The Effect of Traditional Vocal Warm-up Versus Semi-Occluded Vocal Tract Exercises on the Acoustic Parameters of Voice

by

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ABSTRACT

This study investigated the effect of traditional vocal warm-up versus semi-occluded vocal tract exercises on the acoustic parameters of voice. Vocal warm-up is thought to be a pre-requisite for optimal singing, but studies to determine the effects of vocal warm-up have found little support for vocal warm-up making a significant physiologic change. Semi-occluded vocal tract exercises are common practice in vocal warm-up that have been shown to cause changes in the vocal tract that lead to acoustic change. One such change is the singer’s formant. The singer’s formant may be quantified through the singing power ratio (SPR), which compares the intensity of the upper frequency formants with the intensity of the lower frequency formants of an auditory signal. This study addressed three questions: (1) Does vocal warm-up condition significantly alter the singing power ratio (SPR) of the singing voice? (2) Is SPR dependent upon vowel type? (3) Is effort affected by warm-up condition? 13 male singers were recorded under three different conditions: no warm-up, traditional warm-up, and semi-occluded vocal tract exercise warm-up. Recordings were made of these singers performing the Star Spangled Banner, and SPR was calculated from four vowels /i/, /o/, /ʌ/, and /u/. Singers rated their effort singing the Star Spangled Banner under each warm-up condition. Warm-up condition did not significantly affect SPR. SPR was dependent upon vowel type, with SPR being most significant for /i/ and /e/. Effort was not significantly affected by warm-up condition.

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I. LITERATURE REVIEW

Voice production

Phonation, or voicing, at the level of the larynx results in the production of a sound wave (Baken, 1998), which is a pressure disturbance that is propagated through space and time (Hixon, Weismer, & Hoit, 2008). The larynx is a valve located in the front of the neck that houses the laryngeal cartilages, intrinsic laryngeal membranes, intrinsic laryngeal ligaments, and intrinsic laryngeal muscles (Hixon et al., 2008). The vocal folds are two shelf-like structures that extend from the sides of the laryngeal cavity. Between the vocal folds there is an open air space called the glottis. Muscular contraction within the larynx can cause the vocal folds to abduct, meaning to move away from the midline of the glottis, or to adduct, meaning to move toward the midline of the glottis. The larynx is comprised of intrinsic muscles, including the paired thyroarytenoid (TA) muscles, cricothyroid (CT) muscles, lateral cricoarytenoid (LCA) muscles, posterior cricoarytenoid (PCA) muscles, and interarytenoid (IA) muscles (Titze, 2000). Collectively, these muscles are responsible for fine-motor muscle function of the larynx. The TA muscles make up a large portion of the vocal folds. Upon contraction, the TA muscles are responsible for shortening, thickening, and stiffening the vocal folds. Contraction of the CT muscles results in lengthening of the vocal folds. LCA muscle contraction causes adduction of the vocal folds. Contraction of the PCA results in abduction of the vocal folds. The IA muscles work with the LCA to close the glottis, sealing off the posterior glottis (Titze, 2000). Vocal fold vibration occurs when sufficient subglottal air pressure builds beneath the adducted vocal folds (Titze, 1988). The vocal folds self-sustain their oscillatory movement (Titze, 1988), and the oscillation produces a sound. Activation of the intrinsic laryngeal muscles is essential to vocal fold oscillation, as both small- and large-amplitude oscillation require some approximation of the vocal folds. This muscular activation affects the morphology of and stress distribution along the vocal folds (Deguchi, Kawahara, & Takahashi, 2011). Thus, to describe vocal productions and how warm-up affects them, biomechanics of the larynx should be understood.

Laryngeal Biomechanics

The intrinsic laryngeal muscles that comprise the vocal folds act mechanically (Cooper, Patridge, & Alipour-Haghighi, 1993), thus principles of biomechanics can be applied to much of their movement. Fluid mechanics and solid mechanics are the basic building blocks of laryngeal biomechanics (Titze, 2000). Fluid mechanics describe the properties of liquids and gases, while solid mechanics describes the properties of rigid bodies. The simplest component of solids, liquids and gases is a particle, and mechanical principles can describe the bulk movement of a large system of particles. The aggregate of particles may change shape (a deformation), be displaced along a particular path (a translation), or change its orientation with respect to a given axis (rotation; Titze, 2000). When given a continuous mass such as a solid, liquid or gas that is confined to a finite region of space, the forces acting on the mass are also distributed over the confined region of space. Active forces within the larynx result from muscle contraction of the intrinsic, extrinsic, and supplemental muscles (Hixon et al., 2008) and are distributed onto the vocal fold tissues (Titze, 2000).

The most active of the intrinsic laryngeal muscles are the TA muscles, which compose the muscular body of each vocal fold, and the CT muscles, which control tension in the membranes of the vocal folds (Deguchi et al., 2011). The TA is more active during modal speaking, while the CT comes into play for higher fundamental frequencies, such as those encountered in falsetto singing and transition register (Watson, 2009).

There are many ways to quantify how vocal warm-up affects the voice, including how warm-up exercises affect the vocal fold muscles. Vocal warm-up is a sub-maximal activity, the effects of which are thought to parallel those of warm-up for physical exercise (McHenry, Johnson, & Foshea, 2009). Warm-up for physical activity is intended to improve skeletal muscle dynamics to avoid injury and to prepare an individual for athletic demands (Woods, Bishop, & Jones, 2007). Possible physiologic improvements that accompany warm-up for physical exercise include: (1) increased speed and force of skeletal muscle action and relaxation through faster metabolic processes and reduced internal viscosity that leads to smoother contractions; (2) greater economy of movement due to reduced internal viscosity of active skeletal muscles; (3) easier release of oxygen from hemoglobin at elevated skeletal muscle tissue temperature that facilitates more efficient oxygen off-loading to the working muscles; (4) increased nerve transmission secondary to increased tissue temperature that may result in increased contraction speed and reduced reaction time; and (5) increased blood flow through active tissues due to vasodilation that is promoted with increased temperature (McArdle, Katch, & Katch, 1996; Woods et al., 2007). The most notable of these physiological changes from warm-up are increased blood flow and increased skeletal muscle temperature (McHenry et al, 2009).

Knowledge regarding the physiological properties of skeletal muscles and muscle fibers in humans has largely focused on the skeletal muscles of the limbs and trunk, while much remains unknown regarding the properties of human laryngeal muscles (Hoh, 2005). Much of the existing research has examined skeletal muscle fiber types of laryngeal muscles in human and animal models. Skeletal muscle fiber type is determined through identification of the isoform of the myosin heavy chain (MHC), which regulates the contraction speed (Barany, 1967). While there are likely many different skeletal muscle fiber types and hybrid combinations of the basic fiber types, for the purposes of this discussion, the classification will be simplified as follows: Type I, which are slow contracting and fatigue-resistant; and Type II, which are fast-contracting and fatigable. These fiber types differ in regard to the bioenergetic pathway used to generate adenosine triphosphate (ATP), the energy needed to initiate, sustain, and cease muscle contraction. Type I fibers rely on oxygen as the energy substrate for generating a steady supply of ATP. Type II fibers are divided into subtypes IIa, IIx, and IIb. These fibers contribute primarily to muscle speed and power and vary in fatigability. Type IIx and IIb fibers rely on the immediate energy system (phosphocreatine) and glycolysis to varying degrees for generation of ATP (Hoh, 2005).

Teig, Dahl, and Thorkelsen (1978) examined the laryngeal muscles from 3 healthy excised human larynges post-laryngectomy. Frozen pieces of each muscle were stained, and fibers were analyzed under a microscope. The authors described the laryngeal muscles as a hybrid mix of type I and type II muscle fibers. The TA muscle had the highest percentage of type II fibers, at 65±11.6%, and the PCA muscle had the highest percentage of type I muscle fibers at 67±8.6%. The other intrinsic laryngeal muscles had intermediate values. The current body of knowledge indicates that within any species, the TA has faster fibers than the PCA, and the PCA has faster fibers than the CT (Hoh, 2005). It should be noted variation in muscle fiber type distribution occurs from person to person in both skeletal limb muscle and laryngeal muscles due to genetic predisposition. Muscle endurance changes may occur to adapt to changes in functional use as well as hormonal stimuli, but fiber type distribution in an individual remains constant (Hoh, 2005).

In addition to muscle fiber typing, muscle spindle typing is another way to classify muscle fiber cells (Tellis, Rosen, Thekdi, & Sciote, 2004). Muscle spindles are stretch receptors that contain their own skeletal muscle fiber types with unique expression called intrafusal fibers. These intrafusal fibers may be either bag$_1$ fibers, bag$_2$ fibers, or chain fibers (Tellis et al., 2004). The bag$_1$ fibers have elevated levels of tonic MHC, bag$_2$ fibers have elevated levels of neonatal MHC, and chain fibers also have neonatal myosin (Tellis et al., 2004). As mentioned before, MHC determines the contraction time of muscle fibers (Barany, 1967). Tellis et al. (2004) used antibody staining to determine the type and amount of MHC isoform in each muscle fiber of the IA muscle. One major finding was that the muscle spindles of the IA generally had a complex fiber type distribution of 1 bag$_1$ fiber, 1 bag$_2$ fiber, and 4 or 5 chain fibers. Some spindles only contained a bag$_1$ fiber and a few chains, the bag$_2$ fibers being absent in these. Bag$_1$ fibers detect and provide sensory information about shortening during contraction, while bag$_2$ and chain fibers monitor resting length and postural activity of the muscle. Because bag$_1$ fibers were more present in the IA muscle spindles than bag$_2$ fibers and because the IA contains an elevated presence of fast-contracting, fast-fatigable muscle fibers, the IA likely has the ability to contract rapidly and modify the rate of shortening for varying tasks. By this logic, the IA may be important in rapid adduction or abduction tasks such as swallowing and vigorous breathing. The presence of muscle spindles in the IA is a point of distinction from the PCA and TA, as these investigators could not identify spindle structures in the PCA and TA. This could indicate that motor control of intrinsic laryngeal muscles varies depending upon the independent task of each muscle.

To summarize, current knowledge about the composition of the intrinsic laryngeal muscles indicates that the TA muscle is dominated by type II fibers, the PCA muscle is dominated by type I fibers, and the IA muscle is distinctive due to the presence of several muscle spindles per muscle. This indicates that the PCA muscle may be more suited for endurance tasks than the IA and TA muscles (DeFatta & Sataloff, 2012). It should be noted that knowledge of laryngeal fiber typing is limited. Use of only a few larynges from cadavers without knowledge of voice use patterns during their lifetimes limits our understanding of how muscle fiber types present may be reflected in functional voice use. Now that an understanding of the skeletal muscle composition of the vocal fold muscles is emerging, we must now consider how warm-up could affect the laryngeal muscles. While it is impossible to measure the influence of vocal warm-up on the individual intrinsic laryngeal muscles directly, there are ways to study the collective effect of warm-up indirectly, through well-established standardized acoustic measures.

Physiologic Effects of Vocal Warm-up

The physiologic effects of vocal warm-up on vocal fold tissue can be measured indirectly through phonation threshold pressure (PTP). PTP is the minimum lung pressure required to initiate phonation (Titze, 1988, 1992), which is directly proportional to tissue viscosity and may be related to perceptual ease of phonation (Titze, 1988). Theoretically, if warm-up improves the condition of the vocal folds physiologically, PTP would be lowered

(Milbrath & Solomon, 2003). The relationship between a warm-up condition and PTP has been observed as variable in a handful of studies (e.g., Elliot, Sundberg, & Gramming, 1995; Motel, Fisher, & Leydon, 2003). One possibility considered is that vocal warm-up could increase blood flow to the vocal folds and decrease intrinsic laryngeal muscle viscosity and possibly nonmuscular tissue viscosity, thus decreasing PTP (Milbrath & Solomon, 2003). Motel et al. (2003) sought to quantify the effects of a 10-minute vocal warm-up on PTP of soprano singers. In this study, PTP was obtained at the 10%, 20%, and 80% frequencies of the total frequency ranges of ten female voice majors before and after two conditions: vocal warm-up and vocal rest. The warm-up was 10 minutes in duration and consisted of (1) descending legato stepwise scales spanning one octave on /zi/; (2) ascending and descending legato stepwise scales spanning one fifth using on /zi/; (3) ascending staccato major triads on /i/; (4) descending, stepwise thirds on a /trioioi/spanning one half-octave; and (5) allegro ascending and descending scales spanning one octave on /vi/. These exercises were chosen to resemble typical warm-up protocol performed at the beginning of a routine voice lesson. Participants were guided by audio recording, including piano accompaniment. Results revealed that vocal warm-up increased PTP at the 80% frequency. Since greater PTP is associated with greater effort (Titze 1988), the increase in PTP following warm-up may indicate increased muscular force production and/or decreased superficial laryngeal viscosity. Since muscle fiber composition of the TA indicates that it is likely a fast-fatigable muscle (Teig et al., 1978), 10 minutes of warm-up could have fatigued the TA, causing PTP to increase. However, perceptual ratings from participants revealed some participants felt positive benefit from the warm-up, with one in particular stating she felt performance-ready (Motel et al., 2003).

Elliot et al. (1995) collected PTP prior to and following a warm-up in ten male and female amateur singers. The approximately 30-minute warm-up consisted of a softly-sung descending melodic pattern on /mu/, followed by other exercises involving pitch changes, different vowels, and different degrees of vocal loudness. Extremely loud singing was avoided throughout the warm-up. All participants verbally reported feeling that their voice was in better condition following the warm-up. This study focused on comparing the subglottal pressure-fundamental frequency curve of participants to a curve calculated by Titze (1992) that accounts for the decreased vocal fold thickness associated with fundamental frequency increase. The male participant curves approximated the theoretical curves fairly closely. PTP appeared reliably pitch-dependent for the male participants, but the same pattern was not observed in the female participants. No trend in PTP was observed post warm-up, with some participants' PTP increasing, some participants' PTP decreasing, and some participants' PTP not changing significantly at all.

Milbrath and Solomon (2003) studied eight women with chronic vocal fatigue. Phonation threshold pressure (PTP) was used to measure vocal function after 20 minutes of vocal warm-up exercises, after 1 hour of reading aloud, and after 30 minutes of silence. During another session, the vocal warm-up period was replaced with 20 minutes of voice rest and relaxation. PPE was measured after each part of the protocol, and PPE was expected to be directly related to PTP based on the idea that both can reflect ease of phonation (Titze, 1988). Milbrath and Solomon (2003) found instead that neither PTP nor PPE changed significantly with warm-up, nor was it significantly higher after the loud reading activity.

Observing warm-up as a fatigue-resistance or effort reduction maneuver has yielded inconsistent results when quantified by PTP and PPE. Conclusions from empirical research indicate that vocal warm-up exercises do not appear to positively affect PTP or PPE (Milbrath & Solomon, 2003) following vocal loading, and that PTP may actually increase following a warm-up lasting from 10 to 30 minutes (Elliot et al., 1995; Motel et al., 2003). Despite the theoretical implication that increased PTP is related to increased effort when frequency and intensity are tightly controlled, PTP has been observed to increase following vocal warm-up (Elliot et al., 1995; Motel et al., 2003). Motel et al. (2003) proposed two possible reasons that subjective reports indicate ease post-warm-up while PTP increases. One is that the increased PTP at high pitches is related to positive phonatory changes due to an ischemic effect that prevents vascular injury at high-frequency productions or a loss of water in the mucosa. Another is that increased water efflux in the vocal fold from vocal warm-up regimens could facilitate easier phonation. Milbrath and Solomon (2003) also did not find support of warm-up benefit via PTP measurements and suggested that the measurements were not sensitive enough to changes in vocal function that the investigators attempted to induce through warm-up exercises and loud reading. Elliot et al. (1995) suggest that variability in PTP following vocal warm-up could be attributed to individual differences or the complex nature of the vocal folds.

The Body-Cover Theory

The Body-Cover Theory, first proposed by Hirano (1974), describes the tissues of the vocal folds as two groups of layers: cover and body. The “cover” includes the epithelium and the superficial and intermediate layers of the lamina propria, and the “body” is comprised of the deep layer of the lamina propria and the thyroarytenoid muscle. The cover is pliable and does not have contractile properties; rather, its tension is controlled by vocal fold length (Titze, Jiang, & Druker, 1988). The body is less deformable and does have contractile properties, thus, its tension is determined by both length and internal muscle contraction (Titze et al., 1988). As mentioned before, attempts to measure physiologic effects of warm-up on vocal fold tissue have yielded mixed results (Elliot et al., 1995; Motel et al., 2003). Perhaps this is due to difference in behavior among the different layers of the vocal folds (Elliot et al., 1995). Since the cover is very pliable and loosely connected to other tissue layers, its motion is relatively independent of the body, which causes the vocal folds to have non-uniform tissue movement (Titze, 2000).

The general fatigue resistance of the vocal fold muscles indicates that biomechanical or physiological change may be more present in the mucosa than the muscle (Motel et al., 2003). Deguchi et al. (2011) performed a three-dimensional analysis to investigate the effect of activation of the cricothyroid and thyroarytenoid muscles on vocal fold morphology and stress distribution. Their findings indicate that the characteristic deformation most suitable for efficient vibration is effected by the cricothyroid muscle. It was also found that when the thyroarytenoid muscle contracts and becomes the principle stress-bearing component of the vocal folds, tissue motion is limited to the cover. Vocal activity could certainly affect the muscle tissue and lamina propria tissue types differently (McHenry et al., 2009), and inconsistent physiological data regarding the vocal folds could possibly be attributed to this.

Vocal Tract Tuning, Acoustics, and Resonance

Vocal warm-up has also been considered in terms of vocal tract tuning, meaning the changes in glottal and supraglottal setting (Laukkanen, Horacek, & Havlik, 2012). In a study by Laukkannen, Horacek, and Havlik (2012), one male and one female were examined via magnetic resonance imaging (MRI) to determine vocal tract changes post-warm-up. Each participant produced the vowels /a/, /i/, and /u/ 20 seconds before and after a warm-up of their choice lasting for “some minutes” (p. 76). Midsagittal MRI images were analyzed for describing vocal tract size and shape. Specifically, the ratio of the pharyngeal inlet over the epilaryngeal outlet (expressed as A_{ph}/A_e) was calculated. In the male, the main change was that post-warm-up the larynx lowered from the fifth to the sixth vertebrae. In the female no vertical change in position post-warm-up was noted in the larynx except for a slight increase in /u/. Some jaw opening was observed in /a/. The tongue was more curved and frontal after the warm-up, and the pharynx was wider. A_{ph}/A_e increased for both participants: up to 27% for the male and up to 28% for the female across all three vowels. Though the sample size was very small, this study shows that it is possible to observe supraglottal changes post-warm-up.

The sound produced by the vocal folds is shaped by the supraglottal stuctures, which can be represented as a filter characteristic (Fant, 1970). As multiple sound waves move through the vocal tract, resonance occurs. Resonance refers to the natural reinforced oscillation of an object (Titze, 2000). The vocal tract has a natural cavity resonance, and the frequencies of the harmonic spectrum are modified by the vocal tract’s resonance. Specific frequencies from the harmonic spectrum resonate within the supraglottal structures while others are damped by soft tissue in the supraglottal structures. The frequencies that are amplified through resonance form resonant peaks called formants (Fant, 1970). A smooth line called a spectral envelope can be drawn over the selectively-amplified harmonics of the output spectrum of voice, revealing the formant structure of the sound (Fant, 1970). The particular formant frequencies are located on the spectral envelope using linear predictive code (LPC) analysis (Hixon et al., 2008). The first three peaks seen in the spectral envelope are called the F-pattern and are labeled F1 (first formant), F2 (second formant), and F3 (third formant; Fant, 1970). Articulation or filter shape can be inferred from the F-pattern. In general, the first formant, F1, decreases with increased tongue height, F2 increases with increased tongue advancement, and F3 increases as the mouth opening increases in size and becomes less rounded (Stevens & House, 1955). Thus, through resonance we are able to learn about the location, movement, and size of the vocal tract structures. As modifications to the vocal tract may be a consequence of vocal warm-up (Laukkanen, Horacek, & Havlik, 2012), resulting acoustic qualities may be influenced by vocal warm-up. The pharynx inlet and epilarynx outlet area ratio considered by Laukkanen, Horacek, and Havlik (2012) is important in the production of the singer's formant, which enhances acoustic vocal quality.

The Singer's Formant

In Western classically-trained singers, a prominent spectral envelope peak called the singer's formant is often observed (Sundberg, 1974; Sundberg, 1998). Spectral reinforcement of the upper frequencies is much less defined in female voices, making the singer's formant a phenomenon mainly observed in male voice (Morris & Weiss, 1997). The singer's formant can be defined as a strong area of resonance around 3000 Hz, whose resonant frequency can be as wide-spread as 2600-4000 Hz (Morris & Weiss, 1997). The singer's formant is a spectral prominence associated with solo singing and is not seen in choral singing (Sundberg, 1998). Its purpose is to help the voice be heard through an orchestral accompaniment (Sundberg, 1998).

A singer's formant is generated when two or more formants approach each other in frequency, the formant amplitudes increase, and the third, fourth, and fifth formants form a formant cluster (Sundberg, 1974; Sundberg, 1998). Particular parts of the vocal tract are involved in articulatory formation of the singer's formant (Sundberg, 1974). Most predominately, increased density of formants occurs when the larynx is lowered (Morris & Weiss, 1997; Sundberg, 1974; Sundberg, 1998). Sundberg (1974) indicated two ways larynx lowering contributes to the singer's formant. First, it expands the pyriform sinuses and the laryngeal ventricle. Second, it increases vocal tract length. Lowering of the larynx is an essential part of the epilarynx tube and pharynx making separate but complementary adjustments to produce the singer's formant. A small tube directly above the vocal folds with length of about 2 cm constitutes the epilarynx tube (Sundberg, 1974). The larynx is sits directly above the pharynx, which is a larger tube that makes up the remaining throat above the epilarynx tube. (Sundberg, 1974). The articulatory basis for the singer's formant is thought to be associated with a narrowing of the epilarynx tube and a decrease in the epilarynx tube opening to less than 1/6 of the cross-sectional area in the pharynx (Sundberg, 1974). To aid in achieving this ratio, the pharynx widens as the epilarynx tube narrows (Sundberg, 1974; Titze, 2012). The perceptual result of these vocal tract adjustments is a "ringing" quality in the voice (Elkholm, Papagiannis, & Chagnon, 1998; Omori, Kacker, Carroll, Riley, & Blaugrund, 1996). According to Sundberg (1998), presence of the singer's formant in a vowel helps the singer's voice to be heard through orchestral accompaniment by raising the spectral envelope to a frequency range where the sound of the accompaniment is only moderate in competition.

As mentioned before, the singer's formant is a phenomenon seen mainly in classically and operatically trained singers (Millhouse & Clermont, 2006; Morris & Weiss, 1997, Sundberg, 1998; Sundberg, 2001). Morris & Weiss (1997) claim that the singer's formant is unlikely to emerge without training, though many singing teachers believe it is a by-product of good singing technique. Training that targets development of the singer's formant would include exercises that encourage widening the pharynx (Titze, 2012) and lowering the larynx (Weiss, Brown, & Morris, 2001).

In female voices, instead of a cluster of formants, simply strong upper frequency reinforcement has been observed (Morris & Weiss, 1997). The high-pitched female voice does not necessarily need the singer's formant, as the risk of masking from accompaniment is lower in high-pitched female singing because all partials are higher in frequency than the strongest sounds from the accompaniment (Sundberg, 1974). It is also difficult to produce the singer's formant when frequencies are very high. Harmonics in high frequencies are spaced apart more and peaks are often difficult to discern, especially when there is not a partial near the formant frequency (Sundberg, 1998). Thus, observation and measurement of the singer's formant is more precise and discernable in male voices than in female voices.

Measurement of the Singer's Formant

Sundberg (1995) stated that the presence or absence of the singer's formant could be determined by whether the intensity of the formant around 3 kHz is "exceptionally high" (p. 83). The method to determine if the intensity (which Sundberg terms "level") is exceptionally high is to compare the level of the third formant (L3) to expected L3 level based on Fant's (1970) equations for predicting formant levels. If the difference between the observed and expected L3 is greater than or equal to 6 dB, the presence of singer's formant is confirmed. Vowel does influence the relative L3, so the determined level of the singer's formant varies relative to vowel when using this method (Sundberg 1995).

Singing power ratio (SPR) is another method of measuring upper frequency harmonic peaks to distinguish the quality of a trained singing voice from that of an untrained singing voice (Amir, Amir, & Michaeli, 2005; Omori et al., 1996; Watts, Barnes-Burroughs, Estis, &

Blanton, 2006). SPR is defined as the power ratio of the greatest harmonic peak between 2 kHz and 4 kHz (termed singing power peak, SPP) and the greatest harmonic peak between 0 kHz and 2 kHz, expressed in dB (Omori et al., 1996). SPR offers an indirect observation of harmonic tuning of the vocal tract (Watts et al., 2006), which could be influenced by vocal warm-up (Laukkanen, Horacek, & Havlik, 2012).

Vocal Warm-up

Vocal warm-up is thought to be an essential prerequisite for optimal singing (Barr, 2009; Motel et al., 2003). Warm-up exercises are used to address basic aspects of good vocal technique, to teach vocal fundamentals, and to address problems specific to the current repertoire (Hylton, 1995). Singers report greater ease when singing after vocal warm-up (Elliot, Sundberg, & Gramming, 1995), but little has been found regarding how warm-ups affect voice production (Amir et al., 2005; DeFatta & Sataloff, 2012; Elliot et al., 1995; McHenry et al., 2009; Vinturri et al., 2001). Theoretically, warm-up could physically warm the vocal folds (McHenry et al., 2009), prevent vocal fold muscle fatigue (Milbrath & Solomon, 2003; Motel et al., 2003), tune the vocal tract for vocal performance (Laukkanen, Horacek, & Havlik, 2012), or enhance the acoustic quality of the voice (Laukkanen, Horacek, Krupa, & Svec, 2012). Evidence has not supported theories that vocal warm-up does cause physiologic change in the vocal folds (Cooper & Titze, 1985; Elliot et al., 1995; Milbrath & Solomon, 2003; Motel et al., 2003), but vocal tract and subsequent acoustic changes in the voice have been observed following vocal warm-up in research studies (Laukkanen, Horacek, & Havlik, 2012; Laukkanen, Horacek, Krupa, & Svec, 2012).

Warm-up routines for physical activity can vary from passive warm-up, like massage, to general warm-up, like jogging, to a specific warm-up that involves practice of the actual movements of the given activity (McArdle et al., 1996). Likewise, vocal warm-up routines vary in length and content among individual singers and voice teachers (Gish, Kunduk, Sims, & McWhorter, 2012; Milbrath & Solomon, 2003), though most are generally "variations of a few basic themes" (p. 51, Titze, 2001). How to warm-up is a "hotly contested" (p. 142) area for singing teachers (Barr, 2009). Duration of the warm-up session in particular varies considerably among singers (Gish et al., 2012). For example, a duration of around 20 minutes has been suggested (Miller, 1990), but duration of warm-up protocols in studies on the effects of warm-up have ranged from 7 to 30 minutes (Gish et al., 2012). A survey conducted by Gish et al. (2012) indicated that the majority of participants' warm-up routines lasted for 5 to 10 minutes. Elliot et al. (1995) found that a single warm-up session ranging from 10 to 30 minutes improves most singers' self-perception of vocal function, but Miller (1990) warns that singing through a 30 minute warm-up would be detrimental to the quality of the voice in performance. All of these opinions were considered in devising an accurate description of vocal warm-up, with two distinct types being profiled: classical vocal warm-up and semi-occluded vocal tract warm-up.

Traditional Vocal Warm-up

Literature describing warm-up tasks offers a variety of exercises with varied and, at times, conflicting data (Barr, 2009; Gish et al., 2012; Milbrath & Solomon, 2003). Hylton (1995) suggests beginning vocal warm-up with stretching, loosening, and relaxation exercises designed to target coordination of the various muscles involved in singing. Brief aerobic exercise preceding vocal warm-up has also been suggested (Miller, 1990), with the thought that the entire body is the voice instrument (Shear, 2008). McHenry et al. (2009) studied the differential effects of "specific" vocal warm-up and "combined" warm-up (both aerobic exercise and vocal warm-up exercises). The investigators thought that aerobic exercise would have greater impact on core body temperature than specific vocal warm-up alone. Differences in female and male results were hypothetically attributed to unanticipated differences in levels of physical activity, differing vocal fold composition, or difference in level of hyaluronic acid in the vocal folds. Results of the study indicate that exercise combined with a 20-minute vocal warm-up caused a greater decrease in phonation threshold pressure post-warm-up in women of average fitness (McHenry et al., 2009). The observed decrease in PTP indicates that the viscosity and thickness of the women's vocal folds remained low, creating greater ease of phonation initiation (Titze, 1988).

For a combined warm-up, graduated tasks beginning with gentle, brief onsets and offsets are suggested after light physical exercise or diaphragmatic breathing tasks (Miller, 1990). Agility patterns should come next, followed by tasks that target a smooth change in vocal registers (Miller, 1990). Vocal register tasks could include upward and downward glides, scales, and arpeggios. Downward vocalization in which the singer descends from the higher part of the range to the lower part of the range is a suggested exercise for developing uniform tone throughout the range (Hylton, 1995). Ascending and descending scales, arpeggios, and glissandi (gliding across a large range) are also thought to stretch the vocal folds as the singer moves from a low pitch to a high pitch. With exception of glissandi, these exercises target agility and vocal flexibility while also allowing the voice to operate without tension (Gish et al., 2012; Hylton, 1995). Two octave pitch glides on /i/ or /u/ are used to achieve a maximal stretch of the vocal folds. These exercises also work the cricothyroid and thyroarytenoid muscles both separately and together and get the fundamental frequency above the first formant for varying acoustic loads (Titze, 2001).

A warm-up session should conclude with rapid arpeggios and scales spanning the entire range (Miller, 1990). Singing rapid scalewise or arpeggiated passages encourages relaxation of the lower jaw and throat muscles. If a singer has trouble singing rapid scales or arpeggios, it is an indication of unwanted vocal tension. Titze (2001) suggests performing staccato arpeggios to elicit clean and rapid voice onset, establishing a dominant mode of vocal fold vibration. Staccato arpeggios also exercise the adductor and abductor muscles in concert with tensor muscles during pitch change (Titze, 2001).

Humming, or sustained nasal consonants, is a common warm-up component (Gish et al, 2012; Gregg, 1996; Miller, 1986; Miller, 1990; Shear, 2008; Titze, 2001). Vocal exercises that target resonance balancing are important for developing clean on-glides and off-glides in sung vowels (Miller, 1986). Resonance balancing refers to a balance between the resonances of the coupled oral and nasal cavities in the vowels following any of the nasal consonants, /m/, /n/, or /ŋ/ (Miller, 1986). The use of nasal consonants and vowels in vocal warm-up is thought to improve overall vocal quality through resonance and provide maximum vocal economy (Verdolini, Druker, Palmer, & Samawi, 1998). Vocal economy or “Ev-max” is the maximized ratio between voice output (dB) and intraglottal impact stress (kPa) under constant subglottal pressure and frequency conditions (Verdolini et al., 1998). Ideally voice output is maximized while intraglottal impact stress is minimized. Theoretically, nasal consonants and vowels also facilitate an optimal glottal width for sustained oscillation of the vocal folds (Milbrath & Solomon, 2003). A small pre-phonatory glottal width is associated with lowering of PTP (Lucero, 1998), and decreased PTP indicates phonatory ease (Titze, 1988). Humming can be a voice building technique allowing for a clear tone and flow phonation with the least amount of effort from the singer (Gregg, 1996). Humming also “brings the voice forward on the vocal mask” (p. 32, Shear, 2008). However, some in the music community warn against frequent use of nasal consonant warm-ups. When used indiscriminately, nasal consonants can cause unwanted muscular habits like a stiffened tongue, a raised larynx, and a chronically lowered soft palate (Gregg, 1996; Nix, 1999). A proposed alternative warm-up phoneme is the lip trill (Nix, 1999)—a semi-occlusive exercise.

Semi-occluded Vocal Tract Warm-up

Semi-occluded exercises are those that partially occlude the vocal tract causing immediate change in vocal behavior that results in decreased glottal resistance and increased glottal flow (Laukkanen, Lindholm, & Vilkman, 1995). Lip trills and tongue trills are common semiocclusives (Gaskill & Erickson, 2008; Titze, 1996). A voiced lip trill is produced by phonating with a closed lip posture firm enough to occlude the airstream but relaxed enough to allow the lips to vibrate audibly (Gaskill & Erickson, 2008). In a tongue trill, phonation occurs while the airstream causes vibration at the tongue occlusion point at the alveolodental region (Menezes et al., 2011). The vocal tract narrowing associated with semi-occluded vocal tracts increases back pressures of the vocal tract in the form of supraglottal and intraglottal pressures at the level of the glottis. These back pressures keep the vocal folds ideally separated (Titze, 2006). According to models by Story, Laukkanen, & Titze (2000), partial occlusion of the vocal tract may provide impedance that allows for greater ease of phonation. During phonation, the vocal folds alternate open and closed phases through a self-sustaining cycle of elasticity and inertia (Titze, 2000). The vocal folds are inherently elastic, providing their own restoring force, while airflow provides the mass and, therefore, the inertia (Wolfe, Garnier, & Smith, 2009). Impedance has two parts: resistance, which removes energy from a system and reactance, which stores energy within a system. Reactance provides mass, which creates inertia and preserves movement within a system, such as in the vocal mechanism (Story, Laukkanen, & Titze, 2000). Inertive reactance provides an acoustic load in the larynx that helps facilitate self-sustained vocal fold oscillation when the epilarynx tube is wide, as is the case during semi-occluded vocal tract phonation (Titze & Story, 1997). Semi-occluded vocal tract exercises have also been observed to increase thyroartyenoid muscle action relative to cricothyroid muscle action (Laukkanen, Titze, Hoffman, & Finnegan, 2008). Increased thyroartyneoid contraction means more even distribution of muscle tension along the medial surface of the vocal folds instead of concentration in the central medial surface, which is generally where pathologies develop (Menezes et al., 2011).

Another mode of semi-occluded vocal tract warm-up is phonating into a tube or straw (Titze, Laukkanen, Finnegan, & Jaiswal, 2002). Semi-occluded vocal tract exercises with an artificially elongated vocal tract go back to as early as 1899, when Spieβ described the technique of humming into a resonance tube 12 cm in length and 1 cm in diameter (Spieβ, 1899, as cited in Story et al., 2000). There are five main advantages to using a straw or tube instead of lip trills in a semi-occluded warm-up exercise. First, use of a tube causes pressure behind the lips to be three times greater than when phonating on /u/, which points to the straw providing more tissue vibration. The increased pressure is important in guiding the trainee to the sensation of facial tissue vibration, which accompanies impedance matching between the glottis and vocal tract (Titze & Laukkanen, 2007). This sensation is important for motor learning and may reinforce the behavior that creates the vibration of the facial tissue (Guzman, Laukkanen, Krupa, Svec, & Geneid, 2013). Second, added length of an artificial tube lowers the first formant and increases inertive reactance in the vocal tract (Story et al., 2000). In fact, the reactance provided by using a straw is almost as much as that provided by a consonant (Story et al., 2000). When reactance is high, average airflow is reduced, decreasing effort for phonation (Rothenberg, 1984). Third, sound at the larynx is easier to monitor when using a tube or straw, as there is no added vibration at the lips (Titze et al., 2002). Fourth, straw diameter can be adjusted for the resistance needs of the individual, which is ideal for training (Titze et al., 2002). Straw diameter, straw length, and straw material can affect the level of resistance (Simberg & Laine, 2007). Increased resistance due to a smaller diameter or placing the end of the straw in the water may be appropriate for some individuals but damaging for others (Simberg & Laine, 2007). Ideally, resistance would increase the transglottal pressure (i.e., the difference between subglottal and supraglottal pressure) by increasing supraglottal pressure (Titze et al., 2002). If too much resistance is introduced, the subglottal pressure may increase, making transglottal pressure negligible (Bele, 2005). Transglottal pressure is necessary to support self-sustained oscillation (Titze, 2000), so resistance must be carefully controlled as to not hinder this process based on individual needs (Simberg & Laine, 2007). Fifth, semi-occluded vocal tract exercises with a straw promote small-amplitude vocal fold vibration instead of larger collision forces and pressed voice quality (Titze, et al., 2002). Though lung pressures are increased from straw phonation (Titze et al., 2002), supraglottal pressure also remains high. This causes the vocal folds to oscillate with relatively small amplitude despite increased subglottal pressure (Titze et al., 2002).

Single-subject studies have shown that changes in the vocal tract from phonation with an artificially lengthened vocal tract remained after the tube or straw was removed (Guzman et al., 2013; Laukkanen et al., 2012; Vampola, Laukkanen, Horacek, & Svek, 2011). Vampola et al. (2011) observed a raised velum and an expanded cross-sectional vocal tract area in a trained female singer following phonation into a glass resonance tube. Laukkanen et al. (2012) observed an increase in the areas of the oral cavity, pharynx, and epilarynx after phonating into a drinking straw. In both cases, the vocal tract changes were maintained in measurements taken after the tube was removed. A similar study was completed in which a single male subject sustained /a/, phonated into a glass resonance tube, and phonated into a plastic coffee straw (Guzman et al., 2013). An increased ratio of pharynx area to epilaryngeal area (A_p/A_e) was observed after both the tube and straw phonations, with the greatest A_p/A_e occurring after straw phonation. Contact quotient values were decreased during both tube and straw phonation and remained low in vowel productions after the straw or tube was removed. In all of these studies, the vocal tract changes were maintained in measurements taken after the tube was removed. These possible vocal tract changes could have positive consequences for singers. A raised velum closes entry to the nasopharynx, causing higher reactance (Vampola et al., 2011), easing the start of vocal fold oscillation (Titze & Story, 1997). According to Titze (2001), glides, scales, or arpeggios performed with a semi-occluded vocal tract get respiratory muscles into full action quickly, minimize upward force on vocal folds, lower phonation threshold pressure (PTP) by providing an inertive acoustic load, and stretch the vocal folds to their maximum length. The main value of semiocclusives in warm-up is that respiration must sustain oscillation at the vocal folds and lips simultaneously. This forces the singer to raise lung pressure, taxing the respiratory system instead of the larynx (Titze, 1996). Semi-occluded vocal tract exercises are supported as effective warm-up and rehabilitation exercises in the field of speech-language pathology (Gaskill & Erickson, 2008;

Laukkanen, Lindholm, Vilkman, Haataja, & Alku, 1996; Menezes et al., 2011). In dysphonic women a tongue trill exercise decreased noise and increased F_0 in the middle of an utterance (Menezes et al., 2011). Glottal closed quotient was reduced during lip trills when compared to normal speaking in healthy adult male singers (Gaskill & Erickson, 2008). Electromyography (EMG) signals showed a decrease in laryngeal muscle activation during production of the Finnish bilabial fricative /β/ (Laukkanen et al., 1996).

In short, semi-occluded vocal tract exercises and nasal consonants have the potential to create an ideal vocal tract configuration in terms of efficiency, economy, and quality (Gaskill & Erickson, 2008; Laukkanen et al., 1996; Menezes et al., 2011; Titze, 2006). Hence, a semi-occluded vocal tract is frequently used in vocal warm-up routines (Gish et al., 2012).

Conclusion

Common warm-up routines and exercises as well as their underlying physiological contributions to vocal tract tuning have been described. These routines and exercises vary among voice teachers and vocalists in terms of order and duration, but the general idea of warm-up is consistent within the musical community. Attempts to quantify post-warm-up changes via PTP have yielded mixed results, possibly due to the varied tissue layers of the vocal folds and their individual behaviors. For this reason it is also unclear whether the intrinsic musculature of the larynx behaves like skeletal muscle when warmed-up or subsequently exercised. Vocal tract configuration changes brought on by vocal warm-up could enhance the resonant characteristics of the voice. Semi-occluded vocal tract exercises have been observed to encourage more economic phonation. Use of a straw or tube in particular provides the necessary inertive reactance to sustain economic vocal fold oscillation. Semi-occluded vocal tract warm-up exercises could allow the singer to phonate with greater ease, efficiency, and economy after the exercise. It would be important to understand how changes in vocal tract configuration and associated acoustic parameters of the trained voice are affected by two different types of warm-up: classical and semi-occluded vocal tract. This knowledge could guide vocal training and voice therapy management in the future.

II. JUSTIFICATION

Vocal warm-up is considered essential to most singers and voice teachers (Gish et al., 2012). It is believed that voice use in speech and singing becomes easier and smoother following vocal warm-up (Vintturi et al., 2001). Vocal warm-up exercises are also believed to prevent vocal fold injuries (Gish et al., 2012). Though these beliefs are held by many in the singing community (Goldberg, 2007; Miller, 1990) and many speech-language pathologists (McHenry et al., 2009; Milbrath & Solomon, 2003), previous research has failed to demonstrate significant and consistent effects of classical vocal warm-up on the biomechanical or aerodynamic qualities of the voice (Elliot et al., 1995; McHenry et al., 2009; Milbrath & Solomon, 2003; Motel et al., 2003).

Semi-occluded vocal tract exercises have been proven to increase vocal economy and efficiency (Laukkanen et al., 1996; Laukkanen et al., 2008; Titze, 2006). Recent research has focused on the use of drinking straws to semi-occlude to the vocal tract (Laukkanen et al., 2008; Laukkanen et al., 2012, Titze et al., 2002). Single-subject studies have shown that phonation into a straw can cause changes in the vocal tract that remain after the tube or straw is removed (Guzman et al., 2013; Laukkanen et al., 2012; Vampola et al., 2011). Vampola et al. (2011) observed that phonating into a glass resonance tube resulted in a raised velum and an expanded cross-sectional vocal tract area.

The study by Laukkanen et al. (2012) examined via MRI how phonating into a drinking straw affected the vocal tract of a female with extensive vocal training both during and after the semi-occluded exercise. While lying in the MRI machine, the subject first produced [a:], phonated into a drinking straw twice, and then produced [a:] again. Results indicated that the midsagittal area of the vocal tract became larger, especially in the front part of the oral cavity. The ratio of the inlet to the pharynx over the outlet of the epilarynx increased by 27% during phonation into the straw and by 20% after the straw, a change that should help establish a speaker's formant (Sundberg, 1974). Despite this, changes in formant frequencies were small. Frequency differences in F2 & F1, F4 & F3, and F5 & F4 decreased after phonation into a straw, though overall SPL and SPL of the speaker's formant region increased.

The study by Guzman et al. (2013) investigated vocal tract image, acoustic, auditory-perceptual, and contact quotient parameters in a single male participant before, during, and after phonation into both a glass resonance tube and a small plastic coffee straw. CT images were taken during a sustained [a:], while the participant phonated into a glass tube, and while the participant phonated into a plastic straw. After 15 minutes of complete rest and silence, the participant phonated on [a:] again. Recordings were performed separately in a sound-treated booth. Subglottic (oral) pressure and EGG signal were recorded during repetition of the syllable [pa:] at habitual loudness and comfortable pitch before 5 minutes of phonation into a glass tube with habitual pitch and loudness. The syllable [pa:] was repeated again after phonation into the tube, and a sustained [a:] was recorded to assess the effect of tube phonation. After 15 minutes of complete silence, the participant repeated the procedure with a plastic straw of 2.5 mm inner diameter and 13.7 cm length. CT images showed that the velum was raised significantly during tube and straw phonation, decreasing some afterward but remaining higher than before placement of the tube or straw. The A_p/A_e ratio also increased after both tube and straw phonations. As mentioned previously, a higher A_p/A_e ratio is an important factor in production of the singer's formant. Acoustic data in the form of singing power ratio (SPR, a ratio of higher harmonic energy to lower harmonic energy) was in agreement regarding strong acoustic energy in the area of the singer's formant. CQ values decreased during tube and straw phonation and remained low after tube and straw phonation, with straw phonation causing the greatest change.

These studies lend support to the theoretical models by Sundberg (1974) and Titze and Story (1997) regarding vocal tract configuration for clustering of formants, but the observed effects should be tested more broadly. Obviously, there was a lack of external validity since these studies investigated single subjects. Laukkanen et al. (2012) found little formant frequency change when using speaking tasks to elicit the speaker's formant after the participant phonated into a straw for 20 seconds on a sustained [a:]. If instead a singing task was performed with a straw lasting as long as a brief vocal warm up, results could be different. Also, while Laukkanen et al. (2012) studied one subject with extensive vocal training experience and Guzman et al. (2013) studied a trained male singer with 7 years of experience completing semi-occluded vocal tract tasks, the use of a straw could affect the vocal tract of a less-experienced singer differently.

Vocal tract changes like those observed by Laukkanen et al. (2012) may help in forming the singer's formant. Since a large pharynx opening relative to the epilarynx is necessary for production of the singer's formant (Sundberg, 1974), it should be investigated as to how warm-up affects this ratio. Indirectly, it can be derived from acoustic data. The singer's formant can be measured through singing power ratio (SPR), which is the ratio of the highest peak between 2 kHz and 4 kHz and the highest peak between 0 kHz and 2 kHz (Omori et al., 1996). If upper frequency harmonics demonstrate more energy than lower frequency harmonics, as is the case when the singer’s formant is present, SPR will be relatively low (Guzman et al., 2013).

A reliable SPR is more likely to be observed in men than women because female singers have not been observed to produce a singer’s formant with the same reliability male singers do (Morris & Weiss, 1997). The high-pitched female voice does not necessarily need the singer’s formant, as the risk of masking from instrumental accompaniment is lower in high-pitched female singing (Sundberg, 1974). It is difficult to identify the singer’s formant in high-pitched voices. Because harmonics in high frequencies are spaced widely apart, peaks are difficult to discern (Sundberg, 1998). Thus, observation and measurement of the singer’s formant is more precise in male voices than in female voices.

The purpose of this study was to examine how both classical warm-up and warm-up with a semi-occluded vocal tract affect the formant frequencies of the singing voice. One aspect investigated was whether the voice is acoustically different before versus after vocal warm-up. The other aspect investigated was whether a classical warm-up described in music literature affects the acoustics of the voice differently from phonating into a drinking straw for the same duration.

Therefore, three specific questions were addressed in this study:

(1) Does vocal warm-up condition (no warm-up, traditional warm-up, semi-occluded warm-up) significantly alter the singing power ratio (SPR) of the singing voice?

(2) Does SPR differ with vowel type (/i/, /o/, /ʌ/, /e/)?

(3) Is effort, quantified by PPE, affected by warm-up condition (no warm-up, traditional warm-up, semi-occluded warm-up)?

Our hypothesis for the first question was that vocal warm-up would alter the SPR and that semi-occluded vocal tract warm-up would affect the SPR more significantly than no warm-up or traditional warm-up. For the second question, we hypothesized that SPR would be most significant for /i/ and /e/, based on previous findings (Morris & Weiss, 1997). Finally, we hypothesized that PPE would be increased under the no warm-up condition and would be decreased by the traditional warm-up and semi-occluded warm-up, with the greatest decrease happening under the semi-occluded warm-up.

III. METHOD

Participants

For this study, males between the ages of 19 and 50 were recruited to participate. Participants were recruited from voice and music classes on campus, as well as from church and community choirs in the Auburn area. Flyers were posted in university buildings, and information was spread by word of mouth. To be included in this study, the participant must have (a) been male, (b) been a nonsmoker, (c) had no history of asthma (with the exception of childhood asthma) or allergies, (d) had no indications or report of reflux, (e) had no history of laryngeal pathologies or abnormalities, (f) had no history of any serious respiratory infection or illness, (h) passed a pure tone hearing screening of 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz at 20 dB, (i) demonstrated ability to match a pitch to one provided, and (j) been an active singer (i.e., one who sings at least once a week in a chorus or other setting). If any of these requirements were not met, the participant was not permitted to continue in the study. Thirteen men volunteered to participate. The participants ranged in age from 19-42 (M = 22.615, SD = 5.785). The age, voice type, singing style, and amount of years singing for each participant is listed in Table 1 below

Table 1

Demographics of participants

Participant	Age	Voice Type	Singing Style	Years Singing
M01	22	Baritone	Classical	10+
M02	20	Baritone	Classical	8
M03	42	Tenor	Classical	~35
M04	21	Tenor	Jazz, pop, opera, Southern gospel	10
M05	20	Bass	Classical, opera	5
M06	20	Baritone	Opera, jazz, pop, rock, classical	10
M07	25	Tenor	Gospel, classical	"Maybe 10"
M08	20	Tenor	Rock/pop, folk	"a few"
M09	20	Tenor	Gospel, jazz	6
M10	22	Tenor	Pop, classical	10
M11	19	Bass	Classical, pop, Southern gospel (barbershop), choral	"My whole life"
M12	21	Tenor	Pop	6
M13	22	Baritone	Pop, show tunes, classical (in the past)	"My whole life"

Procedure

After receiving permission from Auburn University's Institutional Review Board (see Appendix A for approved informed consent form), undergraduate and graduate students in the Department of Music at Auburn University and other singers in the community were recruited to participate in this study. An investigator visited a local choir and read the recruitment script to the singers (see Appendix C for recruitment script). Recruitment also consisted of one of the investigators inviting students to participate by email with the approved flyer attached (see Appendix B for flyer). Additional participants were recruited through flyers posted in public areas. Participants were also recruited through word of mouth (see Appendix C for script).

Participants who expressed interest in the study were scheduled for data collection. When the participant arrived for data collection, he was given an IRB-approved consent form before providing any information or participating in any procedures (see Appendix A for consent form). Participants were allowed time to review each section of the consent form. After the participant finished reading the consent form, the investigator reviewed the consent form with the participant, providing an opportunity for the participant to ask any questions or to withdraw from the study. Each participant was then asked to initial and sign the consent form, which was witnessed by the investigator. The investigator then provided the participant with an information sheet outlining the basic exclusionary criteria for the study (see Appendix D for exclusionary screener). The nature of this form allowed a potential participant to indicate that he did not meet the exclusionary criteria without indicating which specific criteria he did not meet (i.e., the participant would only indicate yes to all the exclusionary criteria instead of having to indicate which specific criterion). Participants were also given the opportunity to ask any questions regarding the exclusionary criteria. If the participant did not meet any of the exclusionary criteria, data collection proceeded.

After the consent process was complete, the participant was assigned a participant code to ensure that all information and data that was collected was anonymous. The participant was given a demographic questionnaire to gather information such as his age, voice classification, and number of semesters of college-level vocal training (see Appendix E for demographic questionnaire).

Once it was determined that a participant met the inclusionary criteria of the study, a pure tone hearing screening was conducted using a Beltone (Glenview, IL) portable audiometer (Audioscout model). The portable audiometer used was regularly calibrated by Auburn University's Speech and Hearing Clinic, which is part of the Department of Communication Disorders. At the time of the screening, the identification number of the specific audiometer was recorded along with the participant's code, and each of the frequencies tested in the participant's right and left ears. Each of the hearing screenings was conducted in a sound-treated booth. All participants passed the hearing screening at tones of 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz presented at 20 dB (see Appendix F for hearing screening recording form).

Once it was determined that the participant passed the screening, the participant's ability to match pitch was evaluated using the Voice Range Profile (VRP) software option for the KayPENTAX (Montvale, NJ) Computerized Speech Laboratory (CSL) model 4500 hardware. In order to check the participant's ability to match pitch, he was presented with stimulus pitches. The participant was asked to match two given tones with a sustained /a/ vowel. The VRP program provided visual feedback to the participant regarding whether his output was above, below, or on pitch. If the participant was unable to match pitch, he was excluded from the research study.

Upon ability to match pitch, a stroboscopic examination was performed by a certified speech-language pathologist using the KayPENTAX Digital Videostroboscopy System (model 9295) with a rigid endoscope (model 9106). Stroboscopy was reviewed by a certified speech-language pathologist with expertise in the area of voice to evaluate the images for shape, symmetry, and texture of the vocal folds, presence of mucous, thickness of the mucosal cover, degree of edge pliability, presence of vascular markings, presence of redness, degree of glottal closure, vocal fold mobility, and degree of visibility of the mucosal wave. All 13 participants passed the stroboscopic screening.

While participants' hydration was not manipulated through hydration and dehydration procedures, a measure of urine specific gravity was used to control for the participant's degree of hydration. Urine specific gravity measures the density of the urine. The denser the urine, the higher the urine specific gravity, and the more dehydrated the person being studied. According to the instruction manual from the Siemens (Munich, Germany) Multistix 9 SG Reagent Strips for Urinalysis, normal hydration is indicated by a urine specific gravity range of 1.001 to 1.035 g/ml. Though most exercise science literature (e.g., Casa et al., 2000) would consider urine specific gravity between 1.010 to 1.020 to be values of minimal hydration, values between 1.0002 to 1.035 g/ml should be considered normal, assuming kidney function is normal (McPherson & Ben-Ezra, 2011). In order to participate in the study, the participants' urine specific gravity must have been at or below 1.035 g/ml. The participants' urine samples were collected in a bathroom approved by the Auburn University IBC. Hydration level, room temperature, relative humidity level, and acoustic data were recorded on a form (see Appendix H for recording form).

To screen for health of the speaking voice, each participant was asked to read aloud six sentences from the Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V; Kempster, Gerratt, Verdolini Abbott, Barkmeier-Kramer, & Hillman, 2009). The CAPE-V is a tool for clinical auditory-perceptual assessment of voice. The CAPE-V sentences are as follows: (a) The blue spot is on the key again, (b) How hard did he hit him, (c) We were away a year ago, (d) We eat eggs every Easter, (e) My mama makes lemon jam, and (f) Peter will keep at the peak (see Appendix G for instructions to be given to participants). The participant was seated in a chair in a quiet room and instructed to speak at a comfortable pitch and loudness for all tasks. Sentences were recorded with an AKG (Vienna, Austria) headset microphone (model C 420 PP) directly into the CSL program (Kay PENTAX) in the computer. The audio recordings of the sentences were saved to a folder marked by participant number.

Data Collection Procedures

The participants participated in three different conditions: (1) no warm-up, (2) classical warm-up, and (3) semi-occluded vocal tract warm-up. These conditions occurred at least one day apart at approximately the same time of day. Conditions were counterbalanced to minimize order effects. For example, the order of conditions for Participant 1 was 1, 2, then 3; the order of conditions for Participant 2 was 2, 3, 1; and the order of conditions for Participant 3 was 3, 1, 2. Urine specific gravity measurement took place before data collection at each data collection session. All data collection sessions took place in a speech science laboratory room. Under each condition, three separate recordings were made of the participant singing the Star Spangled Banner. For the purpose of acoustic analysis, the participants were directed to sustain the /i/ of “free,” /o/ of “home,” /ʌ/ of “the,” and /e/ of “brave” of the last line for one second each. Between each recording, the participants were given one minute to rest to avoid vocal fatigue. Participants identifying as tenors started on F^4 in the key of B$^{\flat}$ major, and participants identifying as baritones or basses started on E$^{\flat}$ in the key of A$^{\flat}$ major. After singing the Star Spangled Banner, the participant completed a perceived phonatory effort (PPE) rating form (see Appendix K for PPE rating form). The PPE form consisted of a 100 millimeter line, with the left end representing no voicing effort and the right end representing maximum voicing effort. The participants placed a mark on the line that represents the level of effort used. The distance in millimeters from the left end to the mark indicated the participant's effort.

Condition 1 was a baseline measure of the voice with no warm-up. The participant was asked to sing the Star Spangled Banner and to hold out the selected vowels of the last line for three trials with a one minute rest between each recording. After this task, the participant rated the effort they felt while singing on the PPE rating form.

Data from Condition 2 was collected following a classical warm-up based on literature of Western singing (Miller, 1986; Titze, 2001). Participants were shown an instructional video to follow along for a classical warm-up based on literature of western singing. An experienced music professor with special knowledge of vocal pedagogy directed the video-recorded warm-ups. Each voice part was instructed in a separate video. Five types of tasks, all typical to a normal vocal studio warm-up, were performed in Condition 2. These tasks included (1) stretching, (2) resonance balancing, (3) register unification exercises, (4) messas di voce, and (5) agility/flexibility exercises (see Appendix I for specific directions given for these tasks). In total, the classical warm-up lasted approximately 9 minutes with 6 minutes' time of actual singing.

Data from Condition 3 was collected following a semi-occluded vocal tract warm-up. An instructional video (NCVS, 2009) guided participants on how to phonate into a plastic drinking straw of 5 mm diameter for a semi-occluded vocal tract warm-up (see Appendix J for specific directions to be given). The semi-occluded vocal tract warm-up consisted of singing the entire Star Spangled Banner through the straw repeatedly for 6 minutes. Assistance or clarification was not provided during warm-ups unless requested, and the assistance was limited to clarifying directions in the videos leading the traditional and semi-occluded warm-ups.

Under each condition, a recording was made of the participant singing the Star Spangled Banner. A stimulus pitch was provided with a pitch pipe (The Master Key, W. M. Kratt Co.). The participant wore a headset microphone (Isomax E6OP5T, Countryman Associates, Inc.) that was coupled with a Marantz PMD 671 recorder with a 44 kHz sampling rate and a 32-bit quantization rate.

Analysis

Acoustic analysis was performed on speech and singing samples recorded at each data collection session using TF-32 time-frequency analysis software program (Milenkovich, 2005). From the sung vowels of the singing recordings, the amplitude and frequency of the first four resonance peaks, singing power ratio (SPR), and fundamental frequency (F_0) was determined. A linear predictive code (LPC) yielded the frequency and amplitude of each resonance. These data were recorded on a form along with hydration level, room temperature, and room humidity (see Appendix L for recording form).

Calculating SPR required manually measuring the highest resonance peak between 2 and 4 kHz and the highest resonance peak between 0 and 2 kHz and dividing the low frequency peak amplitude by the high frequency peak amplitude. For this reason the amplitudes (in dB) of the first four resonance peaks were recorded. A low SPR would indicate greater amplitude in the high frequency formants, indicating possible presence of a singer’s formant. A high SPR would indicate less amplitude in the higher frequency formants and no singer's formant. Fundamental frequency (F_0) was measured from a single cycle at approximately the same time mark where the spectrum was taken. A measure of total F_0 was also recorded to ensure that all participants in each voice classification had sung roughly the same frequencies. From SPR, both the question "Does vocal warm-up significantly alter the singing power ratio (SPR) of the singing voice?" and the question "Is classical vocal-warm up or semi-occluded vocal tract exercise more effective at increasing the SPR of the singing voice?" could be answered.

Once each participant's first four resonance amplitudes, SPR, and average F_0 were calculated and recorded, the data were analyzed using a repeated measures analysis of variance to determine whether the measurements of SPR, PPE, and measures of resonance amplitude and frequency varied. Three different conditions were analyzed: no warm-up, classical warm-up, and semi-occluded vocal tract warm-up. The factors analyzed were SPR, vowel, and PPE. Resonance amplitude was measured from the first four resonant peaks to determine the frequency location of the peaks and to calculate SPR. Based on past findings, it was expected that SPR would increase following a semi-occluded vocal tract warm-up.

To establish reliability 23% (i.e., 3 participants) of the sample was selected for reanalysis. To establish interrater reliability another person involved with the study also analyzed the data. The first and second raters measurements of SPR were strongly correlated ($r_{inter} = .964$) and yielded a mean absolute difference of .005 SPR.

IV. RESULTS

Data were analyzed using IBM SPSS statistics 21 software. Raw data were examined visually for skewness and kurtosis. Kolmogrov-Smirnov test of normality confirmed that all data were normally distributed. To answer the question of whether there is a significant difference in SPR outcome when analyzing the vowels /i, o, ʌ, e/ across three conditions, data were analyzed with repeated-measures analysis of variance (RM-ANOVA). The dependent variable was singing power ratio (SPR). The two within-subjects factors were vowel (i, o, ʌ, e) and warm-up condition (baseline, traditional, and semi-occluded). Table 2 lists the complete RM-ANOVA results. The main effects for vowel , condition and the vowel condition interaction were tested using the multivariate criterion of Wilks's lambda (Λ). SPR differed significantly across vowel, Λ = .153, F(3, 10) = 18.391, p = .000, η^2 = .847. Pairwise comparisons for vowel revealed the following significant differences: the SPR values for the /i/ vowel were significantly lower than the SPR values for the /o/, /ʌ/, and /e/ vowels; the SPR values for the vowel /e/ were found to be significantly lower than the /o/ and /ʌ/ vowels, and the SPR values for the vowel /ʌ/ were significantly lower than the /o/ vowel. Table 3 lists the results from the complete pairwise comparison analysis. The summary statistics in Table 4 indicate the lower SPR value for the /i/ vowel when compared to the other vowels. The SPR values in Table 4 are mean values across conditions. The mean for the /i/ vowel (M = 1.060) was slightly lower than that for the /e/ vowel (M = 1.221), /ʌ/ vowel (M = 1.363) and /o/ vowel (M = 1.475).

No significant difference was detected for warm-up condition, $\Lambda = .996$, $F(2, 11) = .023$, $p = .977$, $\eta^2 = .004$. A statistically significant interaction was also not observed between vowel and warm-up condition, $\Lambda = .683$, $F(6, 7) = .543$, $p = .763$, $\eta^2 = .317$. Table 4 lists the summary statistics for SPR outcome data across condition.

Table 2

Repeated measures within-subjects analysis of variance results for the effect of vowel and warm-up condition on singing power ratio

		SPR	
Source	df	F	P
Vowel	3	18.391	.000
Error	10		
Condition	2	.023	.977
Error	11		
Vowel x Condition	6	.543	.763
Error	7		

Table 3

p *values for pairwise comparisons between mean SPR values of each vowel*

	Vowel /i/	Vowel /o/	Vowel /ʌ/	Vowel /e/
Vowel /i/				
Vowel /o/	.000*			
Vowel /ʌ/	.000*	.057		
Vowel /e/	.005*	.002*	.002*	

* indicates significance

Table 4

Summary Statistics

		SPR		
Vowel	Condition	M	SD	N
i	Baseline	1.093	.215	13
i	Traditional	1.026	.209	13
i	Semi-occluded	1.060	.186	13
e	Baseline	1.202	.138	13
e	Traditional	1.222	.138	13
e	Semi-occluded	1.239	.173	13
o	Baseline	1.470	.318	13
o	Traditional	1.498	.218	13
o	Semi-occluded	1.458	.305	13
ʌ	Baseline	1.354	.200	13
ʌ	Traditional	1.385	.265	13
ʌ	Semi-occluded	1.351	.233	13

To answer the question of whether there is a significant difference in perceived phonatory effort (PPE) across three warm-up conditions, data were analyzed with a one-way within subjects analysis of variance (RM-ANOVA). The dependent variable was PPE and the one within-subjects factor was warm-up condition (baseline, traditional, and semi-occluded). Table 5 lists the complete RM-ANOVA results. PPE did not differ significantly across the warm-up conditions, $\Lambda = .753$, $F(2, 11) = 1.808$, $p = .209$, $\eta^2 = .247$, indicating that warm-up did not significantly influence perceived phonatory effort.

Table 5

One way within-subjects analysis of variance results for the effect of warm-up condition on perceived phonatory effort

		PPE	
Source	df	F	P
Condition	2	1.808	.209
Error	11		

DISCUSSION

The purpose of this study was to measure the effect of traditional vocal warm-up exercises versus semi-occluded vocal tract exercises and no warm-up exercise on the acoustic parameters of the voice. Three questions were asked in this study. The first question addressed in this study asked whether singing power ratio (SPR) would differ across warm-up condition. Our hypothesis was that SPR would vary significantly across warm-up condition and would be lowest for the semi-occluded vocal tract condition, since previous findings have indicated that semi-occluded vocal tract exercises have resulted in greater amplitude of high frequency formants to low frequency formants (e.g., Laukkanen, Horacek, & Havlik, 2012). Statistical analysis found that in the present study SPR did not differ across warm-up condition. These results indicate that the warm-up conditions did not cause significant changes in SPR. In other words, warm-up condition did not significantly affect the amplitude of high formants relative to low formants. According to Stevens and House (1955), vocal tract shape can be inferred from formant configuration. Laukkanen et al. (2012) found that the ratio of size of the pharynx inlet relative to the epilarynx (entrance to the larynx) outlet area is important in the production of the singer’s formant. Production of the singer’s formant requires narrowing of the epilarynx tube and a decrease in the epilarynx tube opening to less than 1/6 of the cross-sectional area in the pharynx (Sundberg, 1974). The results of the current study suggest that the configuration of the epilarynx relative to the pharynx was not significantly altered under either warm-up condition. A limitation in this assumption is that previous findings suggest that production of the singer’s formant is a skill (Omori et al., 1996; Brown, Rothman, & Sapienza, 2000), meaning that it would not necessarily be a result of warm-up. That said, other studies have indicated that the singer’s formant is not a skill acquired with experience (Lundy, Roy, Casiano, Xue, & Evans, 2000; Mendes et al., 2003; Watts, Barnes-Burroughs, Estis, & Blanton, 2006).

A second question investigated in this study was whether SPR would differ significantly across vowels. Our hypothesis was that SPR would be significantly lower for vowel sounds /i/ and /e/. SPR did differ significantly across vowel, with SPR being significantly lowest on /i/, followed by /e/, /ʌ/, and /o/. The present study found that SPR, a value associated with the singer’s formant, was significantly lower for /i/ and /e/. This is in agreement with the findings of Morris and Weiss (1997) regarding the singer’s formant. In their study, 32 male and female singers were recorded singing five cardinal vowels (/i/, /e/, /ɑ/, /o/, and /u/) at low, mid, and high pitches. The investigators stated that the formants in general were “strongest” for /i/ and /e/ and that the singer’s formant was most often produced on /i/ and /e/ (at rates of 67.5% and 66.25%, respectively). The present study involved participants with varying singing styles and singing expertise (see Table 1 for singer demographics), with some participants being highly trained singers (i.e., vocal music majors) and some with no classical training whatsoever. Morris and Weiss describe their participants as one group of “advanced” singers that “professed having a singer’s formant” compared with a group of “beginning singers, all of whom had considerable choral practice but no active instruction on producing a singer’s formant” (p. 21). Thus, the results are comparable with our study.

The third question asked in the present study was whether effort was affected by warm-up. Perceived phonatory effort (PPE) was obtained to measure how much physical effort the participants felt when singing The Star Spangled Banner under each warm-up condition. PPE was expected to be higher under the no warm-up condition. Instead, PPE was found to not differ significantly across any of the warm-up conditions. These results could be interpreted to mean that effort while singing was not affected by warm-up condition; however, previous research has found PPE to be variable. A study by Milbrath and Solomon (2003), profiled in the literature review, found that PPE did not significantly change with warm-up, nor was it significantly higher after the loud reading activity. The reliability of an analog line bisection task to measure PPE has been questioned. While some studies have elicited a reliable measure through this method (e.g., Solomon, Glaze, Arnold, & van Mersbergen, 2003), others have not (e.g., Milbrath & Solomon, 2003). Due to the variable nature of PPE in previous research and in the present study and the lack of validation of the data collection method, implications based on PPE ratings should be guarded.

Based on the results of this study, vocal warm-up may not have a significant effect on the acoustics of the voice. One goal of singers in performing vocal warm-up is to improve “voice quality,” a set of perceptual descriptions with acoustic correlates (Ekholm, Papagiannis, & Chagnon, 1998). The present study found that acoustics were not significantly altered by a warm-up. Another supposed purpose of vocal warm-up is to warm the vocal fold muscles in the same fashion as an athletic warm-up for the body (McHenry, Johnson, & Foshea, 2009). The limited evidence available indicates that a significant physiologic change in the vocal folds is unlikely (Elliot, Sundberg, &

Gramming, 1995; Motel, Fisher, & Leydon, 2003). In fact, vocal warm-up has been found to increase PTP (Motel et al., 2003), which indicates that warm-up may fatigue the vocal folds. Thus, the role of warm-up exercises in preparation for singing remains in question.

Previous studies have investigated the possibility of semi-occluded straw exercises contributing to vocal tract tuning and improved acoustic output (Guzman et al., 2013; Laukkanen et al., 2012; Vampola, Laukkanen, Horacek, & Svek, 2011). These single-subject studies have shown a change in placement of vocal tract structures that resulted in significant change to formant structure. Length and width measurements were taken to ascertain the area of the vocal tract during a neutral voicing task (i.e., sustained /ɑ/) and during or after a semi-occluded exercise with a straw. In contrast, the present study did not find significant change to formant structure following semi-occluded straw exercises. Our study differed from these previous studies by using participants with varying voice training backgrounds, where the previous investigators used highly trained and experienced singers. In theory, a highly experienced singer would have a lot of practice tuning his or her vocal tract. In addition, the previous protocols involved the use of magnetic resonance imaging (MRI) to measure position changes in vocal tract structures, whereas the current study considered only the resulting acoustic changes that would accompany any vocal tract changes. Further, these studies were conducted in one visit, whereas our study required participants to return twice after the first visit. Lastly, the protocols of the previous studies measured vocal tract changes directly after a short phonation time into the straw. In the present study, participants phonated into a straw for 6 minutes, and the measured segments were taken during a subsequent singing task. Thus the question is raised: are vocal tract changes resulting from semi-occluded exercises with a straw maintained reliably for subsequent phonatory tasks? Long-term effects of semi-occluded exercises with a straw have yet to be studied (Guzman, et al., 2013).

Some observations were made regarding the performance of the participants. Most participants did not perform the messa di voce during Part 4 of the traditional warm-up exercises (see Appendix I for list of traditional warm-up exercises). A true messa di voce involves a gradual increase in loudness followed by a gradual decrease in loudness while producing the same pitch. Only two participants who were classically trained singers performed a true messa di voce. The remaining participants maintained the pitch modeled with no variation in loudness. Perhaps greater direction should have been given to insure that all participants performed the exercise similarly. An interesting observation regarding statistical results was that level of vocal training and singing style did not appear to influence the results. While many of the participants were classically trained singers, some sang as hobbyists in church choirs or local bands. Since the singer's formant is thought to be a product of training (Millhouse & Clermont, 2006; Morris & Weiss, 1997, Sundberg, 1998; Sundberg, 2001) and not all participants were trained singers, it was possible that the results of the present study could have been skewed. Although training and singing genre varied among the participants, no participant was found to be an outlier. A reasonable hypothesis would have been that the non-classically trained singers would have a higher SPR; however, that was not the result. Perhaps the present tasks lacked the specificity to elicit the singer's formant properly, or perhaps the present measurements were not sensitive enough to detect the singer's formant.

Strengths and Limitations

Some strengths of the study should be noted. First, despite a relatively small sample size (n = 13) statistical power was maintained. Further, a repeated measures design was used, allowing each participant to serve as his own control. Another strength in this study is that we were able to apply traditional warm-up exercises and semi-occluded warm-up exercises separately from each other, thus a first attempt to dismantle the influence of the different exercises. Many singing teachers integrate semi-occluded vocal tract exercises with traditional warm-up exercises, so the two are rarely opposed to each other in practice. It may be hard to discern the influence of a particular approach on outcome or what approach works best for a singer if too many approaches are used at once, but observing the results of each type of warm-up exercise separately allowed us to see the results of each individually.

The present study also had some limitations. One such limitation was that most of the participants were younger men. In addition, the warm-ups were short in duration, including 6 minutes of total singing time each (approximately 10 minutes including instruction). That said, some literature advises against warm-ups exceeding 20 to 30 minutes to avoid fatigue (e.g., Miller, 1990), and singing teachers have reported that their ideal vocal warm-up period lasts 5 to 10 minutes (Gish, Kunduk, Sims, & McWhorter, 2012). The question of duration is complicated, as bioenergetics would indicate that a warm-up activity requiring quick contractions instead of steady slow contractions may fatigue fast-twitch muscles. Fast twitch Type II fibers are a significant component of the laryngeal muscle make-up (Hoh, 2005; Teig, Dahl, & Thorkelsen, 1978), so this is an important consideration. Muscle fatigue in vocal warm-up is considered something to be avoided (McHenry et al., 2009; Milbrath & Solomon, 2003), but in warm-up for limb skeletal muscle, fatigue is considered essential for endurance training (McArdle et al., 1996). From this standpoint, the vocal warm-up tasks of the current study may have not been of sufficient length to develop fatigue or of sufficient frequency to train skill. Third, a video-led warm-up was a contrived set-up. A true vocal warm-up would be more nuanced based on individual singer needs and would involve more teacher interaction in the context of a lesson. Finally, measuring SPR may be a limitation due to its lack of specificity. Though SPR allowed for standardized measurement of acoustics, it is not a validated measure and did not indicate whether the singer's formant was present or absent, simply whether formant frequencies greater than 2kHz had more intensity relative to formant frequencies below 2kHz.

Future Research Directions

Future studies may focus on the lasting effects of vocal warm-up on acoustic aspects of the voice by measuring beyond the moments immediately after warm-up. This may be completed by using a similar protocol to the present study but waiting some time before making a recording for acoustic measurement. Instead of measuring the singer's formant via SPR, future studies may isolate the singer's formant, verifying its presence or absence.

Summary

In conclusion, the current study did not find statistically significant changes in SPR across warm-up conditions. This was in opposition to the hypothesis that semi-occluded warm-up would cause a decrease in SPR. SPR was statistically significant across vowels, with /i/ having the most significant SPR. This agrees with previous findings and supports the hypothesis regarding vowels and SPR. PPE did not differ significantly across warm-up condition, despite the expectation that traditional or semi-occluded warm-up would cause a decrease in PPE. Future studies should continue to investigate how warm-up affects the voice and how lasting the effects of semi-occluded exercises on the vocal tract are.

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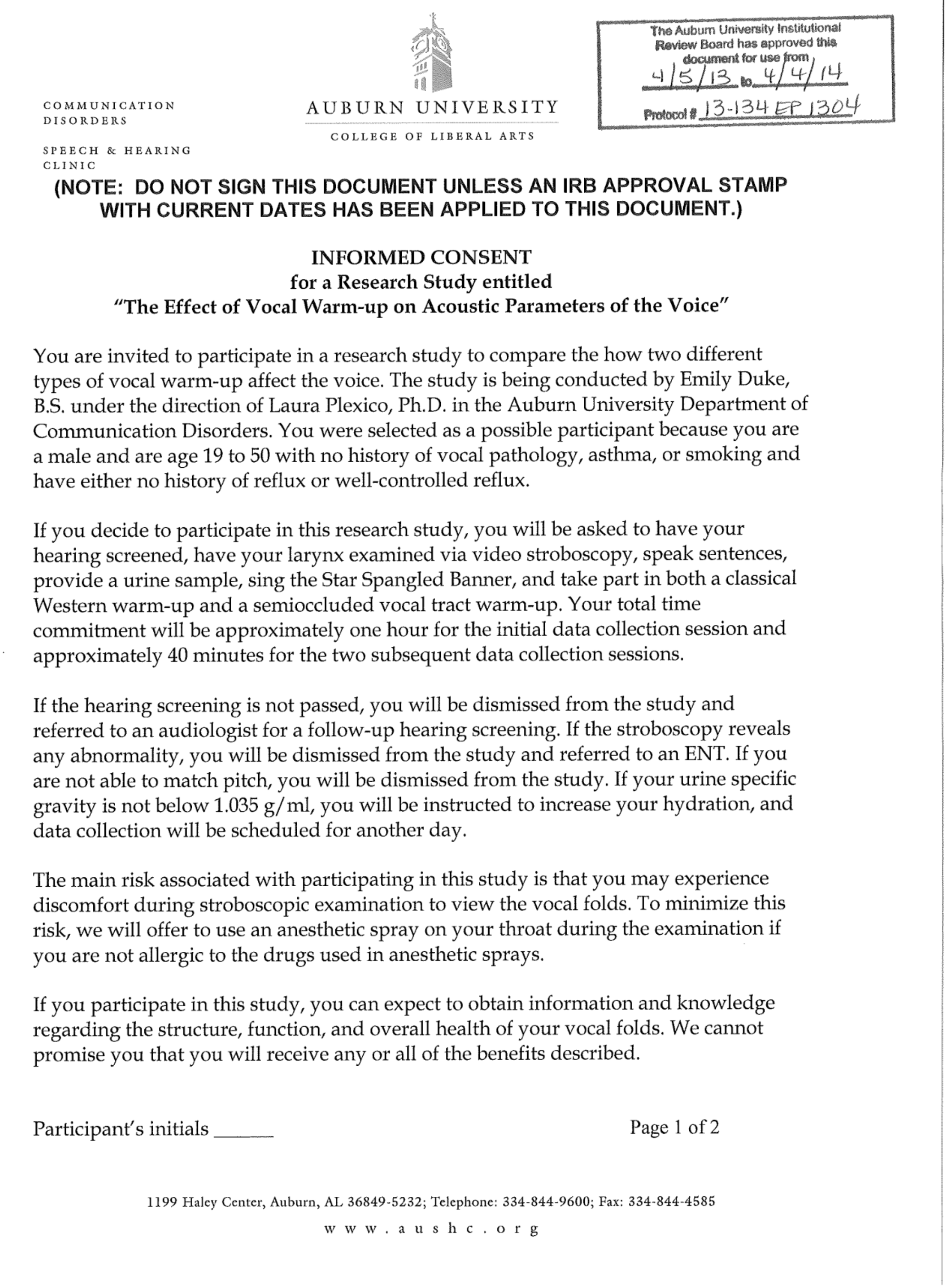
APPENDICES

APPENDIX A



COMMUNICATION DISORDERS

SPEECH & HEARING CLINIC

AUBURN UNIVERSITY

COLLEGE OF LIBERAL ARTS

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Protocol # 13-134 EP 1304

(NOTE: DO NOT SIGN THIS DOCUMENT UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

INFORMED CONSENT
for a Research Study entitled
"The Effect of Vocal Warm-up on Acoustic Parameters of the Voice"

You are invited to participate in a research study to compare the how two different types of vocal warm-up affect the voice. The study is being conducted by Emily Duke, B.S. under the direction of Laura Plexico, Ph.D. in the Auburn University Department of Communication Disorders. You were selected as a possible participant because you are a male and are age 19 to 50 with no history of vocal pathology, asthma, or smoking and have either no history of reflux or well-controlled reflux.

If you decide to participate in this research study, you will be asked to have your hearing screened, have your larynx examined via video stroboscopy, speak sentences, provide a urine sample, sing the Star Spangled Banner, and take part in both a classical Western warm-up and a semioccluded vocal tract warm-up. Your total time commitment will be approximately one hour for the initial data collection session and approximately 40 minutes for the two subsequent data collection sessions.

If the hearing screening is not passed, you will be dismissed from the study and referred to an audiologist for a follow-up hearing screening. If the stroboscopy reveals any abnormality, you will be dismissed from the study and referred to an ENT. If you are not able to match pitch, you will be dismissed from the study. If your urine specific gravity is not below 1.035 g/ml, you will be instructed to increase your hydration, and data collection will be scheduled for another day.

The main risk associated with participating in this study is that you may experience discomfort during stroboscopic examination to view the vocal folds. To minimize this risk, we will offer to use an anesthetic spray on your throat during the examination if you are not allergic to the drugs used in anesthetic sprays.

If you participate in this study, you can expect to obtain information and knowledge regarding the structure, function, and overall health of your vocal folds. We cannot promise you that you will receive any or all of the benefits described.

Participant's initials ______ Page 1 of 2

1199 Haley Center, Auburn, AL 36849-5232; Telephone: 334-844-9600; Fax: 334-844-4585

www.aushc.org

If you decide to participate, you will not be compensated monetarily or otherwise, nor will you be required to provide payment of any kind.

If you change your mind about participating, you can withdraw at any time during the study. Your participation is completely voluntary. If you choose to withdraw, your data can be withdrawn as long as it is identifiable. Your decision about whether or not to participate or to stop participating will not jeopardize your future relations with Auburn University, the Department of Communication Disorders, or Department of Music.

Your privacy will be protected. Any personal information obtained in connection with this study will remain confidential, and data will be recorded anonymously. Information obtained through your participation will be used to fulfill a requirement of a Master of Science degree in Communication Disorders and may be published in a professional journal.

If you have questions about this study, please ask them now or contact Emily Duke at eed0010@auburn.edu or Laura Plexico at lwp0002@auburn.edu. A copy of this document will be given to you to keep.

If you have questions about your rights as a research participant, you may contact the Auburn University Office of Human Subjects Research or the Institutional Review Board by phone (334)-844-5966 or e-mail at hsubjec@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO PARTICIPATE.

______________________________	______________________________
Participant's signature Date	Investigator obtaining consent Date
______________________________	______________________________
Printed Name	Printed Name

____
Co-Investigator Date

____
Printed Name

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APPENDIX B

Vocal Warm-up Research Study
Be part of an important voice research study!

Are you between 19 and 50 years of age?

Do you want to learn about how vocal warm-up affects your voice?

If you answered ***YES*** to these questions, you may be eligible to participate in a vocal warm-up research study.

The purpose of this research study is to determine the effects of classical warm-up and semioccluded vocal tract warm-up on the acoustic parameters of the voice. Benefits include a stroboscopic examination of the vocal folds yielding information on the structure, function, and overall health of your vocal folds and parking vouchers for the clinic parking lot. No medications will be given.

The total time commitment for this study will be approximately one hour for the initial data collection session and approximately 40 minutes for the two subsequent data collection sessions.

Adults between 19 and 50 years of age are eligible.

Please do not participate if you have a history of vocal pathology, asthma, are a smoker, or have reflux that is not well-controlled.

This study is being conducted by Emily Duke in the Department of Communication Disorders at Auburn University.

Please contact Emily Duke at **eed0010@auburn.edu** or **(228) 327-7998** for more information.

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APPENDIX C

My name is Emily Duke, a graduate student from the Department of Communication Disorders at Auburn University. I would like to invite you to participate in my research study to measure the effects of both classical and semi-occluded vocal tract warm-up on the acoustic quality of the voice. You may participate if you are a male between the ages of 19 and 50. Please do not participate if you have a history of vocal pathology, asthma, are a smoker, or have reflux that is not well-controlled.

As a participant, you will be asked to have your hearing screened, have your larynx examined via video stroboscopy, speak sentences, provide a urine sample, sing the Star Spangled Banner, and take part in both a classical Western warm-up and a semi-occluded vocal tract warm-up. Your total time commitment will be approximately one hour for the initial data collection session and approximately 40 minutes for the two subsequent data collection sessions.

The only foreseeable risk is that the stroboscopic exam may cause slight discomfort. Unfortunately, no compensation can be offered, but you will receive a free examination of your vocal folds.

If you would like to participate in this research study, contact Emily Duke at eed0010@auburn.edu or (228) 327-7998.

Do you have any questions now? If you have questions later, please contact me at eed0010@auburn.edu or (228) 327-7998 or you may contact my advisor, Dr. Plexico, at lwp0002@auburn.edu.

APPENDIX D

Participant #:

Pre-Screening Document

Confidentiality Note: All information provided by you is for the sole use of this research study and will not be shared with anyone but those directly involved with the research. Furthermore, answers provided will in no way affect your standing with the University or any other organization.

Please read the following exclusionary criteria to yourself. An answer of yes to any of the following criteria will disqualify you from participation. You do not need to indicate which one of the criteria below apply to you—just whether or not you qualify to participate. If you do not understand the question, please ask the investigator for clarification.

1. Are you under the age 19 or over the age of 50?
2. Do you have any history of voice problems?
3. Do you presently smoke or have you been a regular smoker?
4. Have you ever had a heart murmur, rheumatic fever or respiratory problems?
5. Do you have allergies?
6. Have you ever been told that you have a fast resting heart rate?
7. Have you ever been told by your doctor or nurse that your blood pressure is too high?
8. Have you been told that you have a kidney disorder?
9. Have you been told that you have diabetes or that your blood sugar is too high?
10. Have you had any surgeries that have involved the head, throat, chest or gut or required placement of an intubation tube for general anesthesia in the past 6 months?
11. Do you have any reason to believe that your participation in this investigative effort may put your health or well-being at risk?
12. Are you taking any prescription medicine?

APPENDIX E

Demographic Questionnaire

Participant #:

Age:

Voice Classification (circle one): Bass Baritone Tenor

How long have you been singing?____

What music style do you typically sing (e.g., classical, opera, jazz, pop)?

____

In what setting do you typically sing (e.g., choral singing, solo performance, musical theater)?

____

Do you sing at least once a week? Yes____ No_____

Please list any medications you are currently taking:

____

APPENDIX F

Hearing Screening

Script: I am going to have you sit with your back turned to me. I will place earphones on your ears. When you hear something, please raise your right hand.

	500 Hz	1000 Hz	2000 Hz	4000 Hz
R				
L				

All frequencies were presented at 20 dB.

APPENDIX G

Speaking Voice Screening Tasks

Script: I'm going to have you read some sentences so that the characteristics of your speaking voice can be established. I'll tell you when to go, and you'll start with the first one. After each sentence, you'll take a 30 second rest, and then I'll give you the signal to read the next sentence.

1. The blue spot is on the key again.
2. How hard did he hit him.
3. We were away a year ago.
4. We eat eggs every Easter.
5. My mama makes lemon jam.
6. Peter will keep at the peak.

APPENDIX H

Data Recording Form

Participant #:
Visit #:
Condition:

Hydration level: (g/ml)
Room condition: °F/ %RH

Measurement		Measurement	
Digital imaging of Larynx		Fundamental Frequency (F_0)	
Perceived Phonatory Effort (PPE)			

Resonance Peaks

	Frequency	Amplitude
P1		
P2		
P3		
P4		
Singing Power Ratio (SPR)		

APPENDIX I

Classical Warm-up

The participants will view instructional video segments for each exercise and will be guided with stimulus pitches from a keyboard.

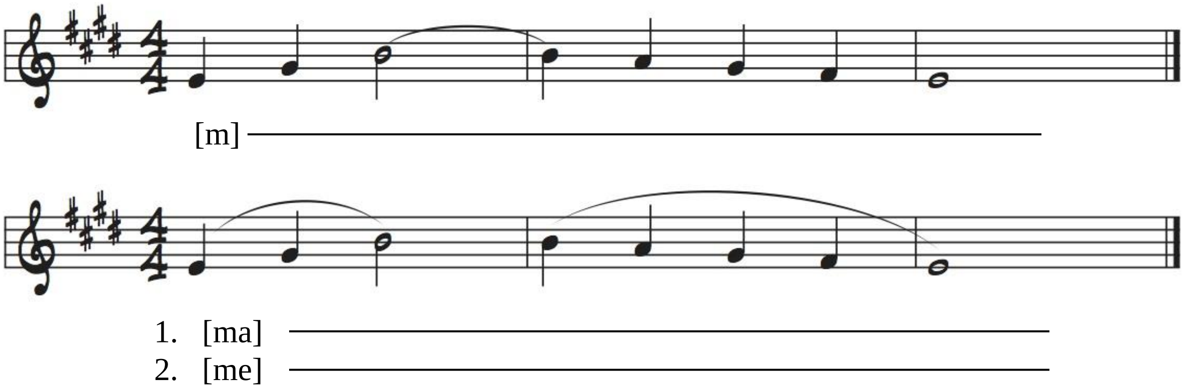
1. Stretching:
   a. Lift your arms above head and stretch them toward the ceiling. Now, let the arms drop to your sides without collapsing your rib cage.

Music for the following exercises can be found on the proceeding pages:

2. Resonance balancing
   a. Exercises 4.2 & 4.3 (first /mɑ/, then /me/) from Miller (1986)
3. Register unification
   a. Exercises 9.9, 9.10, & 9.15 from Miller (1986)
4. Messa di voce (Titze, 2001)
   a. 8 beats each on /a/ at ascending pitches in mid-range
5. Agility/flexibility
   a. Staccato arpeggios (Titze, 2001) from mid-range to lower range then mid-range to high range

Bass/Baritone:

2.



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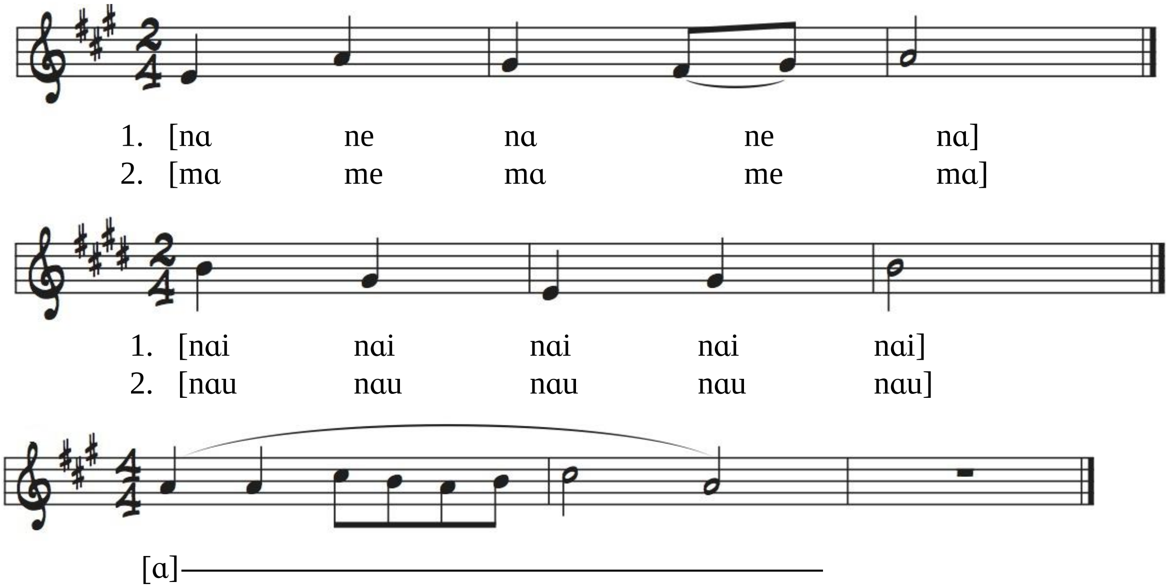

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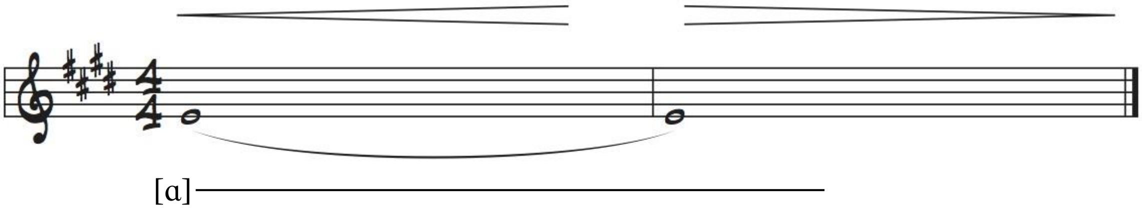

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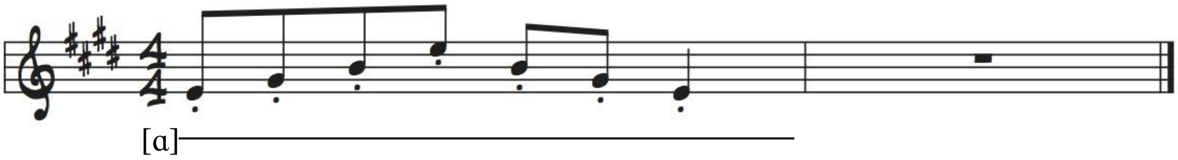
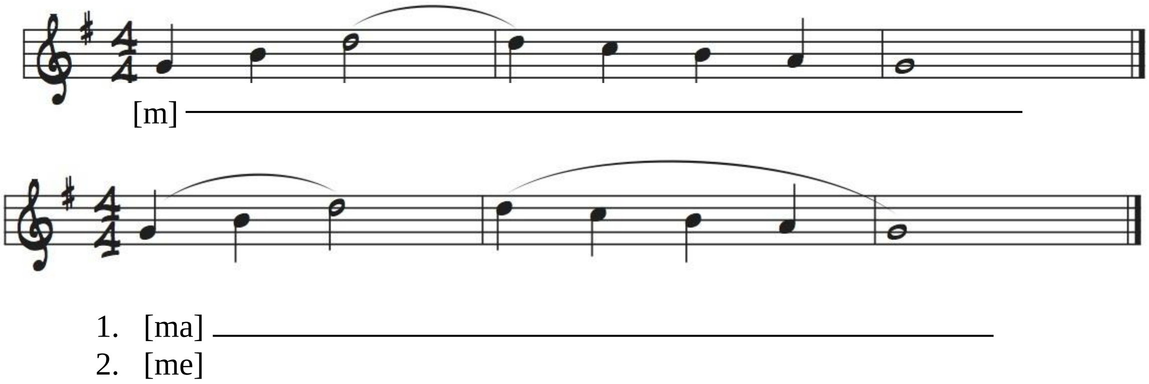
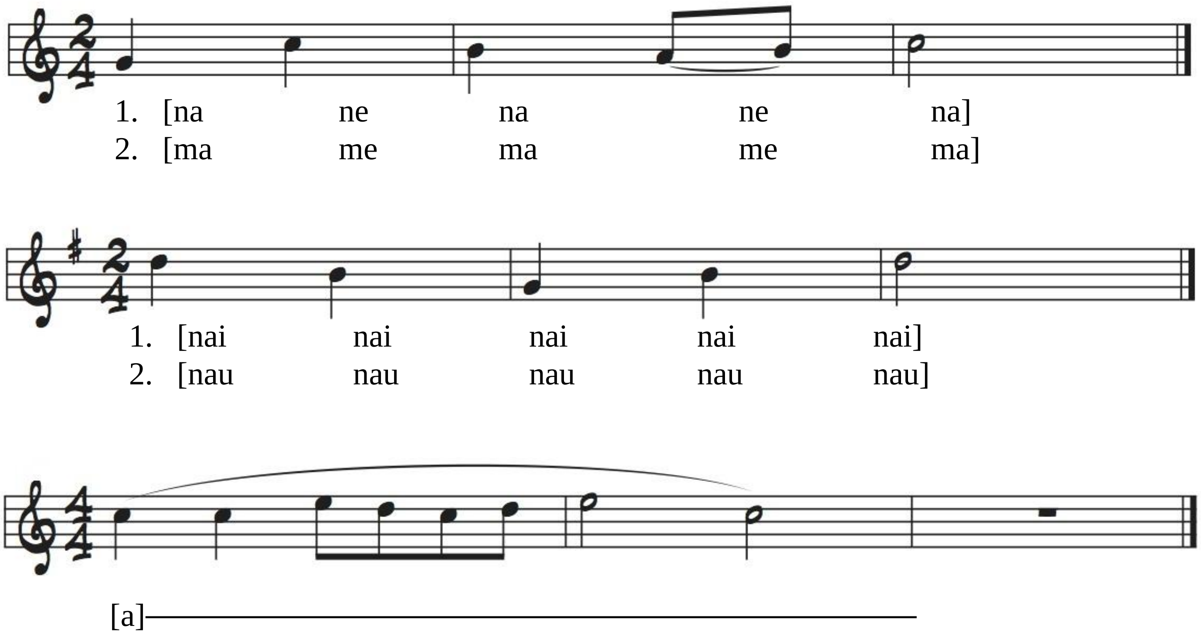


Tenors:

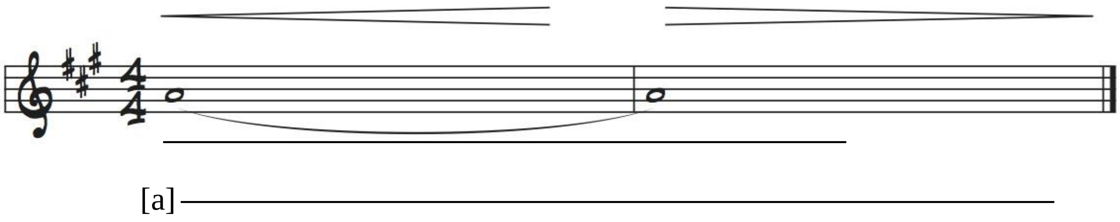
2.


[m]
1. [ma]
2. [me]

3.


1. [na ne na ne na]
2. [ma me ma me ma]
1. [nai nai nai nai nai]
2. [nau nau nau nau nau]
[a]

4.


[a]

5.


[a]

APPENDIX J

Semi-occluded Vocal Tract Warm-up

Participants will watch a video tutorial on how to phonate through a straw (http://www.youtube.com/watch?v=0xYDvwvmBIM).

Participants will then be instructed to sing the Star Spangled Banner through a straw for 10 minutes, repeating the song as needed to fill the 10 minutes.

APPENDIX K

Perceived Phonatory Effort (PPE) Rating Form

Participant #:

Date:

____

No voicing effort	Maximum voicing effort