Effects of Respiratory Muscle Strength Training in Classically Trained Singers

Dissertation

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By

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Abstract

Many voice pedagogy practices revolve around the notion of controlling airflow and lung volumes and focus heavily on the concepts of breath support and breath control. Despite this emphasis, the effects of increased respiratory muscle strength on airflow and phonation patterns in trained singers remain unknown. This study addressed whether singers could increase respiratory muscle strength with resistive training and whether respiratory muscle strength increases had any effect on voice and aerodynamic measures. A single subject design was used to answer the research questions. Improved breath support was hypothesized to manifest in differences in airflow, vibrato, and phonetogram characteristics. Six graduate-level singing students were recruited to complete the protocol which consisted of a baseline phase followed by either inspiratory muscle strength training followed by expiratory muscle strength training or vice versa. Results showed that these singers were able to increase respiratory muscle strength after completing the training program. Consistent changes in measures of aerodynamics and voice were not present among subjects, although some individual changes were noted. Future research may focus on the effects of respiratory muscle strength training in less advanced singers.

Dedication

Dedicated to my husband and parents for supporting me throughout this process and making it possible.

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I first have to express my sincerest gratitude to Dr. Michael Trudeau for his comprehensive support, guidance, and encouragement throughout this process. He has been an influence and role-model not only through this doctoral program, but also throughout my Master's program and as a clinical professional and colleague. This project would not have been possible without the knowledge and support of Dr. Scott McCoy. He has inspired me to learn more than I thought possible. Dr. Trudeau and Dr. McCoy encouraged me to succeed in all ways while balancing life's challenges, and for them I am grateful.

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Although words cannot fully express how grateful I am for all of these individuals throughout this endeavor, I hope to pass such support and compassion along to others in the future.

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Fields of Study

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Chapter 1: Introduction

Breathing for Singing

Singers are musicians whose instruments are comprised of their upper and lower respiratory tracts. Control and proper execution of breathing is therefore essential for mastery of their craft, and singers are often referred to as vocal athletes (LeBorgne & Weinrich, 2002; Sataloff, 1998). The ability to regulate breathing pressure (subglottal pressure; Ps) and airflow for a desired sound is known as breath control and is widely considered one of the requirements for excellence in singing (Brown, 1996; Emmons, 1988; McCoy, 2004; Miller, 1996; Sundberg, 1987; Sundberg, 1990; Thorpe et al., 2001; Vennard, 1967). Well-trained singers have, in fact, been shown to use breath support strategies that differ from non-trained singers (Brown, Rothman, & Williams, 1978; Brown, Hunt, & Williams, 1988; Carroll et al., 1996; Cleveland, 1994; Hoit, Christie, Watson, & Cleveland, 1996; Sundberg, 1987; Watson & Hixon, 1985). As such, supported, controlled breathing is often a primary target of voice pedagogy practices.

Breathing for classical singing relies on and goes beyond the basic physiologic properties of the respiratory system, which include creation of airflow and gas exchange between the environment and blood for sustaining life (Hixon, Weismer, & Hoit, 2008; Levitsky, 2003; West, 1990; Zemlin, 1988). During quiet breathing (i.e., tidal breathing), the inspiratory muscles raise the ribcage and distend the abdomen. The lungs expand secondary to active muscle contraction of primarily the diaphragm and external

intercostal muscles (Hixon, 1991; Hixon, Weismer, & Hoit, 2008; Watson & Hixon, 1985). At rest, inspiration is initiated from a level of about 40% vital capacity, or 40% of the maximum amount of air that can be exhaled after a maximum inhalation (Comroe et al., 1962). Tidal exhalation is passive and the result of relaxation of the inspiratory muscles, elastic recoil of the lungs, and gravitational forces. This passive action returns the lungs to functional residual capacity (FRC), which is when lung and atmospheric pressures are equal (Comroe et al., 1962).

Controlled exhalation to and beyond the point of functional residual capacity, as required for speech and singing, involves an active process whereby the inspiratory and expiratory muscles contract to regulate airflow and pressures based on the volume of air in the lungs (Hixon, 1991; Hlastala & Berger, 2001; Sundberg, 2007). This process of controlling lung volumes and pressure is illustrated in the relaxation curve shown in Figure 1 (Hixon, Weismer, & Hoit, 2008).

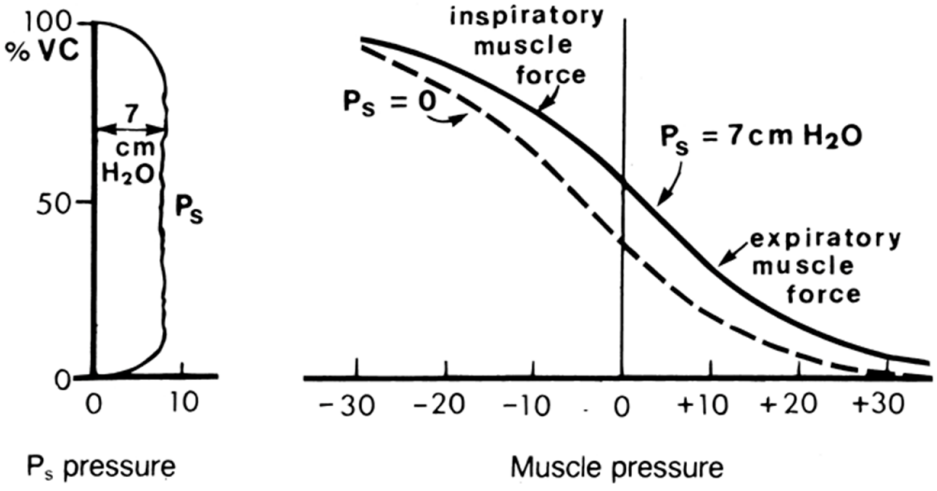

Figure 1. Pressure-volume relationship depicted by the relaxation curve (FRC is equal to zero).

Studies of classical singers have shown that they tend to begin phrases at high lung volumes and end at low lung volumes (Sundberg, 1987; Tang, 2008; Watson et al., 1990). In other words, singing requires a wider range of lung volumes than either speaking or other phonatory tasks and therefore requires increased muscle activity to control the pressures that result. Singing requires increased initiation volumes, closer to 70% to 100% VC, than either speaking (60% VC) or breathing at rest (40% VC) (Thomasson & Sundberg, 1997). Forced inspiration to achieve greater lung volumes relies on contraction of the diaphragm, external intercostal muscles, and often accessory muscles, including muscles of the neck (i.e., sternocleidomastoid and scalenus), anterior thorax (i.e., pectoralis major, pectoralis minor, subclavius, serratus anterior, and transverse thoracis), and posterior thorax (i.e., latissimus dorsimus, serratus posterior, and quadratus lumborum) (Gray, 1926; Hixon, 1991; Zemlin, 1988).

To overcome the strong elastic recoil forces that are generated at higher lung volumes, the inspiratory muscles act to brake the passive forces during expiration. Once the lung volumes and elasticity forces have reached the point of FRC, the expiratory muscles provide an active force to continue to regulate subglottic pressure at low lung volumes (Sundberg, 1992). The muscles involved in active expiration during speech and singing include the abdominal muscles (i.e., rectus abdominus, transverse abdominus, external obliques, and internal obliques) and rib cage depressors (i.e.internal intercostals) (Gray, 1926; Hixon, 1991; Zemlin, 1988).

It has long been established the control of lung volumes has a direct effect on subglottal pressure (Ps), which regulates sound pressure level (SPL) and, therefore, loudness of phonation (Bouhuys, Proctor, & Mead, 1966; Bouhuys et al., 1968; Rubin et

al., 1967). At high lung volumes, Ps is highest, and the perceived effort associated with loud phonation is generally easier than for quieter loudness levels. In contrast, achieving quiet phonation and decreased Ps at high lung volumes is a challenge that singers face and work to achieve regularly. Similarly, it is most difficult to achieve adequate Ps values for loud phonation at lower lung volumes. A doubling of Ps alone will increase SPL by anywhere from 6dB (Sundberg, Titze, & Scherer, 1993) to 9dB (Titze, 1989). In addition, changes in Ps will alter pitch. If changes in Ps are not precisely controlled, pitch changes will occur, which for singers can result in out-of-tune singing and be detrimental to the perceived quality of a voice performance. In fact, it has been shown that 1 cmH_2O increase in Ps can increase the fundamental frequency by 4Hz which may result in singing that is perceived as being out of tune (Baer, 1979; Titze, 1991). Additionally, when the vocal folds are stretched, as for high pitches, a higher Ps is required to produce phonation (Titze, 1989). For singing, unlike for speaking, pitch and loudness need to be controlled independently; consequently, Ps must be tailored for each note sung. Achieving a desired loudness and pitch at any given lung volume, therefore, requires mastery of the ability to regulate subglottal pressure, particularly in the higher reaches of a singer's range (Leanderson & Sundberg, 1988; Sundberg, 1990).

Mastery of subglottal pressure tuning, referred to by singers and pedagogues as breath control or support, is a common theme of pedagogical practice. Pedagogically, there are a wide variety of methods that different voice teachers choose to prescribe. Correspondingly, breathing techniques used among singers are widely variable (Griffin, et al., 1995; Thomasson & Sundberg, 1997; Thorpe, Cala, Chapman, & Davis, 2001). Almost any book or article that discusses singing technique will discuss the importance

of breath support; however, there is no single technique or strategy known to work equally well for every singer.

One disparity often described is the "belly-in" vs. "belly-out" method. The "belly-in" method utilizes breathing with the abdomen pulled inward while the "belly-out" method encourages expansion of the abdominal wall. In looking at the advantages and disadvantages of both, Hixon and Hoffman (1978) noted the increased efficiency of muscle recruitment when in the stretched, versus contracted, state. Theoretically, then, the "belly-in" method would be profitable in recruiting the stretched external intercostals during phonation, but not the contracted abdominal muscles. Conversely, the "belly-out" method would utilize the stretched abdominal muscles but be limited by the contracted state of the diaphragm. At lower lung volumes, however, the diaphragm would become less contracted and more stretched. It is ultimately unknown if either of these is superior to the other for a given individual. (Collyer, Kenny, & Archer, 2009).

Solely discussing the role of certain breathing techniques on the regulation of subglottal pressure ignores the role of the larynx. The degree of vocal fold adduction (i.e. pressed voice vs. breathy voice) will alter the respiratory requirements for producing subglottal pressures (Iwarsson, Thomasson, & Sundberg, 1998; Sundberg, 1993; Sundberg, Iwarsson, & Billstrom, 1995; Titze, 1994). Breathing technique may have a direct effect on the degree of adduction or may be used in conjunction with a certain technique at the level of the larynx. The need to attend to both laryngeal and respiratory factors probably explains why different singers use different breathing techniques to achieve different or the same outcomes. Breathing strategies as well as technique at the level of the larynx both play a role in the regulation of subglottal pressure and are

therefore both important factors when training a voice. While there are many conflicting beliefs among singers and pedagogues, their various techniques all strive to achieve healthy, supported phonation in singers.

Although the role of pedagogical techniques related to the degree of vocal fold adduction and breath support has received some attention, the strength of the respiratory muscles may also affect how singers control phonation and deserves attention as well. Changes in respiratory muscle strength may result in changes in mechanism of breath support and singing technique. Increased inspiratory strength may help regulate subglottal pressure at high lung volumes, while increased expiratory muscle strength may help regulate subglottal pressure at low lung volumes.

Respiratory Muscle Strength Training

Development of effective respiratory muscle strength training programs should consider the key concepts of skeletal muscle strength training. The key concepts of strength training revolve around the idea that muscles need to be targeted directly during training for functional outcomes (specificity) and that they are challenged enough to make gains in strength and adapt to increased stress (overload). Exercises must be adjusted over time to avoid plateauing and for gains in strength to overcome muscle adaptation (progressive resistance) (McCardle, Katch, & Katch, 2007; Powers & Howley, 2002). Specificity is the concept that muscles should be stressed in the way they are to functionally perform as muscles adapt to the nature of the load placed upon them. Overload is forcing muscles to contract at tensions close to their maximum. When the muscles are overloaded to hypertrophy, strengthening occurs. Overload must be increased over time to continue

making strength gains. Adaptation of the muscles to the load or stress makes progressive resistance important for consistent gains (American College of Sports and Medicine, 1998; Fahey, 1998; McArdle et al., 2007; Powers & Howley, 2002). These principles of muscle strength training establish that respiratory training programs must provide adequate and specific loads to expect gains in respiratory muscle strength.

Respiratory muscle strength training programs have utilized pressure threshhold trainers for expiration or inspiration to target the respective muscles. During resistance training, skeletal muscles adapt in response to an increased load (Bandy, Lovelace-Chandler, & McKitrick-Bandy, 1990) and must be forced to overload to hypertrophy, or contract at tensions close to their maximum, for strengthening to occur (Fahey, 1998; Powers & Howley, 2002; McArdle et al., 2007). These principles of muscle strength training establish that respiratory training programs must provide adequate and specific loads to expect gains in respiratory muscle strength.

To provide adequate and specific loads to the respiratory muscles, respiratory muscle strength training programs have utilized pressure threshhold trainers for expiration or inspiration to target the respective skeletal muscles (Sapienza & Troche, 2012). Pressure threshold trainers are flow-independent and provide a consistent pressure threshold that can be controlled and adjusted by the experimenter or clinician and must be overcome by a specific amount of inspiratory or expiratory pressure during respiration. Pressure threshold trainers are typically comprised of a one-way, adjustable, spring-loaded valve attached to a mouthpiece through which one must generate adequate respiratory pressure to breathe (Sapienza & Troche, 2012). A diagram of a respiratory pressure threshold trainer can be seen in Figure 2.

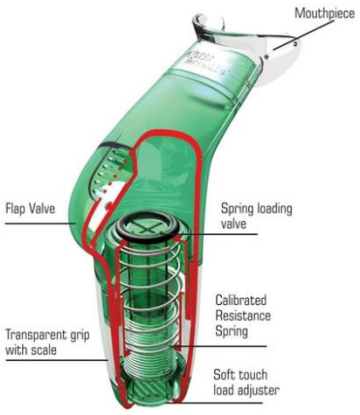

Figure 2. Example of a pressure threshold trainer (www.powerbreathe-usa.com)

Most of the respiratory muscle strength training programs in the literature incorporate these concepts; although, a standard training protocol has yet to be established. Many studies have used a training protocol that trains the muscles at 75% of their maximum expiratory or inspiratory pressures, MEP or MIP, respectively. Many training protocols described in the literature require five repetitions, five times daily, for anywhere from two to eight weeks (Anand, El-Bashiti, & Sapienza, 2012; Baker, Davenport, & Sapienza, 2005; Sapienza, Davenport, & Martin, 2002; Sapienza & Wheeler, 2006). The longest training period occurred in the study by Baker et al., (2005), which compared the effects of a 4-week versus an 8-week expiratory muscle strength training (EMST) program in healthy individuals. Findings indicated that there was not a significant difference in expiratory muscle strength gains between the two groups.

It is unknown exactly what load, frequency, and duration of training will achieve a maximum effect of respiratory muscle strength training; however, threshold training has consistently improved respiratory strength in normal subjects (Baker, Davenport, &

Sapienza, 2005; Enright et al., 2006) and disordered populations including those with COPD (Lisboa et al., 1994; Weiner & Weiner, 2006), cystic fibrosis (Enright et al., 2004; Keens et al., 1977), neurological impairments (Sapienza, 2008), and upper airway obstruction (Baker et al., 2003b; Baker, Sapienza, & Collins, 2003a; Hoffman-Ruddy et al., 2004; Mathers-Schmidt & Brilla, 2005; Sapienza, Brown, Martin, & Davenport, 1999).

Respiratory muscle strength training has not been studied in classical singers, but has been shown to improve speech characteristics in healthy adults (Baker, 2003) and to decrease perceptions of vocal effort in theme park performers (Hoffman Ruddy, 2001). Although singers may be expected to increase respiratory muscle strength with patterns consistent with the studies of RMST on non-pathological subjects, the effects of increased respiratory muscle strength on airflow and phonation patterns in classically trained singers remain undocumented.

Measures of the Singing Voice

Increased respiratory muscle strength may allow a singer to increase maximum phonation time, possibly secondarily to increased efficiency or muscular control of the airflow. Increased respiratory strength in singers may result in changes in subglottal pressure, which may affect maximum sustained phonation time, airflow, lung volume, pitch range, intensity range, and/or measures of vibrato. Subglottal pressure can be measured indirectly by using intra-oral pressure measurements during voiceless consonant production (Lofqvist, Carlborg, & Kitzing, 1982).

Additionally, a singer's ability to regulate fundamental frequency and amplitude can be assessed by means of a voice range profile (VRP), also known as a phonetogram.

Phonetograms tend to reflect the breadth and limits of voices in frequency and amplitude and have been in use for decades in measuring the singing voice (Damaste, 1970; Coleman, 1987). Several studies examining the differences in frequency and amplitude limits between trained and untrained singers found that trained singers exhibit an increased frequency and amplitude range compared to untrained singers (Awan, 1991; Mendes, Rothman, Sapienza, & Brown, 2003; Speyer, et al., 2003; Sulter, Schutte, & Miller, 1995; Wingate et al., 2006).

LeBorgne and Weinrich (2002) examined the effects of vocal training in a group of singers over nine months using the phonetogram as the objective measure. Findings indicated significant increases in frequency range and decreased minimal amplitudes that the singers could produce across frequencies. Coleman (1987, 1993) suggested that a phonetogram quantifies the level of vocal maturation of a singer and that phonetograms are useful to track changes over time and to make decisions regarding demands of various singing roles in comparison with a singer's capabilities. Technology also allows for measurements to be taken systematically of fundamental frequency and amplitude range with the additional measure of airflow included. This may be particularly interesting in evaluating frequencies with reduced or inconsistent amplitude range because control of airflow may be a contributing factor. Improved regulation of airflow and Ps may contribute to the improvements shown in frequency and amplitude range for trained singers.

Vibrato is another measure of the singing voice that can be assessed and may change as a result of respiratory changes. Seashore (1932) first described vibrato as pulses of pitch, loudness, and timbre, which give the voice a sound of flexibility and

richness. Studies have shown that vibrato does improve with training and that vibrato can be changed by singers (King & Horii, 1993; Moorcroft & Kenny, 2012; Murbe et al., 2007). Vibrato is typically characterized by its rate, frequency modulation extent, and regularity (Murbe et al., 2007; Prame, 1994; Sundberg, 1994). Perceptually, vibrato rate is considered normal at a range of 5-7 Hz and extent at +/- 1 semitone (Sundberg, 1994). Vibrato rate is the number of modulations of the fundamental frequency produced per second and vibrato extent is the frequency range that the modulations traverse. Regularity is typically measured as the cycle-to-cycle variations in rate and extent and increased regularity is perceptually considered a sign of a more refined singer. In addition, rates and extents that fall outside the accepted norms typically lead to the perception of a technical problem with the voice. Theories as to the underlying mechanism that drives these modulations include aerodynamic changes and changes in subglottal pressure and air flow (Rothenberg, Miller, & Molitor, 1988; Sundberg, 1994), contractions of the cricothyroid muscle (Shipp, Doherty, & Haglund, 1990) and influences of the supraglottic muscles on the vocal folds and formants (Sapir & Larson, 1993). It is unknown if improved regulation of airflow and Ps through increased respiratory muscle strength will produce measurable change in parameters of vibrato.

The current study's objectives are to determine if a respiratory muscle strength training program will increase respiratory muscle strength and, as a result, improve control of subglottal pressure and airflow (breath support) with measurable change in parameters of the classically trained singing voice. Improved regulation of airflow and subglottal pressure is expected to manifest as increased maximum phonation time, increased frequency and/or intensity range, and improved consistency of airflow rates and

vibrato regularity. These indicators are all desirable characteristics of a singing voice (Stark, 2009). Specifically, the objectives are as follows:

1. To determine to what degree inspiratory muscle strength training (IMST) has an effect on respiratory muscle strength in singers as measured by MIP and MEP.
2. To determine to what degree expiratory muscle strength training (EMST) has an effect on respiratory muscle strength in singers as measured by MIP and MEP.
3. To determine to what degree completion of both IMST and EMST has an effect on respiratory muscle strength in singers as measured by MIP and MEP.
4. To determine if and to what degree an increase in respiratory muscle strength has on voice measures of singers, specifically maximum phonation time, airflow, subglottal pressure, voice range profile, and vibrato characteristics.

Chapter 2: Method

Design

A single subject experimental design (ABD, ACD) with replication across subjects was utilized to evaluate the effects of respiratory muscle strength training on respiratory muscle strength, airflow, and phonation in trained singers. The methodology employed in this design requires repeated measures and continuous assessment, baseline assessment, demonstration of stability of performance, use of different phases, and replication. The details for the implementation and measurement of independent and dependent variables occur in subsequent sections. Independent variables included:

1. Inspiratory muscle strength training (IMST; Phase B)
2. Expiratory muscle strength training (EMST; Phase C)
3. Both IMST and EMST (Phase D).

Five tasks were completed to elicit ten dependent variables. The tasks and variables included:

1. Manometry: Participants inhaled and exhaled as forcefully as possible to elicit:
    a. Maximum inspiratory pressure (MIP)
    b. Maximum expiratory pressure (MEP)
2. Intraoral pressure: Participants repeated /baep/ five times at a comfortable and controlled pitch and loudness to elicit:
    a. Subglottal pressure (Ps)

3. Maximum Sustained Phonation: Participants produced /a/ at a comfortable, controlled loudness for as long as possible to elicit:

a. Phonation Time (MPT)

b. Airflow rate

c. Phonation Volume (PV)

4. Voice Range Profile: Participants produced maximum and minimum loudness across all pitches in her voice range to elicit:

a. Fundamental frequency (F0) range

b. Intensity (SPL) range

5. Sustained Comfortable Vibrato : Participants produced a 5-second comfortable /a/ to elicit:

a. Vibrato Rate

b. Vibrato Modulation

A total of six participants underwent repeated baseline measures (Phase A) to ensure stability of MIP and MEP before initiation of a training protocol. Stability was defined as measures within 5% of each other across three measurement days. After stability of MIP and MEP were achieved, participants were quasi-randomly, alternately assigned to either Training Protocol 1 (IMST followed by EMST; ABD) or Training Protocol 2 (EMST followed by IMST; ACD) based on their date of training commencement. Phase B represented initial IMST as in Protocol 1, Phase C represented initial EMST training as in Protocol 2, and Phase D represented the second training phase of both Protocol 1 and 2, as these phases were not exclusively representative of one training modality. Protocol 1 therefore was represented by 'ABD' and Protocol 2 by

'ACD'. The use of single subject design allowed for examination of treatment effects over time (McReynolds & Thompson, 1986) in this group for which the literature is scarce and does not guide us to expect any specific effect.

Participants

Six participants were recruited and all completed this study. All participants were classically trained female singing students in the Vocal Music graduate program at The Ohio State University. Classically trained was defined as at least 3 years of vocal performance experience in a higher education program and at least 5 years of formal singing lessons. These inclusion criteria were set to study the population in which the effects of RMST on the singing voice would be particularly relevant. Additionally, trained singers were studied because of their ability to perform the voicing tasks correctly and consistently. Master's and doctoral students were identified within the School of Music and were recruited verbally. The purpose and details of the study were explained to potential subjects, as was the voluntary nature of their participation in the study. Exclusion criteria included self-reported pregnancy, history of pulmonary disease, upper respiratory infection, vocal disturbance, and a history of smoking; however, none of the recruited participants fit the exclusion criteria and all were retained for the study. Approval was obtained from the Biomedical Sciences Institutional Review Board of The Ohio State University (Protocol 2013H0081). Upon recruitment, the investigator obtained signed informed consent (see Appendix A).

A summary of participant demographics including age, self-reported voice type, years of training, and assigned training protocol is illustrated in Table 1. The

participants' ages ranged from 24 to 39 years with an average age of 28 (SD= 5.55) years. All participants were studying singing and taking voice lessons with a private teacher throughout their participation in the study. Participants were specifically asked to report any changes in singing activity while participating in the study. An example of a change in singing activity would be a change of voice teacher or change in frequency of voice lessons. No changes in singing activity were reported by any participant.

Subject	Age	Voice Type	Years of Training[1]	Protocol
1	39	Lyric Mezzo Soprano	9	2; ACD
2	24	Coloratura Soprano	4	2; ACD
3	26	Coloratura Soprano	5	1; ABD
4	26	Lyric Soprano	9	1; ABD
5	28	Lyric Soprano	6	2; ACD
6	25	Lyric Soprano	5	1; ABD

Table 1. Participant demographics
1 *Represents years of training at the collegiate level*

Measurement

The study was conducted in the Swank Voice Lab at The Ohio State University. The lab is equipped with the KayPENTAX *Phonatory Aerodynamic System (PAS) Model 6600* (KayPENTAX Corp, Lincoln Park, NJ), *VoceVista 4.3.4*, and a *Pyle*® manometer, all of which were used to collect data in this study. The *PAS* includes a pressure transducer, face mask, and microphone for the measurement of frequency, intensity, airflow and air pressure during phonation. The *VoceVista* software program measures the aspects of vibrato examined in this study. A manometer coupled with vinyl tubing and a

flanged mouthpiece was used to measure maximum respiratory pressures (MIP and MEP).

Measurements were taken repeatedly throughout a baseline phase and two training phases for each participant. During the baseline phase, measures were taken every 1-9 days. In the treatment phases, measurements were collected approximately weekly to obtain information regarding training duration. All instruments were properly calibrated per manufacturer's instructions prior to each task. Five tasks were utilized to obtain measurements of the 10 dependent variables:

1. Manometry was utilized to collect maximum inspiratory pressure (MIP) and maximum expiratory pressure (MEP). These measures were used to indirectly determine respiratory muscle strength. The measurement was taken with a digital pressure manometer connected by 50cm of 2mm i.d. tubing and a 14-guage needle air-leak to a flanged mouthpiece. Participants were trained to the task which included instructing participants to exhale to residual volume (maximum exhalation) before inhaling as forcefully as possible (for MIP) and to inhale maximally (to total lung capacity) before exhaling as forcefully as possible into the manometer (for MEP). The participants wore nose clips during the task to prevent nasal airflow/pressure emission. This was repeated until three measures were found within 5% of each other for each of the MIP and MEP measures. The maximum of the three MIP values was used as the MIP value and the maximum of the three MEP values was used for the MEP value.

2. Subglottic (tracheal) pressure (Ps) was measured using the *PAS* "Voicing Efficiency" protocol. Per the manufacturer's instructions and standard practice in the noninvasive measurement of Ps, participants were instructed to repeat the syllable /baep/ five times on

one breath at a comfortable pitch and loudness. The middle three samples were taken of each repetition and the average was used to obtain the measurement. This was repeated three times. An oral transducer was placed in the mouth and attached to the face mask to be held to the participants' faces by each participant herself in order to capture all airflow during the phonation task. Fundamental frequency and intensity were monitored using the *PAS* software to maintain consistent and standard conditions across trials. Consistency across trials was defined as being within one semitone with regards to fundamental frequency and within 3 dB for amplitude.

3. The Maximum Phonation Time (MPT) task required that each participant sustain a comfortable pitch at a comfortable loudness as long as possible into the *PAS* mask on the vowel /a/. The "Maximum Sustained Phonation" protocol was used. Participants were allowed time during the initial session to practice the task to ensure consistency and eliminate the threat of training to the task for future measurements. Participants completed three trials which were then used to determine a mean value for phonation volume (PV), airflow rate, and maximum phonation time (MPT). The frequency and intensity of phonation were measured by the *PAS* and participants were required to keep these measures consistent throughout the study. Consistency across trials was defined as being within one semitone with regards to fundamental frequency and within 3 dB for amplitude. Any repetition that was not consistent with regards to pitch or amplitude was repeated.

4. A Voice Range Profile (VRP) was completed to collect data on the measures of fundamental frequency range and intensity range. Measures of airflow were obtained for this task as well. Using the "Comfortable Sustained Phonation" protocol on the *PAS*,

each individual began by producing the pitch C4 as quietly then as loudly as possible into the face mask for 3-5 seconds. From this initial production, they were instructed to move down the scale by minor third in the same manner, producing quietest and loudest tones on each pitch, until the lowest pitch in their range was reached. Participants then moved upward in the same fashion from their original C4 pitch until the highest frequency in their range was reached. Target pitches were provided using a piano. For each phonation of 3-5 seconds, only the middle 2-4 seconds were saved to eliminate any possible effect of the onset and/or offset.

4. Measures of vibrato were taken using *VoceVista 3.4.3* (www.vocevista.com). Participants sustained /a/ at a comfortable pitch and loudness for 5-6 seconds with their lips 279 mm from the microphone. The middle 3 seconds of the third harmonic were then analyzed for measures of vibrato rate and vibrato modulation. Modulation measures included frequency modulation, vibrato jitter, and amplitude modulation. Three trials were recorded and mean values were reported. The frequency was measured for each trial with VoceVista and amplitude was measured for each trial using a sound level meter placed 22 cm from each participants' mouth. Participants were required to keep these measures consistent throughout the study. Consistency across trials was defined as being within one semitone with regards to fundamental frequency and within 3 dB for amplitude. Any repetition that was not consistent with regards to fundamental frequency or amplitude was repeated.

Baseline Procedures

The baseline phase was denoted by Phase 'A'. Measures for each dependent variable were taken at each session. Measures were taken every 1-12 days. Frequency depended on the participants' availability. The baseline phase concluded after the participant demonstrated consistency of both MIP and MEP values (within 5%) across three consecutive sessions. The number of baseline sessions required to reach stability ranged from two to seven (mean= 3.67 sessions, SD= 1.75) sessions. This procedure allowed for future performance without treatment to serve as a control for each individual.

Treatment Procedures

1. Training Protocol 1 (IMST followed by EMST; ABD)

Half of the participants (every other) were enrolled in this training protocol. After stable baselines were established as described above, participants were introduced to the IMST device. The IMST phase was labeled Phase 'B'. The Powerbreathe ® is a calibrated inspiratory pressure threshold trainer that has been used in studies looking at the effects of IMST on non-singer and pathological populations and was used in this study for the inspiratory muscle strength training protocol. The investigator first demonstrated proper use. The trainer was then set to 80% of the participant's MIP measured at her last baseline session. Participants demonstrated proper use by completing one set (five repetitions) during the initial treatment session. Once competence was observed in the lab, participants were instructed to complete five sets daily until follow-up. Sets were spaced 1-3 minutes apart. Compliance with the protocol

was monitored with participant logs (monitored weekly) and daily emails ensuring that the sets were completed at home or away from the lab. Follow-up sessions were spaced 5-10 days apart at which time the participants returned to the lab for repeated measures. The trainer continued to be adjusted to 80% MIP from session to session as appropriate to maintain adequate training levels. This continued until MIP was stable across three consecutive sessions with no more than 5% variability. At that time, the IMST was stopped and the EMST trainer was introduced. The Aspire EMST150 ® is a calibrated expiratory pressure threshold trainer that has been used in studies looking at the effects of EMST on non-singer and pathological populations and was used in this study for the expiratory muscle strength training protocol. The EMST protocol is an exact replicate of the IMST protocol other than the difference of exhaling into the EMST device versus inhaling against the IMST device. The EMST trainer was set to 80% of the participant's MEP at each session and training ended after MEP stabilized across three consecutive sessions with no more than 5% variability among measures. Although the EMST was trained alone, this phase (D) occurred after IMST had been completed and therefore represented a combined treatment effect. The training protocols required each participant to possess and use respiratory muscle strength training devices for inspiratory and expiratory muscle strength training. Each participant was given her own device for both IMST and EMST.

2. Training Protocol B (EMST followed by IMST; ACD)

Half of the participants (every other) were enrolled in this training protocol. After stable baselines were established as described above, participants were introduced to the EMST device. The EMST phase was denoted Phase 'C'. The Aspire EMST150 ® is a

calibrated expiratory pressure threshold trainer that has been used in studies looking at the effects of EMST on non-singer and pathological populations and was used in this study for the expiratory muscle strength training protocol. The investigator first demonstrated proper use. The trainer was then set to 80% of the participant's MEP at baseline. Participants demonstrated proper use by completing one set (five repetitions) during the initial treatment session. Once competence was observed in the lab, participants were instructed to complete five sets daily until follow-up. Sets were spaced 1-3 minutes apart. Compliance with the protocol was monitored with participant checklists and daily emails ensuring that the sets were completed at home or away from the lab. Follow-up sessions were spaced 5-10 days apart at which time the participants returned to the lab for repeated measures. The trainer continued to be adjusted to 80% MEP from session to session as appropriate to maintain adequate training levels. This continued until MEP was stable across three consecutive sessions with no more than 5% variability. At that time, the EMST was stopped and the IMST trainer was introduced. The Powerbreathe ® is a calibrated inspiratory pressure threshold trainer that was used in this study for the inspiratory muscle strength training protocol. The IMST protocol is an exact replicate of the EMST protocol other than the difference of inhaling into the IMST device versus exhaling against the EMST device. The IMST trainer was set to 80% of the participant's MIP at each session and training ended after MIP stabilized across three consecutive sessions with no more than 5% variability among measures. Although the IMST was trained alone, this phase (D) occurred after EMST had been completed and therefore represented a combined treatment effect. The training protocol required each participant to possess and use respiratory muscle strength training devices for inspiratory

and expiratory muscle strength training. Each participant was given her own device for both IMST and EMST.

Reliability and Treatment Fidelity

As described earlier, repeated measures of MIP and MEP were taken for each variable during each session to ensure the data points were reliable across repeated productions. Measures of all variables were taken by the same investigator. Participant compliance was achieved through participant education on the use of the devices and daily contact by the investigator to which each participant was required to respond to confirm completion of training.

Data Analysis

Each variable was plotted for each subject to allow for visual analysis of treatment effects across subjects. Specifically, changes in means across phases and latency of changes were examined, as described by Kazdin (2010). Trends at the ends of each phase, when respiratory muscle strength plateaus were reached, were examined and compared. A treatment effect was recognized if the values were consistently different from those at baseline. To assert that there was a change in respiratory muscle strength, the combined treatment effects seen in Phase D were compared to baseline values in Phase A using paired-sample t-tests ($\alpha = 0.025$) for the measures of respiratory strength (MIP and MEP). SPSS Version 19 was used to perform the statistical analysis. The last value of each phase was used for this analysis.

Chapter 3: Results

Respiratory Muscle Strength

Participants who completed Training Protocol 1 (ABD; S3, S4, S6) increased both MIP and MEP while training the inspiratory muscles during the IMST phase (B). MIP increased during the IMST phase by 37%, 101%, and 118% respectively. MEP also increased during the IMST phase by 23%, 45%, and 130% respectively. Individual changes in MIP and MEP over the baseline and IMST training phase can be seen in Figures 3 and 4, respectively.

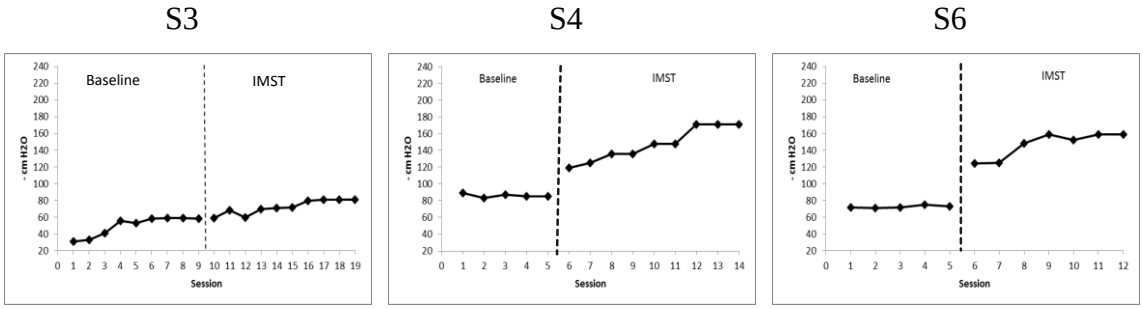

Figure 3. MIP values throughout baseline and IMST training phase for participants who completed Training Protocol 1

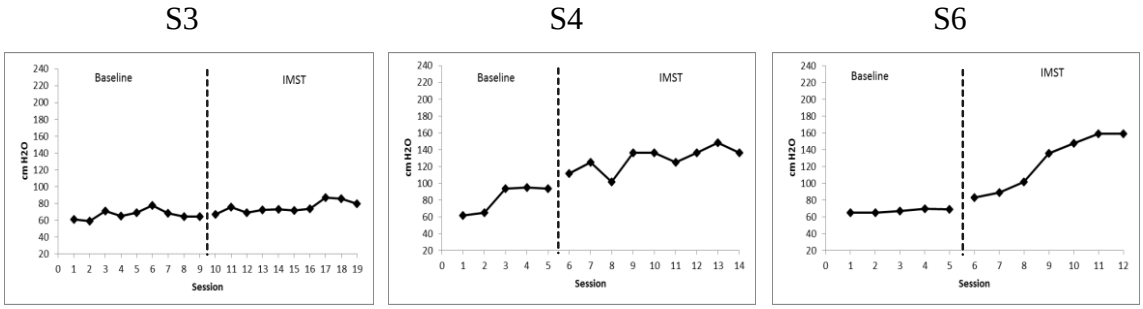

Figure 4. MEP values throughout baseline and IMST training phase for participants that completed Training Protocol 1

Participants who completed Training Protocol 2 (ACD; S1, S2, S5) increased both MEP and MIP while training the expiratory muscles during the EMST phase (Phase C). MEP increased for the three participants during the EMST phase by 70%, 28%, and 137% respectively. It should be noted that gains may have been restricted secondary to the limited maximum training level of the EMST device. Two participants reached the maximum training level (150 cm H_2O) of the device during the study. MIP also increased during the EMST phase by 16%, 33%, and 34% respectively. Individual changes in MEP and MIP over the baseline and EMST training phase can be seen in Figures 5 and 6, respectively.

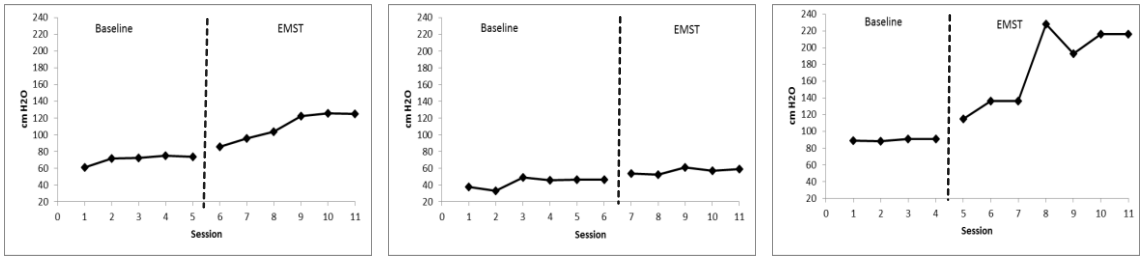

Figure 5. MEP values throughout baseline and EMST training phase for participants who completed Training Protocol 2

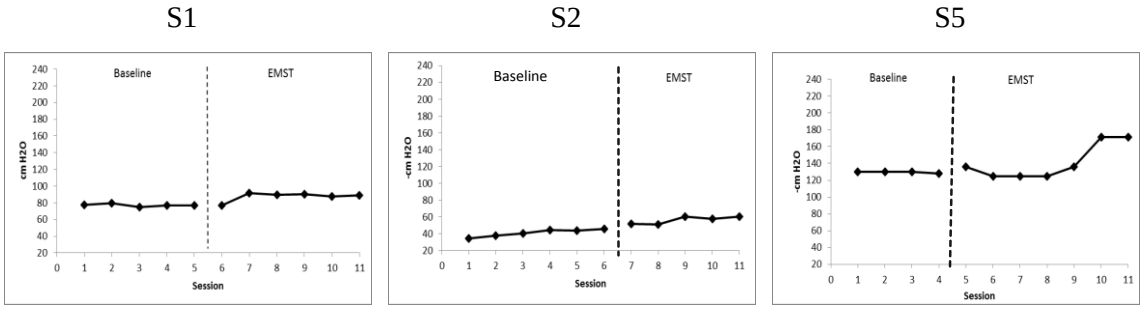

Figure 6. MIP values throughout baseline and EMST training phase for participants who completed Training Protocol 2

Completion of the second phase of training (Phase D) for both groups represented the effects of IMST followed by EMST (Training Group 1) and EMST followed by IMST (Training Group 2). Overall, the participants' mean MIP value increase was 63% from baseline (X= 77.78, SD = 28.30) to the end of Phase D (X= 126.9, SD= 45.28). The combined training effect on MIP was statistically significant with a large effect size, $t(5) = -6.26$, $p = .002$, $d = 1.30$ ($\alpha = 0.025$). The participants' mean MEP value increase was 104% from baseline (X= 73.03, SD= 17.73) to the end of phase D (X= 149.4, SD= 57.45). The combined training effect on MEP was also statistically significant with a large effect size, $t(5) = -4.24$, $p = .008$, $d = 1.80$ ($\alpha = 0.025$). Individual changes in MIP and MEP over the baseline and training phases can be seen in Figures 7 and 8, respectively.

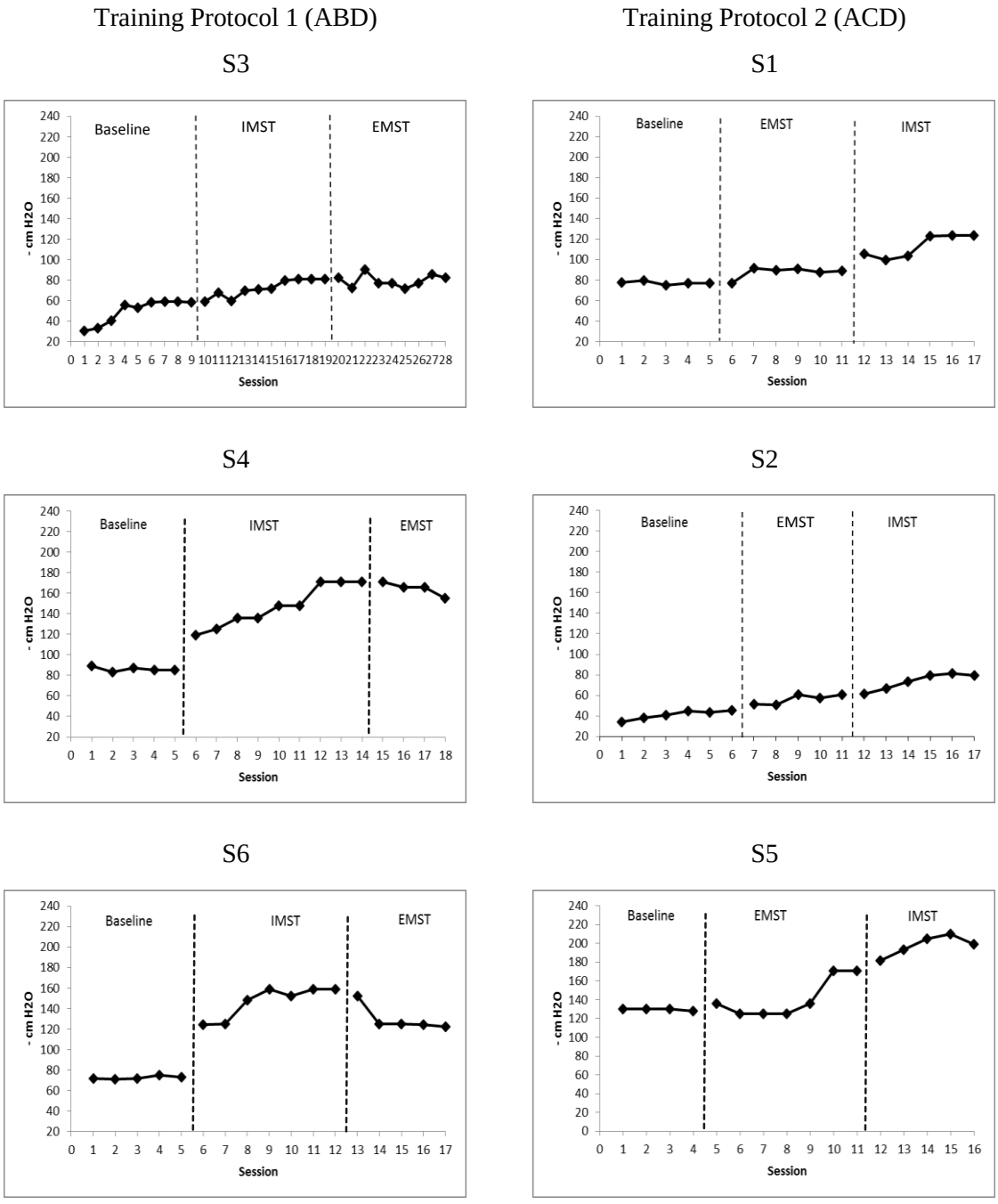

Figure 7. MIP values for all participants across all phases

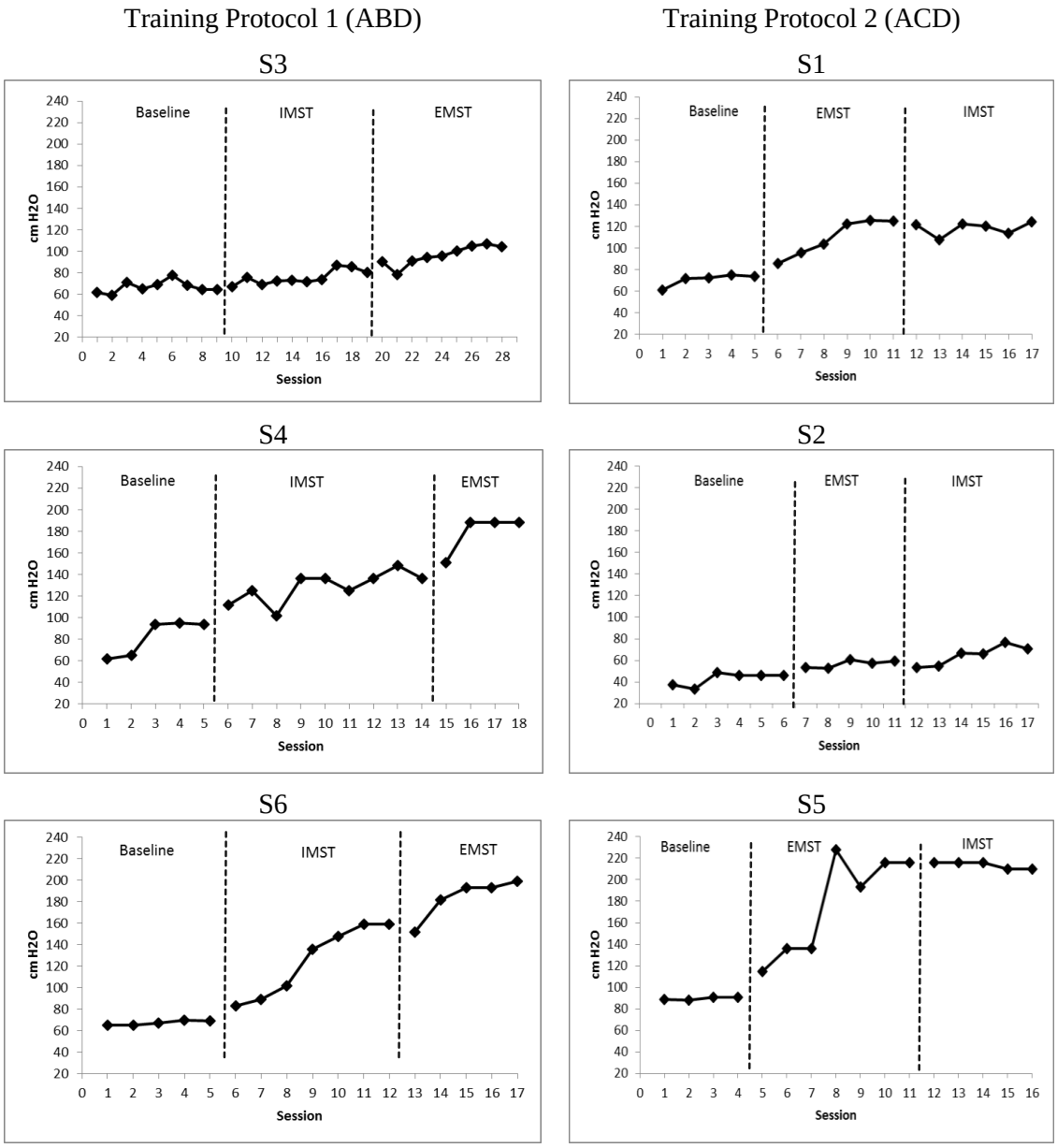

Figure 8. MEP values for all participants across all phases

Subglottal Pressure

Measures of Ps were estimated using intraoral pressures during a repeated /baep/ task. Of the participants who completed Training Protocol 1, S4 was the only participant to demonstrate a change in Ps during respiratory muscle strength training phases. In this participant, an increasing trend was noted during IMST, and a further increase was noted and stabilized during EMST. Of the participants who completed Training Protocol 2, S1 demonstrated an increasing trend of Ps during IMST which remained above any baseline level during the EMST phase. S5 demonstrated Ps values below baseline during the IMST phase; however, baseline values were not stable. The Ps values of all other participants did not demonstrate trends across the phases. Individual changes in Ps across all phases for participants who completed Training Protocol 1 and Training Protocol 2 are illustrated in Figures 9 and 10, respectively.

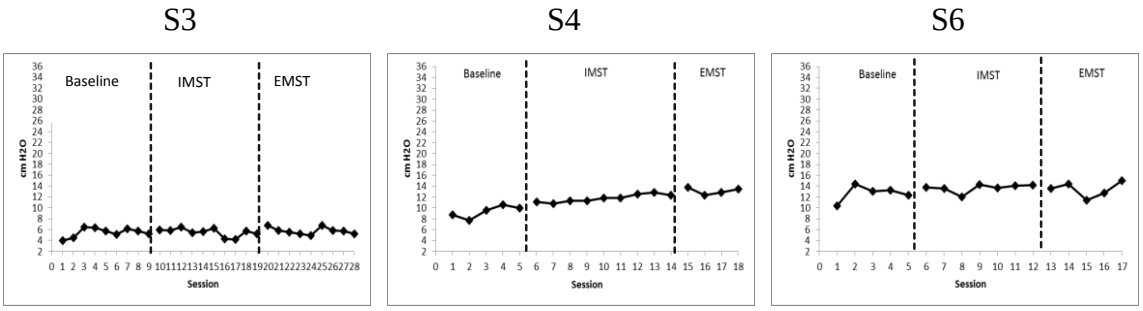

Figure 9. Ps values for participants who completed Training Protocol 1

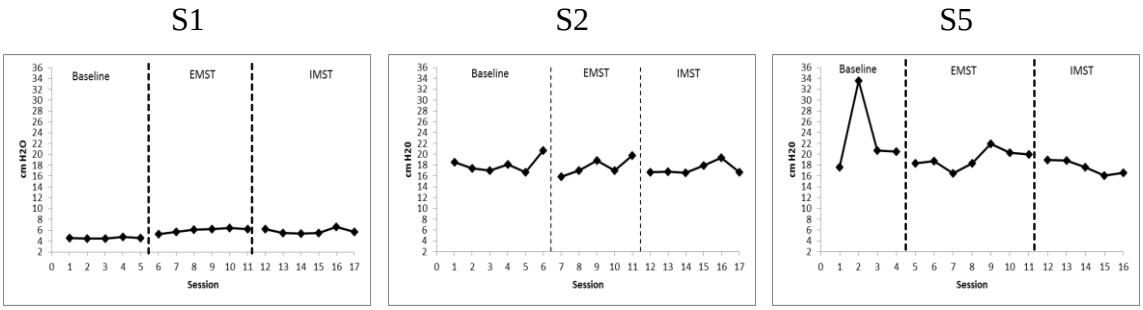

Figure 10. Ps values for participants who completed Training Protocol 2

Maximum Sustained Phonation

Measures of maximum phonation time, airflow rate, and phonation volume were obtained from the maximum sustained phonation task. Of the participants who completed Training Protocol 1, S3 was the only participant to make gains in maximum phonation duration during the IMST only training phase. It is problematic to claim this outcome is a result of IMST because of an unstable baseline. Maximum phonation time again became unstable and decreased during the EMST phase for this participant. Furthermore, S3 did not demonstrate consistent or stable changes in airflow or phonation volume during the maximum sustained phonation task. The other two participants in this group, S4 and S6, did not make initial gains during the IMST period, but did demonstrate times consistently greater than any baseline time during the EMST training phase. S4 did not demonstrate changes in airflow, but did demonstrate a slight increase in phonation volume during the EMST phase as compared to baseline. S6 demonstrated unstable airflow values during all phases and phonation volume was above baseline at the end of the IMST phase and throughout the EMST phase. Baseline trends for all participants were insufficiently stable and changes seen were not consistent among participants.

Maximum sustained phonation values for time, airflow, and phonation volume for these participants are illustrated in Figures 11, 12, and 13, respectively.

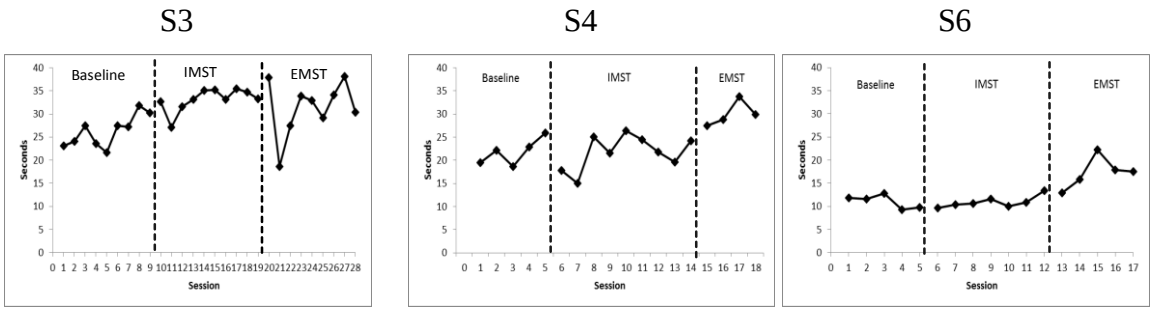

Figure 11. Phonation times during maximum sustained phonation for participants who completed Training Protocol 1

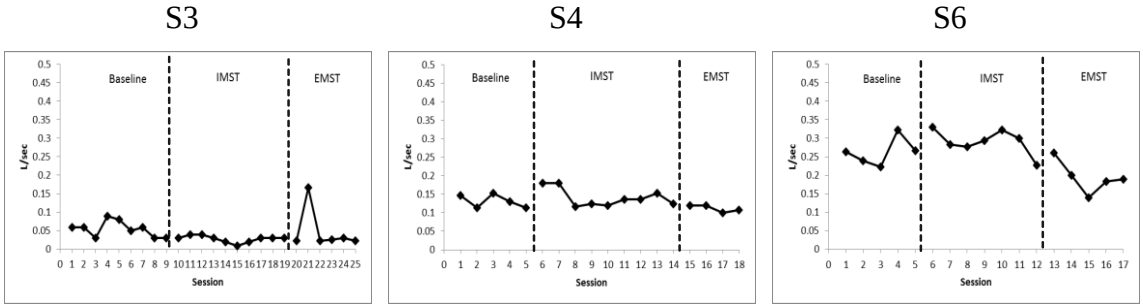

Figure 12. Airflow values during maximum sustained phonation for participants who completed Training Protocol 1

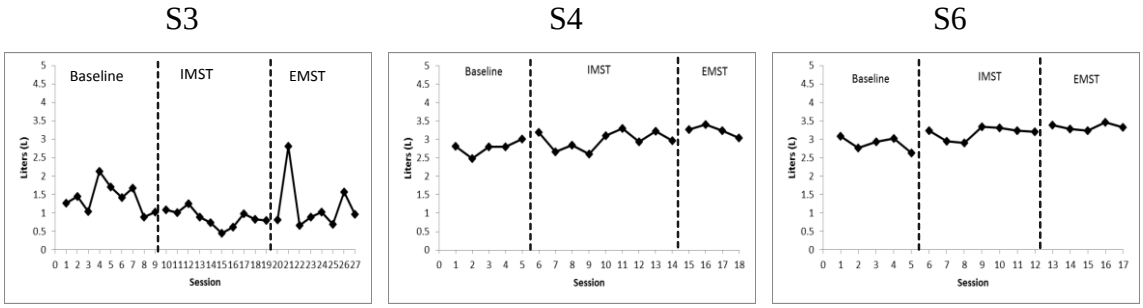

Figure 13. Phonation volume values during maximum sustained phonation for participants who completed Training Protocol 1

One participant who completed Training Protocol 2 (S5) consistently increased maximum phonation time during the EMST training phase above baseline and this was maintained during the IMST training phase. Airflow rates for S5 were not stable for any phase, but showed a decreasing trend during the EMST phase that remained below baseline during the IMST phase. Phonation volume for S5 was above baseline during the EMST phase and remained above baseline during the IMST phase. All other participants who completed Training Protocol 2 did not demonstrate changes in phonation time, airflow, or phonation volume for the maximum sustained phonation task. Baseline trends for all participants were insufficiently stable and changes seen were not consistent among participants. Maximum sustain phonation values for time, airflow, and volume for these participants are illustrated in Figures 14, 15, and 16, respectively.

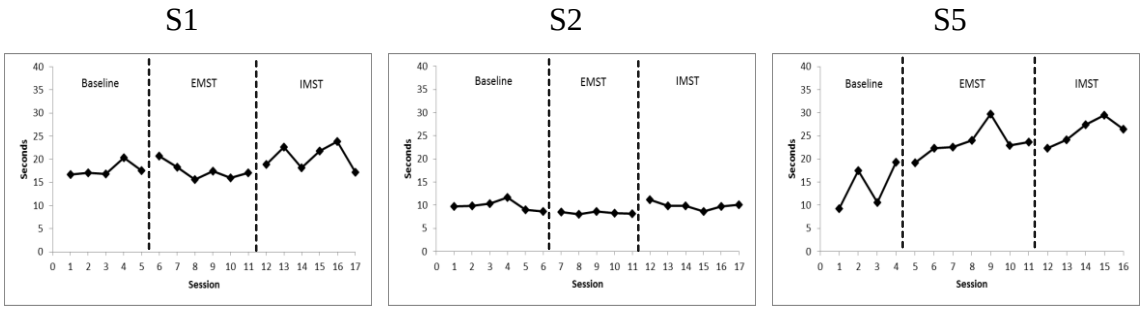

Figure 14. Phonation times during maximum sustained phonation for participants who completed Training Protocol 2

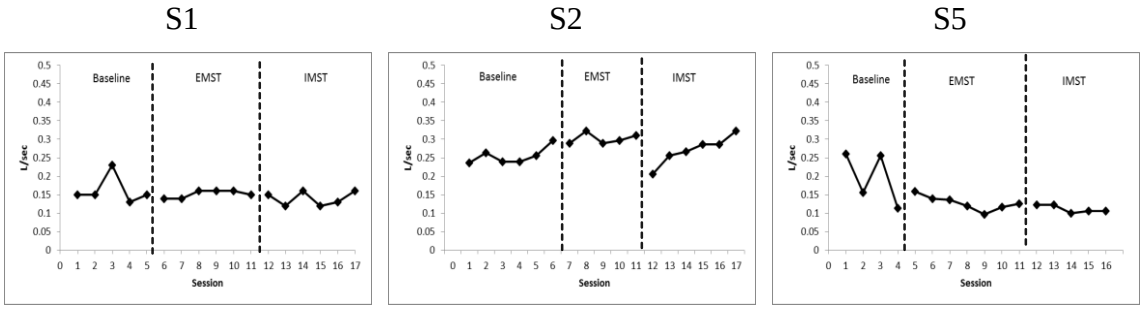

Figure 15. Airflow values during maximum sustained phonation for participants who completed Training Protocol 2

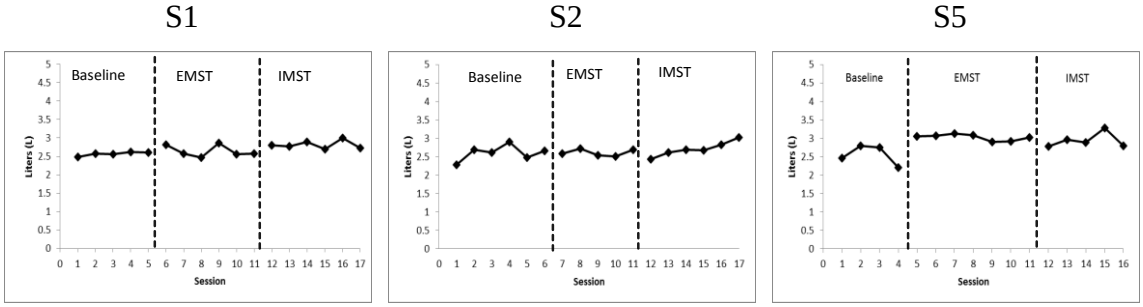

Figure 16. Phonation volume values during maximum sustained phonation for participants who completed Training Protocol 2

Voice Range Profile

Average intensity ranges were calculated using the differences between mean maximum SPL and mean minimum SPL from the last three voice range profiles collected from each phase. Of the participants who completed Training Protocol 1, S3 and S6 increased their SPL range from baseline to the end of the IMST phase, while S5 decreased SPL range from baseline to the end of the IMST phase. S3 decreased from the IMST phase to the combined phase, but remained above baseline. S4 and S6 both demonstrated a decreased SPL range by the end of the combined phase compared to baseline. Of the participants who completed Training Protocol 2, only S5 demonstrated

values above baseline in the training phases. These participant SPL range values are shown in Tables 2 and 3 for Training Protocols 1 and 2, respectively. The combined effect of respiratory training on intensity range for all participants was minimal, with a mean change from 17.4 dB during Phase A to 16.7 dB during Phase D.

Participant	Baseline (A)	IMST (B)	EMST (D)
S3	7.9 dB	9.9 dB	8.7 dB
S4	14.5 dB	12.3 dB	12.4 dB
S6	16.2 dB	21.7 dB	14.4 dB
Mean	12.9 dB	14.6 dB	11.8 dB

Table 2. Mean SPL range across phases for participants who completed Training Protocol 1

Participant	Baseline (A)	EMST (C)	IMST (D)
S1	18.0 dB	16.8 dB	15.9 dB
S2	22.6 dB	21.6 dB	22.0 dB
S5	24.8 dB	25.4 dB	26.5 dB
Mean	21.8 dB	21.3 dB	21.5 dB

Table 3. Mean SPL range across phases for participants who completed Training Protocol 2

Pitch range, using minor third (three semitone) intervals, was also assessed by means of the voice range profile. Of the participants who completed Training Protocol 1,

S6 was the only participant to demonstrate an increased pitch range and increased her lower range by three semitones. The increase occurred during the second training phase (Phase D), while actively training EMST. Of the participants who completed Training Protocol 2, S2 and S5 both increased their lower ranges by three semitones. The increases in these participants occurred during the first training phase (Phase C), while actively training EMST. None of the participants in either protocol decreased pitch range throughout training. Graphs illustrating maximum and minimum intensity levels across pitches are depicted for all participants in Figure 17.

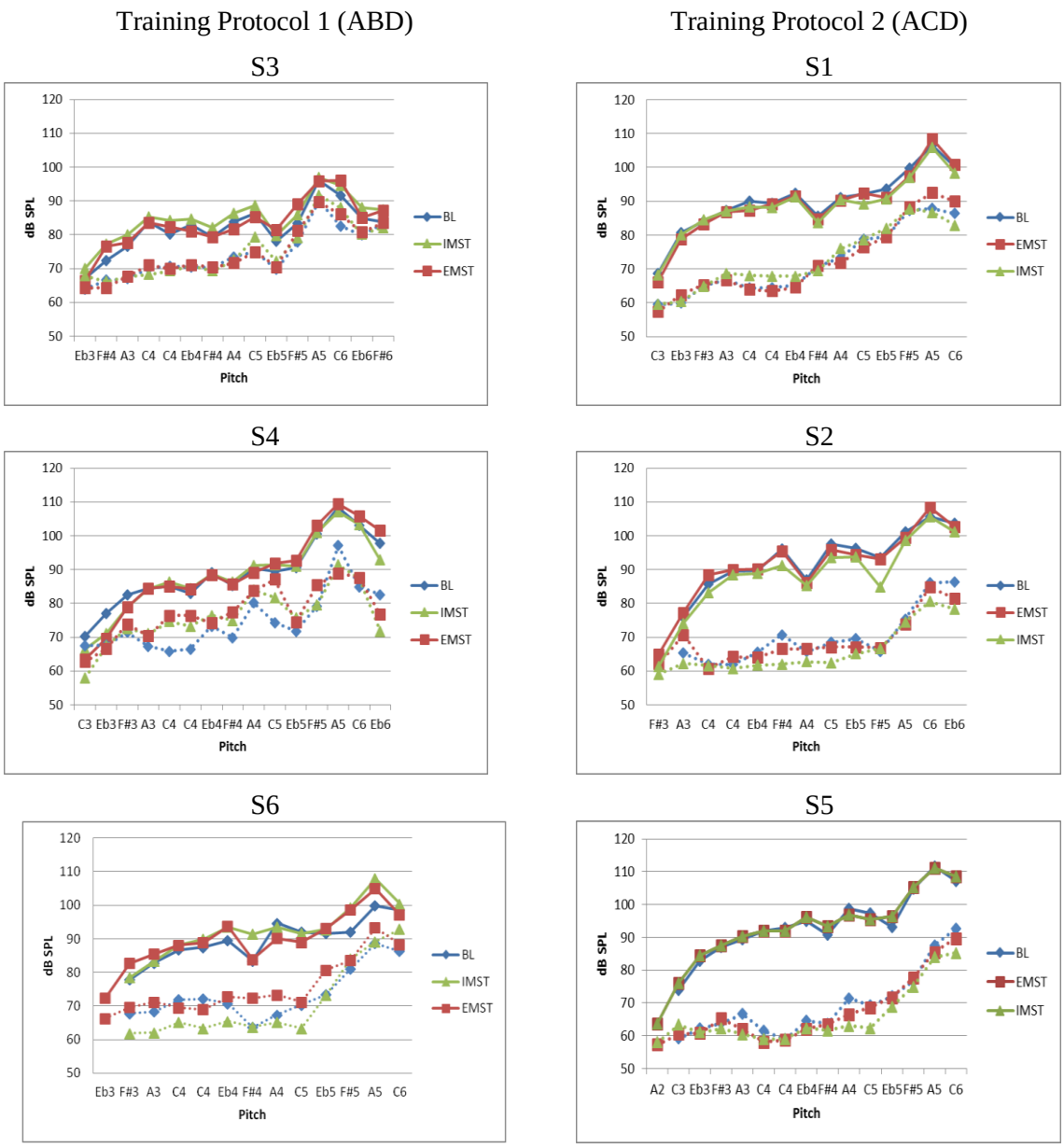

Figure 17. Maximum and minimum SPL for all participants across pitches

Vibrato

Measures of vibrato included rate, frequency modulation, and amplitude modulation. All measures of vibrato were highly unstable throughout all phases. Only one participant (S2) demonstrated vibrato rates consistently faster than baseline. This

change for S2 occurred during the first training phase (EMST; Phase C) and remained above baseline throughout Phase D. Trends for rate, frequency modulation, and amplitude modulation were otherwise not present. Individual changes in vibrato rate, frequency modulation, and amplitude modulation over the baseline and training phases can be seen in Figures 18, 19, and 20, respectively.

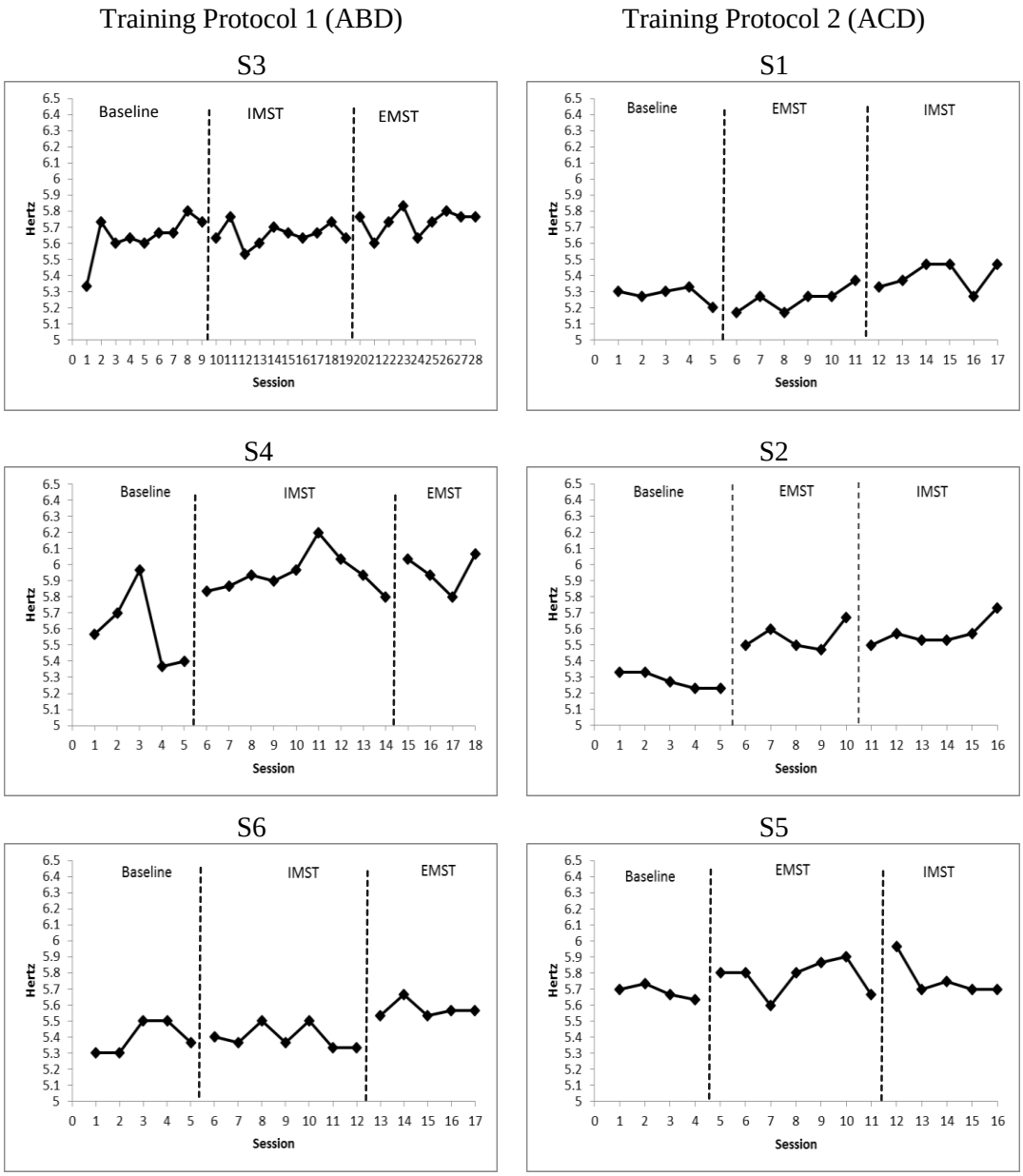

Figure 18. Vibrato rates of all participants across all phases

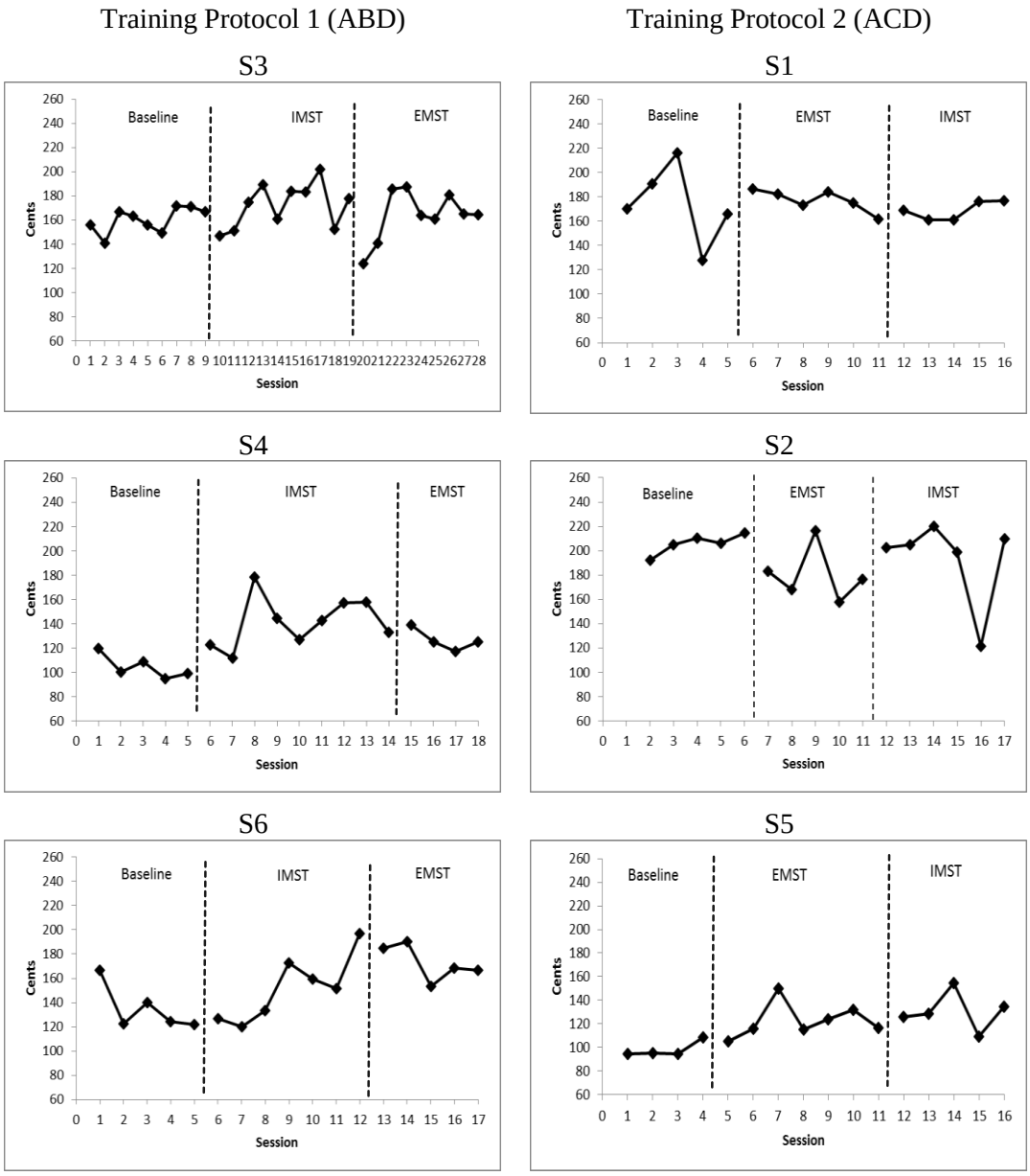

Figure 19. Vibrato frequency modulations for all participants across all phases

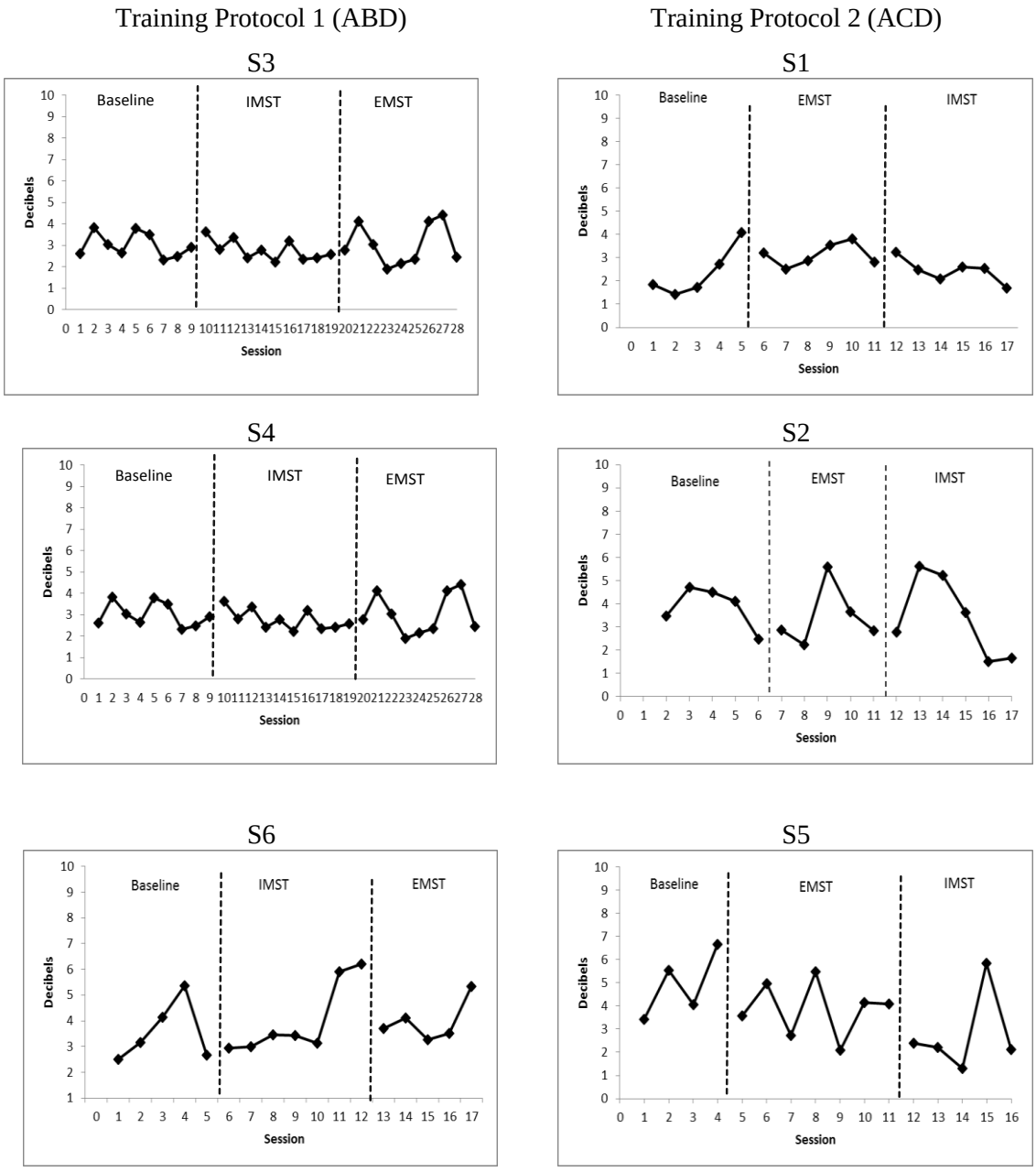

Figure 20. Vibrato amplitude modulations for all participants across all phases

Chapter 4: Discussion

Respiratory Muscle Strength Training

The implementation of a specific respiratory muscle strength training program resulted in increases in respiratory muscle strength among singers in this study. These results were consistent with much of the previous literature surrounding respiratory muscle strength training; however, a generally agreed-upon training program with regards to frequency and duration has yet to be established. A summary of relevant studies is illustrated in Table 4.

Protocols that have trained using loads of 75% to 80% of maximum respiratory pressures have shown increases in targeted muscle strength from 33% to 93% of baseline (see Table 4). Most of the previous studies trained 5 days per week using 5 sets of 5 breaths each training day. Anand et al. (2012) examined the effect of training frequency and found no difference between 3 and 5 days of training per week. The optimum duration of training to achieve maximum strength gains is not known; however, Baker, Davenport, and Sapienza (2005) found that there was no significant difference between 4 and 8 weeks of training.

The current study implemented a training frequency of 5 sets of 5 breaths daily with a load of 80% MIP or MEP, depending on the phase in which the participant trained. The training protocol did not have a set duration; rather, participants trained until a plateau was reached. This plateau was assumed to be the point of maximum strength

gain and was determined by MIP or MEP measures, depending on the phase in which the participant trained, within 5% across 3 sessions (3 weeks).

Study	Population	Training Target	Training Duration	Training Frequency	Training Load	Outcome
Anand et al., 2012	Normal	EMST	4 weeks	3 or 5 days/week 5 sets of 5 breaths	75% MEP	Overall 33% MEP increase; no significant frequency difference
Baker et al., 2005	Normal	EMST	4 or 8 weeks	5days/week 5 sets of 5 breaths	75% MEP	4 wks: 41% MEP increase 8 wks: 51% MEP increase Not significantly different
Enright et al., 2006	Normal	IMST	8 weeks	3 days/week 6 sets of 6 breaths Control: no tx	80% MIP	41% MIP increase tx no increase in control
Sapienza et al., 2002	Normal (band students)	EMST	2 weeks	5 days/week 4 sets of 6 breaths	75% MEP	46% MEP increase
Sapienza & Wheeler, 2006	Normal, multiple sclerosis, and spinal cord injury	EMST	2 weeks	5 days/week 5 sets of 5 breaths	75% MEP	50% increase in all groups
Suzuki et al., 1995	Normal	IMST	4 weeks	2x daily 15 minutes	30% MIP	25% MIP increase
Weiner et al., 2003	Normal	EMST	3 months	6 days/week 30 minutes	60% MEP	24% MEP increase No MIP increase

Table 4. Summary of respiratory muscle strength training protocols and outcomes

Although this was not an objective of the current study, results showed that participants' times to maximum strength gains varied from 3 to 7 weeks. The mean duration of IMST to reach MIP plateau for participants who completed Training Protocol 1 was 6 weeks. The mean duration of EMST to reach MEP plateau for participants who completed Training Protocol 2 was 3.67 weeks. These results indicate a need for further investigation into training duration and frequency to determine the most efficient respiratory muscle strength training protocol for singers.

Determining the most efficient training protocol with regards to frequency and duration would minimize participant burden and potentially maximize compliance with future training programs. Although compliance was not an issue in the current study, it has been shown that treatment or training frequency is inversely related to compliance with a prescribed program (Boulet, 2004; Claxton, Cramer, & Pierce, 2001; Gram et al., 2014; Sclar, Tartaglione, & Fine, 1994). Using a healthy population for the current study may have been a factor in compliance with the program. To help maximize compliance, the current study called for daily completion of the training, which may have provided a consistent schedule that was easy to remember. The participants in this study were highly motivated to complete the training as they were enrolled in higher level education programs and have completed training and lessons addressing breathing and technique to improve their singing. Daily emails were also sent as reminders and confirmations of completion.

Specificity of EMST and IMST in strengthening the targeted muscles has been shown with increases in MEP and MIP, respectively (see Table 4). Weiner et al. (2003) also looked at the specificity of EMST in patients with COPD by measuring MEP and MIP, and found only an increase in MEP, with no increase in MIP, as a result of EMST. The findings in the current study are contradictory and did note increases in MIP as a result of EMST as well as increases in MEP as a result of IMST. On average, the three participants who completed Training Protocol 1 and trained IMST alone increased MIP by 85% and MEP by 66% while specifically targeting the inspiratory muscles. Likewise, the three participants who completed Training Protocol 2 and trained EMST alone increased MEP, on average, by 78% and MIP, on average, by 28%. These limited data

suggest that, among advanced singers, there is an effect of EMST on the inspiratory muscles and of IMST on the expiratory muscles in addition to the expected targeted strength gains. These data also indicate that IMST alone may have a greater overall effect on the respiratory muscles (MIP and MEP combined) then EMST alone.

Some research has measured the effects of EMST on MIP or IMST on MEP in clinical populations with reduced respiratory capabilities. Several studies have used MEP and MIP as outcome measures of an IMST program on patients with multiple sclerosis and found increases in both measures, although the changes in MEP were not statistically significant (Fry et al., 2007; Klefbeck & Nedjad, 2003; Pfaltzer & Fry, 2011). Gosselink and colleagues (2000) examined changes in respiratory pressures in patients with multiple sclerosis as a result of EMST and found that changes in MIP increased more than increases in MEP. MEP has also been shown to increase with MIP as a result of IMST in patients with cervical spinal cord injury (Liaw et al., 2000). Most recently, Iranzo and colleagues (2014) compared the effects of IMST and yoga breathing exercises on MIP and MEP in an elderly population and found that MIP and MEP increased in both groups, but more so in the group receiving yoga breathing exercises than IMST. IMST thresholds in this study were set to 30-50% MIP, which may have limited strength gains.

The task of training itself may have resulted in the crossover of strength gains in the previously mentioned and current studies. IMST, for example, required participants to exhale maximally before inhaling against the training device. Likewise, EMST required participants to inhale maximally before exhaling against the training device. These maximal breathing tasks are not resistance training, but are more extreme and

forceful than singers are used to producing and may have resulted in the noted strength changes.

It is possible, especially in the clinical populations, that lung volume changes could have contributed to the force generating capabilities of the respiratory muscles. Additionally, the length-tension relationship in muscles states that increased force and tension of a muscle can be generated with increased, or optimized, muscle length (Gordon, Huxley, & Julian, 1966). The increased expiratory strength could increase the length, and therefore force generating capacity of the opposing inspiratory muscles and inspiratory muscle strength gains could increase the length, and therefore force generating capacity of the opposing expiratory muscles in all populations (Edman, Elzinga, & Noble, 1978; Schwartzstein & Parker, 2006). Future research is needed to generalize these results and understand the underlying mechanisms for respiratory muscle strength training.

The increases in MEP may have been limited in two participants in this study who reached the maximum level of training of the device (150 cm H_2O) during training. While the EMST150 (Aspire Products, LLC) has been used in previous studies with normal, healthy participants (Baker et al., 2005; Hoffman-Ruddy; Sapienza et al., 2002), the device has been more often used and targeted toward populations with impaired respiratory strength or other limitations. Whether the design of the EMST150 was to accommodate clinical populations with reduced strength or whether the maximum value was placed due to concerns of adverse cardiovascular risks is unknown. Laciuga, Davenport, and Sapienza (2012) were able to determine, however, that a single set (25 repetitions) of EMST at 75% MEP did not alter blood pressure, heart rate, or oxygen

saturation levels in healthy participants. The effects of training at levels higher than 150 cm H_2O on blood pressure, heart rate, or other cardiovascular measures and the cardiovascular effects in clinical populations have yet to be investigated.

It was assumed in this study that participants would present with baseline respiratory strength measures within limits of established norms; however, there is variability among these standards (See Table 5). The baseline MIP and MEP values of the participants in the current study are illustrated in Table 6. The established baseline MIP range was 44.9 to 106.1 –cmH_2O and the established baseline MEP range was 55.4 to 90.9 cmH_2O. As a group, these ranges fell close to previously established values; however, variability exists among the studies.

Study	MIP (-cm H_2O)	MEP (cm H_2O)	Mouthpiece
Black & Hyatt (1969)	71.3 - 101.9	125.3 – 178.3	Tube
Bruschi et al. (1992)	53.6 - 113.8	75.2 - 115.3	Flanged
Leech et al. (1983)	44.8 - 97.8	62.1 - 127.4	Flanged
Rinqvist (1966)	73.4 - 122.3	134.5 - 193.6	Tube
Wilson et al. (1984)	52.0 - 94.8	76.4 - 109.0	Flanged

Table 5. Examples of established normal ranges for MIP and MEP in adult female populations

Participant	Baseline MIP (-cm H_2O)	Baseline MEP (cm H_2O)
S1	77	74
S2	46	46
S3	59	65
S4	85	94
S5	128	91
S6	73	69
Mean (SD)	**78.00 (28.14)**	**73.17 (17.75)**

Table 6. Baseline MIP and MEP values for participants in the current study

Some of the variability and wide ranges within and among the established norms, and perhaps among the participants in the current study, can be explained by the method in which the measures were collected. The type of mouthpiece can greatly influence the pressures measured at the mouth due to varying abilities to generate oral and cheek tension and/or peri-oral leak. The current study utilized a flanged mouthpiece to minimize peri-oral leakage and minimize the effects of cheek or oral tension on the values measured (Figure 21). The maximum pressure generation task is also highly effort dependent when measured at the mouth, as it was for the above mentioned and current studies. The current study attempted to control for this factor by giving consistent directions for the task and by requiring three values to be within 5% of each other for each measurement used. Additionally, the current study enlisted the baseline phase to ensure consistency across time, again within 5%, to achieve the most representative value possible. Despite the limitations of using mouth pressure to estimate respiratory muscle strength, it is a widely accepted, non-invasive, and well-tolerated practice (American Thoracic Society, 2001).

Figure 21. Manometer with flanged mouthpiece used to measure MIP and MEP

Voice Measures

All other measures taken for this study were also well-tolerated, but not without their limitations. The subglottal pressure, maximum sustained phonation, and voice range profile measures were taken using a pneumotachograph. For these tasks, the participants were asked to phonate with a mask held against the face to cover the mouth and nose and direct the sound to a wire screen within the pneumotachograph device (see Figure 22). The wire screen provides a resistance to the flow allowing for measurement of the pressure/flow relationship during phonation (Beranek, 1954; Rothenberg, 1977; Van den Berg, 1962).

The Phonatory Airflow System (PAS; KayPentax®) pneumotachograph used in this study has been validated with good to excellent levels of reproducibility and test-retest reliability; however, the measures used to determine the validity were not taken with singers and did not use fundamental frequencies outside normal speaking range

(Awan, Novaleski, & Yingling, 2013). The pneumotachograph has been shown to distort the radiated sound by damping the formant frequencies and altering the acoustic radiated output at the lips, and is limited in its response to higher frequencies (Badin et al, 1990; Hertegard & Gauffin, 1992; Rothenberg, 1986).

The wire screen on the PAS pneumotachograph is approximately 12.7 cm from the mouth, or the point where the sound radiates from the lips. The presence of the mask itself lengthens the vocal tract, and the further the wire screen from the lips, the more distorted the acoustics become compared to normal phonation. Rothenberg (1973) developed a circumferentially vented (CV) pneumotachograph with the wire screens in the mask itself, limiting the distance from the radiated output, and thus the distortion.

The advanced singers who completed this study did notice the altered acoustic output. For example, several participants reported difficulty singing loudly at the pitch F#4 into the mask, and the difficulty was absent when the mask was removed. Similarly, the participants reported difficulty producing the /a/ vowel at frequencies where no such trouble existed without the mask. Such discrepancies may have altered the output and measurement of the true capabilities of the singers.

It has been well-established that control of the voice requires reliance on feedback in both speech and singing. Several studies have found that speakers modulate their voices as a compensation for induced perturbations in pitch feedback (Burnett et al., 1998; Jones & Mundhall, 2000; Lane & Tranol, 1971; Larson, 1988; Larson et al., 2000). Keough and Jones (2009) examined the effects of changes in auditory feedback in both speakers and singers and found that both groups made adjustments to their intended fundamental frequency as a result of the adjusted feedback. The singers in the study were

more sensitive to the altered feedback, making changes when fundamental frequency was altered by only 6 cents, compared to the speakers who made adjustments at alterations of 26 cents.

Studies have also shown corrective responses in vocalizations when the perceptions of vocal loudness do not equal the intended loudness (Bauer, Mittal, Larson, & Hain, 2006; Heinks-Maldonado & Houde, 2005). Ternstrom (1991) additionally demonstrated this effect by documenting adjustments made by singers in responses to other singers and room acoustics. The distortion of the vocal output by the PAS likely limited true measurement of the intended measures in this study. Future studies of airflow in singers would be more effective with the use of the CV mask to minimize acoustic and perceived distortion that may have affected the results of the current study.

Figure 22. Phonatory Airflow System (PAS, KayPentax®) pneumotachograph

Negligible changes in frequency and intensity ranges measured on the voice range profile may have been affected by the pneumotachograph as well as the experience level of the singers in this study. It is possible that the advanced level of the singers may have achieved frequency and intensity ranges near the inherent physical limitations of their voices prior to beginning the study. Additionally, the singers were concurrently taking voice lessons throughout the study, making it difficult to ascertain whether the small changes that were seen were a result of the respiratory muscle strength increases or of their vocal training outside of the study.

Collegiate vocal training has been shown to change voice range profile outcomes. Leborgne and Weinrich (2002) found an increased SPL range as a result of 9 months in a Master's voice program. Similarly, increased SPL range was found after 4-5 years of training (Murbe, 2002) and 3 years of training (Murbe, 2007). While these studies did not find an increase in frequency range, the current study did show an increase in lower pitch range by one interval (3 semitones) in three of the six participants. The relative contributions of vocal training and/or respiratory muscle strength training on the findings are unable to be determined.

Vocal training has also resulted in changes in measures of vibrato rate and extent. Mitchell and Kenny (2009) investigated the effect of a 2-year tertiary classical singing program on vibrato and found increased vibrato extent and reduced variability of vibrato rate. Similar changes were noted by Ferguson and colleagues (2013) over a 3-year period of vocal training; however, increased vibrato extent was achieved only after the first year

and maintained thereafter. Conversely, Mendes and colleagues (2003) did not find vibrato changes over a 2-year vocal training program.

The advanced singers who participated in this study presented with measures of vibrato that have been shown to be within the range of appealing, which is not surprising given their advanced level of classical singing. Perceptually, rate is considered normal or appealing at a range of 5-7 Hz and extent at +/- 1 semitone (Sundberg, 1994). The rates throughout all phases of the study across all participants ranged from 5.2 Hz to 6.2 Hz. The extents ranged from 94.7 cents to 216.7 cents, which equates to about one-half to one semitones. While the advanced singers demonstrated acceptable values and none would be considered perceptually abnormal with regards to vibrato parameters, they were not highly consistent. The data for each participant revealed variability within each phase. There is no evidence to support whether this trend is typical or atypical in a trained singer or group of trained singers, or whether the changes within participants are perceptually relevant.

Although variability of vibrato measures within the participants was noted, only one participant (S2) made changes across phases (increased vibrato rate) that appeared to be a result of RMST. This participant was the least experienced of all of the advanced singers in this study, having just entered her Master's program. These changes may be a result of the relative lack of experience; she may have less engrained technique or a less sophisticated "system" of singing that was more easily changed by RMST or her voice training compared to the other participants.

Subglottal pressure was estimated in this study using measures of peak oral pressure, first described in 1973 by Shipp and colleagues. This method assumes that

peak oral pressures will equal subglottal pressure during the closure of voiceless stops when the pressure above and below the glottis are equal and was validated by Lofqvist (1982). While this is a widely accepted method for obtaining estimates of subglottal pressure, a common source of error in this measurement can occur if the intrasyllable subglottal pressure is not constant (Hertegard, Gauffin, & Linstead, 1995). Rothenberg (2013) described ways to reduce this error, including the use of repeated "/baep/" syllables instead of the more classically used "/pa/". The use of the voiced initial consonant may help eliminate aspiration of the phoneme, which can lower subglottal pressure after the release. This method was used in this study and demonstration was provided to minimize error. This seems to be the most efficient way of measuring subglottal pressure at this time.

The measures of subglottal pressure did not reveal any consistent changes across the advanced singers who completed respiratory muscle strength training in this study. While two participants demonstrated increases in subglottal pressure throughout the training phases, it is unknown whether this is a desirable change or if it has any impact on their singing voice. Increases in respiratory muscle strength could impact subglottal pressure and airflow by adapting to the changes in lung volume during phonation; however, changes in subglottal pressure can also be achieved by regulating the degree of vocal fold adduction. The force or degree of vocal fold adduction will similarly affect phonatory airflow; increased vocal fold adduction will increase subglottal pressure and decrease phonatory airflow (Leanderson & Sundberg, 1988).

The data from the current study did not reveal consistent changes in airflow, phonation volume, or maximum phonation time. These results could indicate the

advanced level of technique before beginning the study and did not take into account the effects of vocal training throughout the study. Reduced phonatory airflow may increase maximum sustained phonation time, which may seem like an improvement; however, if the airflow is being reduced by excessive glottal adduction, adverse effects such as damaging collision forces may result (Gray, Titze, & Lusk, 1987; Gunter, 2003; Jiang & Titze, 1994; Titze, 1994). Increased phonation time as a result of increased phonation volume without changes in airflow would indicate minimal to no adjustments of vocal fold adduction. Measures of airflow or subglottal pressure alone, however, do not provide information about the efficiency of the voice as a whole. In fact, it has been shown that voices can sound normal without being efficient (Jiang, Lin, & Hanson, 2000). The subglottal pressure and maximum sustained phonation measures taken in this study provided limited information about the entire vocal mechanism by excluding measurements of the activity of the vocal folds.

Future Implications for Respiratory Muscle Strength Training

Vocal efficiency relies on the interaction between the driving force of the airflow and its regulation by the vocal folds and is essential for maintaining a healthy voice and singing career. It is essentially the proportion of power produced in intensity to energy used by subglottal pressure and airflow (Schutte, 1992). Inefficient modes of phonation can be either breathy, with insufficient glottal adduction, or pressed, with excessive glottal adduction (Titze, 1992). The respiratory muscles can improve efficiency by regulating driving forces at high lung volumes (inspiratory muscles) and low lung volumes (expiratory muscles). If the respiratory muscles act optimally to regulate

subglottal pressure, the demands on the vocal folds to make adjustments in subglottal pressure are reduced (Sundberg, 1992).

Increased vocal fold adduction increases the impact stress and the stiffness of the vocal folds (Jiang & Titze, 1994). This results in increased subglottal pressure as well as increased phonation threshold pressure (PTP). PTP is the smallest amount of subglottal pressure required to initiate and maintain vocal fold vibration for phonation (Titze 1988). PTP is measured by acquiring subglottal pressure measures at the lowest volume achieved using a decrescendo task and pairing it with electroglottogram (EGG) measure of vocal fold vibration. The EGG gives information about vocal fold vibration by measuring the time spent during a glottal wave cycle in the closed and open phases (Baken, 1992). Increased closed phase indicated increased glottal adductive force and has been positively correlated with increased impact stress (Verdolini, Chan, Titze, Hess, and Bierhals, 1998).

Titze (1988) described how PTP is influenced by vocal fold viscosity, mucosal wave velocity, glottal adduction, and vocal fold thickness, all of which reflect the status of the vocal fold biomechanical properties. For example, increased viscosity indicates increased laryngeal resistance and therefor the energy required to initiate phonation (PTP) is subsequently increased (Finkelhor, Titze, & Durham, 1988). A decreased PTP, on the other hand, indicates increased vocal fold compliance and mobility, which has been shown to decrease the perception of phonatory effort (McHenry, Johnson, & Foshea, 2009; Motel, Fisher, & Leydon, 2003; Solomon, Ramanathan, & Makashay, 2009). PTP has been positively correlated with vocal fatigue (Chang & Karnell, 2005) and has been shown to decrease as a result of vocal warm-up (Enflo & Sundberg, 2009).

Although it was not measured in this study, PTP may also be a more practical measure than subglottal pressure measured at comfortable loudness levels, because it has more implications for the health and function of the vocal folds themselves, the interaction between the vocal folds and their driving force, and the perceived effort of the singer.

To best determine the effect of respiratory muscle strength training on the efficiency of the vocal mechanism, future studies should implement measures of the vocal folds, including EGG and PTP. It is likely that the participants in the study were sophisticated enough to make modifications at the glottal level to adjust or compensate for any changes made at the respiratory level. As evidenced by Titze (1992), singers can become calibrated to certain measures of pressure and flow and maintain or adjust them by actively shaping the vocal folds. If the singers did make modifications at the vocal fold level to maintain a desired subglottal pressure and/or airflow during the phonatory tasks as a result of voice or respiratory muscle strength training, the measures taken in this study would not illustrate them.

To address the potential confounding effect of voice training on the effects of RMST, future studies should implement a group design that allows for a control group. Additionally, detailed information regarding targets of voice lessons should be taken and compared between subjects. In this study, five of the six participants studied with a single voice teacher. This voice teacher was able to subjectively comment on his perceptions of the participants' voice changes that he believed were a result of RMST. Such changes included perceptions of the voices as "bigger and clearer", "longer", "richer", "more consistent", and requiring "less compensation". Perhaps these effects were not measured in this study as a result of the tasks. Tasks that would more accurately

measure the vocal demands of the singers could include maximum phrase duration requiring varying pitch and loudness instead of maximum sustained phonation, vibrato tasks at more extreme levels of pitch and loudness, and measures of vocal fold adduction and function as stated earlier. Subjective measures of participant perceptions of vocal changes and vocal effort would also add social validity to the results.

It is speculated that the lack of changes in the aerodynamic and voice outcome measure of the study may be related to the advanced technical level of the singers who participated. It would be useful to determine the effect of technique level by comparing these results with those of less advanced singers. To maximize the functionality of RMST in pedagogy practice, further examination of training duration and frequency should be completed in a larger sample. Detraining, or maintenance, effects may also provide information regarding the vocal changes as a result of respiratory muscle strength changes. Comparisons between IMST and EMST on respiratory muscle strength and the effects on vocal function will additionally help guide pedagogy practice.

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Appendix A: Consent to Participate in Research Form

The Ohio State University Consent to Participate in Research

Study Title: Effects of respiratory muscle strength training on airflow and phonation of trained singers

Principal Investigator: **Scott McCoy**

Sponsor: The Ohio State University College of Music

- **This is a consent form for research participation.** It contains important information about this study and what to expect if you decide to participate. Please consider the information carefully. Feel free to discuss the study with your friends and family and to ask questions before making your decision whether or not to participate.
- **Your participation is voluntary.** You may refuse to participate in this study. If you decide to take part in the study, you may leave the study at any time. No matter what decision you make, there will be no penalty to you and you will not lose any of your usual benefits. Your decision will not affect your future relationship with The Ohio State University. If you are a student or employee at Ohio State, your decision will not affect your grades or employment status.
- **You may or may not benefit as a result of participating in this study.** Also, as explained below, your participation may result in unintended or harmful effects for you that may be minor or may be serious depending on the nature of the research.
- **You will be provided with any new information that develops during the study that may affect your decision whether or not to continue to participate.** If you decide to participate, you will be asked to sign this form and will receive a copy of the form. You are being asked to consider participating in this study for the reasons explained below.

1. Why is this study being done?

This pilot study was designed to address the following research objectives:

1. To determine the effects of inspiratory muscle strength training (IMST) alone on respiratory muscle strength and phonation measures including consistency of vibrato, pitch range, intensity range, subglottic pressure, airflow rate and maximum phonation time and volume during phonation.

2. To determine the effects of expiratory muscle strength training (EMST) alone on respiratory muscle strength and phonation measures including consistency of vibrato, pitch range, intensity range, subglottic pressure, airflow rate and maximum phonation time and volume during phonation.

3. To determine the effects of combined IMST and EMST on respiratory muscle strength and phonation measures including consistency of vibrato, pitch range,

intensity range, subglottic pressure, airflow rate and maximum phonation time and volume during phonation.

2. How many people will take part in this study?

Up to 10 participants will take part in this pilot study

3. What will happen if I take part in this study?

You will first be asked to complete a questionnaire to determine your eligibility to participate in the study. Data from non-qualifiers will be retained during the study. Once eligibility is determined, measurements of the dependent variables will be collected via manometry measurements of maximum inspiratory and expiratory pressures, completion of a phonetogram measuring maximum intensity levels (SPL) at each pitch you are capable of producing, repeating the syllable /baep/ on one breath, and sustaining the vowel /a/ at a comfortable pitch and loudness that you may choose. You will then engage in either inspiratory or expiratory muscle strength training protocol during which you will breathe into or out of a pressure threshold trainer set at 80% of your maximum capability measured via manometry as described above. You will take the hand-held threshold trainer home to complete 5 repetitions, 5 times daily and keep track of completion of these sets on a spreadsheet. You will be asked to correspond daily with the investigator via email to ensure completion of the sets at home or away from the lab.

Repeated measures will be collected every 2-3 days.

4. How long will I be in the study?

Each session will last no more than 90 minutes including at least 3 but no more than 10 baseline measures to establish stability and 12-30 training sessions. Number of training sessions and duration of training protocol will depend on the trend and stability of your data. Data will be collected until stability is evident across at least 3 sessions for baseline and each independent variable (inspiratory and expiratory muscle strength training). In addition, you will be required to complete the training protocol at home which will require a weekly commitment of up to 20 minutes daily for the duration of the study. For both the inspiratory and expiratory muscle strength training protocols, you will complete 5 repetitions (each taking about 10-30 seconds), 5 times daily at home.

5. Can I stop being in the study?

You may leave the study at any time. If you decide to stop participating in the study, there will be no penalty to you, and you will not lose any benefits to which you are

otherwise entitled. Your decision will not affect your future relationship with The Ohio State University.

6. What risks, side effects or discomforts can I expect from being in the study?

A risk to participation in this study is the time that you must spend time if you choose to participate in the study. In addition, confidentiality could be a risk; however, all careful measures described previously will be taken to ensure that privacy and confidentiality are maintained. Numerous studies have been published using respiratory muscle strength training protocols in both healthy and medically fragile populations including those with COPD, Parkinson's disease, Cystic Fibrosis, and Upper Airway Limitation in which no harm was done to subjects. This study will employ a respiratory muscle strength training protocol with the same devices used in the above mentioned studies with HEALTHY participants (graduate students). In addition, singers routinely engage in respiratory exercise to improve their singing ability during singing lessons outside this study. We therefore do not anticipate any risk to you in this study.

7. What benefits can I expect from being in the study?

There may be no direct benefit to you for participating in this study. If the training protocols improve breath support and subsequently phonation as expected, you may have improved your phonation/singing skills individually. This is the goal of a singing student and would therefore be considered a benefit of participation in the study. Knowledge of the effects of respiratory muscle strength training may improve pedagogical practice.

8. What other choices do I have if I do not take part in the study?

You may choose not to participate without penalty or loss of benefits to which you are otherwise entitled.

9. Will my study-related information be kept confidential?

Your data will be kept anonymous as possible. Email correspondence with identifiers will be kept in a password-protected email folder and deleted after use to keep your study-related information confidential.

Efforts will be made to keep your study-related information confidential. However, there may be circumstances where this information must be released. For example, personal information regarding your participation in this study may be disclosed if required by state law.

Also, your records may be reviewed by the following groups (as applicable to the research):

- Office for Human Research Protections or other federal, state, or international regulatory agencies;
- U.S. Food and Drug Administration;
- The Ohio State University Institutional Review Board or Office of Responsible Research Practices;
- The sponsor supporting the study, their agents or study monitors; and
- Your insurance company (if charges are billed to insurance).

If this study is related to your medical care, your study-related information may be placed in your permanent hospital, clinic, or physician's office records. Authorized Ohio State University staff not involved in the study may be aware that you are participating in a research study and have access to your information.

A description of this clinical trial will be available on http://www.ClinicalTrials.gov, as required by U.S. law. This website will not include information that can identify you. At most, the website will include a summary of the results. You can search the website at any time.

You may also be asked to sign a separate Health Insurance Portability and Accountability Act (HIPAA) research authorization form if the study involves the use of your protected health information.

10. What are the costs of taking part in this study?

None

11. Will I be paid for taking part in this study?

No, you will not be paid for taking part in this study. By law, payments to subjects are considered taxable income.

12. What happens if I am injured because I took part in this study?

If you suffer an injury from participating in this study, you should notify the researcher or study doctor immediately, who will determine if you should obtain medical treatment at The Ohio State University Medical Center.

The cost for this treatment will be billed to you or your medical or hospital insurance. The Ohio State University has no funds set aside for the payment of health care expenses for this study.

13. What are my rights if I take part in this study?

If you choose to participate in the study, you may discontinue participation at any time without penalty or loss of benefits. By signing this form, you do not give up any personal legal rights you may have as a participant in this study.

You will be provided with any new information that develops during the course of the research that may affect your decision whether or not to continue participation in the study.

You may refuse to participate in this study without penalty or loss of benefits to which you are otherwise entitled.

An Institutional Review Board responsible for human subjects research at The Ohio State University reviewed this research project and found it to be acceptable, according to applicable state and federal regulations and University policies designed to protect the rights and welfare of participants in research.

14. Who can answer my questions about the study?

For questions, concerns, or complaints about the study you may contact ***Christin Ray at 614-293-8074.***

For questions about your rights as a participant in this study or to discuss other study-related concerns or complaints with someone who is not part of the research team, you may contact Ms. Sandra Meadows in the Office of Responsible Research Practices at 1-800-678-6251.

If you are injured as a result of participating in this study or for questions about a study-related injury, you may contact **Christin Ray at 614-293-8074**.

Signing the consent form

I have read (or someone has read to me) this form and I am aware that I am being asked to participate in a research study. I have had the opportunity to ask questions and have had them answered to my satisfaction. I voluntarily agree to participate in this study.

I am not giving up any legal rights by signing this form. I will be given a copy of this form.

Printed name of subject	Signature of subject
	AM/PM Date and time
Printed name of person authorized to consent for subject (when applicable)	Signature of person authorized to consent for subject (when applicable)
Relationship to the subject	AM/PM Date and time

Investigator/Research Staff

I have explained the research to the participant or his/her representative before requesting the signature(s) above. There are no blanks in this document. A copy of this form has been given to the participant or his/her representative.

Printed name of person obtaining consent	Signature of person obtaining consent
	AM/PM Date and time

Witness(es) - *May be left blank if not required by the IRB*

Printed name of witness	Signature of witness
	AM/PM Date and time
Printed name of witness	Signature of witness
	AM/PM Date and time

Appendix B: Participant Demographic and Eligibility Form

Participant Questionnaire

How many years of vocal performance have you had in a higher education setting?_____

Are you a Master's or Doctoral student of Vocal Performance? _____

How many years of formal singing lessons have you had?_____

Are you or could you be pregnant? _____

Do you have a history of smoking? _____

Do you have a known vocal pathology? _____

Do you have a hiatal hernia? _____

Do you have a current rib injury? _____

Do you have a history of spontaneous pneumothorax? _____

Do you currently have any nasal congestion (cold, sinusitis, respiratory tract infection)? _____

Do you have any known respiratory disease? _____

Signature: _____ Date: _____

Printed Name: _____

Appendix C: Verbal Recruitment Script

Verbal Recruitment Script

This pilot study was designed to address the following research objectives:

1. To determine the effects of inspiratory muscle strength training (IMST) alone on respiratory muscle strength and phonation measures including consistency of vibrato, pitch range, intensity range, subglottic pressure, and airflow rate and volume during phonation.

2. To determine the effects of expiratory muscle strength training (EMST) alone on respiratory muscle strength and phonation measures including consistency of vibrato, pitch range, intensity range, subglottic pressure, and airflow rate and volume during phonation.

3. To determine the effects of combined IMST and EMST on respiratory muscle strength and phonation measures including consistency of vibrato, pitch range, intensity range, subglottic pressure, and airflow rate and volume during phonation.

You will first be asked to complete a questionnaire to determine your eligibility to participate in the study. Once eligibility is determined, measurements of the dependent variables will be collected via manometry measurements of maximum inspiratory and expiratory pressures, completion of a phonetogram measuring maximum intensity levels (SPL) at each pitch you are capable of producing, repeating the syllable /baep/ on one breath, and sustaining the vowel /a/ at a comfortable pitch and loudness that you may choose.

You will then engage in either inspiratory or expiratory muscle strength training protocol during which you will breathe into or out of a pressure threshold trainer set at 80% of your maximum capability measured via manometry as described above. You will take the hand-held threshold trainer home to complete 5 repetitions, 5 times daily and keep track of completion of these sets on a spreadsheet. Repeated measures will be collected every 2-3 days at the Swank Voice Lab in Mershon Auditorium.

Each session in the lab will last no more than 90 minutes including at least 3 but no more than 10 baseline measures to establish stability and 12-30 follow-up sessions. Number of follow-up sessions and duration of training protocol will depend on data trends and stability. Data will be collected until stability is evident across at least 3 sessions for baseline and each independent variable (inspiratory and expiratory muscle strength training). In addition, you will be required to complete the training protocol at home which will require a weekly commitment of up to 20 minutes daily for the duration of the study. For both the inspiratory and expiratory muscle strength training protocols, you will complete 5 repetitions (each taking about 10-30 seconds), 5 times daily

You may leave the study at any time. If you decide to stop participating in the study, there will be no penalty to you, and you will not lose any benefits to which you are otherwise entitled. Your decision will not affect your future relationship with The Ohio State University.

A risk to participation in this study is the time that you must spend time if you choose to participate in the study. In addition, confidentiality could be a risk; however, all careful measures described previously will be taken to ensure that privacy and confidentiality are maintained. Numerous studies have been published using respiratory muscle strength training

protocols in both healthy and medically fragile populations including those with COPD, Parkinson's disease, Cystic Fibrosis, and Upper Airway Limitation in which no harm was done to subjects. This study will employ a respiratory muscle strength training protocol with the same devices used in the above mentioned studies with HEALTHY participants (graduate students). In addition, these participants routinely engage in respiratory exercise to improve their singing ability during singing lessons outside this study. We therefore do not anticipate any risk to human subjects in this study.

There may be no direct benefit to you for participating in this study. If the training protocols improve breath support and subsequently phonation as expected, you may have improved your phonation/singing skills individually. This is the goal of a singing student and would therefore be considered a benefit of participation in the study. Knowledge of the effects of respiratory muscle strength training may improve pedagogical practice.

Your data will be kept anonymous as possible. Email correspondence with identifying information will be kept in a password-protected email folder and deleted after use to keep your study-related information confidential. Efforts will be made to keep your study-related information confidential. However, there may be circumstances where this information must be released. For example, personal information regarding your participation in this study may be disclosed if required by state law. Also, your records may be reviewed by the following groups (as applicable to the research):

- *Office for Human Research Protections or other federal, state, or international regulatory agencies;*
- *The Ohio State University Institutional Review Board or Office of Responsible Research Practices;*
- *The sponsor, if any, or agency (including the Food and Drug Administration for FDA-regulated research) supporting the study.*

You may refuse to participate in this study without penalty or loss of benefits to which you are otherwise entitled. If you are a student or employee at Ohio State, your decision will not affect your grades or employment status.

If you choose to participate in the study, you may discontinue participation at any time without penalty or loss of benefits. By signing this form, you do not give up any personal legal rights you may have as a participant in this study.

An Institutional Review Board responsible for human subjects research at The Ohio State University reviewed this research project and found it to be acceptable, according to applicable state and federal regulations and University policies designed to protect the rights and welfare of participants in research.

For questions, concerns, or complaints about the study you may contact ***Christin Ray at 614-214-5753***

For questions about your rights as a participant in this study or to discuss other study-related concerns or complaints with someone who is not part of the research team, you may contact Ms. Sandra Meadows in the Office of Responsible Research Practices at 1-800-678-6251.

If you are injured as a result of participating in this study or for questions about a study-related injury, you may contact ***Christin Ray at 614-214-5753.***

Feel free to ask questions before making your decision whether or not to participate. If you decide to participate, you will be asked to sign a consent form and will receive a copy of the form.

Appendix D: Data Collection Form

Data Collection Sheet (Question 17A) Subject Number: _____

Dependent Variable: _____ Unit of Measurement: _____

Session	Baseline	Training EMST/IMST (circle one)	Training EMST/IMST (circle one)
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