thought to be caused by increased

frequency of reflux in SS. It was also discussed that it is more common than not for individuals with SS to have laryngeal pathologies. *Relevance to current study*: The participants in the current study suffer from the same SS condition and vocal fold hydration and the effect on vowel production was targeted.

Peterson, G., & Barney, H. (1952). Control methods used in a study of the vowels. *The Journal of the Acoustical Society of America, 24*, 175-184. doi: 10.1121/1.1906875

Objective: Researchers sought to evaluate the correlation among a spoken vowel phoneme and what that phoneme was understood or perceived as. *Method*: The participants consisted of 76 participants (15 children, 28 females, and 33 males). They spoke 1520 words and those words were recorded. Seventy listeners were to randomly determine the word or vowel phoneme that was being said. Following that an analysis of ten vowels was done. The frequency and amplitude of the formants were documented. A calibration technique was used to measure the overall recording performance. *Results*: The vowels that were understood by the majority of the listeners were /i/, /er/, /ae/, and /u/. On the flip side, the vowels /a/ and /c/ were quite a bit more difficult. Different dialects were the likely cause for the substitutions that the listeners made out. Overlap of vowel formants was noted, especially among /er/ and /eh/, /er/ and /uu/, /u/ and /uu/, and /a/ and /c/. *Discussion*: A major role in the production and perception of vowels was our previous experiences and knowledge of our language background. Certain vowels were generally able to be perceived more than others. *Relevance to current study*: The current thesis research seeks to determine the clarity of vowels in individuals with Sjögren's Syndrome.

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*, 331-342. doi: 10.1067/S0892-1997(03)00078-X

Objective: The purpose of this study was to analyze the relative effects of three potential laryngeal lubricants on phonatory function (water, Mannitol, and Entertainer's Secret Throat Relief). *Method*: Phonation threshold pressure (PTP) was analyzed in 18 vocally normal, healthy female participants two times prior, to collect a baseline, and then four times

following 2 ml of nebulizing each material. Data was collected from the participants on three separate occasions over a three-week period at one-week intervals. A different nebulized material was inhaled on each occasion. An oral pressure flow system was used to measure PTP for both high fundamental frequency and comfortable productions. *Results*: Following the administration of Mannitol which is an agent that encourages water flux to the luminal airway surface, instant reductions in PTP were noted. However, the effects were short-lived only remaining for 20 minutes. The remaining two nebulized materials didn't achieve any significant post administration effect on PTP. *Discussion*: Because the results of this study were so modest, the authors of the study are cautious in their interpretations. The Mannitol did produce a statistically significant change, but because the effects only lasted for so short a time it has not been approved or endorsed for clinical use. More research needs to be conducted regarding the method of delivery, dosing, and the precise basic effect of Mannitol. The observed effects of Mannitol were considered promising and should be studied further. *Relevance to the work*: Laryngeal hydration treatments were used in the current thesis study to measure voice improvements.

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)

Objective: The purpose of this study was to research if individuals describing vocal fatigue produce adverse phonatory effects of dehydration. *Method*: A control and test group of individuals who had reported vocal fatigue participated in this study. All participants were female and totaled 16 individuals. Each experimental session included an assessment of pitch range determination, nasal resistance, voice measurement pre and post the oral and nasal breathing tasks as well as an analysis of the frequency of respiration during the task. *Results*: Phonation threshold pressure (PTP) increased to a larger extent in the women who reported a history of vocal fatigue as compared to control group following oral breathing at low and moderate humidity levels. However, PTP did not increase in either group after breathing orally while in a humid environment. *Discussion*: Dryness tasks could be unfavorable in

those individuals who have a history of vocal fatigue on voice production when conducted at low and moderate, but not high, ambient humidity levels. This was demonstrated from the emergence of between-group variations in PTP. Due to the phonatory effects of dehydration, it is suggested that individuals who report vocal fatigue may demonstrate impaired compensation to airway drying due to breathing orally short-term. *Relevance to current study*: The phonatory effects of laryngeal dehydration were assessed in the current thesis work.

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

Objective: The purpose of this study was to investigate whether accelerated oral breathing challenges are detrimental to phonation. A secondary objective was also included to determine whether individuals at increased risk for developing voice problems (smokers) have greater adverse phonatory effects after accelerated breathing challenge than nonsmoking controls. *Method*: Twenty-four females participated in the study (12 smokers and 12 non-smoking controls). The study took place over two days that differed in ambient humidity. Phonation threshold pressure (PTP) measures were collected before and after short-term accelerated and habitual breathing challenges. Respiratory measures were also collected during the 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. *Discussion*: 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 on phonation were considered in the current thesis work.

Sivasankar, M., & Fisher, K. V. (2002). Oral Breathing Increases P*th* and Vocal Effort by Superficial Drying of Vocal Fold Mucosa. *Journal of Voice, 16,* 172-181. doi:10.1016/S0892-1997(02)00087-5

Objective: This article shows that the airway of a human can dry out superficially by short periods of oral breathing. When a person participates in oral breathing the depth of the sol layer of the vocal folds is decreased. However, the depth of the sol layer will increase with nasal breathing as this also increases the humidity of the inhaled air. *Method:* This study consisted of 20 female participants. They were instructed to oral-breathe, and then nasal-breathe for 15 minutes prior to measuring phonation threshold. The phonation threshold is the minimum pressure required to initiate and sustain vocal fold oscillation. *Results:* Short-term oral breathing increased phonation threshold pressure while short-term nasal breathing did not. *Discussion:* The authors theorize that healthy subjects are put at risk for symptoms of increased vocal effort by breathing orally. *Relevance to the current work:* The effects of laryngeal dehydration on vocal production and effort were both key components of the current thesis work.

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:10.1044/1092-4388(2003/110)

Objective: The purpose of this study was to determine whether or not oral breathing is more detrimental to phonation in typical subjects who have previously experienced vocal attrition. *Method*: This study comprised of two groups, a control of 20 and a group of 20 who had previously experienced vocal attrition. All 40 women had typical vocal health and voicing at the time of the study. The researchers randomly divided the groups into either oral or nasal breathing in which they endured oral or nasal breathing for 15-minutes. The groups were compared in both perceived expiratory vocal effort and phonation threshold pressure (PTP). *Results*: Post- and pre-challenge changes in PTP and effort showed that unlike nasal breathing, oral breathing elevated phonation threshold pressure at high, low, and comfortable pitches. The difference in PTP was also significantly larger in participants with vocal attrition than in the other group. All participants in the control group demonstrated a reduction in PTP with nasal breathing but this was not the case for the group of participants with the history of vocal attrition. *Discussion*: It is speculated that delayed or deficient compensatory responses to superficial laryngeal dehydration produces greater increases in PTP in participants

reporting vocal attrition. Vocal attrition may be aggravated when speakers participate in obligatory oral breathing. Following obligatory breathing, PTP and vocal effort increase by depleting the sol layer. This helps to provide some backing to superficial hydration in maintaining ease of phonation. *Relevance to current work*: Laryngeal dehydration and the effects it has on phonation and speech were relevant to the current thesis project.

Strange, W. (1989). Evolving theories of vowel perception. *The Journal of the Acoustical Society of America, 85,* 20812087. doi:0001-4966/89/052081/-07$00.80

Objective: The researchers wanted to review evolving theories on vowels. *Method:* The theories that were discussed first included the *simple* target model, which is the belief that there is a distinct formation in the vowel tract that can be plotted by F1 and F2 formants. Second is which considers the obstacles of undershooting in steady continuous speech. *Results:* Other factors need to be contemplated when perceiving vowels because coarticulation produces a significant measure of overlap on variety of vowels and the actual vowel target. The challenges of coarticulation are mainly addressed by the dynamic specification approach. Vowels that are coarticulated are more precisely distinguished than vowels that are spoken in isolation. There are many researchers that figured the syllable nucleus, vowel duration, and the transitions of the formants both in and out of the syllable nucleus provide information that help listeners to identify the vowel. *Discussion*: It was thought that it may be time to merge the two vowel theories discussed in the research study because perceptual relevant and dynamic information in CVC syllables are carried by the initial and final transitional sections of that syllable. *Relevance to current work:* Insight was shown into two evolving theories on vowels. Multiple vowel theories on perception were contemplated for the current thesis study.

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

Objective: The purpose of this study was to analyze throat dryness, vocal effort, and phonation threshold pressure in participants with Sjögren's Syndrome (SS) following the

effects of a laryngeal desiccation challenge and two nebulized hydration treatments. *Method*: A 15-minute laryngeal desiccation (drying) challenge was completed by 11 participants with Primary Sjögren's Syndrome. The drying challenge consisted of transorally breathing dry air which was <1% relative humidity. Either treatments of water (3 mL) or isotonic saline was nebulized for two successive weeks by the participants. Preceding and following the desiccation challenge, Self-perceived vocal effort, PTP, and mouth and throat dryness were analyzed both preceding and following the drying challenge, and at 5, 35, and 65 minutes following the nebulized treatments. *Results*: There were statistically significant gains in PTP, vocal effort, and mouth and throat dryness following the laryngeal desiccation challenge. Although the following was not statistically significant there were still greater treatment effects observed with the saline than with the water. There was also more of a correlation between throat dryness and PTP than with throat dryness and vocal effort. *Discussion*: After being exposed to dry air for a short period of time gains in perceived dryness, PTP, and vocal effort were observed. Individuals could experience voice problems resulting from chronic dryness. Benefits following nebulized treatments could be seen in those with chronic dryness. *Relevance to current work*: Much of the current thesis was based off of this study. Both use the same population of participants as well as laryngeal nebulizing treatments.

Verdolini, K., Min, Y., Titze, I. R., Lemke, J., Brown, K., Jiang, J., & Fisher, K. (2002). Biological mechanisms underlying voice changes due to dehydration. *Journal of Speech, Language, and Hearing Research*, *45*, 268-281. doi:10.1044/1092-4388(2002/021)

Objective: The purpose of this study was to analyze if there were any links in systemic dehydration, secretory dehydration, or both, provide gains in PTP that are known to occur following treatments of dehydration. *Method*: Four participants (two male, two female) all healthy college students participants were enrolled in the study. It was conducted as a double-blind placebo-controlled approach. Three treatments were carried out on separate days to each participant. The treatments were: 60-mg dose of a diuretic, Lasix (LA), a single 50-mg dose of an oral antihistamine, diphenhydramine hydrochloride (DH), and a placebo. Weight, which approximated systemic dehydration, saliva viscosity which estimated secretion dehydration and PTP were all recorded as critical post-treatment

measures. *Results*: A 1% reduction in total body mass was noted when systemic hydration was induced. Increases in PTP were recorded 5-12 hours after the whole body dehydration. Neither secretory dehydration nor deviations in PTP were noted following DH. *Discussion*: Systemic dehydration can mediate gains in PTP. The influences of secretory dehydration on PTP are unclear. *Relevance to current study*: This research discusses systemic and surface hydration that was discussed in the current thesis work.

Vorperian, H. K., Kent, R. D. (2007). Vowel acoustic space development in children: A synthesis of acoustic and anatomic data. *Journal of Speech, Language, & Hearing Research, 50,* 1510-1545. doi:10.1044/1092-4388(2007/104)

Objective: The purpose of this research was to consolidate the information on formants of vowels in English speakers in males and females from infancy to adulthood. They considered the maturation of VSA in affect to anatomic-acoustic characteristics in English. *Method*: They analyzed like research from 14 different sources on vowel formant frequencies. *Results:* The development of vowels can be described acoustically by using F1-F2. The arrangement of F1-F3 may be more delicate to differing ages and genders. *Discussion:* There is an inverse relationship between age and formant frequency. As increases in age are observed decreases in formant frequencies are also shown. Distinctions in formant frequencies were visible between men and women. Differences were noted by age four and were most noticeable by the age of 16. The maturing of the vocal tract naturally happens with age and is what formant frequency changes are linked to. Producing non-nasal vowels generally happens around age 1 because that is when the velopharyngeal function matures. *Relevance to current work:* Vowel formant frequencies in the current thesis were analyzed and compared with typical normed formant frequencies. Vorperian and Kent studied the vowel acoustic space and vowel formants.