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# Thyroarytenoid and cricothyroid muscular activity in vocal register control

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THYROARYTENOID AND CRICOTHYROID MUSCULAR ACTIVITY

IN VOCAL REGISTER CONTROL

by

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

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To my parents, who have been nothing but dedicated to me all my life!

The thyroarytenoid and cricothyroid muscles are true synergists.

Faaborg-Andersen, 1957, p. 56

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## ABSTRACT

Register and pitch are two distinct perceptual entities of the human voice. Without clear evidence for the use of the terminology, sources have begun to refer to lighter, or “falsetto”, register as being “cricothyroid dominant” and heavier, or “chest”, register as being “thyroarytenoid dominant” (Bateman, 2002; McCoy, 2004; Henrich, 2006; Spivey, 2008; Edwin, 2008; Phillips, Williams, & Edwin, 2012). The same intrinsic laryngeal musculature (i.e. the cricothyroid, CT, and thyroarytenoid, TA, muscles) play a role in the control of both register and pitch. Higher-pitched phonation, typically used to produce falsetto register, is mediated primarily by the cricothyroid (CT) muscle. The thyroarytenoid (TA) muscle plays a larger role in controlling lower-pitched voicing, the pitch range in which chest register tends to be used (Titze, 1989b; Shipp and McGlone, 1971). Despite their frequent co-occurrence, high and low pitched phonation are not controlled in the same way as light and heavy register productions.

The purpose of this study was to examine the ratio of CT and TA muscular activity in the control of chest and falsetto registers. Data were collected from untrained voice users: four females and one male. Hooked-wire electrodes were inserted into both the CT and TA muscles of each participant in order to collect electromyographic (EMG) data during glissando from low to high pitch on the vowel /i/ twice per subject, and tasks eliciting maximal activation of CT and TA muscles. A trained singing instructor with 17 years of experience determined and recorded the occurrence of register transition during each glissando. CT and TA EMG activity data from the glissando were normalized relative to maximum elicited CT and TA activity, and were then retrospectively analyzed. The CT:TA ratio was a comparison of maximal CT activation and maximal TA activation.

CT muscular dominance was defined as a ratio of CT:TA activity greater than 1 (i.e. CT:TA greater than 1). TA dominance was defined as a ratio of CT:TA activity less than 1 (i.e. CT:TA less than 1).

During glissando, all subjects experienced register transition from chest to falsetto register. In all subjects, the majority of chest register, and all of falsetto register, was produced with CT muscular dominance. Only the 3-4 lowest semitones, on average, in chest register were TA dominant. The transition from chest to falsetto register consistently *did occur* when the CT muscle was dominant, however, register transition did not occur as CT muscle activity began to dominate TA muscle activity. Results of the study showed that CT muscular dominance did not define falsetto register, nor was chest register defined by the TA muscular dominance.

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# CHAPTER I
# INTRODUCTION

Vocal registers are perceptual elements of the human voice that reflect laryngeal physiology. For this reason, an analysis of vocal registers is pivotal to understanding how speakers and singers control voicing. Numerous studies have been performed to determine what it is that acoustically, perceptually, and physiologically distinguish vocal registers from each other. Electromyographic (EMG) studies have been conducted on several intrinsic laryngeal muscles (e.g. thyroarytenoid (TA) and cricothyroid (CT) muscles) to determine what their role may be in register control. The role these intrinsic laryngeal muscles play in register control is not fully understood. In an attempt to describe the complex physical mechanism underlying vocal register transitions in simplified terms, the labels “TA-dominant voice production” (TDP) and “CT-dominant voice production” (CDP) have been in increasingly popular use for at least ten years as synonyms for chest and falsetto register, respectively (Bateman, 2002; McCoy, 2004; Henrich, 2006; Spivey, 2008; Edwin, 2008; Phillips, Williams, & Edwin, 2012).

Registers are defined as a series of vocal tones that are perceived to be of similar timbre and produced in a similar physiologic manner (Garcia, 1841). The most well-described registers in singing are chest/modal register, and falsetto/head register. Chest and head registers were originally named for the physical location in the body where the singers felt vibration when producing them (Sundberg, 1983; Scotto Di Carlo, 1994; O’Connor, 2011). In chest register, singers may experience a distinct sensation of resonance and vibration in their chest, particularly in the sternum or breastbone area. In head register, singers may experience a sensation of resonance in the head. A register transition is what occurs as a vocalist changes from one vocal register to another, and occurs during what vocal pedagogues have named the "zona di passaggio" or "the passage", which is when the vocalist will transition from chest to falsetto register, or falsetto to chest register.  The passaggio typically occurs during the same narrow range of pitches for a given vocalist during glissando from low to high or high to low.

In terms of register production, there are many theories about how register is controlled.  Current theories of register control suggest that singers shift from chest to falsetto register by shifting longitudinal tension from the TA muscle to the vocal ligament, altering the proximity of the vocal processes of the arytenoid cartilages (Van den Berg, 1963), by altering the vocal fold abduction and amplitude of vibration (Titze, 1988a), and/or by changing the amount of longitudinal and horizontal collision of the vocal folds (Vilkman, 1995).

EMG studies addressing register control have explored two major experimental conditions: register transition with constant, or nearly-constant pitch, and register transition with pitch change.  (Sawashima, Gay, & Harris, 1969; Shipp and McGlone, 1971; Gay, Hirose, Strome, & Sawashima, 1972; Baer, Gay, & Niimi, 1975; Kochis-Jennings, Finnegan, Hoffman, & Jaiswal, 2012). The transition from chest to falsetto register during sustained pitch phonation involves a reduction in EMG activity of both the TA and CT muscles (Sawashima et al., 1969; Gay et al., 1972; Baer et al., 1975). During register transition with pitch change, from lower to higher pitch, the CT and TA muscles both increase their activity (Sawashima et al., 1969; Shipp & McGlone, 1971; Gay et al., 1972; Baer et al., 1975) or maintain higher levels (Kochis-Jennings et al., 2012) of activation.  In this way, the highest activation levels of CT and TA EMG activity often correspond with high pitched voicing in falsetto register, and the lowest levels of CT and TA EMG activity occur during low pitched voicing in chest register (Sawashima et al., 1969; Gay et al., 1972; Baer et al., 1975; Kochis-Jennings et al., 2012).

Many prominent vocalists, vocal pedagogues, and voice scientists have used the terms TDP and CDP, or describe register control relating to dominance changes of TA and the CT muscle activation (Hirano, 1987; Miller, 1996; Bateman, 2002; Henrich, 2006; Edwin, 2008; Perna, 2008; NATS, 2010; Aldrich, 2011; Fleming-DeBerger, 2011; Gundersen, 2012; Phillips, Williams & Edwin, 2012). This terminology suggests that when the CT muscle "dominates" the TA muscle, (i.e. the CT muscle becomes relatively more active than the TA muscle), the vocalist will be singing in falsetto register, and when the TA muscle "dominates" the CT muscle, (i.e. the TA muscle becomes relatively more active than the CT muscle), the vocalist will be singing in chest register. EMG data have never been examined to test the usage of this terminology: the ratio of CT to TA muscular activity has not been studied in a systematic way to determine the role of CT and TA muscular dominance in register control.

The purpose of this study is to analyze the ratio of CT to TA EMG muscular activity during voicing in chest and falsetto registers, in order to help clarify whether CT or TA muscular dominance plays a role in vocal register control, and to better illuminate the physiological mechanism of register control. We will test the proposed hypothesis that chest register production is thyroarytenoid muscle dominant, and that falsetto register production is cricothyroid muscle dominant.

# CHAPTER II
# REVIEW OF THE LITERATURE

Vocal register has previously been studied, in relation to thyroarytenoid and cricothyroid muscle activity using EMG, to uncover some of the mechanisms of vocal register control, and general laryngeal function. However, an analysis of CT versus TA muscle activity dominance in relation to vocal register control has not been studied, though CT muscle dominance in falsetto register and TA muscle dominance in chest register are frequently used to describe register control. The aim of the literature review will be to describe the relevant laryngeal structures, describe registers and register transition, explore the theoretical and physiological mechanisms of register control, and to introduce the popular usage of the terms TA dominant and CT dominant production, to convey the frequency of their usage.

## Laryngeal Structures, Locations, and Basic Physiology

In this discussion of pitch and register control, the CT and TA muscles will be discussed primarily. The TA and CT muscles are two of the five intrinsic laryngeal muscles. The TA muscle is bilateral, symmetrically paired, and the only muscle that underlies the vocal folds. It attaches anteriorly on the midsaggital plane of the internal face of the thyroid cartilage. Posteriorly, it attaches to the vocal and muscular processes of each arytenoid cartilage. The CT muscle connects the anterior surfaces of the external faces of the cricoid and thyroid cartilages. It is also bilaterally paired and symmetrical, though there are two bellies per side, called the pars recta and pars oblique, totaling four muscle bellies of the CT in every normal larynx. The pars recta is vertically oriented, from the superior-medial border of the cricoid cartilage to the inferior-medial border of the thyroid cartilage. The pars oblique is more diagonally oriented, from the superior-medial border of the cricoid cartilage to the inferior-lateral border of the thyroid cartilage.

In terms of activity of the TA and CT muscles, Hirano (1974) studied the tissue layers of vocal folds. He identified that the CT elevates the cricothyroid arch and depresses the thyroid lamina when activated. This directly decreases the cricothyroid space, which increases the length of the vocal folds, leading to a lengthening and a stiffening of the vocal folds. Also, the TA stiffens, and slightly adducts the vocal folds, which can result in changing the amplitude of vibration of the vocal folds. The amplitude of vocal fold vibration, as well as whether the vocal fold vibration reaches the TA muscle, will help determine if TA muscle activity will increase or decrease amplitude of vocal fold vibration (Titze, Jiang, & Drucker, 1988b).

**Vocal Register and Control of Register**

Within the human voice, register transitions, or passaggi, occur over a sequential range of pitches which some vocal pedagogues use to determine the singer’s vocal fach (i.e. soprano, alto, tenor, baritone) and voice type (dramatic, lyric, coloratura, spinto, etc.) Callaghan (2000). Vocal registers are qualities of voicing (Garcia, 1841; Titze, 2000), and the two most studied vocal registers are “chest” and “head”. Acoustically, the spectral slope differs in chest and falsetto.

Each human voice has what is called a “zona di passaggio”, in which a register transition from head to chest or from chest to head will occur, depending on whether one is ascending or descending in pitch. The register transitions, or passaggi, within any vocal range, are most easily identified during glissandos (vocal pitch glides) when a vocalist doesn’t make any effort to unify their timbre, or voice quality, throughout the glissando. The vocal registers known as “chest” and “head” tend to be produced during low pitched and high-pitched phonation respectively. It is possible, with a limited range of pitches, to produce low-pitched head register sounds, and high-pitched chest register sounds. In the passaggio, there is an audible change in the vocal quality or even a momentary cessation of phonation (Callaghan, 2000). The locations of passaggi in certain vocal ranges have been suggested by vocal pedagogue Richard Miller (1996). The general trend is that the major register shift occurs lowest in the baritone and highest in the tenor and alto (Callaghan, 2000). See Table 1 for description of pitch range (Koth, 2009), and first and second passaggio locations (Miller, 1996).

Table 1. Pitch Range and Register Transition Information

| | **Pitch Range** | **First Passaggio** | **Second Passaggio** |
|---|---|---|---|
| **Female Voices** | | | |
| Soprano | C4-A5 (260-880 Hz) | E4b, 311 Hz | F5#, 740 Hz |
| Alto | F3-D5 (175-587 Hz) | G4, 392 Hz | D5#, 622 Hz |
| **Male voices** | | | |
| Tenor | B2-G4 (20-390 Hz) | C4#, 277 Hz | F4#, 370 Hz |
| Baritone | G2-E4 (98-330 Hz) | A3#, 233 Hz | D#4, 311 Hz |

**Register Control Theory**

*Vocal Fold Longitudinal Tension and Medial Compression of Vocal Processes:*

Van den Berg (1963) conducted many studies of the vibrating vocal fold in vivo and of excised larynges, in order to better understand laryngeal dynamics and the production of voicing. From this experimental and observational work, Van den Berg (1963) developed his theory that the main vocal registers are produced by longitudinal tension and stress changes in vocal ligaments and vocal muscles. This inference was made from Van den Berg's knowledge of physics, videostroboscopic images of the vocal folds, and previous experiments that coupled airflow and artificial external longitudinal forces on an excised larynx. Van den Berg (1963) observed that vocal register changes would occur as the vocal folds elongated. Once the vocal folds reached their maximum phonatory length, the register would no longer change beyond falsetto, though the longitudinal tensions would continually increase. He theorized that chest register required less longitudinal tension on the vocal ligament and more on the TA muscle; mid register required some longitudinal tension on both the TA and the vocal ligament; and falsetto register required the most longitudinal tension of the ligament and less longitudinal tension of the TA muscle. Elongation of the vocal folds was positively correlated with the longitudinal tension of the vocal ligament. Van den Berg (1963) theorized that changing longitudinal stress would affect the vocal register as vocal folds continued to elongate, and even after maximum vocal fold elongation was reached. Van den Berg (1963) also theorized that increases of medial compression of vocal processes could cause register transition from falsetto to mid or from mid to chest register.

*<u>Theoretical Framework for Vocal Registers:</u>* Titze (1988a) wrote a review of the literature about vocal register and classified different types of register transitions. The two classes of register transitions were known as periodicity transitions, of which there exists only one (the transition from vocal fry register to chest register), and timbre transitions, of which there are several, such as the transition from chest to falsetto register

or chest to middle register. The periodicity transition is described as occurring at a specific fundamental frequency known as the crossover frequency, below which the voice quality is pulsed, and above which the quality of the voice is smooth and continuous. The timbre transition is a voice quality change that occurs rapidly and occurs as a result of change (either gain or loss) of high frequency sound energy at the source. Titze (1988a) theorized that timbre transitions can occur due to changes in the closure of the glottis (i.e. the degree of vocal fold adduction, or the amplitude of vibration). Titze (1988a) introduced the term "abduction quotient", which is defined as the ratio of the prephonatory position of the vocal folds (measured at the vocal processes) to the amplitude of vocal fold excursions. Affected by the glottal shape are the glottal flow and glottal flow derivative, which showed the most significant changes during timbre register transition. An important acoustic variable that showed the most change during timbre transitions was the spectral slope of the sound. For falsetto and light registers, there was a steeper slope ("spectral slope") than there was for heavier registers.

*Collision Mass of Vocal Folds:* Vilkman (1995) inferred from his EGG data about register transition that a certain collision mass was needed during phonation to cause the perceptual change from falsetto to chest register. Vilkman (1995) noticed that the vocal folds remained closed for longer as one transitioned from falsetto to chest register, and also that the EGG signal increased its amplitude from falsetto to chest, but that the increase in amplitude from falsetto to chest was not sufficient to cause a register transition. From these data, Vilkman (1995) theorized that more than increased closing phase and amplitude of the EGG waveform were needed to cause register transition. Vilkman (1995) referred to this additional factor as a "critical mass" which was defined as contact between vocal folds or processes that would yield a powerful enough collision between the vibrating folds in the vertical and longitudinal dimensions as to produce a register transition.

**Experimental Electromyography: Register Control**

To illuminate the mechanism underlying register control at the level of the larynx, CT and TA muscle EMG data have been analyzed, and will be described in the literature review. The focal experimental conditions are (1) register transition with constant vocal pitch and (2) register transition with pitch change.

*Register Transition With Constant or Nearly-Constant Pitch:* The CT and TA muscles are both more active in chest register than in falsetto register at constant pitch. As pitch changed slightly, the same results are found. (Sawashima et al., 1969; Gay et al., 1972; Baer et al., 1975; Kochis-Jennings et al., 2012).

Sawashima et al. (1969) recorded TA and CT muscle activity of two untrained male singers using concentric needle EMG. The subjects maintained constant vocal pitch on a sustained /a/ and transitioned from chest register to falsetto register one subject was able to transition from chest to falsetto register at 220 Hz, while the other subject sustained 240 Hz in chest register, and then 230 Hz in falsetto register. For both subjects, the TA and CT both decreased their activation level, though the TA muscle decreased its activation level at a sharper rate than did the CT muscle for both subjects.

Gay et al. (1972) recorded TA and CT muscle activity, using EMG, of four adult males with no vocal training, and one adult female with voice training. Three of the subjects sustained /a/ on a constant, or near constant, pitch and transitioned from chest to falsetto. All three subjects had greater TA and CT EMG activity in chest than falsetto register. One of the three subjects was able to transition from chest to falsetto register at the same pitch (185 Hz). Of the other two subjects, one had a 10 Hz increase in fundamental frequency from chest to falsetto register, and the other subject had a 100 Hz increase in fundamental frequency from chest to falsetto register. The CT EMG activity decreased at a greater rate than did the TA EMG from chest to falsetto register for the subject whose pitch increased 10 Hz from chest to falsetto register. The other two subjects were unable to complete this task, and are of unreported gender.

Baer et al. (1975) recorded muscle action potential data from the TA and CT muscles of four untrained singers using EMG on sustained /a/. One of the four subjects, a male, was able to transition register with constant pitch. This task was repeated successively 10-20 times at the following three frequency levels: 220 Hz, 330 Hz, and 440 Hz. It was found that both the CT and TA increased their activity when transitioning from falsetto to chest register on a sustained pitch. The TA had the most consistently sharp rates of EMG activity increase from falsetto to chest register at all three fundamental frequencies analyzed. The CT muscle had sharp rates of increase comparable to the TA muscle from falsetto to chest register at 220 and 330 Hz; but at 440 Hz the CT EMG activity increased at a much shallower rate than did the TA EMG. Baer et al. (1975) stated that these results are consistent with the notion that the TA muscle may be more important for register control than the CT muscle, which may be more important for fundamental frequency control. In terms of subject participation in this task, only one of four subjects was capable of performing this task. The other three subjects were not. Of the other three subjects, one was a female, but the gender of the other two subjects was not reported.

The TA and CT muscles required more activation in chest than in falsetto register while phonating the same pitch, (Kochis-Jennings et al., 2012). In their study, the TA and CT EMG activity levels were recorded from seven adult female subjects: one non-trained, three classically trained, and three non-classically trained. The subjects were asked to sustain a pitch on either /i/ or /ne/ while singing within chest register or within falsetto register. This task was completed several different times on various pitches in both chest and falsetto registers. In this way, the TA and CT EMG activity levels were compared at the same pitch across both registers. One of the subjects had successful recordings from the CT and TA muscle during chest and falsetto. The other two subjects had successful recordings only from the TA muscle in chest and falsetto. The other four subjects did not produce same pitched data in chest and falsetto register.

*Chest Register, Falsetto Register, and Register Transition with Changing Pitch:* CT and TA muscle activity increased while transitioning from chest to falsetto register with pitch increase, (Shipp & McGlone, 1971) and during ascending musical scales in chest and falsetto register (Hirano et al., 1969; Gay et al., 1972; Kochis-Jennings et al., 2012).

Shipp & McGlone (1971) recorded CT and TA EMG activity from 14 adult males with unknown vocal training status. Subjects were expected to phonate the vowel /a/ at 10%, 30%, 50%, 70% and 90% of their individually determined maximal pitch range in a randomly determined order. Subjects completed this task one time at 25% of their individually determined maximum intensity level and one time at 75% of their maximum intensity level. The data collected at each individual frequency level were then averaged across all the intensity levels and groups to determine percentage of maximal activation of the TA and CT at each individual level of their pitch range, at what was assumed to be the median vocal intensity level. The register transition was estimated to occur at around 50% of the maximum pitch range. Both CT and TA EMG activity were positively correlated with increased pitch throughout the pitch range. The CT muscle EMG activity continued to increase more rapidly throughout the pitch range, such that it increased even more in high pitch falsetto than in lower pitched chest, with the largest magnitudes of muscle activation change seen in the CT EMG data, which increased by nearly 50% between 70%-90% of the vocal pitch range. The TA muscle began more maximally activated than the CT muscle at the low part of the pitch range and steadily increased its activity throughout the pitch range. From 50-70% of the vocal pitch range, the TA muscle activity increased much less than the rest of the pitch range.

Hirano et al. (1969) obtained EMG recordings from the TA and CT muscles of two male professional singers, three non-singing males, and one female professional singer. In chest register, the TA and CT EMG activity increased with pitch. In falsetto register, the TA EMG activity increased with pitch, and the CT EMG activity increased with pitch until the highest pitches. Sometimes the CT muscle did not increase during production of the highest pitch falsetto productions. The three singers completed all the tasks. The three non-singers completed only a small part of the singing samples. It was not clear when non-singer data were factored into the results.

Gay et al. (1972) recorded TA and CT EMG data during arpeggio of 10-20 repetitions of /a/ in chest and falsetto registers for one trained female subject. They found

TA and CT EMG activity increases in chest and falsetto registers were positively correlated to increases in pitch, and that the patterns of TA and CT EMG activity in chest and falsetto register were the same. The other 4 subjects did not complete this task, or did not have correct TA or CT electrode placement.

Kochis-Jennings et al. (2012) compared EMG activity in the TA and CT muscles during sustained /i/ or /ne/ at 3-5 frequencies in chest and falsetto registers of 7 total female singers, three classically trained, three non-classically trained, and one untrained. They found that there was an increase in both CT and TA EMG activity that correlated positively with pitch increase in chest and falsetto register. Four subjects had successful TA EMG recordings during pitch increase in chest and falsetto registers. TA EMG activity increased or was maintained during pitch increase in chest and in falsetto. Only one subject had a successful recording from the CT muscle during this task, but demonstrated robust activity increase during both chest and falsetto register. The one subject with successful CT EMG activity recordings also had successful TA EMG activity recordings.

**Pitch and Control of Pitch**

*Theory: Body-Cover Model of Pitch Control:* Hirano (1974) popularized the body-cover theory of vocal fold vibration through careful analysis of the tissue layers within the larynx: differentiating between the more superficial, non-muscular vocal fold cover, from the deeper, muscular vocal fold body. Fujimura (1981) modeled and analyzed Hirano's research relating to the tissue layers of the vocal folds. He mathematically defined forces, displacements, and constants relating to the cartilages, muscles, and tissue layers intrinsic to the larynx. He made several equations, one relating length of the cover to forces acting upon the cover; another relating length of the body to forces acting upon the body. Fujimura argued that the vocal fold cover would never be actively lengthened, as it contains no muscle fibers, whereas the vocal fold body could be actively shortened, as it does contain muscle fibers. He suggested that different amounts of tension might result in the production of different vocal registers or pitches.

Expanding on Fujimura's (1981) work, Titze et al. (1988b) explored the functional implications of the tissue layers, and further described the body-cover model as it related to pitch and register control. They maximally stimulated the TA and CT muscles of 3 canines to observe changes in vocal fold length. From these changes in vocal fold length, and levels of stimulation of the TA and CT muscles, several equations were written which related vocal fold length, strain, TA muscle activity, CT muscle activity, and stress on the body (both active and passive) and cover (passive stress only). They discovered that the CT muscle has a mechanical advantage over the TA muscle at the cricothyroid joint. The CT muscle has a maximum torque-ratio advantage of four over the TA muscle in canines. This maximum torque ratio was used in the equations written about active and passive stress on the body or cover of the vocal folds, length, and strain. This ratio suggests that when the CT muscle is more active than the TA muscle, the CT muscle is responsible for the majority of the rotation around the cricothyroid joint and vocal fold elongation.

Fujimura (1981) and Titze et al. (1988b) both theorized that pitch and register could be predicted based on TA and CT activity. The TA and CT muscles, when activated, passively or actively either stress or relax the body or cover of the vocal folds, and thus alter the length, stiffness, and/or tension of the vocal folds. This adaptation of

Hirano's (1974) study of the vocal folds and concept of the body-cover model of pitch control seems conceptually related to Van den Berg's (1963) idea of longitudinal strain of the ligament and/or TA muscle affecting vocal register.

**Thyroarytenoid and Cricothyroid Dominant**

**Production Terminology**

Chest register is frequently described as "thyroarytenoid dominant", and falsetto register as "cricothyroid dominant", as if synonyms. The terms and their underlying concepts have been used by voice scientists (Hirano, 1987), in books (Miller, 1996; Phillips, Williams & Edwin, 2012), in University Dissertations and published projects through the University of Victoria, British Columbia**,** University of Miami Florida, University of Maryland, and Rice University (Bateman, 2002; Perna, 2008; Aldrich, 2011; Fleming-DeBerger, 2011; Gundersen, 2012), vocalist journals, such as the Journal of Singing (Edwin, 2008), and by professional vocal pedagogy organizations (NATS, 2010).

Hirano (1987) stated "in the modal voice, TA activity is dominant over CT activity. As the fundamental frequency increases, both TA and CT activities increase. However, TA remains dominant" (p. 215) and "in falsetto, TA contracts weakly or completely relaxes" (p. 220) as the CT muscle continues to increase its activation. Hirano defines modal voice as comprising chest, mid, and head registers such that the voice transitions from chest to mid and mid to head register as CT muscle activity increases within modal register. Hirano then states that the CT muscle becomes increasingly more active in falsetto register, while the TA muscle activity is diminished or completely stopped.

Edwin (2001), in a discussion about belting, asserts that it is “not chest voice singing…although [it is] thyroarytenoid-dominant,” implying that chest voice singing is thyroarytenoid dominant. In her review of vocal register terminology, Bateman (2002) described falsetto register as occurring when the TA muscle is relaxed. Vocal pedagogue McCoy (2004) contrasted chest and falsetto registers such that they “will be labeled according to laryngeal function: thyroarytenoid-dominant versus cricothyroid-dominant”. He does not make the assertion that the TA relaxes during falsetto register voicing, but he explains CDP and TDP with descriptions that characterize the acoustic and EGG data relating to falsetto and chest registers, respectively. McCoy describes that:

> TDP is characterized by a relatively high closed quotient (the ratio of time the glottis is closed versus open), which generally exceeds 50%. During TDP the vocal folds are thickened by contraction of the TA muscles, resulting in greater mass per unit of length. They also exhibit a vertical phase difference during each cycle of vibration. Because the area of contact between the folds is wide and glottal closure is rapid and prolonged, the sound produced has a shallow spectral slope, generally twelve dB/octave or less, with strong acoustic energy in high harmonics.
>
> CDP contrasts sharply with TDP… [it is characterized by] narrow area of glottal contact during vocal fold oscillation. Vertical phase differences cease to exist and mucosal movement occurs almost exclusively along the medial margins of the vocal folds. Closed quotient typically drops to less than 40%. Amplitude of high harmonics is reduced in CDP relative to TDP because of the slower glottal closing rate, longer open phase, and narrower area of contact between the folds during oscillation.

Edwin (2008) also stated “the register in which the TA muscles often are most active is traditionally called the chest voice, while the register in which the CT muscles often are most active is traditionally called the head voice or falsetto”; and that both male and female classical music and contemporary commercial music (CCM) singers who perform a majority of their songs in their TA-dominant (“chest” or “mix”) register would do well to exercise extensively in their CT-dominant (“head” or “falsetto”) register to establish a healthier balance and coordination of vocal fold activity (Edwin, 2008).

Fleming-DeBerger (2011) included in her dissertation’s glossary of terms: “Chest register: TA dominant vocal production, often referred to as “chest voice”, and “Head register: CT dominant vocal production, often referred to as “head voice”, as if the terms were fully accepted and verified to be true. In his dissertation, a manual intended to educate organists to work with choral groups, Gundersen (2012) states that “register isolation work allows voice users to experience the sensations, which relate to dominant TA (chest voice) or dominant CT (head voice) muscle activity.” Phillips et al. (2012) stated: “traditionally, men are expected to speak and sing in their TA-dominant [chest/mix] register, while women are expected to…sing in their CT-dominant [head] register”.

**Statement of the Problem and Purpose**

**of the Present Study**

Despite our incomplete understanding of these mechanisms of pitch and register control, the terms CDP and TDP are used to describe both register control (McCoy, 2004; Phillips et al., 2012). There has never been a systematic study of the ratio of cricothyroid and thyroarytenoid muscular activity as related to vocal register. This terminology has been used increasingly for the past two and a half decades without supportive EMG evidence. The terminology may have arisen from two main ideas (1) pitch control (typically productions of falsetto register are associated with high CT activity) and (2) in order to shift from falsetto to chest at the same pitch singers increase adduction (i.e. with TA and LCA muscular activity increase). Pitch increase has been shown to be associated with increased cricothyroid muscle activity. The activity of the cricothyroid muscle in pitch control might have been adapted to explain register control, while discounting the activity of the thyroarytenoid muscle.

Register control is a physiological function that is not fully understood, so it is difficult to label the vocal registers based on function of the larynx. The idea that a balance of intrinsic laryngeal muscle activity relates to register control is reinforced by the CDP and TDP terminology. The aim of the study is to test the hypothesis that chest register productions are thyroarytenoid muscle dominant, and that falsetto register productions are cricothyroid muscle dominant. By testing this hypothesis, it will be possible to verify whether “TDP” and “CDP” are useful and accurate terms in relation to vocal register control.

# CHAPTER III
# METHODOLOGY

## Participants

The data was previously collected, and is reanalyzed for the present study. Five adults participated in this study: four females, and one male. All subjects were native English speakers who were not trained as vocalists, actors, or speakers. A head and neck examination was completed to confirm that the participants' medical histories and/or physical conditions would not interfere with EMG measurements of normal laryngeal muscle activity during vocalization and other tasks including swallowing, cough, valsalva, and high frequency phonation. This pre-experimental examination involved a head and neck screening, which included mirror or nasendoscopic laryngeal examination to confirm normal vocal fold structure and function, including normal vocal fold mobility. Additionally, participants did not have medical histories of hearing, speech, or voice problems, including immobile vocal folds, neck or chest surgery, bleeding problems, or use of blood thinners such as aspirin or coumadin within two weeks of the day of the experiment, nor allergy to anesthetic agents used in the study. Participants gave informed consent to participate in the experiment for which they were financially compensated. The University of Iowa Institutional Review Board approved this research.

## Procedures

The data were collected at the University of Iowa Hospital and Clinic's (UIHC) Otolaryngology Department for a previous research project, and the methods used for the previous project are reported here. All five participants were prepared for simultaneous recording of laryngeal muscle activity and acoustic signal.

To prepare for the EMG, (0.5 cc) 2% lidocaine with 1:100,000 epineiphrine was injected subcutaneously above the CT ligament. Bipolar stainless steel hooked-wire electrodes (50 μm diameter) were inserted, using a 1.5 inch, 25 gauge needle, into the TA and CT muscle. The ends of the inserted wires had previously been stripped of 1-1.5 mm of insulation. Several procedures were undertaken before and after each study in order to verify the correct placement of the EMG into the CT and TA muscles. If predictable EMG activity associated with sustained phonation was observed, after having observed the electrode pass through the CT membrane, the electrode was judged to be in the TA muscle. If there was a combination of increased EMG activity associated with increased pitch and minimal EMG activity while participant lowered the jaw, and the CT membrane was not penetrated during the hooked wire electrode insertion, it was judged that the hooked wire electrode was in the CT muscle. These verification procedures, were completed at the beginning and at the end of each study to confirm that the hooked-wire electrodes did not physically move.

Hooked-wire electrodes are less likely to affect vocal performance than needle electrodes, because hooked wire electrodes do not affect laryngeal elevation, nor do they generally cause discomfort during vocal tasks. Only if the hooked-wire electrode is placed too medially in the vocal fold, close to the mucosa, can cause pain. In that case, the electrodes are removed and placed more laterally.

To record the acoustic signal, a condenser microphone (headset model C410, AKG Acoustics) with an AC power supply (model N62E, AKG Acoustics) was placed 6 cm in front of the participant. All signals were amplified and low pass filtered at 2.5

kHz, and digitized at 5000 samples/sec per channel by a computer system used for data analysis (WINDAQ, Dataq Inc., Akron, OH).

*Speech Sample:* The participants produced two ascending glissandos on the vowel /i/ and a variety of other tasks to stimulate maximal TA and CT muscular activation: swallowing a bolus of water, cough, valsalva, loud speech, and loud non-speech, high-pitched phonation. Before stimulating the glissandos, participants were asked to “start as low as you can and go as high as you can” and were provided with a model by the investigator. Participants weren’t instructed to control vocal intensity. Glissandos were used to obtain a range of fundamental frequencies that were used to test the model, rather than to assess participant range.

*Measures:* Mean measures of TA and CT muscle activity and fundamental frequency during the two glissandos for each participant were acquired with Windaq signal processing and analysis software. TA and CT muscle EMG signals were first aurally and visually assessed for confirmation that they were free of artifact. Second, the EMG signals were rectified and smoothed using a moving average (with a 50 ms window). Third, each of the glissando was divided into about 50 ms segments and mean measures of TA and CT muscle activity were obtained for each segment. Mean fundamental frequency produced during each segment was determined from the audio signal by calculating total number of complete cycles in the segment and after dividing the number of cycles by the number of seconds. Because cycles didn’t always end at the 50 ms mark, the fundamental frequency was calculated by taking the last complete cycle above 50 ms. As a result, the analysis segments ranged in length from 50 to 58 ms.

Mean measures of maximum TA and CT activation were then gathered during the task that elicited the greatest activation of that particular muscle. Mean measures of activity during 50 ms segments were how maximum activity levels were obtained for the TA and CT muscles. These measures were then used to calculate the percent of maximum activity for the TA and CT muscles, referred to as simply the TA and CT muscular activity or TA and CT EMG activity. The TA and CT EMG activity were calculated by dividing the individual EMG activity levels elicited during the experimental trials by the maximum possible TA and CT EMG activation from the elicitation tasks. The resultant values are the TA and CT EMG values, respectively. Calculating the TA and CT EMG activity is particularly important to normalize the data and minimize the effects of electrode placement, or minimizes variability in the data, so that comparisons of activity level can be made between different muscles and across participants (Halaki and Ginn, 2001).

Aiding in interpretation of the results, each glissando was assessed aurally to determine the occurrence of the vocal break. A professional singing teacher who had had 17 years of teaching experience judged subject's vocal registers and register transitions. Timbre was the perceptual factor used to judge chest register productions. The productions perceived to be rich in timbre were judged to be chest voice, while those productions with poorer timbre were judged to be falsetto register. In most subject cases, the register transition was distinct and abrupt, and exhibited a sudden change in timbre that was perceptually distinct from other productions. Trained singers learn how to mix registers and use a mixed sound for a large portion of their pitch range, while untrained singers are less able to produce a mix or extend this mix over a wide part of the range.

Because of this, in the majority of cases, subjects went directly from a clearly chest production into a clearly falsetto production. The shift was recorded in terms of the first tone produced in falsetto. This point of register transition was located on the audio record, then the fundamental frequency where the vocal break occurred was calculated by taking the closest 50 ms segment to the break, calculating the number of cycles and dividing it by that time period. This process was again repeated in order to ensure accuracy and reliability. Intrajudge agreement was within 5 Hz for 100% of the measures.

Subjects were able to vary intensity in a natural and unrestrained manner, which was why vocal intensity was not controlled. The untrained subjects allowed intensity to fluctuate by 8-12 dB without any particularly consistent pattern over the course of the ascending glissando. The register transition was typically accompanied by a diminishment of intensity, especially if there was a vocal break.

These data were retrospectively analyzed and plotted in scatterplots in Microsoft Excel for the current study. The following data sets were plotted relative to co-occurring fundamental frequencies in each glissando: CT to TA muscle activity, CT muscular activity, and TA muscular activity. Location of chest and falsetto register was also noted within each glissando. The CT:TA muscle activity ratio was interpreted as a ratio of CT to TA muscular dominance. If the value of CT:TA muscular activity was greater than one, it was interpreted as the CT muscle being dominantly active, and if the ratio was less than one, it was interpreted as the TA muscle being dominantly active. If the ratio was equal to one, it was interpreted that neither the CT nor TA muscles were dominant.

# CHAPTER IV
# RESULTS

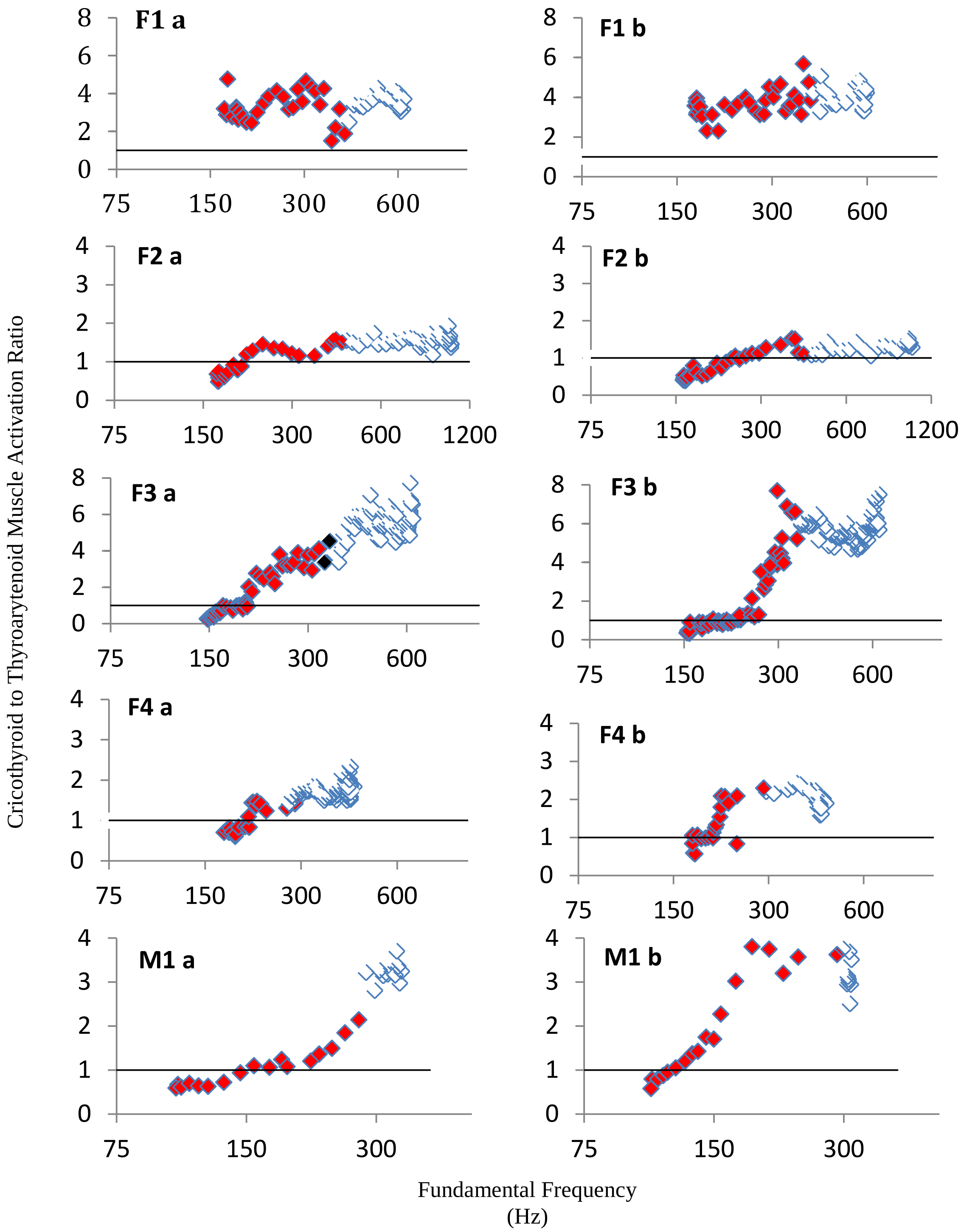
The purpose of this study was to determine if CT or TA muscle activity dominance is involved in vocal register control, and whether CDP and TDP are appropriate descriptions of vocal register control. The normalized EMG data of the CT and TA muscles during glissando are described below. First, data relating CT:TA dominance, register control, and/or fundamental frequency are described with reference to relevant figures and tables. Second, other register-related observations are delineated. The major findings are then summarized.

Figure 1 shows how the ratio of CT to TA muscle activation, CT:TA, (on the vertical axis) changed across chest and falsetto registers as a function of fundamental frequency (on the horizontal axis) during two glissandos produced by each of five subjects. Fundamental frequency is displayed in a logarithmic scale with a base of 2 in order to mimic the log base 2 relationship found among subsequent octaves. For example, 440 Hz is the fundamental frequency of the musical note A in the piano's fourth octave. Doubling the fundamental frequency to 880 Hz produces the musical note A in the piano's fifth octave, yielding a one-octave increase with a doubling of fundamental frequency. Each row shows data from one subject, with female subjects in rows 1-4 and from the male subject in row 5. The left column (column a) contains data from the first glissando and the right column (column b) contains data from the second glissando. The filled red square data points represent the productions in chest register. The unfilled square data points represent productions in falsetto register. Filled black square data points found in one graph represent productions occurring during a smooth transition.

The horizontal line indicates a CT:TA ratio that is equal to one. TA muscle dominant productions would fall below the line and CT muscle dominant productions would be above the line.

Several main observations can be made regarding the data presented in Figure 1. First, CT:TA dominance did not control vocal register. Chest register productions were not defined by TA dominance, nor did CT dominance define falsetto register productions. At the horizontal line representing the point of CT and TA muscular equivalence (i.e. CT:TA ratio equal to 1), no significant register events, like register transitions, occurred. Chest register productions occurred when the TA muscle was dominant (i.e. CT:TA less than 1), as well as when the CT muscle was dominant (i.e. CT:TA greater than 1), represented by square-shaped gray data points above and below the horizontal line (i.e. with TA dominance and with CT dominance). Falsetto register productions only occurred while the CT muscle was dominant (i.e. CT:TA greater than 1), represented by unfilled data points above the horizontal line. Second, CT:TA ratio values tended to increase in chest and then falsetto register with ascending pitch. At the highest pitch levels, there were more erratic CT:TA ratio values. For example, Subjects F4 and M1 had a large increase of EMG activity with pitch increase until the highest pitches, where there was a decrease in decrease in CT:TA ratio activity due to a decrease of CT muscle activity (which is displayed in more detail in Figure 2).

Figure 1. CT:TA Ratio and Fundamental Frequency (on a Logarithmic Scale) during Glissando.




Note: The filled, gray diamonds are chest register productions; unfilled diamonds are falsetto register productions; filled, black diamonds are productions during register transition from chest to falsetto. Horizontal like at y=0 represents equivalent CT and TA activity

Table 2 describes numerically the same data displayed in Figure 1. In the two glissandos produced by each subject, information is provided regarding first production in falsetto register or the range of frequencies over which the register shift occurred, type of register transition (smooth or distinct), and the summed average of the ratio of CT to TA activity of five recorded productions just before and just after the register transition. The column relating to frequency or range of frequencies at which register transition occurred divides chest register productions from falsetto register productions. All chest register productions occurred below this frequency, and all falsetto register productions occurred at or above this frequency. The CT:TA ratio values during register transition characterized by a distinct break were not measured because there was no phonation during the break. For the register transitions characterized by a smooth transition, CT:TA ratio values during register transition were measured for subject F3, but not for subject F1.

Table 2 shows the shift in register occurred at an average CT:TA ratio of 2.9 before register transition, with a standard deviation of 1.7, and at an average CT:TA ratio of 3.1 after register transition, with a standard deviation of 1.5. TA dominance (i.e. CT:TA less than 1) was never seen immediately before or after transition into falsetto register. The variability of the data was much lower within subjects than across subjects, which probably has to do with electrode placement. It is likely that electrodes were placed at varying levels of depth and at varying angles relative to the muscle fibers among subjects, therefore picking up disparate levels of EMG activity.

The majority of subjects had a higher CT:TA ratio value after register transition in comparison to before register transition (i.e. average of 2 before register transition, and average of 3.1 after register transition). Specific CT:TA ratios before and after register transition were not directly related to varying pitches within or across subjects. For example, at a higher pitch, subject F1's CT:TA ratio was less before and after register transition than at lower pitch.

Table 2. Register Transition Location, Type, and Bordering CT:TA Values

| Subject | Gliss-ando | First Recorded Falsetto Production after Register Transition or Range of Frequencies over which Register Shift Occurred (Hz) | Type of Register Transition | Average CT:TA activation of 5 productions before register transition | Average CT:TA activation of 5 productions after register transition |
|---|---|---|---|---|---|
| F1 | a | 413 | Smooth transition | 2.6 | 3.2 |
| | b | 400 | Smooth transition | 3.7 | 3.5 |
| F2 | a | 420 | Distinct break | 1.3 | 1.5 |
| | b | 440 | Distinct break | 2.0 | 2.3 |
| F3 | a | 332-357 | Smooth transition | 3.5 | 4.1 |
| | b | 346-355 | Smooth transition | 6.6 | 5.9 |
| F4 | a | 280 | Distinct break | 1.3 | 1.5 |
| | b | 280 | Distinct break | 1.3 | 1.2 |
| M1 | a | 293 | Distinct break | 2.0 | 3.1 |
| | b | 293 | Distinct break | 4.2 | 4.2 |
| Average | | | | 2.9 | 3.1 |
| Standard Deviation | | | | 1.7 | 1.5 |

Table 3 provides information regarding the average number, and standard deviation of semitones (i.e. each semitone is equivalent to 1/12 of an octave) of TA muscle dominant vocal productions throughout the vocal range, the total number of semitones produced in chest register, total number of semitones produced in falsetto register, and the total number of semitones produced in glissando. The top two rows represent female average and standard deviation data, and the bottom two rows represent male average and standard deviation data.

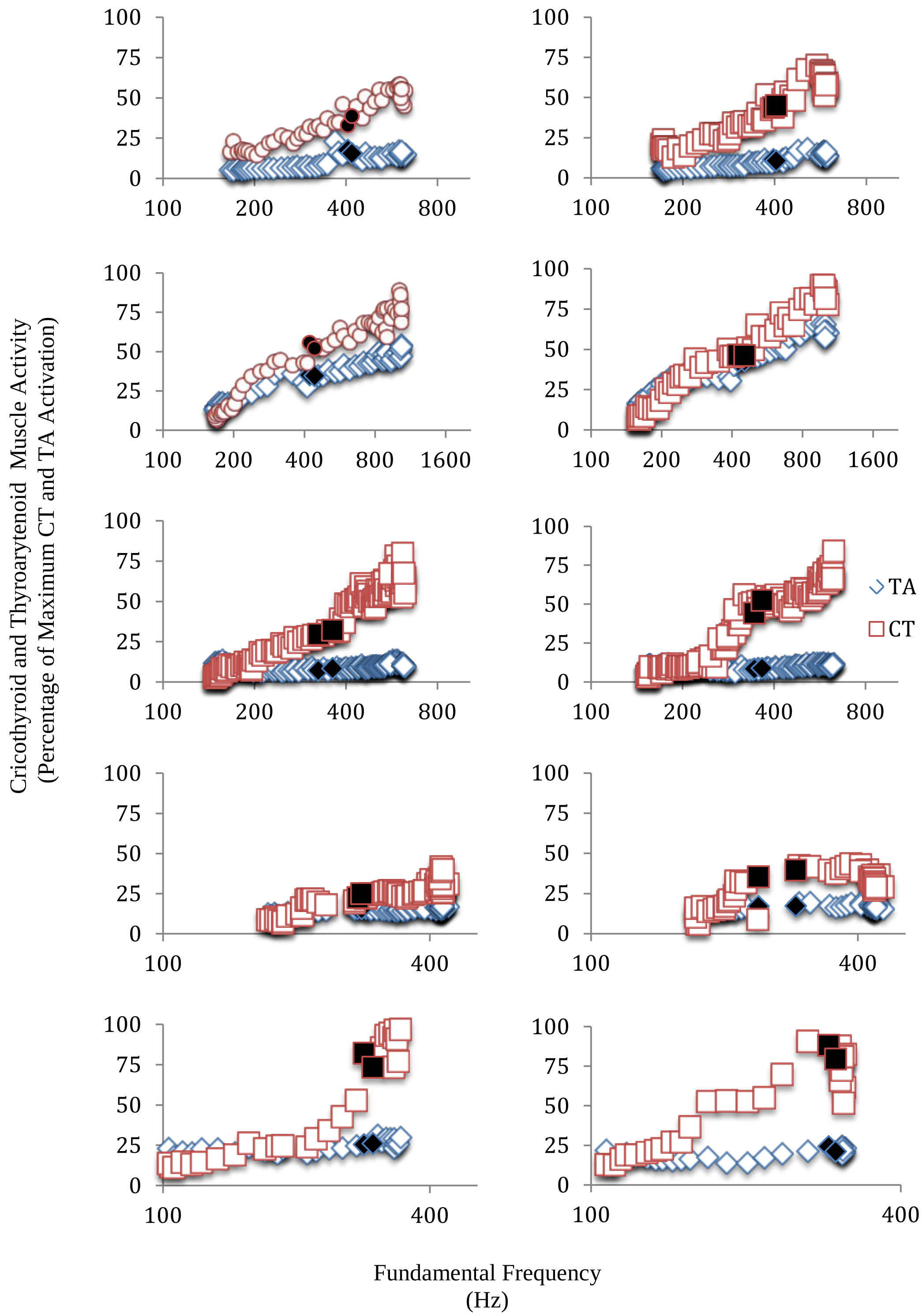
Table 3. Quantity of Semitones in Chest Register, Falsetto Register, and Pitch Range (rounded to the nearest whole number)

| | All TA dominant productions and ave. pitch range (semitones, Hz) | CT dominant productions and ave. pitch range in chest register (semitones, Hz) | Chest Register productions and ave. pitch range (semitones, Hz) | Falsetto Register (semi-tones) | Pitch Range (semi-tones) |
|---|---|---|---|---|---|
| Female Average | 3<br>(162-203 Hz) | 10<br>(199-352 Hz) | 13<br>(162-352 Hz) | 11 | 24 |
| Standard Deviation | (2.4) | (4.1) | (4) | (3.6) | (6.3) |
| Male Average | 4<br>(105-131 Hz) | 14<br>(143-287 Hz) | 18<br>(105-287 Hz) | 3 | 21 |
| Standard Deviation | (3.5) | (3.5) | (0) | (2) | (2) |

The TA muscle activation was greater than CT muscle activation for only a few of the lowest pitched productions in chest register. Throughout the pitch range, on average, 3 semitones were produced with TA EMG dominance for female subjects, and 4 semitones for the male subject. Only 3-4 semitones out of 21-24 semitones in the pitch ranges of all subjects were TA dominant. The remainder of the pitches produced in chest, and then falsetto, registers were CT dominant. For females, 10 of the 13 semitones produced in chest were produced with CT dominance, and for males, 14 out of 18 semitones produced in chest were produced with CT dominance. For female subjects, TA dominant voicing corresponded to fundamental frequencies between 162-203 Hz. For male subjects, this corresponded to fundamental frequencies between 105-275 Hz. CT dominant voicing from 199-352 Hz and 143-287 for females and males. Because the TA muscle is only dominant during very low-pitched voicing, and the CT muscle quickly becomes dominant, TA dominance is not descriptive of much of the vocal range.

Figure 2 illustrates change in CT and TA muscle activation during both glissandos produced by each subject. This figure is arranged similarly to Figure 1. Squares represent CT muscle activation and diamonds represent TA muscle activation. Black data points represent the boundaries of the register transition. CT muscle activity increases robustly with pitch, while TA muscle activity increases shallowly. For most subjects, the TA EMG activity begins dominant to the CT EMG activity, as diamond-shaped data points start above square-shaped data points. However TA activity is only slightly greater than CT activity and due to robust increase of CT activity over the course of the glide, the CT muscle quickly becomes dominant to the TA muscle within chest register, and maintains dominance throughout falsetto register.

Figure 2. Cricothyroid and Thyroarytenoid Activity as a Function of Fundamental Frequency on a Logarithmic Scale




Note: The unfilled diamonds represent TA activity; unfilled squares represent CT activity; filled black data points represent the boundaries of register transition.

Tables 4-7 provide numerical information that correspond with Figure 1 and 2 about the female and male subjects, respectively. These tables include information regarding the range of fundamental frequencies, CT EMG activity, TA EMG activity, and CT:TA ratios produced by each subject during each glissando. Tables 4 and 5 provide ranges of data during chest register productions and Tables 6 and 7 indicate ranges of data during falsetto register productions. Averages of the data pertaining to individual subjects are included in bold above the corresponding standard deviations, which are included in the bottom row.

In chest register (Tables 4 and 5), the CT muscle attained much higher levels of activation than the TA muscle. The CT muscle was roughly two times or more active than the TA muscle at maximal levels of activation. As female subjects increased pitch within chest, the CT muscle reached 42% maximal activation, and the TA reached 22% maximal activation (Table 4). As the male subject increased pitch within chest, the CT reached 87% maximal activation, and the TA reached 25% maximal activation (Table 5). The CT:TA ratio reached an average maximum of 3.6 in chest register.

In falsetto register (Tables 6 and 7) CT EMG activity continued to dominate the TA EMG activity in all male and female productions after the 3-4 lowest semitones in chest register (Table 3). For all subjects, the CT muscle had higher levels of activity than the TA muscle in falsetto register (Table 6 and 7). As female subjects increased pitch within falsetto, the CT muscle's activation levels measured from 37% to 69%, and the TA muscle activation measured from 18% to 27% (Table 6). For the male subject, the CT EMG ranged from a minimum of 63% to a maximum of 95% in falsetto and the TA

EMG ranged from 20% to 28% (Table 7). There was not a specific value of CT:TA activity that was related to register transition (Figure 1, Tables 4-7).

Table 4. Female Chest Register

| Subj. | Gliss-ando | Fundamental Frequency (Hz) | | CT activity (% max activation) | | TA activity (% max activation) | | CT:TA (ratio of % max activation) | |
|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max |
| **F1** | a. | 167 | 405 | 14 | 46 | 5 | 23 | 1.5 | 4.7 |
| | b. | 171 | 397 | 13 | 52 | 5 | 11 | 2.3 | 5.7 |
| **F2** | a. | 167 | 412 | 6 | 45 | 11 | 39 | 0.5 | 1.5 |
| | b. | 159 | 425 | 6 | 50 | 15 | 43 | 0.4 | 1.5 |
| **F3** | a. | 163 | 324 | 3 | 30 | 6 | 14 | 0.2 | 4.1 |
| | b. | 153 | 340 | 3 | 56 | 6 | 12 | 0.3 | 7.7 |
| **F4** | a. | 172 | 275 | 6 | 23 | 11 | 16 | 0.6 | 1.5 |
| | b. | 172 | 239 | 6 | 35 | 10 | 17 | 0.6 | 2.1 |
| Average. | | **165** | **352** | **7** | **42** | **9** | **22** | **0.8** | **3.6** |
| Stand. Dev. | | 6.8 | 69 | 4 | 12 | 4 | 12 | 0.7 | 2.3 |

Table 5. Male Chest Register

| Subj. | Gliss-ando | Fundamental Frequency (Hz) | | CT activity (% max activation) | | TA activity (% max activation) | | CT:TA (ratio of % max activation) | |
|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max |
| M1 | a. | 104 | 284 | 11 | 82 | 18 | 26 | 0.6 | 3.2 |
| | b. | 107 | 290 | 13 | 91 | 14 | 24 | 0.6 | 4.2 |
| Average | | **105** | **287** | **12** | **87** | **16** | **25** | **0.6** | **3.7** |
| Stand. Dev. | | 2.1 | 4.2 | 1 | 6 | 3 | 1 | 0 | 0.7 |

Table 6. Female Falsetto Register

| Subj. | Gliss-ando | Fundamental Frequency (Hz) | | CT activity (% max activation) | | TA activity (% max activation) | | CT:TA (ratio of % max activation) | |
|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max |
| **F1** | a | 418 | 627 | 37 | 58 | 11 | 17 | 2.5 | 4.3 |
| | b | 405 | 598 | 38 | 70 | 10 | 18 | 3.3 | 5.1 |
| **F2** | a | 421 | 1040 | 52 | 89 | 35 | 54 | 1.2 | 1.9 |
| | b | 453 | 1028 | 46 | 90 | 43 | 66 | 1.1 | 1.5 |
| **F3** | a | 361 | 627 | 31 | 78 | 8 | 14 | 3.8 | 7.7 |
| | b | 356 | 630 | 46 | 84 | 8 | 12 | 4.7 | 7.5 |
| **F4** | a | 281 | 430 | 22 | 42 | 14 | 19 | 1.4 | 2.3 |
| | b | 290 | 456 | 27 | 43 | 16 | 19 | 2.3 | 1.9 |
| Average | | **373** | **679** | **37** | **69** | **18** | **27** | **2.5** | **4.0** |
| Stand. Dev. | | 62 | 232 | 10 | 20 | 13 | 21 | 1.3 | 2.5 |

Table 7. Male Falsetto Register

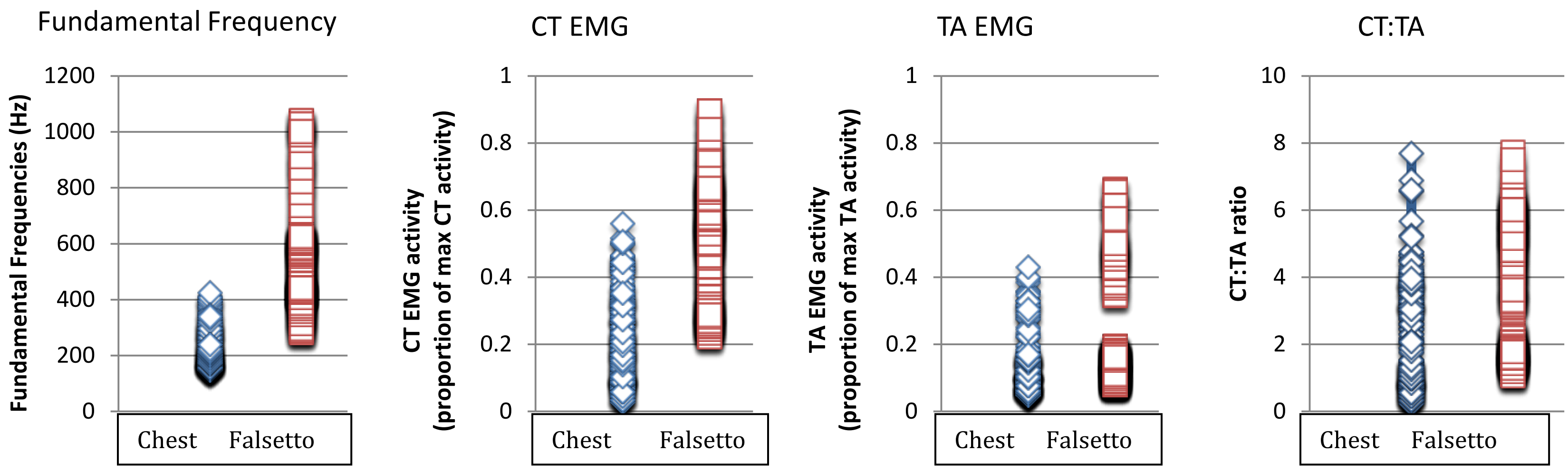
| Subj. | Gliss-ando | Fundamental Frequency (Hz) | | CT EMG activity (% max CT activation) | | TA EMG activity (% max TA activation) | | CT:TA (ratio of % max activation) | |
|---|---|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max | Min | Max |
| **M1** | a. | 298 | 344 | 73 | 102 | 26 | 31 | 2.8 | 3.7 |
| | b. | 299 | 312 | 52 | 88 | 14 | 24 | 2.5 | 4.2 |
| Average | | **298** | **328** | **63** | **95** | **20** | **28** | **2.6** | **3.9** |
| Stand. Dev. | | 0.7 | 22 | 15 | 10 | 8 | 5 | 0.2 | 0.3 |

Figures 3 and 4 show a summary of the chest and falsetto register data for female and male subjects, respectively. Figure 3 is organized such that each graph from left to right represents two ranges of data relating to fundamental frequency, CT EMG, TA EMG, and CT:TA values in chest and falsetto registers. The data to the left, diamond-shaped, within each chart represents chest register and the data to the right in each chart, square-shaped, represents falsetto register. Figure 4 has the male data organized in the same way as the female data are organized in Figure 3.

Figures 3 and 4 show that falsetto register had only CT dominant productions, and that chest register had both CT and TA dominant productions (i.e. falsetto register was seen at CT:TA ratio values greater than 1, and chest register values were seen at CT:TA ratio values from nearly 0 to 8). Similarly, Figures 3 and 4 show much higher CT EMG values in falsetto than in chest register, and much higher values of CT EMG activity in falsetto register than TA EMG values in chest or falsetto register. This reinforces the idea that the CT EMG activity continues to increase with register transition and increasing pitch, and also exceeds TA EMG activity, and the ensuing fact that the CT muscle is relatively more active than the TA muscle during register and pitch transition in falsetto and in chest, except for the lowest 3-4 semitones. Also, in terms of fundamental frequency, Figures 3 and 4 reinforce the fact that falsetto register occurs in a higher pitch range than does chest register. In both Figures 3 and 4, there was a greater density of higher CT:TA ratio values in falsetto than in chest register. The male subject had a significantly smaller falsetto register range than did the female subjects (Figure 1, 3, 4, and Table 6 and 7). Figure 4, which only demonstrated the data from one subject, reflected a distinct transition from chest to falsetto register with pitch increase.

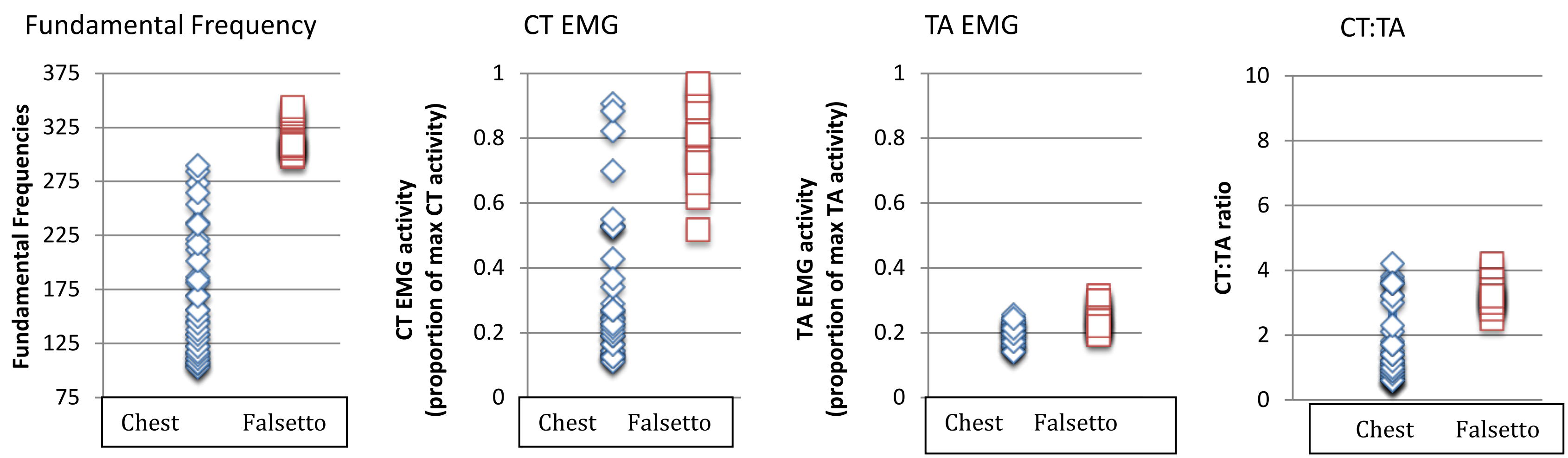
In terms of other observations from the data, Table 8 emphasizes the frequency at which register shift occurred, the maximum attained fundamental frequency, and the pitch range location of register shift. The values relating to pitch range location of register shift (register shift/maximum attained frequency) are included in bold. Transition from chest to falsetto register tended to occur at nearly the same percentage

Figure 3. Female Subjects' (F1-4) Ranges of Fundamental Frequency, CT EMG, TA EMG, CT:TA Values in Chest and Falsetto Register




Note: The unfilled diamond shaped data points represent chest register productions and the unfilled square shaped data points represent falsetto register productions.

Figure 4. Male Subject (M1) Ranges of Fundamental Frequency, CT EMG, TA EMG, CT:TA Values in Chest and Falsetto Register




Note: The unfilled diamond shaped data points represent chest register productions and the unfilled square shaped data points represent falsetto register productions.

of maximal attained pitch for each subject. Females had register transition nearer to the middle of their glissando, and the male subject had register transition toward the higher pitches of his glissando, highlighting the fact that females have a larger falsetto range, and the male subject, a larger chest range. For example, F1 had register transition at 66% of her maximum pitch range during her first glissando, and at 67% of her maximum pitch range during her second glissando. Register transition occurred in a range of 40-67% maximal attained pitch for females. The male subject had register transition at 85% of his maximal attained pitch in the first glissando and then at 94% of the maximum attained pitch in the second glissando.

Table 8. Pitch of Register Shift Relative to Overall Pitch Attained

| Subj. | Gliss-ando | Frequency at which register shift occurred (Hz) | Max. Freq. (Hz) | Pitch range location of register shift (register shift/maximum attained frequency) |
|---|---|---|---|---|
| F1 | a | 413 | 627 | **66%** |
| | b | 400 | 595 | **67%** |
| F2 | a | 420 | 1040 | **40%** |
| | b | 440 | 1028 | **43%** |
| F3 | a | 332-357 | 627 | **53-57%** |
| | b | 346-355 | 630 | **55-56%** |
| F4 | a | 280 | 430 | **65%** |
| | b | 280 | 456 | **61%** |
| M1 | a | 293 | 344 | **85%** |
| | b | 293 | 312 | **94%** |

### Summary

The hypothesis was not verified to be true. CT:TA dominance was not shown to be related to register control as register transition did not occur in conjunction with the CT:TA ratio reflecting equal CT and TA muscle activity. The CT:TA ratio demonstrated CT dominance in chest register as well as in falsetto register, just before and after the register transition from chest to falsetto, respectively. The TA muscle activity was seen to be dominant to the CT muscle activity only in the lowest 3-4 semitones in chest register. At higher pitches, the CT muscle activity was always dominant to the TA muscle activity. In support of that, the CT muscle attained higher levels of activation than did the TA muscle in both chest and falsetto registers for all subjects. Throughout the pitch range, the CT muscle activity increases robustly, and the TA muscle activity increases slightly or maintains a given value. It is therefore not accurate to use the terminology "Cricothyroid Dominant Production" to describe falsetto register production or "Thyroarytenoid Dominant Production" to describe chest register production.

There was a consistent location of register transition within each subject's glissando. The register transition was consistent within subject. Also, males had a much larger chest range than the females, and females had a much larger falsetto range than did males.

# CHAPTER V
# DISCUSSION

The primary purpose of this study was to determine whether falsetto register is characterized by CT muscle dominance and chest register characterized by TA muscle dominance. Testing the hypothesis helped to clarify the validity of the TDP and CDP terminology. The results of this study indicate that CT dominance did not cause transition to falsetto register, nor did TA dominance define chest register. The majority of chest register, and all of falsetto register, were produced with CT muscular dominance. Only the lowest 3-4 semitones in chest register were produced with TA dominance, and the subsequent 8-15 semitones of chest register and 3-11 semitones in falsetto register were then produced with CT dominance. Because so little of the pitch range is produced with TA muscular activity dominance, but so much of it is produced with CT muscular activity dominance, and a transition from TA to CT dominance does not result in register transition, it seems inappropriate to define the vocal registers based on CT or TA muscular dominance.

To develop the significance of the results from the present study and to establish the consistency seen in similar studies, the results are first compared and contrasted with data from relevant literature. Discussion of the results, any unexpected data points, and what physiological phenomena these data may be reflecting then follows. There is next a discussion of the possible origins of CDP and TDP terminology, the limitations of the study, and future research directions.

**Comparison of Current Results to Previous Studies**

*Register Transition With Pitch Change:* The CT and TA EMG activity data analyzed in this study were consistent with data from previously reported studies of register change during glissando. CT muscle activity increased with register transition from chest to falsetto register during pitch increase for all subjects. For four of five subjects, TA muscle activity increased slightly with register transition from chest to falsetto register during pitch increase: much less robustly than did the CT. This finding was consistent with previous reports (Hirano et al., 1969; Gay et al., 1972; Kochis-Jennings et al., 2012).

However, our measures of relative activity of CT and TA muscles were different than those reported by Shipp & McGlone (1971). Shipp & McGlone (1971) reported TA muscle activity ranging from 30%-75% maximal activation throughout the pitch range for his male subjects. In the present study, TA muscle activity ranged from 16%-28% for the male, and 9%-27% for the females, throughout their pitch ranges. This difference is attributable to the fact that Shipp & McGlone (1971) used a phonatory task to determine the maximum activation of both the CT and TA muscles, and the present study used both phonatory and non-phonatory tasks for data normalization of the TA and CT muscles. Because the CT muscle is maximally active during high-pitched phonation, Shipp & McGlone (1971) CT EMG data are used for comparison, but not their TA EMG data.

CT muscle activity does increase more with pitch increase than does the TA muscle activity, and this disparity is due to the fact that the TA muscle is maximally activated during swallow, not phonation (McCulloch, Perlman, Palmer, and Van Daele, 1996), whereas the CT muscle can be maximally (i.e. 100%) active during phonation.

McCulloch et al., (1996) recorded EMG activity data from the TA muscle of one female and six male subjects during a variety of phonatory, valsalva, and swallow tasks. They found that, of these tasks, phonation required the lowest levels of TA muscle activation, followed by valsalva, and then by swallow for the highest level of TA muscle activation. Of phonatory conditions, low pitch phonation required the least TA EMG activity, then comfortable pitch required the second most, and high-pitched phonation required the highest level of TA EMG activation. The average maximal activation of the TA muscle at high-pitched phonation was 40.5% with a standard deviation of 19.4%. In the present study, average maximal TA activity did not exceed 28%, which confirms McCulloch et al.'s (1996) data. Valsalva required an average of 60% TA EMG activity, and swallow required an average maximal activation of the TA muscle of 81% with a standard deviation of 8.8%. This highlights the fact that the TA muscle serves a wide range of functions, and is activated with register transition and increasing pitch, increasingly activated to adduct the vocal folds further, closing the glottis, and serving the functions of valsalva and swallow.

The CT muscle reached significantly higher levels of maximal activation than the TA muscle at higher pitches in the present study, which confirms previous fundamental frequency and register related literature (Kochis-Jennings et al., 2012). CT muscle activity will dominate TA muscle activity as pitch increases, because the two muscles start with similar levels of activation, and then the CT muscle increases at a faster rate and to a higher level of activation than does the TA muscle (Shipp and McGlone, 1971; McCulloch et al., 1996).

Another observation based on the present data is that there seems to be a different mechanism for pitch control at the highest pitches in the vocal range. At the highest pitches in falsetto in the present study, CT activity was shown to decrease for many of the subjects (Figure 2). CT muscle activity increase lengthens the vocal folds, so the present data support the previous finding of decreased vocal fold length with pitch increase (Nishizawa, Sawashima, & Yonemoto, 1988).

**Understanding CDP and TDP Terminology**

This terminology likely has several origins. First, the mechanisms of pitch and register control may have been conflated. Both the CT muscle (i.e. the primary muscle of pitch control), and the TA muscle increase activation with pitch (Sawashima et al., 1969; Baer et al., 1975), yet CDP is often described as having a relaxed or inactivated TA muscle (Hirano, 1987; Bateman, 2002). TA and LCA muscular activation are important for vocal fold adduction, which is relatively greater in chest than in falsetto, and as a result may lead people to believe that chest register, or lower pitches, are thyroarytenoid dominant. Second, the CT or TA muscular dominance nomenclature might have resulted from the notion that the CT and TA muscles were both capable of maximal activation during phonation. Previous to the McCulloch et al. (1996) study, it may have been thought that the TA muscle, like the CT muscle, was capable of attaining maximal activation during phonatory tasks.

Register has a different control mechanism than does pitch. The CT muscle has been considered by many to be the primary intrinsic laryngeal muscle in pitch control (Sawashima et al., 1969; Baer et al., 1975; Titze et al., 1988b), but a primary intrinsic laryngeal muscle in register control has not been defined. An argument has been made that change in TA muscle activity may be more important than change in CT activity for register control (Baer et al., 1975). Both CT and TA muscle activity increased with transition from falsetto to chest register at sustained lower and mid-level pitches (Sawashima et al., 1969; Gay et al., 1972; Baer et al., 1975), but not at higher pitches (Baer et al., 1975). Baer et al. (1975) reported CT and TA muscle activity levels of one subject during register transition at steady pitch (220 Hz, 330 Hz, and 440 Hz), and found that the TA muscle activity seemed to change the most consistently with register transition. Both the CT and TA muscle activities increased during transition from falsetto to chest register at 220 Hz and 330 Hz; but at 440 Hz, the CT muscle activity change was negligible, while the TA muscle activity still increased to produce chest register. Additionally, the TA and LCA muscles are important for vocal fold adduction. The vocal folds are generally more adducted in chest register than in falsetto register, and this may be another reason that the TA muscle is considered to dominate the CT muscle in chest register. It is not clear if the TA muscle is the primary muscle in control of register, and it seems doubtful that the CT muscle is in control of register, so it is uncertain to label the vocal registers based on dominance of the activity of one of those two muscles.

The TA does not become maximally activated during phonation, though it does continue to increase in activation to varying degrees until the highest pitches in falsetto register. The TA muscle does not “relax” during productions of falsetto register (Hirano, 1987; Bateman, 2002). The TA is maximally activated during non-phonatory, as opposed to phonatory, tasks. TA activity measurements will not increase above 40.5% maximal average activation during phonation (McCulloch et al., 1996), and the CT EMG can increase up to 100% maximal activation during phonation (Shipp & McGlone, 1971;

Kochis-Jennings et al., 2012). While the idea of the CT and TA EMG activity levels reaching maximum activation may lead to discussion of dominance of one muscle over the other, it seems there is more to the picture of register control than CT to TA dominance. It is incomplete to say that falsetto is “the register in which the CT muscles often are most active” (Hirano, 1987; Edwin, 2008), because while the CT muscle is more maximally activate than the TA muscle in falsetto register, both CT and TA muscles approximate their maximum phonatory activation levels within falsetto register (i.e. the CT muscle at 95% activation and the TA at ~28% activation).

Because pitch change and register transition tend to occur simultaneously, higher pitches occurring in conjunction with falsetto register, and lower pitches in conjunction with chest register, it may be difficult to uncouple the two functions, but there is clear evidence that there are different mechanisms at play in pitch and register control. Due to what is known about the TA and CT EMG activity during phonatory and non-phonatory tasks, as well as pitch increase, it is expected that the CT muscle would begin to dominate the TA muscle with increasing pitch, and then continue to dominate the TA muscle until the end of the pitch range, which was confirmed by the present study.

This is a preliminary study to determine if there are physiologic (EMG) data to support the use of the term TDP as a synonym with chest register, and CDP as a synonym with falsetto register. The data represent a narrow population and could be vulnerable to judgment reliability. Our subjects were all untrained voice users, and only one of them was male, so the data aren’t necessarily representative of those populations.

It would be interesting to conduct this study again on more subjects, particularly with more males and subjects with singing training to see if the results would remain consistent or if they would change. There have not been many EMG studies of the larynx looking at register control that have used modern techniques of normalization, so it would be a huge asset to increase available data. It would be good to try to understand what is different about subjects like F1, whose TA activity level is never dominant to the CT activation level. As chest register and falsetto register occurred within similar ranges of CT:TA activity on average for the female subjects and for the male subject, it would be interesting to explore these values to see if there is some way to define the “zona di passaggio” with a certain combination of CT:TA ratio activity and airflow (i.e. CT:TA ratio range in chest register for females: 0.8-3.6, for males: 0.6-3.7; and CT:TA ratio range in falsetto register for females: 2.5-4.0; and for males: 2.6-3.9). It would be interesting to further explore the theory of increased vocal process adduction in chest register by introduced by Van den Berg (1963), and verified by Kochis-Jennings et al. (2012), as it relates to TA and LCA (lateral cricothyroid) EMG, and whether the increased TA and LCA activity in chest register is related to vocal processes adducting.

# CHAPTER VI
# CONCLUSION

In testing the stated hypothesis that falsetto register is due to cricothyroid dominance and chest register is due to thyroarytenoid dominance, the hypothesis was not proven true. There is not a relationship between CT dominance and the transition from chest into falsetto register, nor is chest register controlled by TA dominance. As a result of that, the use of the terminology CDP and TDP was not verified to be appropriate for describing falsetto and chest register, respectively.

The delineation of chest and falsetto register with TDP and CDP terminology is misleading. Muscular dominance does not lead to register transition and, unlike the CT muscle, it is not possible for the TA muscle to become maximally activated within the phonatory range, so the CDP and TDP terminology does not seem an accurate description of the physiology underlying register control.

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