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Investigating the utility of ultrasound visual biofeedback in voice instruction for two different singing styles

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INVESTIGATING THE UTILITY OF ULTRASOUND VISUAL BIOFEEDBACK IN VOICE INSTRUCTION FOR TWO DIFFERENT SINGING STYLES

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has been approved as meeting the requirement for the Degree of Master of Arts in College of Natural Health Sciences, School of Human Sciences, Program of Audiology and Speech-Language Sciences.

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ABSTRACT

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Purpose: The purpose of this study was to investigate the potential utility of incorporating real-time visual biofeedback using ultrasonography to teach important concepts of vocal pedagogy to voice students. Exploration of innovative teaching tools, such as ultrasound visual biofeedback (U-VBF) in singing instruction, may contribute to bridging the gap between voice science and pedagogy by providing alternative ways to improve students' kinesthetic awareness, clarify complex topics in voice physiology and acoustics, and create a common dialogue between different professionals specializing in voice. The primary research questions addressed in this study were: (a) To determine the current knowledge and attitude among voice teachers regarding use of visual biofeedback in singing instruction; (b) To determine voice teachers' interest in learning about technology, specifically U-VBF; (c) To identify external variables that influence voice teachers' perceptions of the usefulness and ease of use of U-VBF; and (d) To determine voice teachers' attitudes of using U-VBF in teaching after viewing an instructional video.

Methods: A pre-post survey design was adopted to assess perceptions, attitude, and interest of professional voice teachers regarding use of U-VBF before and after viewing of an instructional video on the use of ultrasound to teach concepts, such as vocal timbre, for two different singing styles: musical theater and opera. Multi-sampling methods were used to recruit professional voice teachers across the U.S. and abroad. Survey data were collected between

February and April 2021. Following assumptions made by the Technology Acceptance Model (TAM) regarding user technology acceptance and behavior, data based on a final sample size of 56 participants were analyzed via descriptive statistics and thematic analysis of qualitative data.

Results: Despite being largely unfamiliar with U-VBF, most participants initially expressed high expectations, believing it to be helpful in singing instruction, but difficult to use. Those who expressed more positive opinions regarding use of U-VBF in singing instruction also expressed higher levels of interest in using it in their teaching. Perceived usefulness, ease of use and interest of U-VBF were not found to be prominently related to select external variables. While perceived usefulness of U-VBF slightly declined post-viewing of the instructional video, perceived ease of use and participants' opinions of effective use increased. Interest in the use of U-VBF as well as likelihood to use U-VBF marginally increased after viewing the video.

Conclusions: These findings agree with the assumptions made by the TAM regarding associations between familiarity, perceived usefulness, perceived ease of use, and interest. Comparison between the rankings for perceived usefulness of U-VBF pre- and post-viewing of the instructional video suggests a general sense of uncertainty among voice teachers regarding use of U-VBF in singing instruction. While teachers conveyed high levels of interest, opinions of U-VBF to teach vocal pedagogy concepts slightly declined following viewing of the instructional video, suggesting a lowering of expectations. However, increased perceptions regarding ease of use indicated high levels of believed self-efficacy in using U-VBF. Understanding the relationships between perceived usefulness, ease of use, and interest can shed insight on whether voice teachers would adopt U-VBF as a supplementary tool in singing instruction.

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TABLE OF CONTENTS

CHAPTER

IV. continued

CHAPTER

APPENDIX

LIST OF TABLES

Table

LIST OF FIGURES

Figure

Figure

TERMINOLOGY

Belting: a singing style specific to musical theater that is characterized as an extension of modal or chest voice to a higher pitch range through articulatory adjustments, including a higher laryngeal position and anterior placement of the tongue so that a “bright” and “speech-like” timbre is produced (Bourne & Garnier, 2012).

Chest register (voice): classically conceived of as the lowest register of the voice; however, it is more recently aligned with conceptions of vocal resonation, specifically the sympathetic sensations felt in the chest as result of vocal fold vibration and change in vocal timbre often described as having as a richer, darker, and heavier tone quality (Stark, 2008).

Chiaroscuro: a term used in classical singing pedagogy to describe a balance between light and dark vocal timbres, which is characterized by a comfortably low laryngeal position, appropriate vowel modification, a strong fundamental, and a rich spectrum of higher harmonics (Stark, 2008).

Contemporary Commercial Music (CCM): a term used to describe nonclassical singing styles such as musical theater, pop, rock, gospel, jazz, etc. (LoVetri, 2008).

Formant: historically defined as a broad peak in the output spectral envelope of speech and singing; however, the term has also been used to refer to a resonance of the vocal tract. The first two formants (F1 and F2) are largely responsible for vowel intelligibility, while F3-5 contribute more to tone quality and carrying capacity of the voice (Wolfe et al., 2008).

Formant tuning: refers to articulatory adjustments made during singing to match a resonance frequency to a particular harmonic to initiate changes in intensity and tonal quality (Titze, 1995).

Head register (voice): classically conceived of as the register above chest voice; however, it is more recently aligned with conceptions of vocal resonation and was redefined as the sympathetic vibrations felt along the bridge of the nose and cheekbones during singing of higher pitches and change in vocal timbre often described as having a lighter and brighter tone quality (Stark, 2008).

Legit: short for "legitimate;" refers to a singing style in musical theater that is characterized by a bright, but warmer tone than what is heard in belting. It is considered to be the closest in timbre to what is heard in classical singing (Green et al., 2013).

Mix: refers to a singing style in musical theater that is an intermediary between belting and legit, which is characterized by a balance between head and chest registers, speech-like quality, and bright timbre (Green et al., 2013).

Musical Theater (MT): a type of theatrical performance which integrates song, dance, and spoken dialogue (The Editors of Encyclopaedia Britannica, 2020).

Opera: a form of theatrical entertainment in which most of the words in a dramatic or comedic script are sung and is often accompanied by an orchestra or large ensemble of different musical instruments (Weinstock & Hanning, 2021).

Passive modification: a term proposed by Bozeman (2013) in his book *Practical Vocal Acoustics,* which describes a change in vowel quality during a change in pitch while retaining vocal tract shape. The change in vowel quality results from a change in relationship between the stable formant frequencies and the shifting harmonics.

Resonance: refers to an increase in amplitude of a vibration as a result of an applied force synchronized with the natural frequency of a vibrating object (Behrman, 2018). In voice science, resonance relates to the configuration and resulting filter function of the vocal tract (Wolfe et al., 2008). It is often used interchangeably and incorrectly to refer to intensity, focus, and tone quality of the singing voice.

Singer's formant: a clustering of the third, fourth, and fifth formants (F3, F4, F5) to form a prominent peak in the spectrum envelope around 3kHz in all vowel spectra, which assists in amplifying the singing voice over competing acoustic signals (i.e., a full orchestra). It is particularly apparent in the male singing voice and classical singing style (Sundberg, 1987).

Source-Filter Theory: describes a linear system where sound is produced by the vibration of the vocal folds (for voiced phonemes), turbulent airflow (for unvoiced phonemes), or another sound source which is then shaped by a filter (resonances of the vocal tract) created by varying configurations of the vocal tract to produce different perceived vowels and consonants (Behrman, 2018).

Ultrasonography: a radiologic technique in which high-frequency sound is used to image soft-tissue structures for the purpose of diagnosis or as a treatment approach in providing real-time visual biofeedback (Sugden et al., 2019).

Visual Biofeedback: a therapy technique used to provide visual information on the movement and/or position of a body part, such as the tongue, during a behavior of interest, such as in speech or singing (Preston, McAllister Byun, et al., 2017).

Vocal timbre: in vocal pedagogy, refers to the tone quality of the singing voice, often specified by descriptions such as color, warmth, bright, or dark as influenced by the harmonic content of the waveform, time envelope (attack, sustain, and release), and vibrato or frequency modulation (Sundberg, 1987).

Vocal tract: often described as the “filter,” and is conceived as an open-closed tube of varying diameters along its length of which changes in configuration initiate changes in resonant frequencies and vocal timbre. Anatomy of the vocal tract encompasses the pharynx, oral and nasal cavities, and includes the larynx, pharyngeal walls, jaw, tongue, and lips (Behrman, 2018).

Vowel equalization: a strategy used in singing to create changes in resonance, often to preserve timbral unity through conscious manipulation of the larynx, tongue, jaw, and lips; typically involves the neutralizing of vowels to obtain a balanced timbre through centralized tongue postures (Dromey et al., 2011).

Zona di passaggio: a cross-over or transition point in a singer’s register where modifications must be made to the vocal tract to preserve timbral unity, relative vowel intelligibility, and intensity (Bozeman, 2013).

CHAPTER I

INTRODUCTION

In 2019, the National Association of Teachers of Singing (NATS) reprinted an article originally published in 1959 by Van den Berg and Vennard advocating for the development of objective definitions for terminology used in the instruction of singing (Van den Berg & Vennard, 1959). Controversy between the art and the science of the voice has been a prime subject of debate since the invention of the laryngoscope by Manuel Garcia II in 1855 (Stark, 2008). Over the years, efforts to bridge this divide have been made by organizations such as NATS to establish a standard vocabulary across singing styles. Additionally, contributions from neighboring fields, including laryngology, speech-language pathology, and vocology have provided further enlightenment on the function of the singing voice, and prompted the formation of interdisciplinary foundations such as The Voice Foundation, the Pan American Vocology Association (PAVA), and The National Center for Voice and Speech (NCVS).

Although surveys (Ware, 2013) have reported integration of voice science with traditional use of imagery in voice instruction, conflicting terminology reflects persisting disagreements and confusion across disciplines concerning the main aspects of vocal technique, including loudness/intensity, breath management, resonance, vibrato, and registration (Hoch & Sandage, 2017). Consequently, pedagogical dialogue has remained vague, with many teachers continuing to rely on imagery to depict physiology or convey proprioceptive and acoustic sensations associated with the desired singing style (Ekholm et al., 1998; Kwak et al., 2014; R. Miller, 2006). In his book *The Art of Singing*, R. Miller (1996) cautions against the use of imagery in singing instruction, arguing that it is more likely to hinder rather than aid a young singer's vocal development. While imagery may serve a purpose in assisting understanding of the anatomy and physiology of the voice, it will not be effective if an incongruity exists between teacher and student in their respective understanding of how these descriptions pertain to function (R. Miller, 1996). According to R. Miller (2006): "In attempting to communicate impressions, instincts, and descriptive language, the teacher may not communicate the concrete information that the student requires" (p. 200). Given the turn-taking that occurs between initiating and responding in a voice lesson, misinterpretation can occur when the student's singing behavior influences the teacher's feedback, or when a student makes changes in his/her singing behavior as a result of feedback (Welch et al., 2005). Consequently, cues such as "placing the tone" or "singing into the mask" may invite a young singer with little to no knowledge of anatomy and physiology of the voice to adopt poor vocal habits. Furthermore, several surveys have noted the variability in self-reported knowledge among voice students with regard to anatomy and physiology of the voice (Braun-Janzen & Zeine, 2009; Kwak et al., 2014; Sielska-Badurek et al., 2017). Coupled with the demands of rigorous practice and performance schedules and inadequate knowledge of the function of singing, voice students may adopt maladaptive habits increasing their risk of developing a voice disorder (Kwak et al., 2014).

In their article, Van den Berg and Vennard (1959) recommended three ways in which to approach more objective vocabulary including the dissemination of acoustic samples demonstrating specified techniques, acoustic analysis of voice samples, and investigation of physical changes associated with acoustic correlates through the use of technology such as the X-ray. In particular, the use of acoustic analysis of spectrograms has been explored to better understand the singing voice. Spectrography has also been used as an instructional tool in the voice studio. The development of computer software such as the Madde Voice Synthesizer, WingsingAD, PRAAT, and Voce Vista has provided accessible methods offering visual real time biofeedback to voice students and objective assessments and clarification of instructions for voice teachers (Bozeman, 2013; Howard et al., 2005; D. G. Miller, 2008).

In addition to acoustic analysis, imaging technology such as magnetic resonance imaging (MRI) and most recently, ultrasound, has also been used to advance research investigating vocal tract configuration during singing as well as to examine the physiological differences between singing styles, the two most commonly explored being musical theater and classical singing or opera (e.g., Bresch & Narayanan, 2010; Echternach et al., 2008, 2010, 2014; Hosbach-Cannon et al., 2020; Sundberg, 2009). Recently, with increased affordability and access via portable devices that can be linked to PCs, laptops, and iPhones, ultrasound has become a popular mode of visual biofeedback in speech-language pathology, specifically in clinical application. As a non-invasive means with which to visualize tongue movement during speech or sustained voice tasks, ultrasound visual biofeedback (U-VBF) has been used to supplement intervention approaches for residual speech sound errors and motor speech disorders, as well as for assisting in accent modification (e.g., Bernhardt et al., 2005; Cleland et al., 2018; Gick et al., 2008; Sugden et al., 2019). Positive outcomes from these studies support the potential benefit of U-VBF in voice instruction, particularly in achieving the desired vocal timbre of the preferred singing style. Additionally, provision of a visual reference might contribute more clearly to knowledge of performance and results, improving both the voice students' and teachers' understanding of vocal acoustics (Hosbach-Cannon et al., 2020; Howard et al., 2005).

Despite increased inquiry regarding the efficacy and use of U-VBF in speech-language pathology, a dearth of research currently exists for its potential use in enhancing traditional voice training. Recent efforts to adopt an evidence-based framework for voice pedagogy have encouraged consideration of research, expertise and experience of the teacher, student goals and perspectives as foundational to successful instruction (Gill & Herbst, 2016; Ragan, 2018). Consequently, it is imperative that voice teachers develop clearer language to describe the physiological and acoustic characteristics associated with the terminology they employ. Additionally, speech-language pathologists (SLPs) choosing to specialize in voice therapy for singers, need to be knowledgeable of the language present in the voice studio, as well as of the different demands and physiological maneuvers used to achieve the desired vocal timbre when addressing voice dysfunction.

The development of a shared vocabulary among voice teachers and SLPs can further promote interdisciplinary collaboration aimed at the (re)habilitation of the singing voice with respect to the aesthetics and performance demands for the preferred singing style. Continued research exploring the efficacy and effectiveness of visual real-time biofeedback methods, such U-VBF in voice instruction, could provide valuable insight to both voice teachers, their students, and SLPs, and encourage a common dialogue by contributing toward development of objective definitions for subjective terminology.

Study Purpose

The present study investigated attitudes and perceptions of professional voice teachers regarding the potential utility of U-VBF in singing instruction, and opinions regarding whether information from U-VBF can serve as an effective instructional tool in singing instruction for different pedagogical concepts, such as achieving the desired vocal timbre. This research may help to better integrate the understanding and adoption of voice science tools in the voice instruction of singers.

Specific Aims (SA)

The specific aims of this study included the following:

SA1 To administer a survey to professional voice teachers who teach at a university, college, or private studio that determines current attitudes toward use of technology providing real-time visual biofeedback in voice instruction.

SA2 To distribute an instructional video on the basics of ultrasound and use of U-VBF in instruction of vocal timbre for two different singing styles (musical theater and classical singing).

SA3 To administer a post-video survey that evaluates changes in perception toward use of U-VBF to teach different vocal pedagogy concepts, such as vocal timbre, in voice instruction.

Research Questions (Q), Hypotheses (H), and Assumptions (A)

This study was guided by the following research questions, hypotheses, and assumptions.

Q1 What is the current knowledge and attitude among voice teachers regarding use of real-time visual biofeedback in singing instruction?

H1 Voice teachers' perceptions of usefulness and ease of use of visual biofeedback systems will be informed by previous experience and what they know about them.

A1 Attitude is often influenced by knowledge and experience. Currently, minimal qualitative studies have been conducted to investigate knowledge of or experience with technology providing visual biofeedback in the voice studio. Previous surveys by Ware (2013) and Gerhard and Roscow (2016) suggest that perceptions of usefulness and availability of different types of technology among voice teachers and students alike, are informed by degree of awareness, knowledge, and experience.

Q2 How interested are voice teachers in learning about using technology, such as ultrasound, to provide visual biofeedback in singing instruction?

H2 Voice teachers will express a high level of interest in learning more about how technology, such as ultrasound, can be used to provide real-time visual biofeedback in the voice studio.

A2 Results from previous experimental and survey-based studies (Barnes-Burroughs et al., 2008; Howard et al., 2005), have indicated generally positive attitudes among voice teachers toward interest in learning more about and using new technology in the voice studio.

Q3 What external variables influence voice teachers' attitudes of perceived usefulness and ease of use of U-VBF in singing instruction?

H3 Attitudes toward U-VBF will be influenced by external variables, such as age, voice type, years of teaching experience, education level, knowledge regarding voice anatomy, physiology, and acoustics, setting as a voice teacher, and place of residence (region).

A3 External variables influence perceptions of usefulness and ease of use, which in turn informs attitude toward use of a system.

Q4 After viewing an instructional video on the use of U-VBF during singing, what are voice teachers' attitudes regarding perceived usefulness and ease of use of U-VBF in singing instruction, and what is their level of interest in learning more about U-VBF and their reported intention for using it in the future?

H4 Viewing of an instructional video demonstrating use of U-VBF during singing will increase voice teachers' level of interest and attitudes regarding perceived usefulness and ease of use, as well as intention to use this mode of biofeedback in the future.

A4 Training is an important influential component for promoting positive perceptions and intention to use a new technology system, such as U-VBF, as a supplementary teaching tool in singing instruction.

CHAPTER II

REVIEW OF LITERATURE

Literature Overview

The following review discusses issues with terminology commonly used in vocal pedagogy, specifically, vocal resonance and vocal timbre, and includes literature relevant to understanding the role of lingual movement in the singing of musical theater and classical singing styles. Literature focusing on the application of visual biofeedback, including current research on U-VBF is next discussed, followed by an investigation into voice teachers' attitudes toward including voice science and technology in singing instruction.

Vocal Resonance *versus* Vocal Timbre

Opinions regarding vocal technique tend to be highly subjective. Perceptions of the act of singing are often based off aural perceptions, impressions of proprioceptive feedback, aesthetic preferences, and the personal experiences and training of the voice teacher. Consequently, definitions of terms for concepts related to vocal technique tend to be inherently subjective and are not always based on anatomical or acoustic reality. For example, terms such as vocal resonance and vocal timbre have often been used interchangeably in vocal pedagogy; however, important distinctions exist between the two. The following section briefly discusses the difference between vocal resonance and vocal timbre.

Vocal Resonance

Resonance is a term in singing that, as Vennard (1967) noted, "has been used so much that it means something different almost every time it is used" (p. 13). In fact, vocal resonance is defined in several different ways within the fields of voice pedagogy, speech-language pathology, and voice science.

In voice science, resonance is broadly defined as an increase in amplitude of a vibration due to an applied force that is synchronized with the natural frequency of an object (Behrman, 2018). Regarding speech and singing, resonance stems from the resulting acoustical effects exerted on the sounds that propagate through the vocal tract Fant, (1960). The word formant has often been equated with resonance; however, the two terms are conceptually distinct. Historically, formant has been defined as the peak frequency or pressure maxima in the spectrum envelope of the output sound (Titze et al., 2015; Wolfe et al., 2008). Resonant frequencies as originally described by Fant (1960), relate to the physical properties or configuration and resulting filter function of the vocal tract (Wolfe et al., 2008). Considering these distinctions, formants are interrelated but not necessarily synonymous with resonance frequencies.

From the voice therapy perspective, resonant voice is defined as being easily produced with a forward focus and perceived increase in loudness or carrying capacity of the voice (Rakerd et al., 2019). As defined by Boone et al. (2010), resonance is a “selective amplification and filtering of the complex overtone structure by the cavities of the vocal tract after the tone has been produced by the vibration of the vocal folds” (p. 285). Resonance is also used in relation to normal or abnormal function of the soft palate (Boone et al., 2010), prompting some voice pedagogues to argue against the use of the term resonance to describe aspects related to tone quality in singing (Hoch & Sandage, 2017).

In vocal pedagogy, resonant voice has been linked to proprioceptive sensations of vibration felt in the face, leading to use of descriptors such as “singing into the mask,” “placement” or “ring” (Salvador & Strohauer, 2010). Other descriptors based off acoustic and proprioceptive impressions include "color," "balance," and "clarity/focus," (Ekholm et al., 1998; R. Miller, 1996; Van den Berg & Vennard, 1959). Apart from being connected to vocal timbre, resonance is also referenced in relation to the singer's formant or a clustering of formants resulting in a perceptual increase in the acoustic carrying capacity of the voice (Sundberg, 1987). Resonance work in the voice studio typically focuses on improving tone quality and projection of the singing voice, often with use of different metaphors and explanations based on the experience of the voice teacher.

As evident, resonance is a term with several connotations both within voice science, speech-language pathology, and vocal pedagogy. To avoid confusion between terminology, Titze et al. (2015) proposed use of consistent symbolic notation to clarify references to harmonics, resonances, and formants. The proposed nomenclature will be used in later discussion to distinguish between harmonics (f_n) with the fundamental frequency being (f_0), formants (F_n), and resonant frequencies (R_n).

Vocal Timbre

Interchangeable use of resonance and vocal timbre in singing instruction may stem from the close relationship between these two concepts. Resonances produced by configuration of the vocal tract are important in the production of phonemic information and contribute to loudness and efficiency. Changes in the shape of the vocal tract alter the amplitude and harmonics of the original sound resulting in the unique tonal quality of the voice or what is perceived as vocal timbre. (Wolfe et al., 2008). Vocal timbre is an important subject in vocal pedagogy as tonal ideals define the aesthetic requirements of the singing style. For example, the term *chiaroscuro* is most notably referenced in classical singing to describe the ideal tone quality indicative of bel canto or beautiful singing (Stark, 2008). Translated from Italian, chiaroscuro is interpreted as a combination of light and dark resonances, resulting in a “balanced,” “round,” and “warm” tone quality with clean vowel definition (Dromey et al., 2011). This bright/dark tone quality is often referred to by voice teachers and singers as being “resonant” (R. Miller, 1996).

In his treatise, *The Art of Singing*, Manuel Garcia (1924) connected changes in vocal timbre with changes in the shape of the vocal tract as influenced by laryngeal height and movement of the soft palate, tongue, and lips. For classical singing Garcia simplified the nuances of vocal timbre into two principles qualities: clear and “sombre” timbres (Garcia, 1924, p. 4). These tone qualities were as Garcia believed, inextricably connected with the vocal registers. While a clear timbre, when generated correctly, contributed more brilliancy to the chest register, a more sombre timbre was necessary in adding a perceptual quality of roundness and warmth, which became increasingly more necessary with the singing of higher pitches. Garcia also attributed qualities of the voice as being directly influenced by vibratory nature of the vocal folds. For example, the ringing quality of the voice was achieved by an increased percentage of glottal closure time within a given cycle and resulting greater number of overtones (Doscher, 1994). In contrast, a “veiled” or breathy vocal quality was associated with reduced glottal closure (Garcia, 1924, p. 7).

In the realm of opera, tonal ideals are also used to classify voices according to voice type or *fach* (Bozeman, 2013). Voice quality is influenced by a multitude of factors including integrity of vocal fold vibration, build-up of adequate subglottic pressure to initiate and sustain phonation, and vocal tract tuning characteristics (Stemple et al., 2020). Specifically, the fluctuating dimensions of the vocal tract cross-sectional area, cavity shape, and points of articulatory contact of the tongue, lips, and teeth play an integral role in the perceived timbre of the voice (Stemple et al., 2020). Some knowledge of acoustic-source-filter theory and the resonant characteristics of vowels in relation to articulatory processes is necessary for understanding resonance in relation to the perceived timbre of the singing voice, as well as pedagogical topics in singing such as vowel modification.

Acoustic Source-Filter Theory

The modern conception of the acoustic theory of speech production, also referred to as source-filter theory, can be largely attributed to the work of Gunnar Fant (1960). Fant's schematics show that speech sound production occurs as a result of two independent components: a sound source and a filter. Focusing on vowel production, the vibrating vocal folds act as the source by generating acoustic energy, which is the fundamental frequency and its spectrum envelope of higher harmonic partials (Titze, 1994). The supragottal vocal tract, which includes the pharynx, oral, and nasal cavities, act as an acoustic resonant filter amplifying certain harmonic frequencies, while damping others (Fant, 1960). These amplified or resonant frequencies, known as formants, are directly informed by the area function of the length and cross-section of the vocal tract and the distance from the glottis (Behrman, 2018).

The sound transfer ability, or transfer function of the vocal tract, can be conceptualized simplistically by visualizing the system as an open-closed tube. The adducted vocal folds represent the closed end, while the mouth (and nose if the velum or soft palate is lowered) serves as the open end (Behrman, 2018; Fant, 1960). Each formant is associated with a standing sound wave, where the pressure antinode occurs where the vocal folds are adducted (i.e., the closed end of the tube). While the open-closed tube provides a simplified framework from which to understand the nature of the vocal tract's transfer function, the vocal tract is more accurately conceptualized as a series of conjoined cylindrical tubes of varying diameters that act as a coupled system (Titze, 1994). For example, the oral cavity and the pharynx are conceived as a double resonator, in which different points of constriction created by the lips or tongue separate the oropharynx into two resonating cavities (Appleman, 1967). If one part of the system is set into vibration, then another part of the system will also be forced to vibrate. As a result, the influence of each resonator on the other modifies the total system (Appleman, 1967). The overall change in size and shape of the vocal tract influences the perception of speech sounds, specifically vowels, by altering its resonant frequencies and gives the voice its distinctive tone quality or timbre.

Formant Frequencies of Vowels

The transfer function and resulting pattern of formant frequencies are determined by changes in the cross-sectional area of the vocal tract, which is influenced by movement of the jaw, tongue, velum, and lips (Sundberg, 1987). Although an infinite number of formant frequencies exist theoretically, only the first five contribute to perception of voiced sounds. The third through fifth formants (F3-F5) contribute to the carrying power of the voice and tone quality, while the first two formants (F1, F2) are primarily responsible for vowel intelligibility (Sundberg, 1987; Titze, 1994). Multiple studies have investigated the relationship between formant frequencies and their relationship with vowel intelligibility. In one seminal work, Peterson and Barney (1952) compared F1 and F2 measurements to listener perceptions of 76 speakers (33 men, 28 women, and 15 children) reciting ten English vowels in monosyllabic words. The resulting vowel quadrilateral in which the frequency of F1 is plotted against the frequency of F2 is still utilized widely today by speech-language pathologists, voice scientists, and voice teachers alike to differentiate between the different vowels. Although the first two formants are directly influenced by modifications of the vocal tract via positioning of the jaw and larynx, vowel intelligibility is primarily dictated by tongue height (high, mid, low) and advancement (front, back), as well as degree of lip rounding. The fourth formant (F4) is particularly relevant for vocal timbre and is primarily influenced by the length and cross-sectional area of the vocal tract, as informed by laryngeal position (Sundberg, 1987).

Influence of Tongue Movement on Vowel Articulation

As a muscular hydrostat, the tongue is capable of a complex range of movements. Articulation for speech and singing are comprised of rapid adjustments in lingual positioning. A number of studies have employed visual imaging to further investigate how the shifting of the tongue influences the perception of different vowels. Using measurements from lateral X-rays of a subject producing prolonged vowels, Lindblom and Sundberg (1971) constructed a model of the articulatory system and found that tongue height, as defined by the position of the tongue body in relation to the pharynx, was inversely related to the first formant (F1). As tongue height increases, pharyngeal space also increases, and F1 lowers (Sundberg, 1987). Anterior-posterior positioning, the "direction of the tongue," or tongue advancement directly influences the second formant (F2), such that as the tongue advances in the oral cavity, the size of the pharyngeal space increases and F2 increases (Lindblom & Sundberg, 1971; Sundberg, 1987).

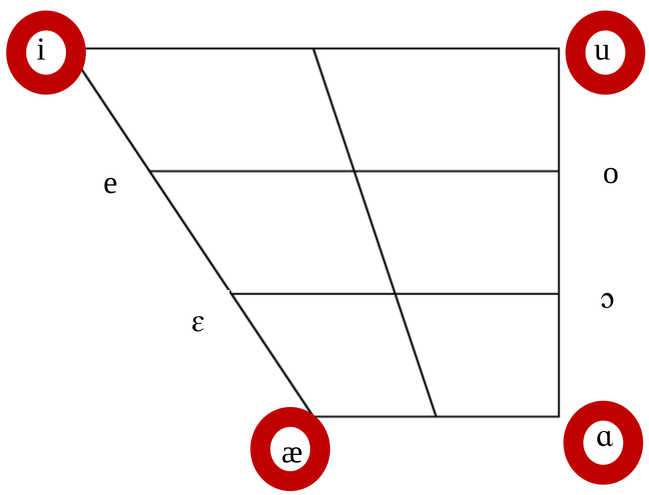
Ladefoged et al. (1978) used X-ray measurements of five different English speakers to develop an algorithm on the first three formants in an attempt to estimate vocal tract shape. Results were generally consistent with previous findings from Fant (1960), who provided tracings of vocal tract shapes for Russian vowels, as well as from Peterson and Barney (1952), and Lindblom and Sundberg (1971), although variation across speakers were noted. Ladefoged et al. found that as the tongue advances forward and assumes a higher position for a high, front vowel such as /i/, F1 is lowered while F2 is raised. Conversely, as the tongue moves posteriorly and retracts downwards for low, back vowels such as /a/, F1 is raised while F2 is lowered. Lip rounding, such as for the vowel /u/, results in uniform lowering of both F1 and F2 (Ladefoged et al.,1978).

Influence of Other Tongue Characteristics on Vowel Articulation

While the relationship between tongue height and advancement and F1 and F2 are well established, research has suggested that other parameters, such as tongue contour, may influence frequency patterns in vowels. In a correlational study involving eighteen healthy adults (8 men, 10 women), S. A. S. Lee et al. (2015) used ultrasonography to investigate formant articulation relationships in corner vowels (/ɑ/, /i/, /u/, /æ/; see Figure 1). Participants were instructed to sit upright and produce prolonged iterations of the target vowels. An ultrasound transducer was held by a physician at the midsagittal plane of the mandible to capture images of tongue movement for each vowel.

Figure 1

Vowel Diagram Showing Circled Corner Vowels



In addition to influence of tongue height and tongue advancement, S. A. S. Lee and colleagues proposed that the shape of the tongue body also plays an important part in the different formant patterns of vowels. As tongue body shape can vary between individuals, differences of tongue shaping, can cause small, but influential changes in the shape of the vocal tract during speech. Length of the anterior oral cavity (L_{AOC}), defined as the linear distance from the peak of the tongue dorsum to the tip of the lower incisors, was measured to analyze changes in F2. Length of the posterior tongue surface (L_{PTS}), or the length from the tongue peak to the boundary where the tongue contour was obscured by the acoustic shadow of the hyoid, was also measured for comparison with changes in F1. This parameter was chosen as the shape and length of the tongue base can also influence vowel formants and their resulting clarity. Comparison of formant frequency and tongue image movement indicated a negative, weak correlation between F1 and tongue height in comparison to a stronger negative correlation between F1 and L_{PTS}. The correlation between F2 and tongue advancement, as well as L_{AOC} were both significant, although a slightly stronger correlation existed between F2 and $L_{AOC.}$

Influence of Tongue Movement on Vocal Timbre

Apart from influencing vowel intelligibility, tongue movement also affects the overall length of the vocal tract and configuration, influencing vocal focus. Vocal focus, which is often referred to by voice teachers as “ring,” “ping,” or “placement” (R. Miller, 1996), describes the relationship between vocal tract length and the perceived brightness or darkness of the voice (Bressmann et al., 2017). A bright or forward focus results from a shortened pharyngeal space, raised larynx, and higher tongue arch, raising F1 and F2 and resulting in a higher sound level of the singer’s formant. Conversely, dark, or backward focus results from a lengthened vocal tract and posterior placement of the tongue arch, which lowers the formant frequencies and sound level of the singer's formant (Vurma & Ross, 2002). Muscles from the tongue and mandible attach to the hyoid bone from above and in front to form what is known as the hyoid sling. As a result, the muscles of the tongue directly influence the position of the larynx (Stemple et al., 2020).

Laryngeal position plays a crucial role in vocal timbre. Sundberg and Nordström (1976) demonstrated the effect of laryngeal position on formant frequencies of twelve Swedish vowels produced by two adult speakers, one a phoniatrician and the other a singer. Using long-term-average-spectrum analysis, raising of the larynx during production of front vowels was observed to correlate with an increase in F2 and relatively little change in F1. For back, low vowels, both formant frequencies increased with a higher laryngeal position. Laryngeal height additionally impacted F3 and F4 values. In general, a drop in F3 and F4 frequencies was associated with a lowered larynx, while an increase in these frequencies coincided with a raised larynx. A surprisingly low F3 value was noted for the singer, which the investigators attributed to the tongue being pulled slightly back during the sustained spoken vowel tasks.

While Sundberg and Nordström (1976) attribute their observations primarily to laryngeal height and its influence on the overall length of the vocal tract, they noted difficulty in controlling for changes in tongue position due to the connection of both structures via the hyoid bone. Bressmann et al. (2017) investigated whether global tongue movements would change with a shift in laryngeal height. Sixteen female college-age students were asked to produce a "forward" and "backward" voice. Forward voice entailed raising the larynx and bringing the tongue forward without changing pitch, while backward voice involved lowering the larynx and retracting the tongue in a yawn-like maneuver. Participants were asked to read a total of seven sentences (six with no nasal phonemes and one rich with nasal consonants) while tongue movement was captured via ultrasound. Analysis showed that mass and mobility of the posterior portion of the tongue decreased, and cumulative displacement was low for the forward voice. Conversely, the center of the tongue had higher cumulative displacement and average mobility for the backward voice. This finding was in contrast to an earlier study by Bressmann (2012), which observed reduced movement of the central and posterior tongue with backward voice. The investigators attributed these differences to variation in instruction regarding the extent of lingual contortion to produce a backward focused tone.

The relationship between tongue movement and laryngeal position is an important topic in voice pedagogy, particularly in relation to vocal timbre. The most common vocal faults related to resonation mentioned by pedagogues include over-brightening or over-darkening the tone (McKinney, 1994). Although tonal imbalance can stem from several sources, tongue tension is cited as one of the more common observations (R. Miller, 1996). A tense tongue will result in a high larynx, shortening the vocal tract, resulting in a perceptually flat and bright timbre (Bressmann et al., 2017; Timerding, 1997). Tension particularly at the base or root of the tongue is a common issue among singers attempting to achieve a darker tone (Timerding, 1997). Tongue tension additionally influences vowel intelligibility and overall clarity of articulation during singing (McKinney, 1994). As observed by Sundberg and Nordström (1976), during the sung phrase, the singer assumed a lower laryngeal position with the tongue tip articulating with the gumline of the lower back teeth. This positioning of the tongue is associated with a balanced tone and articulatory freedom (R. Miller, 1996). Hypo- or hyper-functional use of the tongue disrupts this balance, directly influencing formant frequencies of the vowels, as evidenced by Bressmann et al. (2017).

Acoustic and Physiological Characteristics of Singing

Singing involves the same anatomical structures for fine motor adjustments as speech to control acoustic resonances of the vocal tract. While research regarding formant frequencies in the speaking voice has provided valuable information for speech-related therapies, the body of literature investigating acoustic characteristics of the singing voice and differences between styles of singing is relatively small. Studies regarding the speaking voice provide valuable information on acoustic properties of vowels and tonal quality; however, voice scientists and pedagogues alike have speculated how much of these findings can be generalized to singing. While some voice pedagogues adhere to the old adage *Si canta come si parla* (One speaks as one sings), others support the idea of speaking and singing as two distinctly different behaviors. Verdolini and Krebs (1999) describe an interference hypothesis in which speaking patterns may negatively influence singing. D. G. Miller (2008) argues that while the acoustic theory of speech provides a framework in which to understand vowels and their modifications in terms of formant frequencies, the adjustment of the vocal tract needed to produce a desired timbre is more specific for singing than for speech.

Several key characteristics differentiate speech from singing including duration of pitch and loudness, relative timing, and coarticulation (Verdolini & Krebs, 1999). In speech, pitch quickly fluctuates within an utterance producing the intonation or prosody that communicates the tonal meaning of a spoken message. In contrast, singing requires sustaining target pitches without fluctuation. These sung phrases often vary widely in pitch, particularly in opera, and are produced at greater intensity levels achieved through different resonance strategies collectively referred to as formant tuning (Titze, 1995). In speech, the relative timing between vowels and consonants is approximately 1:5, whereas the ratio is reversed in singing, as vowels are significantly lengthened (Verdolini & Krebs, 1999). Timing of coarticulation, or when a speech sound is influenced by a neighboring (pre- or post) speech sound, differs in the context of singing compared to that of speech. In singing, it is important that coarticulatory influence be minimized in order to sustain the vowel sound and emphasize timbral unity, although vowel intelligibility is often reduced (Gregg & Scherer, 2006). All of these differences in fundamental parameters require variations in fine motor movements that are cultivated through explicit instruction.

The primary goal of speech is to transmit an intelligible linguistic message, whereas in singing, greater emphasis is often given to tonal beauty (Carlsson-Berndtsson & Sundberg, 1992). Classical singers dedicate years of study to obtain well-balanced resonance and the desired chiaroscuro (light/dark timbre) throughout their range, all while generating the acoustic carrying power to project their voices over full orchestral accompaniment (R. Miller, 1996). Although musical theater singers devote more attention to intelligibility, they must also meet specific tonal requirements suitable to the musical style of the show (Green et al., 2013). In addition to timbre, diction or the singing of sung text must be continuous and flow smoothly, independent of phonemic context and pitch. This technique referred to as *legato* singing requires coordination of articulatory adjustments for a vowel that the singer must maintain for several beats before moving to the next phoneme (Appleman, 1967). Lastly, in comparison to speech, singing requires deliberate manipulation of vocal timbre for the purpose of artistic expression by making intentional adjustments to the shape of the vocal tract.

Acoustic and Physiological Characteristics of Classical Singing

Acoustic characteristics of the singing voice alongside their perceptual correlates have most frequently been studied in classical singing. Several key characteristics differentiate opera from other singing styles including a low larynx, presence of the singer's formant, the chiaroscuro timbre, and vowel modification (Sundberg, 1970, 1974, 1977). While laryngeal height generally varies in normal speech, it remains relatively stable throughout the singer's respective range. This lower posture of the larynx decreases the frequency values of F3 and F4, lending the voice the *scuro* or "warmth" and "depth" associated with the classical singing voice (R. Miller, 1996). Additionally, a lower laryngeal position enables a singer to achieve what is known as the singer's formant (Sundberg, 1974). Specifically, noticeable in male singers, the singer's formant is defined as a clustering of third through fifth formants (F3, F4, and F5) around 2.8 kHz-3 kHz, which produces a "ringing" quality to the voice (Story, 2004). In comparing spectrographic measurements of various Swedish vowels from four operatic male singers to values obtained from Fant (1960), Sundberg (1974) hypothesized that a lower laryngeal position resulted in expansion of the laryngeal ventricle or sinus of Morgagni and the piriform sinuses, increasing the cross-sectional area of the vocal tract. Using a model constructed from a brass cylindrical tube 3.1 cm in diameter, Sundberg (1974) found that widening both of these structures played a role in the formation of the singer's formant by raising F3 toward F4 and facilitating a gain of 20 dB, allowing a singer to project over a full orchestra in a large auditorium.

In investigating the articulatory differences between speech and singing, Sundberg (1970) used sonograms and X-ray images to compare the formant frequencies of nine Swedish vowels spoken and sung by four trained male bass (or low voice) singers with different tonal qualities (classified as dark to light). Results indicated overall differences in formant frequencies between speech and singing when controlling for pitch and loudness. The third formant (F3) was raised for back vowels, while lowered for front vowels. The fourth (F4) and fifth formant (F5) were significantly lower in comparison to speech with the distance between F3 and F4 reduced for all vowels, indicating the pattern of the singer's formant. A lowered F2 corresponded with a lower laryngeal position, while increased jaw opening, and advancement of the tongue tip was deemed a compensatory movement to raise a lowered F1 and F3 for back vowels as a result of a low laryngeal position. Sundberg (1970) associated these adjustments with the concepts of "covering," "darkening," or "vowel coloring," all of which fall in the realm of vowel modification.

Role of Vowel Modification

In classical singing, differences in formant frequency patterns are attributed to the adjustments needed to maintain unity of vocal timbre across a wide pitch range. There is always a least one value of f_0 that matches either the first (R1) or second resonant (R2) frequency. This alignment between the fundamental harmonic and formant frequency causes a sudden increase in sound level and change in timbre. Formant frequency tuning, more commonly referred to as vowel modification, enables singers to successfully take advantage of this matching of harmonic and formant frequencies to increase perceived volume, vocal ease, and unity of timbre through conscious manipulation of formant frequencies (Appleman, 1967; D. G. Miller, 2008). These changes in vocal tract resonance are facilitated primarily by adjustments of the tongue, jaw, and lips all while maintaining a low laryngeal position (Carlsson-Berndtsson & Sundberg, 1992).

Vowel modification is a primary topic of discussion in vocal pedagogy. In his book *The Science of Vocal Pedagogy*, Appleman (1967) described it as a process of phonemic migration and subsequent vowel coloring dictated by conscious manipulation of the articulators. Influenced by the book *An Outline of English Phonetics* by Daniel Jones (1914), Appleman published a detailed analysis of speech sounds in singing, including formant charts depicting migration characteristics of each vowel alongside writing and visual descriptions of specific physiological requirements. Contained within these charts, Appleman demarcated pure vowel boundaries, or the range of frequencies for the first and second formants (F1, F2) in which perceptual integrity of the vowel remained unchanged. To achieve a pure vowel, Appleman stated that the tip of the tongue must always be placed against the bottom front teeth, a posture later noted by Sundberg and Nordström (1976) and supported in other pedagogical texts (e.g., R. Miller, 1986; Sundberg, 1987; Vennard, 1967).

In his treatise, Coffin (1987) devised a system of vocal exercises in which to facilitate vowel tracking throughout a singer's range based on tongue positioning for each vowel. Arguing that singing required gradations of change in vocal tract shape, Coffin introduced a color-coded chromatic vowel chart to assist singers with achieving balanced resonance in a process he referred to as resonance tracking. Hopkin (1997) introduced the concept of vowel equalization, positing that a balanced timbre could be achieved through centralized tongue postures, resulting in more neutralized articulatory gestures for vowels. This idea was later tested by Dromey et al. (2011) in a study involving graduate and undergraduate amateur singers between the ages of 18 to 25 years (n = 16). Participants were asked to sing opposite front and back vowels (/i/ to /u/ and /e/ to /o/) and open and closed vowels (/i/ to /e/ and /u/ and /o/) in a legato line. Following a brief training session and the description of vowel equalization from Hopkin (1997), participants repeated the singing tasks while maintaining a steady jaw position. Participants were also asked to balance /ɑ/ with /e/ and /o/, noting connections between sensations and tongue movement. Using PRAAT acoustic analysis software, formant tracks of vowel segments were generated and compared. Comparison of pre- and post-instruction measures showed that following a singing training session, singers were successfully able to assume more neutral tongue placements, achieving chiaroscuro, while maintaining relative vowel intelligibility.

One path for continued research includes perception of vowel quality both in timbre and intelligibility before and after vowel equalization. In terms of perceptual acceptability, vowel modification appears to be confined to a singer's higher range. Carlsson-Berndtsson and Sundberg (1992) found that nineteen singing teachers preferred a recording of a synthesized sung chromatic scale ranging an octave from C4 (261 Hz) to C5 (523 Hz), in which formant frequencies were unchanged in comparison to others where vowel modification occurred. The test range represents the modal register in a female singer's voice, where a sufficient number of harmonics fall below the first resonant frequency (R1). Carlsson-Berndtsson and Sundberg concluded that vowel modification within the lower range disrupted both vowel intelligibility and timbral unity, unless such a change was desired for emotional effect. Active vowel modification involving deliberate adjustment of vocal tract shape becomes necessary at higher pitches where harmonics are more spread out (Bozeman, 2013). Sound is attenuated in proportion to the distance of the first harmonic or fundamental (f_0) from R1. The higher the pitch, the more important f_0 becomes for loudness of the tone (Sundberg, 1977). Consequently, when singing high pitches, singers maintain sound pressure level (SPL) and timbral unity through articulatory adjustments, including movement of the tongue to prevent f_0 from rising above F1 (Titze, 2004).

Imaging Studies of Vowel Modification

Several imaging studies have investigated lingual movement during vowel modification in relation to acoustic and perceptual changes. Using magnetic resonance imaging (MRI), Sundberg (2009) recorded articulatory modifications employed by a professional operatic soprano when singing an ascending-descending melodic sequence on vowels /a, e, i, u, o/ at a comfortable loudness level ranging between pitches C4 (262 Hz) and G5 (784 Hz). Observed articulatory changes included jaw opening at higher pitches on close, front vowels (/i, e, u/), as well as lowering of the tongue dorsum to increase the length of the vocal tract. In contrast, jaw opening and tongue height for low, back vowels (/o, a/) were kept relatively constant up until the point at which f_0 crossed above R1. This "cross-over pitch" represents the *zona di passaggio* at which singers must modify vowels to maintain unity of timbre and vocal ease (Bozeman, 2013). Sundberg (2009) hypothesized that the singer was able to raise R1 and maintain volume and timbral unity by lowering of the tongue dorsum when singing higher pitches on closed, front vowels. From these observations, Sundberg (2009) concluded that tongue shape plays a key role in the tuning of formant frequencies.

In another study utilizing real-time MRI, Echternach et al. (2010) investigated changes in vocal tract shapes at registration points between four young, pre-professional sopranos. When singing scales on the vowel /a/, the investigators noted minimal articulatory adjustments in shifting between modal-middle and middle-upper registers, potentially showing the influence of vowel equalization proposed by Hopkin (1997). However, when f_0 approached or surpassed R1 (around F#5 or 750 Hz), active shifts in vocal tract shape were achieved through widening of the pharynx and lips, jaw opening, and elevation of the tongue dorsum, which the investigators hypothesized was associated with reduced pharyngeal constriction. Similar patterns of vowel modification were seen in a previous study employing a similar design involving two male professional singers, one a baritone and the other a tenor (Echternach et al., 2008). The subtle modifications observed by Echternach et al. (2008, 2010) across singer's registers support the pedagogical concept of passive modification in which the shape of the vocal tract is maintained while pitch moves, preserving both intelligibility and tone quality of the sung vowel (Bozeman, 2013).

While studies have noted general patterns of modification, a great amount of variability exists between singers. Differences in voice type (i.e., sopranos, tenors, basses), vocal tract length, and pitch range influence different passaggi points, influencing the resonance strategies used to maintain unity of vocal timbre (Bozeman, 2013). Echternach et al. (2010) noted differences in degree of articulatory adjustments between singers. In a study investigating differences in resonance strategies of 27 classical singers who ranged from low (altos, baritones) and high voice types (soprano, tenors), Heinrich et al. (2011) found that all singers varied values of R1 and R2 in response to variations in f_0. Sopranos raised R1 toward f_0 when singing in the higher part of their range ($500 < f_0 < 1000$ Hz). These results agree with Sundberg (2009) and Echternach et al. (2010), as well as with other previous studies (c.f. Joliveau et al., 2004; Sundberg & Skoog, 1997). In general, altos, tenors, and baritones appeared to adjust F1 over a smaller range than sopranos. Garnier et al. (2010) found that coloratura sopranos, who frequently vocalize in the highest parts of their range (ranging from C6 to D7; 1000-2300 Hz) past the upper limit of R1, resort to tuning R2 to the second harmonic ($2f_0$). Observations for more frequent vowel modification in soprano singers seem reasonable as they tend to sing for extended periods in their upper range, necessitating a sacrifice of vowel intelligibility for timbral unity and beauty.

Overall, vowel modification through conscious adjustments of the tongue, jaw, and lips, allows singers to achieve optimal sound and adeptly navigate singing across their entire pitch range, while maintaining balanced resonance. Resonance strategies are well-documented in classical singing; however, recently researchers have turned their attention to the difference between physiological and acoustic characteristics in other styles of singing, most notably, musical theater.

Acoustic and Physiological Characteristics of Musical Theater Singing

In contrast to opera, musical theater is unique in that it adopts whatever musical style suits its purpose (Green et al., 2013). Repertoire covers a wide spectrum of styles, with pedagogy drawing from techniques used both in classical singing and in nonclassical styles or Contemporary Commercial Music (CCM). Differences of voice quality in musical theater and classical singing reflect variations in a number of variables, including shaping of the vocal tract.

Acoustic characteristics of musical theater have primarily been obtained through comparative studies with classical singing. Schutte and Miller (1993) investigated differences in formant frequency patterns in relation to configurations of the vocal tract between classical and the nonclassical style singing of Broadway belting. As of yet, no uniform definition for belting exists, and its characteristics continue to be a subject of debate among voice pedagogues and scientists (Echternach et al., 2014; Popeil, 2007). Typically, belting is often described in relation to a register function, specifically the extension of the modal or chest voice to high fundamental frequencies via a higher laryngeal position and recruitment of the thyroarytenoid (TA) muscle to increase the mass of the vibrating vocal folds (Bourne & Garnier, 2012). Additional changes in vocal tract shape, such as a higher and more forward position of the tongue, have been hypothesized to contribute to a perceptually "bright" sound with little to no vibrato and a speech-like quality (Bourne & Garnier, 2012; Echternach et al., 2014; LeBorgne et al., 2010). Using EGG (electroglottograph) measurements, Schutte and Miller (1993) found that singing with the chest register involved a longer closed phase of the glottal cycle (>50%), requiring increased vocal effort. From spectrographic analysis, the first two resonant frequencies R1 and R2 appeared to be higher with R1 rising toward the second harmonic ($2f_0$). In comparison, singing in the classical style in the middle register showed lower R1 and R2 values falling below $2f_0$. The authors hypothesized that this R1:$2f_0$ tuning was associated with the more "open" singing posture in belting (Bozeman, 2013). Schutte and Miller (1993) also observed that R1:$2f_0$ tuning produced a difference in sound pressure (SPL) of more than 10 dB between the second and first harmonic and described this occurrence as a key feature of belting.

In contrast to the pattern of R1:$2f_0$ tuning observed by Schutte and Miller (1993), Bestebreurtje and Schutte (2000), noted the absence of this resonance adjustment in their case study involving a female singer belting isolated vowels (/ε/, /a/, /i/, /u/) on pitches G4 (392 Hz) and B4-flat (466 Hz). The authors concluded that these variations in results were most likely due to physiological differences, as well as the influence of other variables including skill level and artistic preference. Despite this difference, Bestebreurtje and Schutte (2000) observed vowel modifications for closed, back vowels such as /u/ to more open vowels to enhance higher harmonics, which the researchers deemed a primary feature of belting. Additionally observed, was a detuning of F1 for the vowel /i/ via opening of the vowel toward /e/, which they posited occurred as a result of efforts to maintain a "speech-like" quality during singing.

In their study, Björkner (2008) compared voice source characteristics and formant frequencies in ten professional singers, including five operative baritones and five male musical theater (MT) singers, all collectively between the ages of 29 to 44 years of age. Singers were asked to sing three repetitions of the syllable /pae/ in their chest/modal register, first at $C^{\#}3$ (139 Hz) and then an octave higher at $C^{\#}4$ (278 Hz). For the MT singers, closed quotient (CQ) values, or the percentage of the glottal cycle in which airflow is prevented by adduction of the vocal folds, were found to be greater and correlated with a weaker fundamental. Additionally, MT singers exhibited higher formant frequency values in their singing, agreeing with the observations noted in previous studies (c.f. Schutte & Miller, 1993; Sundberg et al., 1993). The researchers attributed these values, along with higher CQ values and the absence of the singer's formant to distinct timbral differences between opera and musical theater singing.

Unlike classical singing, which shares basic foundational aesthetic requirements concerning vocal timbre, belting is just one of the vocal qualities that can be adopted in musical theater. Other singing styles within the genre, such as "legitimate" or "legit" and "mix" specify different timbral requirements. For example, "legit" is more closely associated with the classical singing technique than belting and is characterized by a "round resonant tone" with rounded vowels and consistent vibration throughout (Green et al., 2013, p. 325). However, in comparison to opera, distinct acoustic and physiological differences for "legit" distinguish it as a separate style from classical singing. In describing "legit," Schutte and Miller (1993) hypothesized that the articulatory adjustments for R1:2f_0 tuning were maintained, while vocal-fold function was relaxed into a falsetto adjustment to preserve intelligibility and a brighter timbre. In a semi-structured interview of twelve international pedagogues (ages 21-38 years), Bourne and Kenny (2015) found that "legit" was associated with a more speech-like quality in comparison to classical singing. Regarding "mix," no consensus existed between pedagogues concerning its distinct acoustic characteristics, although it is generally considered to be an intermediate between "belting" and "legit" (Bourne & Kenny, 2015). Additionally, different subtypes of belting have emerged, described by their perceptual tonal qualities, such as "ringy," "brassy," "nasal," or "heavy," thereby muddying the waters in pedagogical terminology (LeBorgne et al., 2010; Popeil, 2007).

In an attempt to provide more objective definitions, Bourne and Garnier (2012) investigated the physiological and acoustic differences between different belting styles and legit singing. Six professional female MT singers were asked to sustain the vowels /e/ and ɔ/ on four pitches in three different styles including “chesty” (or “heavy) belt, “twangy” belt, and “legit.” Three of the participants additionally sang in “mix.” Analysis of audio and EGG measurements showed higher CQ and SPL values for “chesty” belt in comparison to “legit.” Additionally, R1 values remained relatively stable across all four pitches for the “legit” style, whereas for “chesty” belt, all but one of the singers exhibited R1:2f_0 tuning for both vowels up to C5 (523 Hz). This finding contrasted with the hypothesis made by Schutte and Miller (1993) about the presence of R1:2f_0 tuning in “legit.” A similar study conducted by Lebowitz and Baken (2011) also found variability in use of R1:2f_0 formant tuning in both legit and belting, concluding that this acoustic characteristic might not be as reliable a marker for musical theater singing as originally proposed.

Bourne and Garnier (2012) additionally found that R1 values were higher for belting than “legit,” although the researchers noted variation between singers and pitches. The researchers attributed R1:2f_0 and increased CQ values as contributors to an increase in SPL compared to “legit,” where lower CQ values were observed, and vowel modification was absent. No evidence of R1 tuning was observed for “legit,” deviating from observations of R1:f_0 tuning in the singing of classical sopranos for higher pitches (over B4-D5; Carlsson-Berndtsson & Sundberg, 1992; Joliveau et al., 2004). Similar to “chesty” belt, R1:2f_0 tuning was observed for “twangy” belt up until C5 (523 Hz). Vocal tract behavior for “mix” varied between singers. While one singer displayed R1:2f_0 tuning, the other two singers’ output more closely resembled the physiological and acoustic characteristics of “legit.” A similarity shared between all four singing styles was an absence of tuning of R2, which the researchers hypothesized allowed the singers to preserve vowel intelligibility and retain a more "speech-like" quality despite some loss of the distinction in vowel height due to R1:f_0 tuning (Bourne & Garnier, 2012). In comparing belt qualities, the researchers concluded that variations, such as "chesty" and "twangy" belt, did not significantly differ in regard to production; however, higher R2 values for "twangy" belt were attributed to a more forward tongue placement. Lastly, "mix" was characterized as having the most variation across singers due to differences in resonance strategies, resulting in a vocal timbre somewhere between "belt" and "legit."

The results from these research studies highlight several notable acoustic differences in musical theater compared to opera. These characteristics include the general presence of R1:2f_0 tuning, specifically in belting, a higher laryngeal position, wider mouth opening, open vowels, and a higher, more forward tongue placement. The degree to which these characteristics can be generalized outside of research, however, is limited by small sample sizes and lower evidence study designs. Social validity, however, is supported by qualitative studies documenting teachers' perceptions of musical theater singing. For example, four of the twelve teachers interviewed by Bourne and Kenny (2015) referred to the tongue as being further forward and higher in the mouth for "belting," "legit," and "mix" compared to classical singing, along with a wider mouth opening, higher laryngeal position, and some pharyngeal constriction. Although continued research including larger sample sizes and controls are needed to verify objective data with qualitative observations, this research, nonetheless, sheds light on the distinct differences in production and resonance strategies singers use to achieve the desired timbre associated with musical theater singing.

Imaging Studies Comparing Musical Theater and Classical Singing

Only recently have researchers turned their interest toward directly investigating the physiological changes associated with these acoustic differences through the use of imaging studies. Small-scale studies employing magnetic resonance imaging (MRI), and most recently, ultrasound, have provided preliminary insight into the specific articulatory adjustments that singers make to achieve the appropriate vocal timbre for musical theater and classical singing.

In a pilot case study, Echternach et al. (2014) used MRI to investigate differences in vocal tract shape in a professional female singer for two singing styles in musical theater: “heavy” belting and head voice. The participant sang ascending pitches from G3 (196 Hz) to C6 (1000 Hz) on the vowel /e/ followed by a descending triad starting on C5 (523 Hz) on the vowels /a, e, i, o, u/ in both chest and head register respectively. To assess perceptual acoustic changes associated with varying widths of the pharyngeal cavity, the singer was asked to sustain the vowel /a/ on C4 (261 Hz) three times, varying pharyngeal space characterized as neutral, constricted, and wide. Differences in vibrato style including “classical” and “jazzy,” were also explored.

Clear differences in vocal tract shape for the vowel /e/ in chest voice compared to head voice were observed. Similar to previous studies, laryngeal height was much higher in belting in comparison to the classical singing approach. Greater jaw opening, a narrower pharynx, and slightly higher tongue dorsum were additionally noted for belting, aligning with the idea that the vocal tract assumes a trumpet-like configuration for musical theater singing as opposed to an “inverted megaphone” shape for classical singing (Sundberg et al., 1993; Titze & Worley, 2009). Regarding vibrato, changes in vocal tract shape were minimal for the “classical” vibrato in comparison the “jazzy” vibrato, where laryngeal position was noted to be higher. Although belting is often considered to be vibrato free, musical theater singers often add vibrato at the ends of phrases for artistic effect, possibly warranting additional vocal tract adjustments (Echternach et al., 2014; LeBorgne et al., 2010).

Although MRI studies have provided valuable information on changes in vocal tract shape during classical and musical theater singing, several limitations restrict the generalizability of these results. MRI necessitates that the study participant be supine, which does not mimic the natural condition of singing, and may influence specifically laryngeal and jaw positioning (Echternach et al., 2014; Traser et al., 2013). Additionally, the level of MRI background noise limits concurrent acoustic analysis (Hosbach-Cannon et al., 2020). Ultrasonography provides a noninvasive means by which to view the vocal tract in the upright position and produces little competing background noise. In a recent study, Hosbach-Cannon et al. (2020) used ultrasound to investigate differences in tongue position and laryngeal height between twenty college-aged singers (10 musical theater; 11 opera) between the ages of 18 to 30 years. Participants were asked to sing sustained vowels /i/ and /a/ three times at a comfortable loudness level at pitches C4 (261 Hz) and C5 (523 Hz) for females and C3 (130 Hz) and C4 (261 Hz) for males. Vibrato was controlled in an attempt to capture clearer images and reduce potential error measurements. Additionally, jaw opening was controlled using a bite block 9.5 mm in diameter to isolate tongue movement. Simultaneous acoustic analysis was conducted to determine significant formant differences, specifically for F1 and F2 between each group.

Results of the study showed that the MT singers tended to sing with a slightly higher larynx as measured by higher hyoid position during the low pitch tasks in comparison to the opera singers. Surprisingly, both groups exhibited similar higher laryngeal positions for high pitch tasks, although MT singers displayed slightly higher positions. Difference in tongue height was also measured between the two groups. In contrast to previous studies (c.f. Bourne & Garnier, 2012; Echternach et al., 2014), the MT singers in the study exhibited lower tongue height, specifically for the vowel /i/ compared to the opera singers. The opera singers additionally exhibited more shifts in tongue height between low and high pitch tasks. Tongue advancement did not significantly differ between groups, although MT singers tended to maintain a more anterior placement through their range, possibly to maintain a shorter vocal tract. In contrast, opera singers demonstrated greater changes in posterior tongue movement, supporting previous pedagogical views and research regarding vowel modification. When comparing formant frequency measures, Hosbach-Cannon et al. (2020) found that both groups demonstrated similar F1 and F2 measures for the vowel /i/, but different measures for the vowel /a/, where MT singers had slightly higher measures for F2 during both low and high pitch tasks. Additionally, F1 increased for MT singers during both singing tasks, possibly indicating the R1:2f_0 tuning postulated by previous studies (Björkner, 2008; Bourne & Garnier, 2012; Schutte & Miller, 1993).

Differences in the results of Hosbach-Cannon et al. (2020) from previous hypotheses regarding tongue movement for these two styles could be attributed to the controlling of jaw movement using a bite block. As noted by Sundberg (1970), compensatory movement of the tongue is difficult to control for during singing, as vocal tract configurations typically rely on several adjustments of different articulators, all of which are interconnected. In classical singing, vowel modification often requires adjustments in both lingual and jaw position. In a pilot study involving five professional opera singers, A. Nair, Nair, and Reishofer (2015) used both ultrasound imaging and MRI to investigate how classical singers lowered the posterior mandible in a technique termed the Lower Mandible Maneuver (LMM) to create resonance adjustments while singing. The researchers observed that when singers used the LMM, the larynx lowered, elongating the pharynx, and causing the floor of the tongue to sit lower in the oral cavity. As a result, more active movement of the tongue was required to achieve the points of articulation for different vowels (A. Nair, Nair, and Reishofer, 2015). In their study, Hosbach-Cannon et al. (2020) noted greater lingual movement in opera singers compared to musical theater singers, which they hypothesized were compensatory movements due to the restricted jaw opening. Additionally, from years of continuous training, singers may have been attempting learned motor patterns associated with vowel modification which was limited by the placement of the bite block.

The study by Hosbach-Cannon et al. (2020) is the first known to employ ultrasound to assess physiological and acoustic variations between musical theater and opera. Continued research with larger studies including comparisons between different populations (i.e., professional singers *versus* voice students) would help to determine which resonance strategies are routinely used by musical theater and classical singers and contribute toward forming more objective definitions for concepts associated with vocal timbre. Due to the complex nature of singing, it is difficult to control for all of the variables that can potentially influence study results. Minute differences in size, shape, and density of anatomical structures comprising the vocal tract as well as differences in production of perceptually similar sounds make it challenging to isolate the primary physiological movements and acoustic characteristics of different singing styles. (G. Nair, 1999). Additionally, choices for control of variables such as vibrato or jaw movement may actually limit generalizability, as these conditions may be perceived as unnatural by the singer.

Also challenging, is the wide variation in subjective interpretation of vocal timbre within these singing styles and application of different singing techniques, which can result in physiological and acoustic differences (Schutte & Miller, 1993). In their study, Lebowitz and Baken (2011) found that although 15 out of 20 musical theater singers were students in the same voice studio, each varied in their approach to belting. Consequently, due to lack of consensus for terms such as belting, legit, and mix, investigations may face limitations in external validity. Studies incorporating perceptual measures, such as acceptability ratings, may provide a framework in which to compare physiological and acoustic measures with what is generally accepted as the perceptual characteristics for a given singing style.

Types of Feedback in Voice Training

Voice instruction is a form a behavior modification, in which the voice teacher provides various modes of support through models, visual, verbal, and tactile cues, as well as different types of feedback (G. Nair, 1999). Feedback can be either interpersonal (extrinsic) or intrapersonal (intrinsic; Welch et al., 2005). Interpersonal feedback may be provided verbally by the teacher, or come from an instructional tool, such as a mirror or audio recording of the singer’s performance. Verbal comments provide information on the student’s progress and can include either precise instructions or descriptive imagery about anatomical adjustments. Audio feedback from recordings can assist in tuning the student’s ear to good and bad tonal qualities and use of a mirror can assist in demonstrating posture, breathing, the location and degree of success in releasing visible muscle tension, mouth and jaw movement, and other aspects of artistic expression (G. Nair, 1999). In contrast, intrapersonal feedback encompasses the singer’s perception and interpretation of the sound being produced (Welch et al., 2005). Types of feedback, whether interpersonal or intrapersonal can either provide specific qualitative information on the production attempt, what is referred to in motor learning literature as knowledge of performance, or on the level of correctness of the attempt which is defined as knowledge of results (Maas et al., 2008; Verdolini & Krebs, 1999).

Although these traditional methods of feedback are often effective, there exists a critical period in the teacher-student interchange that is open to potential misinterpretation (Welch et al., 2005). Delayed feedback may prevent the student from recognizing and associating sensory cues with correct tongue movement. Additionally, it can be difficult for teachers to evaluate whether there is congruence between their understanding and perception of good voice technique and that of the student's. Real-time visual biofeedback has the potential to supplement instruction in the voice studio by assisting voice teachers in bridging this gap.

Potential Benefits of Real-Time Visual Biofeedback in Voice Training

Visual biofeedback involves the use of instrumentation, such as a spectrogram or ultrasound image, which can provide a clear external reference, enhance awareness of a maladaptive response (i.e., tongue tension), and promote proprioceptive awareness and self-monitoring as the individual learns to associate physical adjustments with positive or negative changes of the response. This can manifest as reduced tension and increased freedom of production, or external confirmation of acceptable vocal timbre from the voice teacher (Gruzelier & Egner, 2004). In this way, biofeedback can serve as a tool in which to support the interpersonal feedback from teacher to student, as well as to inform the student's intrapersonal feedback system that shapes perceptions of acceptability of the singing behavior in connection to the desired outcome (i.e., vocal timbre; Welch et al., 2005). Additionally, visual biofeedback allows the voice teacher to quantify what is being heard and clarify pedagogical terms reducing miscommunication and misinterpretation on the part of the student (G. Nair, 1999).

Research has demonstrated a close relationship between speech production and perception (Klaus et al., 2019; Lametti, Krol, et al., 2014; Lametti, Rochet-Capellan, et al., 2014). Shuster et al. (1995) hypothesized that children with residual speech sound errors possess incorrect auditory percepts or mental expectations of how the phoneme in error should sound. Similar observations were made by McAllister Byun and Tiede (2017), who noted reduced perceptual sensitivity between /r/ and /w/ contrasts in children with persisting /r/ phoneme errors. In the voice studio, a mismatch between production and perception can occur when what the voice teacher hears as an acceptable sound is perceived by the student as being incorrect. Conversely, the student may associate incorrect production with a sound they perceive as being acceptable (Verdolini & Krebs, 1999). In providing a visual reference, visual biofeedback allows a student to bypass potentially incorrect aural perceptions and more quickly accomplish the anatomical shifts needed to produce the desired sound (McAllister Byun & Hitchcock, 2012; Shuster et al., 1995; Verdolini & Krebs, 1999). In this way, visual biofeedback can assist in connecting visual, auditory, and kinesthetic sensations to form a more correct and detailed percept.

Visual-Acoustic Biofeedback

Visual-acoustic biofeedback, specifically in the form of a spectrogram or a Linear Predictive Coding (LPC) spectrum have been utilized in speech-language pathology with generally positive outcomes for the treatment of residual speech sound errors, motor speech disorders, phonatory disorders, and accent and voice modification therapies (Kawitzky & McAllister, 2018; Maryn et al., 2006; Sugden et al., 2019). Both spectrograms and LPC spectra provide graphic representations of formants. With explicit instruction, clients can be taught to recognize, and match formant patterns associated with the targeted sound. Effective use of spectrograms and LPC have been explored in case series and single-subject designs in teaching correct production of the /r/ phoneme (McAllister Byun, 2017; McAllister Byun & Hitchcock, 2012; Shuster et al., 1992, 1995). In the field of voice therapy, Kawitzky and McAllister (2018), used a real-time LPC spectrogram in aiding transgender women (*n* = 12) with formant manipulation to achieve increased perception of femininity in their voices. Case reports and small single-subject studies have also supported positive outcomes for the use of real-time spectrograms in vowel production training for adults and children with profound hearing loss (Ertmer & Maki, 2000; Ertmer et al., 1996; Maki et al., 1981).

Various modes of visual-acoustic biofeedback have been explored in voice instruction for both actors and singers. In a small, comparative study, Rossiter et al. (1996) investigated the influence with and without visual biofeedback of voice development for two amateur, male singers. Visual biofeedback was presented through the system known as ALBERT (Acoustic Laryngeal Biofeedback Enhancement Real Time), which provided information on the voice source and acoustic characteristics, specifically closed quotient (CQ) time, fundamental frequency, formant energy, and intensity (measured in SPL). Results suggested that biofeedback, when focused on a specific aspect of vocal production, aided in supporting development and acquisition of new skills. The researchers also concluded that biofeedback, when based on a specific parameter, had the greatest impact during initial use. Similar trends are noted in speech-language research, in which visual biofeedback is associated with increased gains in acquisition of a targeted speech sound (McAllister Byun, 2016; McAllister Byun & Hitchcock, 2012).

In a prospective study, Laukkanen et al. (2004) investigated the efficacy of spectral feedback in comparison to traditional voice training without biofeedback. Twelve student actors were randomly assigned to two groups, one the control and the other the biofeedback group, which included use of an LPC spectrogram. Both groups were provided voice exercises focused on improving vocal resonance and facilitating a ringing voice quality. Results indicated that students in the group provided with visual-acoustic biofeedback demonstrated greater gains in perceptual qualities of pitch, loudness, and quality according to ratings from two professional voice trainers, who were blind to the nature of the recordings. Evidence of social validity was also seen in positive reports from study participants in practicing vocal exercises with visual biofeedback. Overall, the researchers concluded that visual biofeedback appeared to increase efficiency in voice training, although they cautioned against excessive reliance on this mode of feedback. While all participants within the biofeedback group exhibited perceived improvements in voice quality, the researchers noted the presence of increased phonatory efforts for some. They recommended that visual biofeedback be used strategically in voice instruction alongside other modes of sensory feedback.

Use of visual-acoustic biofeedback as a means in which to clarify singing technique has been a prominent subject of interest in voice pedagogy. In the book *Voice: Tradition and Technology --A State-of-the-Art Studio*, D. G. Miller and Schutte contributed a chapter describing how use of spectrum analysis can provide insight in the instruction of concepts that voice students often find difficult to grasp (D. G. Miller & Schutte, 1999). D. G. Miller later developed a system for voice analysis, research, and instructional use known as Voce Vista, which includes real-time spectrography, power spectrum displays, and electroglottographic analysis. In his book, *Resonance in Singing: Voice Building through Acoustic Feedback*, D. G. Miller (2008) provided an intensive guide on voice acoustics and how to use each of these systems to teach singers about formant tuning. Another instructional tool utilizing visual-acoustic feedback, the Madde voice synthesizer was developed by Swedish engineer, Svante Granqvist.

Unlike Voce Vista, the Madde synthesizer is a free download and pairs acoustic information with a virtual keyboard. The system is programmable to represent different voice types with number of frequency locations of up to six vocal tract formants and allows for adjustments in the following parameters: bandwidth of formants, vibrato rate and extent, total number of source harmonics, and net roll-off in power of the voice source harmonics spectrum (Bozeman, 2012).

Although it is unclear how often either the Madde synthesizer or Voce Vista are used in the every-day voice studio, some ecological validity is supported in the reviews from professors and pedagogues at universities with vocal pedagogy programs. In his review, Bozeman (2012) supports the use of the Madde synthesizer as an instructional tool in teaching voice students the fundamentals of acoustics, as well as a supplement to traditional voice instruction. Specifically, Bozeman (2012) discusses how both the Madde synthesizer and Voce Vista can be used to teach voice students about the relationship between harmonics and formants, and how their interaction informs vocal timbre. Despite these noted benefits, however, some factors limit the use of these two systems, including technical restrictions and varying knowledge levels of voice acoustics among voice teachers and students.

In a recent summary of the final keynote panel of the 10th Pan-European Voice Conference (PEVOC), Gill and Herbst (2016) reiterated the need for monitoring quality voice training at the university level. They likened voice teachers to “voice builders,” who are responsible for establishing motor control and behavioral patterns which will allow for healthy voice production for a preferred singing style (Gill & Herbst, 2016, p. 172). Voice teachers, consequently, must be knowledgeable of the details of anatomy and physiology of the voice, and acoustic principles of voice production. Currently, no standard certification requirements exist to teach voice, resulting in a wide array of different teaching backgrounds and levels of knowledge regarding the science behind the voice and voice function. In order to successfully use visual-acoustic biofeedback in the voice studio, teachers must be able to make connections between acoustic displays, perceived sound, and production of sound, all of which require in-depth knowledge of anatomy and physiology of the voice, and voice acoustics.

An additional limitation of visual-acoustic feedback is that it provides only indirect feedback on physiological movements. While acoustic analysis may show the result of a specific singing behavior, it provides no information on the physiological movement associated with the produced sound. While attempts have been made to isolate acoustic features for singing, such as in the creation of a formant range profile by Titze et al. (2017), no standard norms yet exist for acoustic parameters defining acceptability for a specific singing style. Consequently, while visual-acoustic biofeedback provides opportunities for discussion, learning, and experimentation in aligning desirable tonal quality with kinesthetic sensation, it cannot be used necessarily as a means for correction. As Bozeman (2013) commented, “Spectography doesn’t tell you what is good, bad, or indifferent. It simply displays what is.” (p. 103) Lastly, the validity of the information provided by spectrographic displays significantly decreases at higher frequencies, where harmonics become progressively more spaced apart. While spectrums have been found to be accurate for frequencies between 100-300 Hz, measurement error dramatically increases for frequencies 350-500 Hz and higher (Erickson & D’Alfonso, 2002; Monsen & Engebretson, 1983). As singing involves a substantially wider range than speech, some singers, such as higher voice types (i.e., soprano and tenors) may receive less benefit from these feedback mechanisms.

Ultrasound Visual Biofeedback (U-VBF)

With an increase in affordability, availability, and portability of imaging devices, such as 2-D portable ultrasound machines, ultrasound visual biofeedback (U-VBF) has become a recent topic of interest both in research and in clinical application. Tongue position and movement are not highly visible and can therefore be challenging to describe. Additionally, not all individuals have enough kinesthetic awareness to modify maladaptive movements following verbal cues or teacher modeling (S. H. Lee et al., 2005). Without being invasive, ultrasound provides a dynamic display of the tongue in both the midsagittal and coronal planes (Bryan, 2002; S. H. Lee et al., 2005). When an ultrasound probe or transducer is placed under the chin, reflected sound produces a dynamic image of the tongue surface. Probes attached to a personal computer with ultrasound software allow for the image to be converted into a computer image, allowing for real-time visualization of tongue movement during production of a speech or singing task (S. A. S. Lee et al., 2015).

Ultrasound visual biofeedback (U-VBF) provides a visual reference that aligns with acoustic feedback and can be used to provide explicit, objective information on performance and cue the singer to modify his/her tongue position. Positive outcomes have been noted in speech-language pathology in addressing persisting speech sound errors. Cleland et al. (2015) found that when paired with traditional therapy, U-VBF resulted in positive outcomes for eight children (ages 6-10 years) with residual speech errors. A later study by Cleland et al. (2018) also found significant positive outcomes in rate of acquisition for the targeted speech sounds among twenty children (ages 6-15 years) with speech sound disorders, although no significant effects were noted for generalization. Similar results regarding acquisition compared to generalization were noted in studies by Preston et al. (2013) and Preston, Leece, et al. (2017) in treatment involving U-VBF for children with childhood apraxia of speech (CAS). Consequently, researchers have recommended that U-VBF be introduced as a supplementary tool in the initial stages of treatment and gradually faded as the client acquires the new motor skill.

Efficacy of U-VBF has also been explored in pronunciation training and accent modification (Gick et al., 2008; Ouni, 2014). In a pilot study, Gick et al. (2008) investigated the use of U-VBF in L2 pronunciation training for phonemes /r/ and /l/ for three Japanese linguistics students. Participants participated in a 30-minute training session, in which they were taught how to interpret ultrasound images of their productions. Following the session, all three participants were able to accurately produce the target sounds in all word positions. Although the results of this study may have been skewed by the participants' familiarity with linguistics, the findings do indicate that small articulatory adjustments can be achieved for targeted sounds. These results indicate that benefit from U-VBF may have potential to help singers increase their self-awareness of tongue movement and achieve positive changes in vocal timbre. This potential for an improvement in sensory awareness was later demonstrated in a comparative study consisting of 24 participants randomly assigned to either an experimental or control group (Ouni, 2014). Participants in the experimental group received a short training session (15-20 minutes) for the interpretation of ultrasound images. A comparison of pre- with post-U-VBF showed that individuals who received biofeedback learned new articulatory gestures more accurately and were more aware of tongue movement in relation to specific speech sounds.

Given these positive outcomes in behavioral approaches in speech-language pathology, U-VBF appears to provide useful information about the acoustic adjustments that singers must learn to navigate when singing, such as achieving the desired vocal timbre. Using ultrasound to find the appropriate tongue shape and placement that best predicts the formant frequencies associated with a vowel when singing and the desired vocal timbre may clarify pedagogical language of the teacher and assist the student in developing greater self-awareness and monitoring. The idea of providing visual biofeedback of tongue movement has existed in the minds of some voice pedagogues; however, its potential as an instructional tool in voice training has been relatively unexplored. Appleman (1967) proposed the use of visual biofeedback through palatograms and linguagrams to help voice students increase articulatory awareness. Currently, there appears to be only one case study that supports the use of U-VBF in the voice studio. In a case study involving two male opera students (both tenors) A. Nair, Schellenberg, and Gick (2015), provided a 10-minute training session involving ultrasound as part of a master class. Both singers exhibited clear visual adjustments in articulation for specific vowels, which were subjectively perceived with positive changes in timbre and resonance.

While the study conducted by A. Nair, Schellenberg, and Gick (2015) provides suggestive evidence for the efficacy of U-VBF in improving singers' vocal timbre, further research is needed to explore the benefits, limitations, and efficacy of use of ultrasound in supplementing traditional voice instruction. One avenue of interest includes investigating the ecological validity of U-VBF by gathering qualitative data on teachers' and students' perceptions of the use of ultrasound. Questions regarding the ease in which teachers and students can learn how to use an ultrasound probe and read ultrasound images would provide valuable information on the utility of U-VBF. Additionally, studies employing subjective ratings of perceptual changes in vocal timbre pre- and post-U-VBF would shed insight on the effectiveness of U-VBF in instruction for concepts such as formant tuning and serve as a point of comparison with the observations made by A. Nair, Schellenberg, and Gick.

Attitudes Toward Voice Science and Technology in Singing Instruction

While modern technology has made it possible to align objective measurements with perceptions of voice quality and timbre, it is unclear as to how many voice teachers actually utilize these technological tools. Past studies consisting of surveys investigating attitudes and use of computer technology providing real-time feedback in the voice studio appear to be generally positive. Howard et al. (2005) gathered overall perceptions from two voice teachers and four of their students after a twelve-month period in which a specially designed software package known as WinSingAd was used to teach concepts important to vocal technique. Results indicated that while the two teachers differed in their use of the technology in their teaching, both supported its usefulness as an added instructional tool, and felt that it did not distract or hinder the focus of the lesson. The students similarly voiced positive opinions, despite initial reservations about the technological knowledge required.

Overall, the incorporation of technology appeared to benefit voice instruction by clarifying teacher pedagogies and expectations through provision of real-time visual feedback. However, it is important to consider the limitations of the study, including the small number of participants and the level of familiarity of the two teachers with voice physiology and acoustics. In explaining images from spectrograms, both teachers' interpretations were based off broader interpretations of what was being displayed, with each teacher employing different descriptive language to convey their observations to their students. Although Howard et al. (2005) noted that this ambiguity in interpretation of the displays did not appear to hinder the student's progress if a clear teacher-student connection was maintained, interpretation was not always scientifically accurate. A spectrogram can provide valuable information if it is understood. However, misinterpretations do little to clarify vocal pedagogy, and these programs may need to be further modified to account for the varying knowledge of vocal acoustics among voice teachers.

Initial reservations may be based on other factors also, such as the length of time it takes in which to become familiar with a specific program. In a survey assessing the current use of studio technology, as well as readiness to adopt use of other technologies in the voice studio, Barnes-Burroughs et al. (2008) found that although voice teachers expressed positive attitudes toward future use of new technology in the voice studio, they preferred the use of traditional studio items such as mirrors, tape/digital recorders, and pianos. A more recent survey by Gerhard and Roscow (2016) investigated the differences in opinion regarding the utility of different technology found in the voice studio between vocologists and student singers. Their results indicated significant differences in opinion between these two groups regarding both availability and utility of types of equipment in the voice studio. For example, a relatively large proportion of vocologists (77%) rated availability and usefulness of acoustic analysis technology compared to 7% of voice students. The low ratings for usefulness directly correlated with availability, as well as awareness. Ratings in level of usefulness from students with reported background knowledge more closely agreed with those made by vocologists than with students with no reported familiarity.

From these studies, it can be concluded that the absence of technology in the voice studio may be due more to a general lack of awareness, rather than of interest. In a survey conducted by Ware (2013), which evaluated the use of science and imagery in the voice studio, 76% of respondents rated both as being equally helpful, while 83% reported believing that a blended approach combining science and imagery, led to the most successful outcomes for their students. Overall, 84% of respondents reported consciously applying voice science in their teaching. A disconnect, however, was revealed when only 56% of respondents believed that voice science was actively being incorporated into voice instruction. As no recent studies have investigated the extent to which technology and voice science is being applied by singing teachers, it is difficult to gauge the level of acceptability for introduction of new modes of biofeedback such as portable ultrasound into the voice studio. In exploring the use of technology in voice instruction Howard et al. (2005) list several points for consideration, including the extent to which technology will be accepted in the voice studio, its ease of use, the type of data offered and whether it is easily understood by teachers and voice students, and how the provided data inform singing technique.

Summary and Significance

It is one thing to read and grasp the basics of the anatomy, physiology, and acoustics of the singing voice, but it is another to apply this knowledge. Visual biofeedback, such as U-VBF, has the potential to make complex topics related to the singing voice easier to understand and thereby, more meaningful to both voice teachers and their students. Additionally, U-VBF can enrich student knowledge and potentially eliminate misinterpretation by providing clear visual comparisons between correct and incorrect attempts. Positive outcomes regarding the use of U-VBF in the field of speech-language pathology supports the potential benefit of this mode of feedback in voice instruction. The present study will provide insight on perceptions and interest in the use of U-VBF as a potential supplementary tool in the voice studio for teaching techniques such as vocal timbre to adjust for singing in different styles, such as musical theater and opera. As Appleman (1967) wrote

> Vocal pedagogy cannot survive as an independent education entity if the physiological and physical facts which comprise its core remain subjects of sciolism (superficial knowledge). Researchers must constantly interpret these scientific facts so that they may become realistic pedagogical tools which may be employed by future teachers of voice. (p. 5)

LoVetri (2012) voiced a similar opinion regarding the need for standardizing terminology in musical theater pedagogy by seeking out objective definitions, stating “When vocal pedagogy can be hooked to vocal function as understood in voice science, the entire profession will be better off." (p. 6)

Investigation into the utility of new technology such as ultrasound to provide clear, real-time visual biofeedback in no way intends to replace traditional methods of voice instruction. Rather, contributions of voice science to the realm of singing have the potential to enhance current instruction by reducing incongruities in the terminology used and serve as a means in which to improve both voice teachers' and their students' knowledge of vocal function. Additionally, this knowledge will benefit speech-language pathologists in educating and assisting voice teachers and coaches in how to promote vocal health of their students.

CHAPTER III

METHODOLOGY

Study Objective

This study investigated the potential utility of ultrasound visual biofeedback (U-VBF) in voice instruction. A survey-based methodology was adopted to assess current perceptions and attitudes of professional voice teachers regarding value and use of visual biofeedback in the voice studio, and whether these opinions changed after viewing an instructional video demonstrating use of U-VBF in singing instruction.

Specific Aims (SA)

SA1 To administer a survey to professional voice teachers who teach at a university, college, or private studio that determines current attitudes toward use of technology providing real-time visual biofeedback in voice instruction.

SA2 To distribute an instructional video on the basics of ultrasound and use of U-VBF in instruction of vocal timbre for two different singing styles (musical theater and classical singing).

SA3 To administer a post-video survey that evaluates changes in perception toward use of U-VBF to teach different vocal pedagogy concepts, such as vocal timbre, in voice instruction.

Research Questions (Q), Hypotheses (H), and Assumptions (A)

Q1 What is the current knowledge and attitude among voice teachers regarding use of real-time visual biofeedback in singing instruction?

H1 Voice teachers’ perceptions of usefulness and ease of use of visual biofeedback systems will be informed by previous experience and what they know about them.

A1 Attitude is often influenced by knowledge and experience. Currently, minimal qualitative studies have been conducted to investigate knowledge of or experience with technology providing visual biofeedback in the voice studio. Previous surveys by Ware (2013) and Gerhard and Roscow (2016) suggest that perceptions of usefulness and availability of different types of technology among voice teachers and students alike, are informed by degree of awareness, knowledge, and experience.

Q2 How interested are voice teachers in learning about using technology, such as ultrasound, to provide visual biofeedback in singing instruction?

H2 Voice teachers will express a high level of interest in learning more about how technology, such as ultrasound, can be used to provide real-time visual biofeedback in the voice studio.

A2 Results from previous experimental and survey-based studies (Barnes-Burroughs et al., 2008; Howard et al., 2005), have indicated generally positive attitudes among voice teachers toward interest in learning more about and using new technology in the voice studio.

Q3 What external variables influence voice teachers' attitudes of perceived usefulness and ease of use of U-VBF in singing instruction?

H3 Attitudes toward U-VBF will be influenced by external variables, such as age, voice type, years of teaching experience, education level, knowledge regarding voice anatomy, physiology, and acoustics, setting as a voice teacher, and place of residence (region).

A3 External variables influence perceptions of usefulness and ease of use, which in turn informs attitude toward use of a system.

Q4 After viewing an instructional video on the use of U-VBF during singing, what are voice teachers' attitudes regarding perceived usefulness and ease of use of U-VBF in singing instruction, and what is their level of interest in learning more about U-VBF and their reported intention for using it in the future?

H4 Viewing of an instructional video demonstrating use of U-VBF during singing will increase voice teachers' level of interest and attitudes regarding perceived usefulness and ease of use, as well as intention to use this mode of biofeedback in the future.

A4 Training is an important influential component for promoting positive perceptions and intention to use a new technology system, such as U-VBF, as a supplementary teaching tool in singing instruction.

Participant Recruitment and Selection Criteria

Permission for research and recruitment was obtained from the Institutional Review Board (IRB) at the University of Northern Colorado (UNC; see Appendix A). Study participants were initially recruited through stratified random sampling from the National Association of Teachers of Singing (NATS) member directory. An IRB approved description of the study including eligibility criteria, informed consent, and upon consent, a link to the pre-video survey, instructional video, and post-video survey were distributed via email to a 10% sample of voice teachers listed in the NATS member directory from a database stratified by four main regions within the United States (West, Central, South, and East) and music style taught (musical theater or opera/classical). Additional information on the breakdown of region by number of voice teachers and a 10% sample is provided in Appendix B. Information regarding the study and link to the surveys and instructional video was also posted on the NATS research page (https://www.nats.org/surveys.html) and displayed in the e-newsletter *Intermezzo.* Teachers were encouraged to share this information and the survey link with their colleagues.

Due to an initial low response rate, the original sample size was increased by 10% increments from the database compiled from the NATS member directory. Recruitment strategies were also diversified to improve the size of the sample. Snowball sampling was adopted by distributing a description of the study with a promotional flyer (see Appendix C) to online forums and groups for professionals involved in voice pedagogy, voice science, or voice therapy, including the American Speech Hearing Association (ASHA) Special Interest Group (SIG) 3, Voice and Upper Airway Disorders, and four social media groups on Facebook and Instagram.

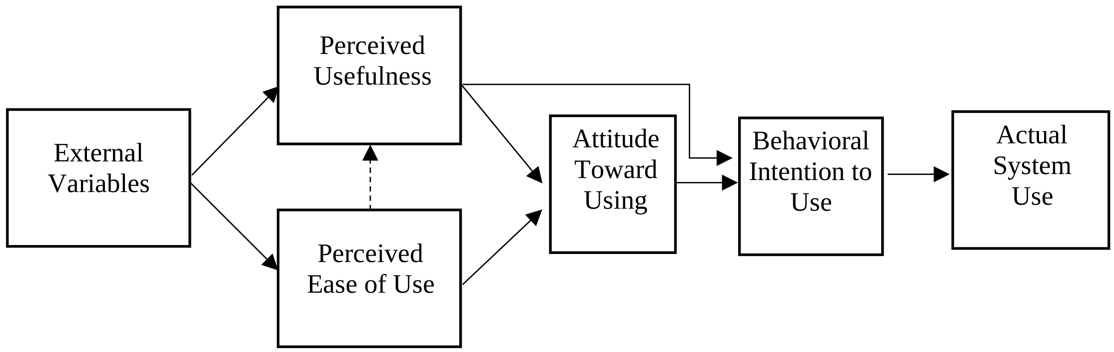
To participate in the study, voice teachers had to have minimally a master's degree (MM, MA), an equivalent degree, or a bachelor's degree (BA, BM) with additional training compatible with what is received in a master's program for voice, opera, musical theater, or voice pedagogy. Eligible participants also needed to teach voice at a university, conservatory or private voice studio and teach primarily either opera or musical theater. Originally, eligibility criteria included listing as a NATS member with contact information (i.e., email) included in the NATS online directory; however, due to initial low response rate, this requirement was amended to allow for snowball sampling. Additionally, participation was extended to professional voice teachers outside of the U.S. Details regarding the sampling plan and the numbers of subjects that were approached, responded and had complete data for analysis are provided in Chapter IV.

Description of Outcome Measures

Primary outcome measures included voice teachers' perceived usefulness, perceived ease of use, and behavioral intention to use U-VBF in voice instruction before and after viewing of an instructional video. The study was designed with respect to the Technology Acceptance Model (TAM) originally developed by Davis (1989). According to the TAM (see Figure 2), people are more inclined to use new technology if they regard it as being important (*perceived usefulness*) or if it is easy to use (*perceived ease of use*; (Davis, 1989). Both perceived usefulness and ease of use influence attitude toward use, which in turn informs interest (*behavioral intention to use*) and predicts actual system use. Secondary outcome measures included external variables that potentially inform conceptions of perceived usefulness and ease of use, such as age, education, formal training, years of teaching, voice type, setting for instruction, and location (region).

Figure 2

The Technology Acceptance Model (TAM)



Note. This figure is adapted from "User Acceptance of Computer Technology: A Comparison of Two Theoretical Models," by F. D. Davis, R. P, Bagozzi, and P. R. Warshaw, 1989, *Management Sciences, 35*(8), p. 985 (https://doi.org/10.1287/mnsc.35.8.982). Copyright 1989 by INFORMS.

Procedures

Data Collection Methods

Data were obtained through two surveys developed by the primary researcher via Qualtrics software, Version April 2021, a technology program designed for online survey creation and data collection (Qualtrics, 2005). An anonymous link to the surveys was distributed to NATS members and displayed on the NATS online research page, ASHA SIG 3 page, and four social media groups for professional voice teachers and singing voice specialists. Following providing informed consent, participants were invited to complete an initial survey after which they were directed to the instructional video demonstrating use of U-VBF during singing and the post-survey. After completing the post-survey, participants had the opportunity to enter their name in a raffle for one of two $100 Amazon gift cards as a part of participating in the experiment. All identifying personal information was de-identified and assigned a Login ID for analysis.

Development of Surveys

The two surveys for pre-viewing and post-viewing of the instructional video were developed by the primary researcher to fit the purpose of the study aims and research questions. The format for the surveys was informed by the Technology Use and Attitudes in Music Learning Survey (Waddell & Williamon, 2019) and the TAM (Davis, 1989), the latter of which was created to examine user acceptance of technology before and after implementation through two specific variables: perceived usefulness and perceived ease of use. Questions for the pre-survey were developed to measure voice teachers' current perceptions of VBF, U-VBF, and its potential use in the voice studio, as well as interest in learning more about this type of feedback. For the post-survey, questions were developed to gauge a change in perception following viewing of an instructional video demonstrating use of U-VBF for singing instruction.

The pre-video survey (see Appendix D) was composed of three sections. The first section was designed to gather information reflecting demographic and personal characteristics identified as potential influential external variables, including region, voice type, formal training, total years of teaching voice, and experience attending or teaching a class covering the anatomy, physiology, and/or acoustics of the singing voice. Region was identified as a potential influential external variable, as different geographic regions vary in number of music conservatories and universities, which may inform level of knowledge and awareness of newer aspects of vocal pedagogy, such as classes in singing acoustics and use of acoustic biofeedback systems such as Voce Vista. Voice type was also included as singers of different voice types often rely on and teach different tactile cues associated with perceptual timbral qualities. The second section of the pre-video survey included questions aimed at investigating levels of knowledge and attitude toward using visual biofeedback technology, such as U-VBF, in the voice studio. Lastly, a third section contained questions pertaining to perceived usefulness, ease of use, and interest in learning more about U-VBF. Both quantitative and qualitative research strategies were considered in question development. To quantify data, a 5-point Likert-scale and dichotomous (yes/no) questions were used, while three open-ended questions allowed for participants to voice their perceptions regarding use of U-VBF in the voice studio.

Following completion of the pre-video survey, participants were redirected to the instructional video and post-video survey (see Appendix E). The format of the post-video survey was modeled off the pre-video survey and included two sections: (a) perceptions and attitudes of the U-VBF instructional video and (b) perceptions and attitudes for U-VBF in singing instruction. A 5-point Likert-scale was used to quantify participants' responses regarding their perception of the degree to which the instructional video was informative and helpful, and whether their opinions regarding usefulness and ease of use of U-VBF in voice instruction changed. Two open-ended questions invited participants to share their opinions. To verify face validity of the pre- and post-U-VBF measures, the surveys were reviewed by two professional speech-language pathologists and one voice teacher with extensive experience in voice pedagogy and in teaching musical theater and classical singing styles. Adjustments to survey content regarding clarity, appropriateness, and comprehensiveness of each item were made.

Ultrasound Visual Biofeedback (U-VBF) Instructional Video

An instructional teaching video offers a low-cost and practical method for disseminating information on the potential use of real-time visual biofeedback in the voice studio to a larger sample of the population of interest. A video demonstrating use of U-VBF as an instructional tool during singing was created by the primary researcher (KS). The overall length of the video was 17 minutes and included information on (a) how ultrasound imaging works; (b) interpreting ultrasound images by identifying primary reference points; (c) ultrasound imaging of spoken and sung vowels with accompanying images of spectrograms showing formant patterns for each vowel, accompanied by a brief overview of relevant topics in voice physiology and acoustics; and lastly (d) examples of adjusting vocal timbre using U-VBF (see Table 1). Information was provided through a combination of live demonstrations, pictures and informational slides using Microsoft PowerPoint, scanning video clips, labeled still images from ultrasound, and spectrograms showing formant patterns of target vowels. Information regarding use of ultrasound and interpretation of images was adapted from the protocol developed by Preston, McAllister Byun, et al. (2017) on use of U-VBF in a clinical context for remediation of speech sound errors. To ensure clarity and validity, content for the video was be previewed by two speech-language pathologists who are experts in voice acoustics and the use of U-VBF, and one professional voice teacher.

Table 1

Outline of Instructional Video Content

Sections	Content	Approximate Duration
(1) How does ultrasound visual biofeedback work?	Definition of *Ultrasound* Visual Biofeedback (U-VBF)	4 min
	Turning on machine and calibration	
	Positioning of transducer	
	Verification of image	
(2) Interpreting ultrasound images	Basic interpretation of sagittal images	4 min
	Example spoken consonants (/t, d, n/, /k, g/) to orient user to tongue position (location of anterior tip and posterior/tongue dorsum)	
	Indicate landmarks of the tongue (tip, blade, dorsum, root, shadow of mandible and hyoid)	
	Tracing tongue contour	
	Troubleshooting image quality	
(3) U-VBF and vowels	Overview of how sounds are produced in the mouth and basic acoustics of vowels	5 min
	Example of spoken vowels (/i, ɛ, ɑ, o, u/) with spectrogram displays	
	Example of sung vowels (/i, ɛ, ɑ, o, u/) in classical and musical theater singing styles with spectrogram displays	
(4) U-VBF and vocal timbre	Comparison of changes in tongue contour for bright/dark timbre with spectrogram displays	4 min
	Total Time:	17 min

Ultrasound Equipment and Software. Real-time B-scan ultrasonography using a portable unit (Articulate Instruments, Echo B) with a 70% field of vision (FOV) and scanning rate of up to 140 frames/second (fps) was used with a small 10 mm radius convex transducer with a frequency of 5-8 MHz (Articulate Instruments Ltd., 2004). This frame rate has proven to be adequate for most articulatory movements, excluding consonant sounds that require fast tongue tip movements (Gick, 2002; Stone, 2005). As vowels are of primary interest in vocal timbre and singing, the sampling rate was deemed adequate to provide clear output for the purposes of this research. Ultrasound imaging was viewed using two software systems, Sonospeech™ (Articulate Instruments Ltd., 2004), and Echo Wave II (TELEMED Ultrasound Medical Systems, 2018) on Windows 7/8/10.

Ultrasound Procedures and Demonstration. Procedures for how to use the ultrasound transducer and demonstrations of U-VBF in singing were modeled and recorded by the primary researcher. Recording of images was completed using an Apple iPhone 10 Pro fixed to a tripod. Still images were captured using the freeze frame button to pause ultrasound scanning and pictures were taken using the screenshot function on the computer. For imaging, the transducer was held so that a sagittal view of the tongue was displayed. Instructions for holding and positioning the transducer and orientation for primary reference points, such as the acoustic shadow of the mandible and hyoid, the root, dorsum and tip of the tongue, and tongue surface were presented through verbal and visual explanations. Once orientation and major landmarks were explained, examples of spoken and sung vowels were provided by still captures of ultrasound images and via dynamic recordings of lingual movement for each vowel. Vowels (/i, ɛ, ɑ, o, u/) from the standard vowel quadrilateral were selected to show differences in tongue movement between vowels requiring varying degrees of tongue height and anterior/posterior positioning within the oral cavity. A similar procedure was employed for demonstrating differences in lingual movement for bright and dark vocal timbres, as well as two recorded song excerpts including singing in the musical theater and classical styles.

Singing Tasks. Ultrasound imaging with concurrent audio recordings of singing tasks were recorded by the primary researcher. These excerpts included sung vowels (/i, ɛ, ɑ, o, u/) on pitch C4 (261 Hz) at a comfortable loudness level in both classical and musical theater singing styles, and sung demonstrations of shifting timbre through changes in lingual movement. Pitch and intensity were controlled using a dBA sound meter and I-Phone app Tonal Energy Tuner and Metronome to direct focus toward timbral changes associated with tongue movement. The pitch C4 (261 Hz) was chosen, as it can be comfortably sung in both classical and musical theater singing styles for the female voice (Björkner, 2008; Hosbach-Cannon et al., 2020). Additionally, two short song excerpts from the musical theater and operatic literature were included to show visualization of lingual movement during connected singing.

Spectrograms of Spoken and Sung Vowels. Pictures of spectrograms showing formant patterns (F1-F5) were presented alongside still captures of ultrasound images of spoken and sung vowels. The purpose of including this information was to provide a clear visual anatomical reference to clarify acoustic concepts, such as changes in formant patterns and subsequent perceptual changes in vowel intelligibility and tone quality due to lingual movement. Wide-band spectrograms were generated for ultrasound recordings of the selected vowels by using the spectrogram button in Sonospeech™ (Articulate Instruments Ltd., 2004). Select parts of the recording (i.e., the midpoint of each spoken and sung vowel) were isolated using the zoom bar and selection box. The spectrogram window could then be viewed underneath the exemplar window and an image captured using the screenshot feature on the computer.

Data Preparation

To test study hypotheses, questions from the pre- and post-surveys were initially coded into discrete categorical variables. To measure perceptions of usefulness and ease of use, categorical variables for familiarity, helpfulness, usefulness, likelihood of use, and interest, were quantified into rank ordinal variables using a 5-point Likert scale. For example, variables were ranked from low (1) to high (5) as follows: *not at all* (1); *slightly* (2); *somewhat* (3); *moderately* (4); *very* (5). Additional transformations of variables, either to ordinal values or merging of categorical variables into a new variable, were conducted to simplify analysis. The following paragraphs explain this process in more detail.

Degree of Completion

To measure completion, participants were assigned a unique Login ID. Time stamps recording beginning and completion of both surveys were also used to link participants' responses for both the pre- and post-surveys. The variable "Complete" was coded with the following values: 0 = Pre- / Post-Surveys Incomplete, 1 = Pre-Survey Complete / Post-Survey Incomplete, 2 = Pre-Survey Incomplete / Post-Survey Complete, and 3 = Pre- and Post-Survey Complete. This coding system allowed for the overall number of incomplete (0), partial (1,2), and complete responses (3) for both surveys to be identified. Degree of completeness was determined by the percentage of the survey questions completed, as well as answering of questions specifically related to U-VBF.

Participant Age and Region

Age and region were categorized for descriptive analyses. Participants' reported ages were organized into four groups informed by quartiles, based on the range (23-72 years) and mean (approximately 46 years), which were coded as the following: 1 = 23-35 years, 2 = 36-45 years, 3 = 46-58 years, and 4 = 59-72 years. When evaluating the association of age with other variables, age was assessed as a continuous variable. Region was categorized into the variables "Central," "Eastern," "Southern," "Western," "International," and "Unknown." Regions within the United States (Central, Eastern, Southern, Western) were defined according to grouping of states as organized by the NATS member directory as shown in Table 2.

Table 2

U.S. States Organized by Region Adapted from National Association of Teachers of Singing (NATS) Member Directory

Region	States
Central	Iowa (IA), Illinois (IL), Indiana (IN), Missouri (MO), MN (Minnesota), MI (Michigan), ND (North Dakota), OH (Ohio), WI (Wisconsin)
Eastern	Connecticut (CT), Delaware (DE), Massachusetts (MA), Maryland (MD), Maine (ME), North Carolina (NC), New Hampshire (NH), New Jersey (NJ), New York (NY), Pennsylvania (PN), Rhode Island (RI), South Carolina (SC), Virginia (VA), Vermont (VT), West Virginia (WV)
Southern	Alabama (AL), Arkansas (AR), Florida (FL), Georgia (GA), Kentucky (KY), Louisiana (LA), Mississippi (MS), New Mexico (NM), Oklahoma (OK), Tennessee (TN), Texas (TX)
Western	Arizona (AZ), Alaska (AK), California (CA), Colorado (CO), Hawaii (HI), Idaho (ID), Kansas (KS), Montana (MT), Nebraska (NE), Nevada (NV), Oregon (OR), SD (South Dakota), Utah (UT), Washington (WA), Wyoming (WY)

Education and Years of Teaching Voice

To analyze relationship of educational level with participant responses, the variable "Educ" was created and coded into the following three categories: BA/BM, MM/MA and DMA/PhD. The variable "V_Yrs" was created to characterize the total number of years teaching voice and was organized into the following four groups: 1 = 0-10 years, 2 = 11-17 years, 3 = 18-27 years, 4 = 28-45 years.

Singing Style Taught

The variable "Style_Teach" was created to characterize type of singing style taught which was further organized according to the following seven categories: 1) Musical Theater, 2) Musical Theater / Opera, 3) Musical Theater / Contemporary, 4) Musical Theater / Opera / Contemporary, 5) Opera, 6) Opera / Contemporary, and 7) Contemporary. This allowed for more cohesive organization of participant's responses when assessing overall characteristics of the sample, and for later analysis to investigate the third research question.

Statistical Analysis

Tests of the primary hypotheses were restricted to participants who fully completed both the pre- and the post-surveys (n = 56) for the purpose of analyzing change in perceptions following viewing of the instructional video demonstrating use of U-VBF in singing instruction. Due to the small sample size, this study was considered to be exploratory in nature; therefore, data were primarily analyzed using descriptive statistics following the assumptions made by the TAM model regarding system use (Davis, 1989), as well as through thematic content analysis of qualitative data following the recommendations of Braun and Clarke (2006).

For the first research question, univariate analysis via descriptive statistics was conducted to gauge participants' current knowledge and familiarity of visual biofeedback systems and U-VBF. Percent frequency distribution for variability and central tendency (i.e., mode, median) were used to examine how familiar participants were with ultrasound and U-VBF. Bivariate analysis through crosstabulation of data was conducted to compare participants' responses to different questions and evaluate for potential relationships between variables such as familiarity and knowledge of U-VBF and perceptions of its usefulness and ease of use in singing instruction. Responses to open-ended questions were collated into themes to provide a rich description of the data set and inform identified relationships from the Likert-scale questions.

Univariate and bivariate analysis via descriptive statistics were used for the second research question to investigate participants' levels of interest, and likelihood to use this mode of visual biofeedback in the future. For the third research question, crosstabulation of participants' ratings for perceived usefulness and ease of use of U-VBF, as well as for interest in learning more about U-VBF and using it in their teaching, with select influential external variables (i.e., education, number of years teaching voice, region, etc.) was conducted to examine the existence of potential relationships between variables.

Lastly, for the fourth research question, differences between frequency distributions and central tendency measures for participants' pre- and post-video ratings of perceived usefulness, ease of use, interest, and likelihood of use were compared to examine whether participants' opinions regarding U-VBF changed. Thematic content analysis was again employed to organized participants' impressions post-viewing of the instructional video into themes to better understand their perceptions regarding the utility of U-VBF.

CHAPTER IV

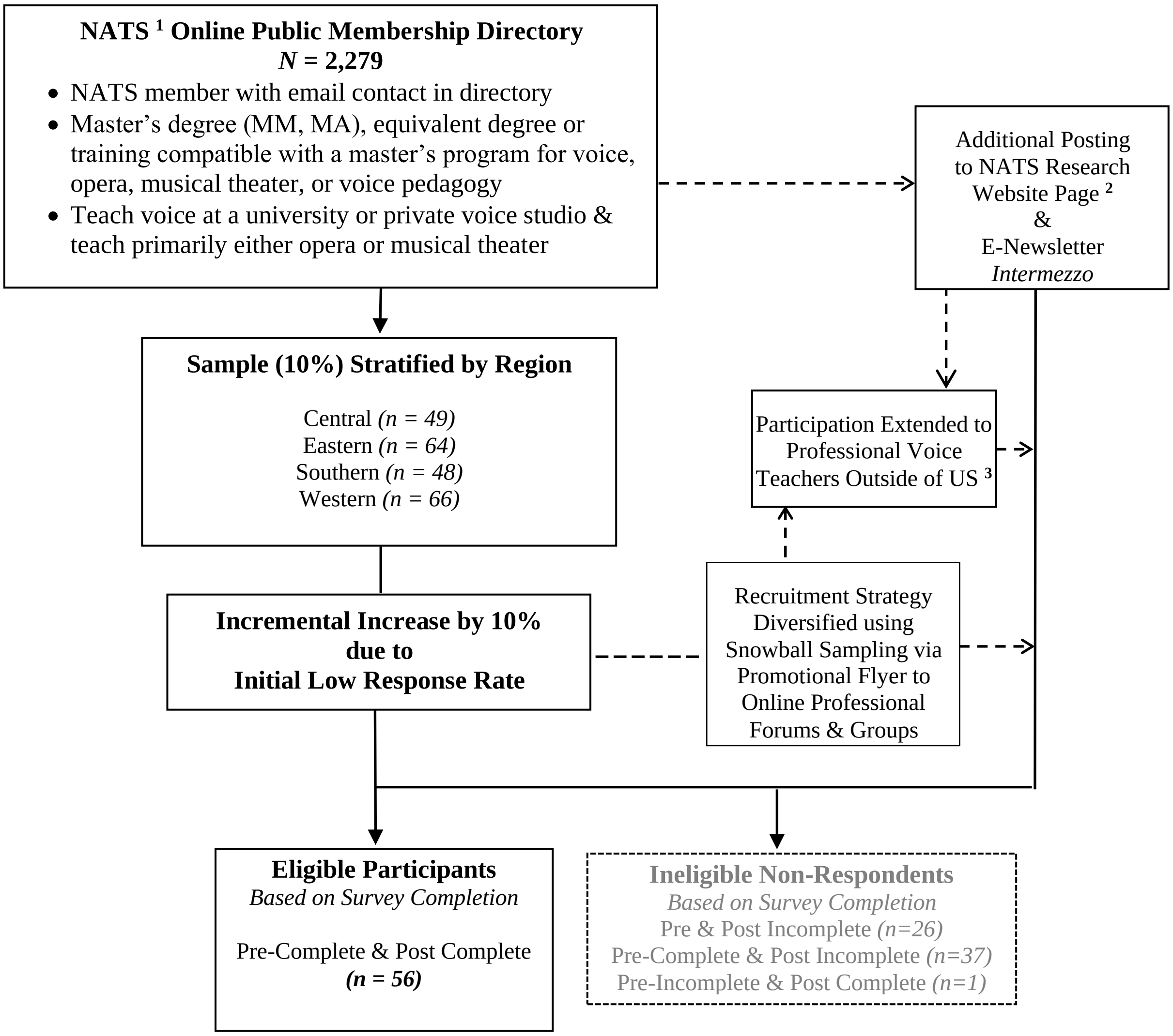
RESULTS

Establishment of Sample Size

The purpose of this study was to assess perceptions and attitudes of professional voice teachers regarding value and use of visual biofeedback in the voice studio and whether these perceptions changed after viewing an instructional video demonstrating use of ultrasound visual biofeedback (U-VBF) in singing instruction. Figure 3 summarizes the recruitment strategy, sample size, data collection, and the numbers of participants by survey completion status. A total of 120 responses were collected. Of this total, 26 had significant missing data both the pre- and post-surveys regarding questions measuring perceptions of usefulness and ease of use of U-VBF. Significant missing data were defined as completion of the pre- and/or post-survey being less than 50% or if questions regarding perceptions of U-VBF were left unanswered. One was complete for the post-survey but was missing important data for the pre-survey, eliminating the possibility for comparison between pre- and post-video perceptions of U-VBF. Of the remaining 93 responses without missing data, 37 participants completed the pre-survey only and 56 completed both the pre- and post-surveys. All analyses were based on the participants who completed both surveys (n = 56) as the goal was to assess changes in perceptions from pre- to post-viewing of the video.

Figure 3

Recruitment, Sample, and Completion of Pre-Survey and Post-Survey



Note. This figure details the recruitment process for study participants. The solid lines represent the original process, while the dashed lines indicate the modifications to increase the sample size.

[1] National Association of Teachers of Singing; [2] https://www.nats.org/surveys.html;

[3] Participation extended since many voice teachers visiting professional website forums and groups are from outside of the U.S.

Respondent Characteristics

Table 3 provides descriptive characteristics of the participants who completed both the pre- and post- surveys (*n* = 56). Questions from the initial portion of the pre-survey gathered data for demographic information such as region, age, level of education and formal education as a voice teacher, voice type, number of years teaching voice, singing styles taught, experience with taking and/or teaching classes in voice anatomy/physiology and acoustics, experience and knowledge of acoustic visual biofeedback software, and prior observation of U-VBF.

The age range for respondents who completed both the pre- and post- surveys was relatively broad, with participants being between the ages of 23 to 72 years. Most respondents (80.4%) reported being between the ages of 23-59 years, while 19.6% reported being between the ages of 59 to 72 years. The majority of respondents reported either living in a state located in the Central (28.6%) or Western (25.0%) regions of the United States with the fewest responses coming from abroad (7.1%). Of the total sample, two respondents (3.6%) listed region as “unknown.”

Table 3

Characteristics of Respondents who Completed both the Pre- and Post-Survey

	Pre- & Post-Survey	
	#	%
Age		
23-35	14	25.0
36-45	15	26.8
46-58	16	28.6
59-72	11	19.6
Region *		
Central	16	28.6
Eastern	9	16.1
Southern	11	19.6
Western	14	25.0
International	4	7.1
Unknown	2	3.6
Education		
BA/BM	3	5.4
DMA	15	26.8
PhD	3	5.4
MM	25	44.6
MA	7	12.5
Other	3	5.4
Voice Type		
Soprano	26	46.4
Alto	14	25.0
Tenor	12	21.4
Baritone	2	3.6
Bass	2	3.6

Table 3 (continued)

	Pre- & Post-Survey	
	#	%
Voice Formal Training as Teacher		
Yes	52	92.9
No	4	7.1
Years Teaching Voice		
0-10	19	33.9
11-17	10	17.9
18-27	19	33.9
28-45	8	14.3
Singing Styles Taught		
Musical Theater	0	0.0
Musical Theater / Opera	15	26.8
Musical Theater / Contemporary	6	10.7
Musical Theater / Opera / Contemporary	29	51.8
Opera	3	5.4
Opera / Contemporary	2	3.6
Contemporary	1	1.8
Setting as a Voice Teacher		
Private Studio	31	55.4
College/University	23	41.1
Conservatory	2	3.6
Vocal Anatomy-Physiology, Taken Class		
Yes	55	98.1
No	1	1.8

Table 3 (continued)

	Pre- & Post-Survey	
	#	%
Vocal Anatomy-Physiology, Taught Class		
Yes	22	39.3
No	34	60.7
Vocal Acoustics, Taken Class		
Yes	47	83.9
No	9	16.1
Vocal Acoustics, Taught Class		
Yes	17	30.4
No	39	69.6
Vocal Acoustics Software, Ever Used		
Yes	33	58.9
No	23	41.1
Vocal Acoustics Software Analysis, Type^		
PRAAT	2	3.6
Voce Vista	17	30.4
Madde Synthesizer	2	3.6
Sing & See	1	1.8
Other^	11	19.6
Never Used	23	41.1

Table 3 (continued)

	Pre- & Post-Survey	
	#	%
Ever Observed Use of Ultrasound Visual Biofeedback		
Yes	9	16.1
No	47	83.9
Don't Know	0	0.0

***** Regions defined as: Western (*AZ, AK, CA, CO, HI, ID, KS, MT, NE, NV, OR, SD, UT, WA, WY*), Central (*IA, IL, IN, MI, MN, MO, ND, OH, WI*), Southern (*AL, AR, FL, GA, KY, LA, MS, NM, OK, TN, TX*), and Eastern (*CT, DE, MA, MD, ME, NC, NH, NJ, NY, PA, RI, SC, VA, VT, WV*).

^ Other vocal acoustic software included: Estill Voiceprint, PitchLab App, VisiPitch, Real Time Pitch, Spectroid and Voice Pitch Analyzer, DA Tuner, Sonospeech, Spectogram App, Overtone Analyzer, VoiceAnalyst, CSL

For voice type, approximately the majority (46.4%) reported their voice type as being Soprano, while 25.0% reported being Alto, 21.4% Tenor, 3.6% Baritone, and 3.6% Bass. For education, most respondents (44.6%) reported earning a Master of Music, 26.8% a DMA, while the remaining 28.6% reported a BA or BM, MA, PhD, or equivalent experience to the training received for a master's degree in voice performance, musical theater, or vocal pedagogy. Approximately 48.0% reported having taught for more than 17 years with the majority (51.8%) teaching musical theater, opera, and contemporary singing styles. Only four participants out of the total sample (7.1%) reported having no formal training in singing instruction. In regard to setting, most participants taught in a private studio (55.4%), while 41.1% taught at a college or university and 3.6% taught in a conservatory.

While the majority of respondents reported having taken a class in vocal anatomy and physiology (98.1%), and vocal acoustics (83.9%), a smaller number reported having taught a class in either of these subjects. In regard to past use VBF software programs, 41.1% reported having never used software for vocal acoustic analysis. Approximately 30.0% reported having used Voce Vista, while 19.6% reported use of other vocal acoustics software programs and technology systems including Estill Voiceprint Plus, PitchLab App, Visi-Pitch ™, Real Time Pitch, Spectroid, Voice Pitch Analyzer, DA Tuner, SonoSpeech, Spectrogram App, Overtone Analyzer, Voice Analyst, and Computerized Speech Lab ™ (CSL). Of the total sample, the majority (83.9%), reported no prior observation of U-VBF.

Tests of Primary Hypotheses

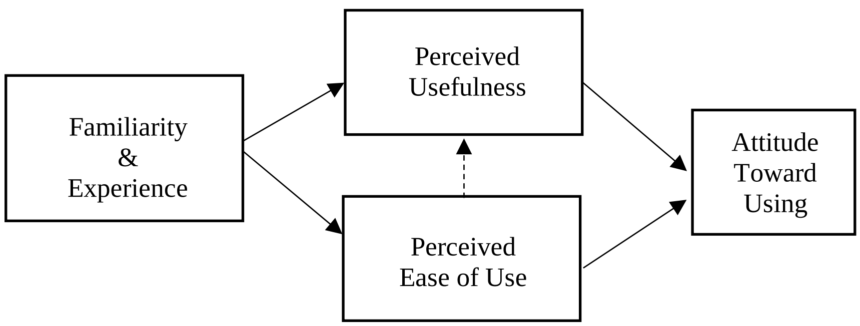
The plan of analysis for the primary hypotheses was informed by the assumptions made by the Technology Acceptance Model (TAM; Davis, 1989). Collected data were analyzed through descriptive statistics using the IBM Statistical Package for Social Sciences (SPSS), Version 27.

Current Perceptions of Visual Biofeedback Systems: Hypothesis 1

The first research question focused on identifying current knowledge and attitude among voice teachers regarding use of real-time visual biofeedback (VBF) software in singing instruction, including both acoustic VBF and ultrasound visual biofeedback (U-VBF). The TAM (Davis, 1989) was used to form the hypothesis that attitude, as informed by perceptions of usefulness and ease of use of VBF and U-VBF, would be influenced by previous experience and degree of familiarity (see Figure 4). Greater familiarity or experience with using visual biofeedback systems was hypothesized to be associated with more positive perceptions of usefulness and ease of use, and subsequently more positive attitudes toward use.

Figure 4

The Impact of Familiarity and Experience on Attitude Toward Using Visual Biofeedback, Excerpt from the Technology Acceptance Model (TAM)



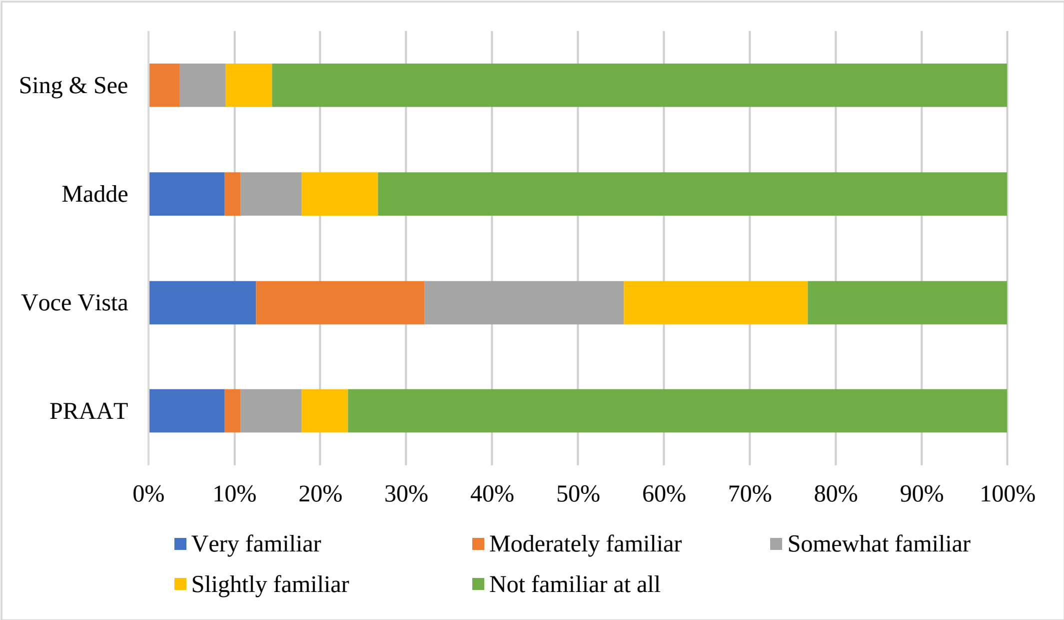
Note. This figure shows the relationship between familiarity and experience on perceptions of usefulness and ease of use and subsequently attitude toward using a technology system. Adapted from "User Acceptance of Computer Technology: A Comparison of Two Theoretical Models," by F. D. Davis, R. P, Bagozzi, and P. R. Warshaw, 1989, *Management Sciences, 35*(8), p. 985 (https://doi.org/10.1287/mnsc.35.8.982). Copyright 1989 by INFORMS.

Familiarity, Knowledge, and Perceived Usefulness of Visual Biofeedback (VBF)

Voice teachers were asked to rank on a 5-point Likert scale with 1 (*not at all*) to 5 (*very*), the degree to which they were familiar with different acoustic visual biofeedback (VBF) software programs, how helpful they found these programs to be, and how likely they were to use them in singing instruction if available. Most participants reported being generally unfamiliar with all four of the listed VBF software (PRAAT, Voce Vista, Madde Synthesizer, Sing & See; see Figure 5). Participants were most familiar with Voce Vista (approximately 32.1%), which is consistent with the respondent characteristics in which a higher percentage of participants reported experience in using Voce Vista for vocal acoustic analysis. Participants were the least familiar with Sing & See (85.7%) and PRAAT (76.8%).

Figure 5

Percentages of Degree of Familiarity of VBF Software Programs



To determine perceptions of usefulness and ease of use, participants were asked to rate how helpful they believed use of VBF was in singing instruction (perceived usefulness), and how likely they were to use VBF in their teaching. Analysis of responses was carried out via descriptive statistics, specifically central tendency (median, mode) and frequency of response (see Table 4). Due to the overall lack of familiarity reported for all four VBF software systems, participants mostly reported neutral perceptions of the usefulness of VBF in singing instruction (*Mdn* = 3, *Mode* = 3). A more positive perception was found for participants' ratings regarding their likelihood to use VBF in singing instruction (*Mdn* = 4, *Mode* = 4), with the majority (62.5%) reporting being moderately likely to use VBF.

Table 4

Ratings of Perceived Usefulness and Likelihood to Use VBF in Singing Instruction

	Rating Response Frequency *n* (%)					Median	Mode
	1	2	3	4	5		
How Helpful is VBF in Singing Instruction	2 (3.6%)	7 (12.5%)	27 (48.2%)	15 (26.8%)	5 (8.9%)	3	3
How Likely to Use VBF in Teaching	1 (1.8%)	4 (7.1%)	5 (8.9%)	35 (62.5%)	11 (19.6%)	4	4

Note. 1 = Not at all, 2 = Slightly, 3 = Somewhat, 4 = Moderately, 5 = Very

Familiarity, Knowledge, and Perceived Usefulness of Ultrasound Visual Biofeedback (U-VBF)

On the same 5-point Likert scale, voice teachers were asked to rank their familiarity of how ultrasound worked and their understanding of its use as a visual biofeedback tool in singing instruction. Central tendency measures indicated that most participants reported being somewhat familiar with how ultrasound worked (*Mdn* = 3, *Mode* = 3). Of the total sample (*n* = 56), 32.1% reported being slightly familiar, while 37.5% reported moderate familiarity (see Table 5).

Table 5

Ratings of Familiarity with How Ultrasound Works

	Rating Response Frequency *n* (%)					Median	Mode
	1	2	3	4	5		
Familiarity with How Ultrasound Works	8 (14.3%)	18 (32.1%)	21 (37.5%)	7 (12.5%)	2 (3.6%)	3	3

Note. 1 = Not at all, 2 = Slightly, 3 = Somewhat, 4 = Moderately, 5 = Very

When asked whether they had previously observed U-VBF, only 16.1% of the sample answered "yes," while the majority (83.9%) answered "no." This response trend was reflected in participants' ratings for how knowledgeable they were about using U-VBF to provide visual biofeedback in singing instruction (see Table 6). Most participants (60.7%) reported knowing nothing at all, while 33.9% expressed knowing only a little. Only three participants (5.36%) reported being moderately to very knowledgeable of using U-VBF in singing to visualize movements of the tongue, the majority (58.9%) indicated being unfamiliar; however, a slightly larger number (10.7%) reported being moderately to very familiar (see Table 7).

Table 6

Ratings of Knowledge of U-VBF to Provide Visual Biofeedback for Singing Instruction

	Rating Response Frequency *n* (%)					Median	Mode
	1	2	3	4	5		
Knowledgeable of U-VBF in Singing Instruction	34 (60.7%)	11 (19.6%)	8 (14.3%)	1 (1.8%)	2 (3.6%)	1	1

Note. 1 = Not at all, 2 = Slightly, 3 = Somewhat, 4 = Moderately, 5 = Very

Table 7

Ratings of Familiarity of Visualization of Tongue Movements Using U-VBF

	Rating Response Frequency *n* (%)					Median	Mode
	1	2	3	4	5		
Familiarity of Visualizing Tongue Movements with U-VBF	33 (58.9%)	8 (14.3%)	9 (16.1%)	4 (7.1%)	2 (3.6%)	1	1

Note. 1 = Not at all, 2 = Slightly, 3 = Somewhat, 4 = Moderately, 5 = Very

Collectively, these results indicate low levels of familiarity and knowledge among voice teachers regarding ultrasound and its use as a visual biofeedback tool. However, when asked to rank how helpful they believed U-VBF would be in singing instruction, perceptions were relatively positive (*Mdn* = 4, *Mode* = 4) with most participants rating U-VBF as being either somewhat helpful (30.4%), moderately helpful (33.9%), or very helpful (19.6%; see Table 8).

Table 8

Ratings of Perceived Helpfulness of U-VBF in Singing Instruction

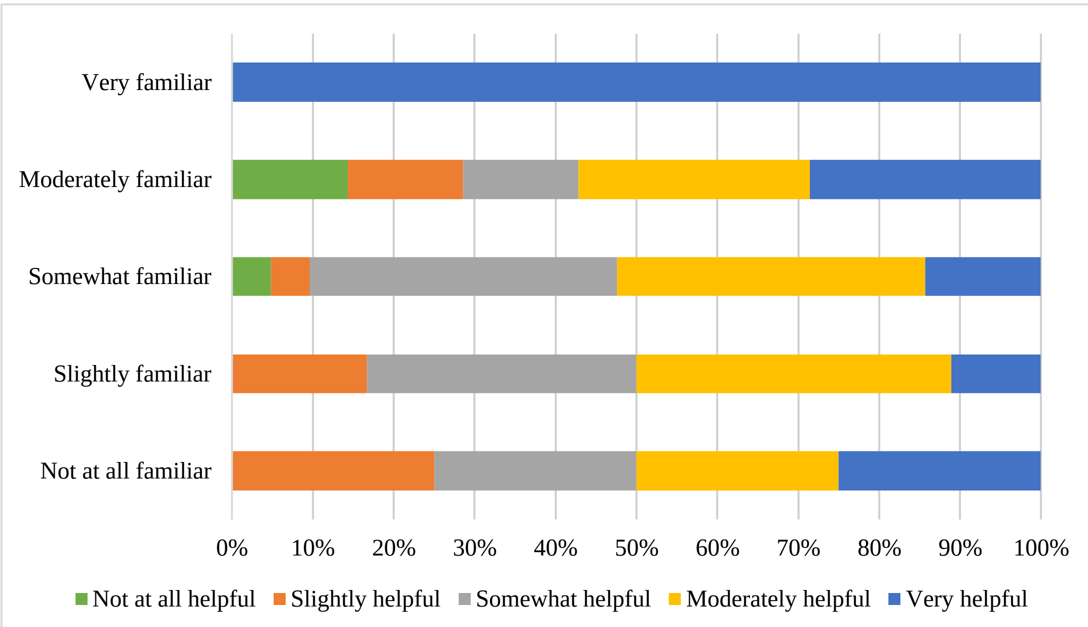
	Rating Response Frequency *n* (%)					Median	Mode
	1	2	3	4	5		
Perceived Helpfulness of U-VBF	2 (3.6%)	7 (12.5%)	17 (30.4%)	19 (33.9%)	11 (19.6%)	4	4

Note. 1 = Not at all, 2 = Slightly, 3 = Somewhat, 4 = Moderately, 5 = Very

Crosstabulation of responses was conducted to evaluate trends in responses between familiarity, knowledge, and perceived usefulness of U-VBF. The two participants who reported being very familiarity with how ultrasound works also perceived U-VBF to be very helpful in singing instruction. Of those reported moderate familiarity, most (57.2%) perceived U-VBF as being moderately to very helpful, while the remaining 42.9% were divided in opinion between U-VBF being not at all helpful to somewhat helpful. Surprisingly, the majority (85.1%) of those who reported being not at all to somewhat familiar (*n* = 47), expressed positive opinions regarding the potential usefulness of U-VBF in singing instruction. Of those who reported being somewhat familiar with how ultrasound works (*n* = 21), most (76.2%) believed U-VBF to somewhat to moderately helpful, while 14.3% believed it to be very helpful. Of those who reported no to slight familiarity of ultrasound (*n* = 26), the majority perceived U-VBF to be helpful to some degree. In general, opinions tended toward the more neutral ratings of somewhat and moderately helpful (see Figure 6).

Figure 6

Crosstabulation between Ratings of Perceived Helpfulness of Use of U-VBF in Singing Instruction by Ratings of Familiarity with How Ultrasound Works

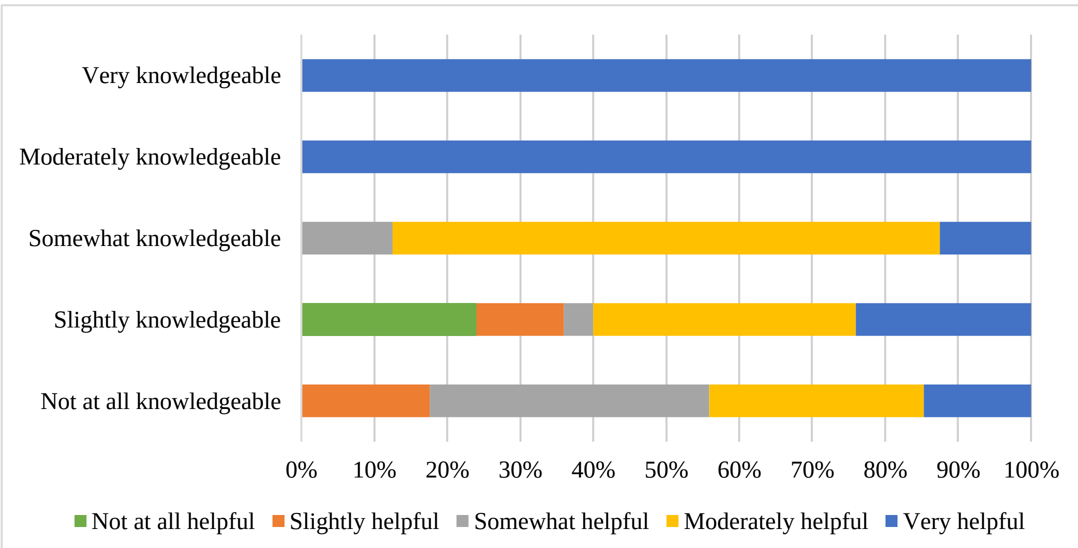


Positive opinions regardless of degree of knowledge and familiarity were observed when comparing participants' ratings for usefulness of U-VBF with their knowledge of its use in singing instruction (see Figure 7). Those who reported being not at all to slightly knowledgeable of the use of U-VBF in singing instruction had neutral to positive opinions regarding its usefulness. Of the 34 participants who reported having no knowledge of U-VBF, 44.2% believed U-VBF to be moderately to very helpful, while 35.3% believed it to be somewhat helpful and 17.6% believed it to be slightly helpful. Of the participants who reported being slightly knowledgeable (n = 11), 45.4% perceived U-VBF to be moderately to very helpful, while 18.2%

believed it to be not helpful at all. Those who were somewhat knowledgeable of use of U-VBF (n = 8), 75% believed U-VBF to be moderately helpful. Although positive ratings appeared to increase with greater degree of knowledge, the smaller proportion of participants who reported being moderately to very knowledgeable (n = 3) did not allow for a clear comparison with the responses of those who reported being somewhat knowledgeable to having no knowledge at all.

Figure 7

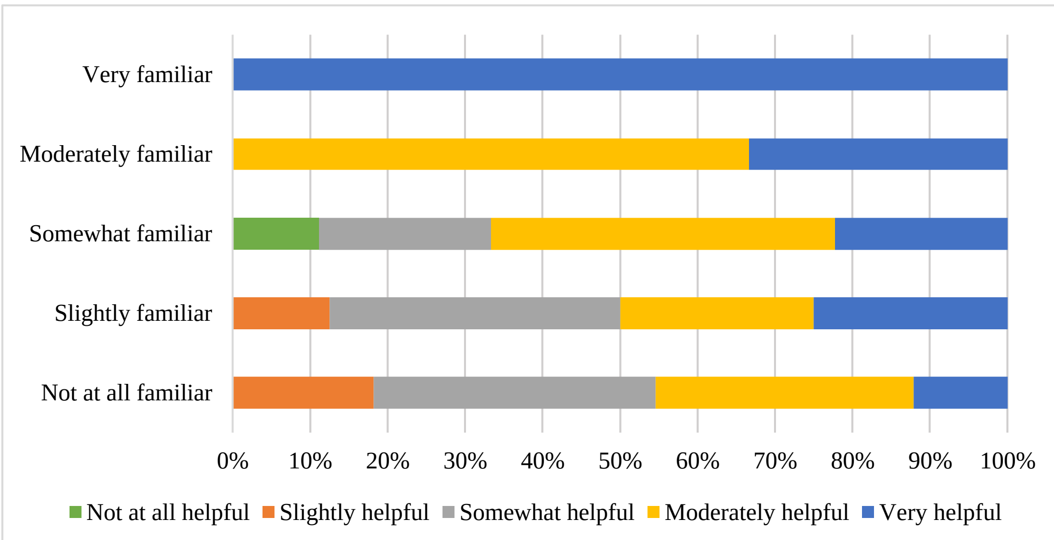
Crosstabulation between Ratings of Perceived Helpfulness of U-VBF by Ratings of Knowledge of U-VBF in Singing Instruction



Of those who reported being not at all familiar with using ultrasound to visualize tongue movements (n = 33), the majority (36.6%) rated U-VBF as being somewhat helpful, while 33.3% believed it to be moderately helpful, 12.1% as very helpful, and 18.2% as somewhat helpful (see Figure 8). Of interest, one participant who reported being somewhat familiar with use of ultrasound to visualize tongue movements, rated U-VBF as being not at all helpful. More positive perceptions appeared to be associated with greater familiarity; however, like previous analysis, the number of those who reported being moderately (n = 4) to very familiar (n = 2) was much smaller in comparison to those who reported being somewhat (n = 9), slightly (n = 8), or not at all (n = 33) familiar, therefore limiting the degree of comparison.

Figure 8

Crosstabulation between Ratings of Perceived Helpfulness of U-VBF in Singing Instruction by Ratings of Familiarity of Visualizing Tongue Movements with U-VBF



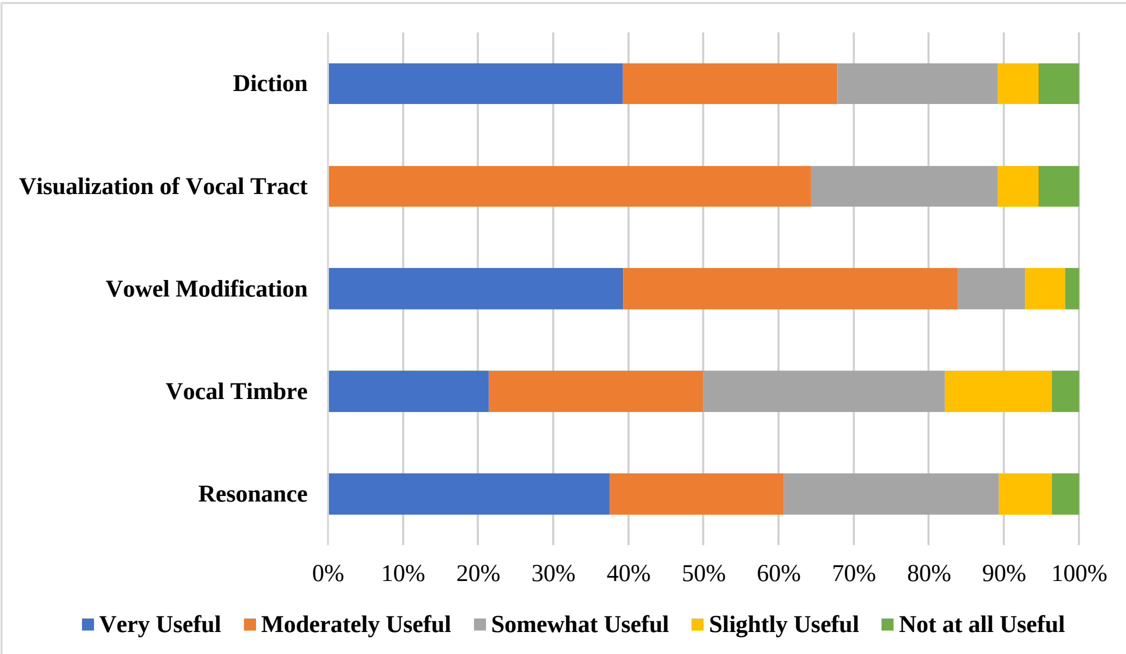
From these findings, it was assumed that specific knowledge of U-VBF contributed to more positive perceptions of its usefulness in voice instruction than from general knowledge of ultrasound alone. In general, participants who reported less familiarity and knowledge of U-VBF provided more neutral ratings (3 = *somewhat*; 4 = *moderately*) of the usefulness of U-VBF, while the few who reported greater familiarity and knowledge tended have slightly more positive opinions. Only one individual, who reported moderate familiarity of use of ultrasound to show tongue movements, rated U-VBF as not helpful for teaching vocal pedagogy concepts. Overall, as indicated by their ratings, most participants appeared to express positive expectations regarding use of U-VBF in singing instruction, despite their minimal familiarity and knowledge of it. Lastly, while most participants had not previously observed use of U-VBF, the majority (51.0%) believed it would be moderately to very useful in singing instruction.

Perceived Usefulness of Ultrasound Visual Biofeedback in Teaching Vocal Pedagogy Concepts

To further examine voice teachers' opinions regarding the utility of U-VBF in singing instruction, participants were asked to rate on a 5-point Likert scale, with 1 being *not at all* to 5 being *very*, how useful they believed U-VBF to be for teaching specific concepts related to vocal pedagogy. Common concepts were identified as vocal resonance, vocal timbre, vowel modification, and diction. Participants were also asked to rate how useful they believed U-VBF would be in visualization of vocal tract shape and size. Overall, most participants felt that U-VBF was moderately to very useful for all the identified vocal pedagogy concepts (see Figure 9). Central tendency measures indicated positive opinions regarding the usefulness of U-VBF to visualize the vocal tract (*Mdn* = 4, *Mode* = 4) and in teaching vocal resonance (*Mdn* = 4, *Mode* = 5), vowel modification (*Mdn* = 4, *Mode* = 4), and diction (*Mdn* = 4, *Mode* = 5). More neutral opinions were expressed for the role of U-VBF in teaching vocal timbre *Mdn* = 3.5, *Mode* = 3). Further analysis using crosstabulation between variables revealed no noticeable trends differentiating participants' responses based off knowledge and experience of U-VBF.

Figure 9

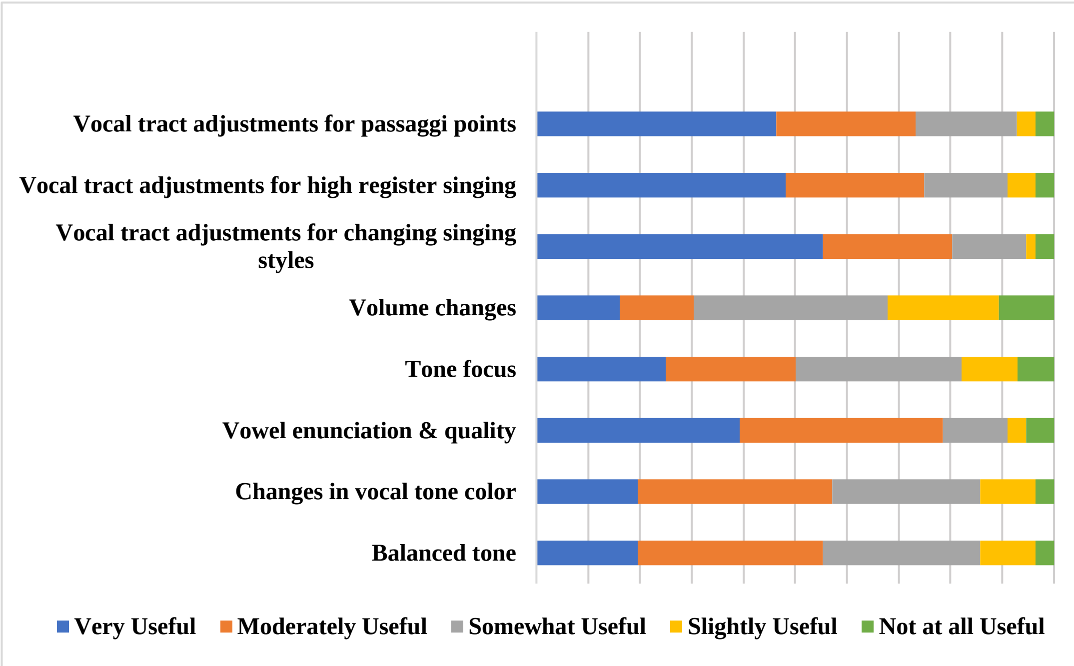
Percentages of Ratings for Perceived Usefulness of U-VBF in Teaching Vocal Pedagogy Concepts



Regarding pedagogy concepts specifically related to vocal timbre, opinions were generally positive with most participants rating U-VBF as being moderately to very useful for tone focus, vowel enunciation and quality, changes in vocal tone color, balanced tone, and vocal tract adjustments for passaggi points, high-register singing, and for changing singing styles (see Figure 10). Central tendency measures indicated more neutral opinions regarding the usefulness of U-VBF in teaching tone focus (Mdn = 3.5, *Mode* = 3) and volume changes (*Mdn* = 3, *Mode* = 3). Further analysis for the existence of potential relationships between ratings of perceived usefulness of U-VBF, knowledge and familiarity of ultrasound and U-VBF were not strongly apparent. Rather, participants provided neutral ratings for usefulness of U-VBF to teach tone focus and volume changes regardless of their prior knowledge and familiarity.

Figure 10

Percentages of Ratings for Perceived Usefulness of U-VBF in Teaching Vocal Pedagogy Concepts Related to Vocal Timbre



Familiarity, Knowledge, and Ease of Using Ultrasound Visual Biofeedback

Following the assumptions made by the TAM (Davis, 1989), it was hypothesized that greater familiarity and knowledge of U-VBF would be positively related to voice teachers' perceptions of its ease of use in singing instruction. Participants were asked using a 5-point Likert scale with 1 (*extremely difficult*) and 5 (*extremely easy*), to rate their opinions regarding how easy it would be to use U-VBF in their teaching. Central tendency measures indicated that opinions ranged between neutral to guarded (Mdn = 3, *Mode* = 2). Most participants either rated U-VBF as being somewhat difficult to use (37.5%) or chose the neutral rating of *neither easy nor difficult*, while 8.9% rated it as being very difficult (see Table 9). Of the total sample (*n* =56), only fifteen participants believed U-VBF as being easy to use, with 21.4% choosing the rating of *somewhat easy*, and 5.4% choosing the rating *extremely easy*.

Table 9

Ratings of Perceived Ease of Use of U-VBF in Singing Instruction

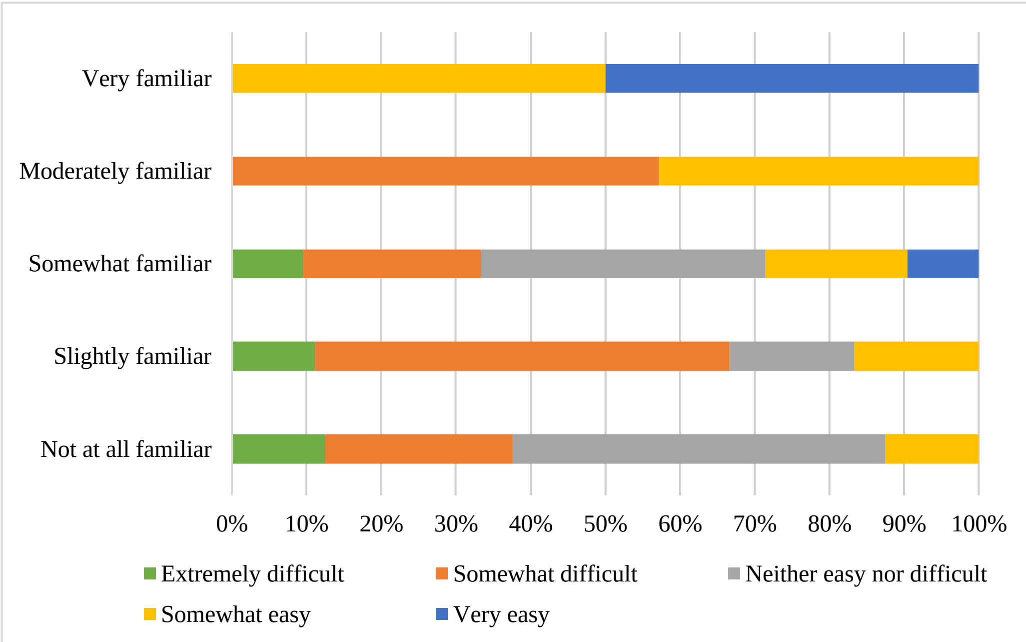
	Rating Response Frequency *n* (%)					Median	Mode
	1	2	3	4	5		
Perceived Ease of Use of U-VBF	5 (8.9%)	21 (37.5%)	15 (26.8%)	12 (21.4%)	3 (5.4%)	3	2

Note. 1 = Extremely difficult, 2 = Somewhat difficult, 3 = Neither easy nor difficult, 4 = Somewhat easy, 5 = Extremely easy

Crosstabulation between participants' ratings for ease of use of U-VBF and their familiarity and knowledge of how ultrasound works was conducted to further examine the relationship between these variables (see Figure 11). Analysis revealed that in general, despite possessing some familiarity with how ultrasound works, most participants perceived it to be somewhat difficult to use or were uncertain, choosing the rating of *neither easy nor difficult*. Of those who reported being moderately familiar with how ultrasound works (*n* = 7), four participants believed ultrasound to be somewhat difficult to use. This finding might be explained by greater familiarity with use of ultrasound in diagnostic procedures, such as monitoring the growth and development of a fetus, as compared to its therapeutic uses.

Figure 11

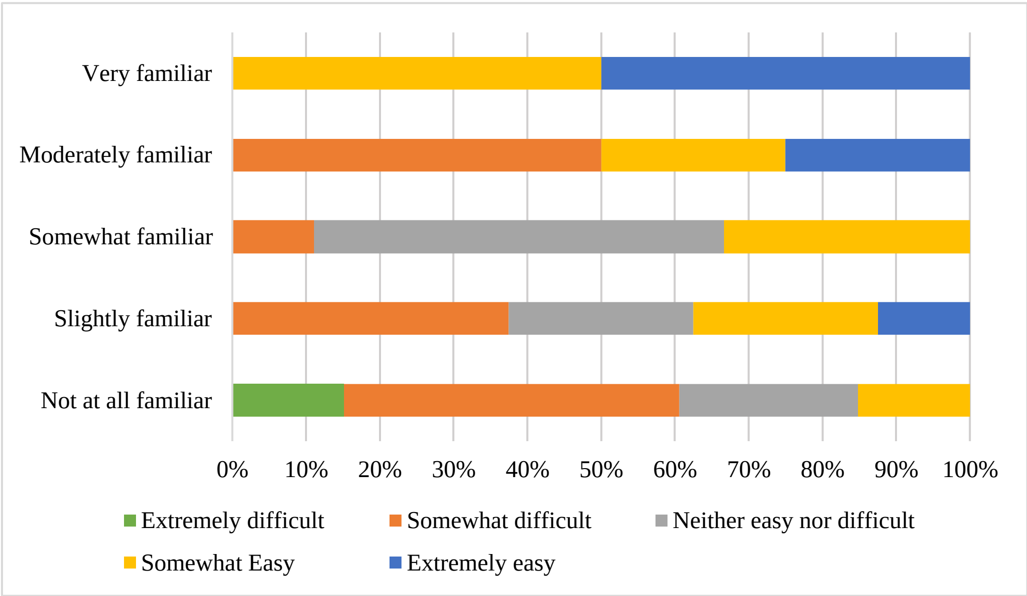
Crosstabulation between Perceived Ease of Use of U-VBF in Singing Instruction by Familiarity with How Ultrasound Works



A similar trend was apparent in relation to participants' degree of familiarity with the use of ultrasound to visualize tongue movements (see Figure 12). Those who were not at all familiar (*n* = 33) largely believed U-VBF to be somewhat difficult to use (45.5%), although 15.2% felt it would be somewhat easy to use. The majority of those who reported being slightly familiar (*n* = 8), felt that U-VBF would be somewhat difficult to use, while 25% expressed uncertainty by choosing the neutral rating of *neither easy nor difficult*; however, the remaining 37.5% believed U-VBF to somewhat to extremely easy to use. Opinions were more neutral among those who reported being somewhat familiar (*n* = 9). Surprisingly, half of those who reported being moderately familiar (*n* = 4) rated ultrasound as somewhat difficult to use. Of the two individuals who were very knowledge of using U-VBF to visualize tongue movements, one believed U-VBF to be somewhat easy to use while the other believed it to be extremely easy to use.

Figure 12

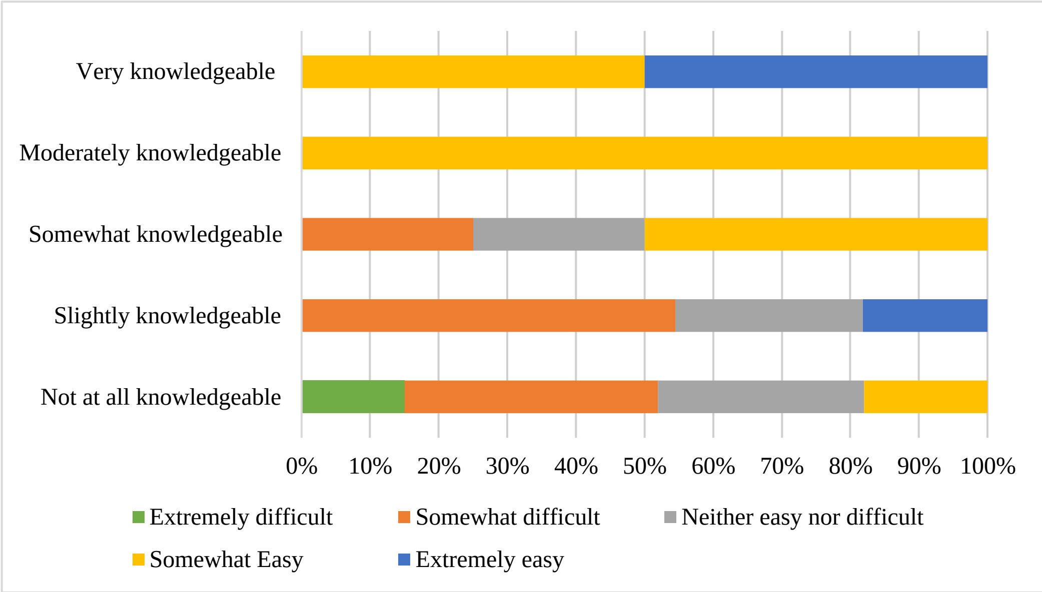
Crosstabulation between Ratings of Perceived Ease of Use of U-VBF by Ratings of Familiarity of Visualizing Tongue Movements with U-VBF



Similar to previous data, ratings for perceived ease of use increased with degree of experience, in this case, knowledge of using U-VBF in singing instruction (see Figure 13). Of the total sample (*n* = 56), one participant reported being moderately knowledgeable, while two participants reported being very knowledgeable with the use of U-VBF in singing instruction. These individuals felt that U-VBF was moderately to extremely easy to use. Of those who reported being somewhat knowledgeable (*n* = 8), half believed U-VBF to be somewhat easy to use. Opinions were more guarded in responses from participants who reported minimal to no familiarity. Of the total sample (*n* = 56), the majority reported being not at all familiar (*n* = 34), approximately half of which believed U-VBF to be difficult to use. Six participants felt U-VBF would be somewhat easy to use despite reporting no prior familiarity with U-VBF in the voice studio.

Figure 13

Crosstabulation between Ratings of Perceived Ease of Use of U-VBF by Ratings of Knowledge of U-VBF in Singing Instruction



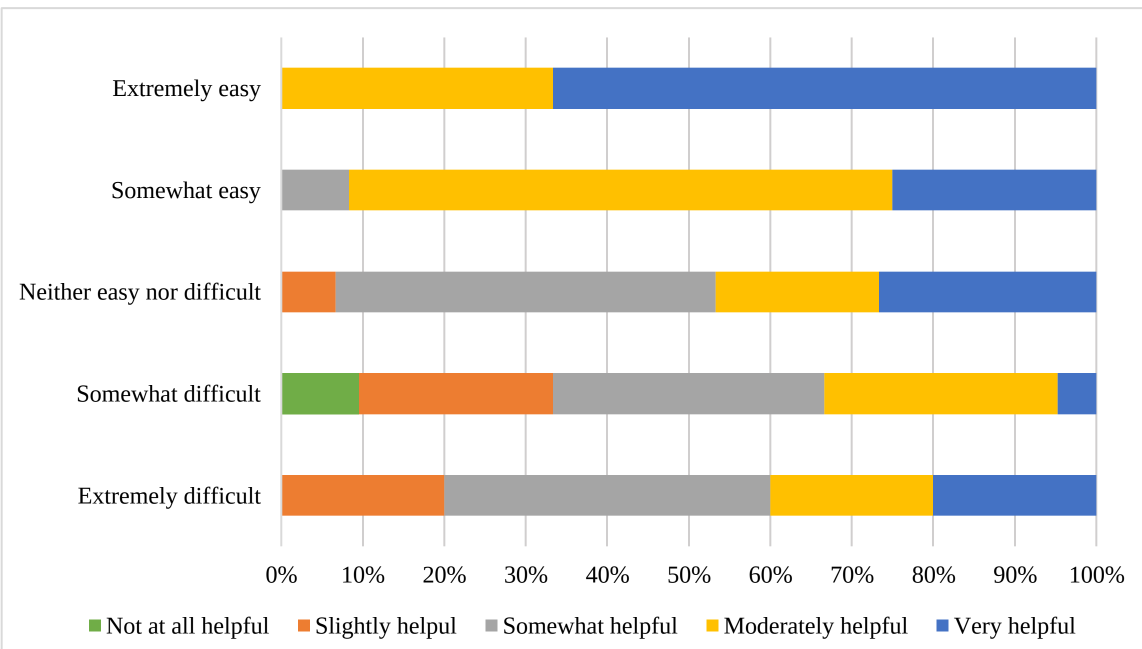
Despite apparent reservations regarding ease of use of ultrasound as a visual biofeedback tool, participants did convey overall positive opinions regarding how easily they could learn to use U-VBF if provided training. Of the total sample (*n* = 56), the majority (96%) agreed, overall suggesting a high degree of self-efficacy.

Relationship between Ease of Use and Perceived Usefulness

According to the TAM, perceived ease use indirectly informs perceived usefulness (Davis, 1989). Based off these assumptions, it was hypothesized that those who perceived U-VBF to be easier to use would believe it to be more helpful in singing instruction. Crosstabulation of participants' ratings for perceived helpfulness of U-VBF and its ease of use in the voice studio were conducted (see Figure 14). Analysis revealed that in general, those who perceived U-VBF to relatively easy to use, also regarded it as being moderately to very helpful in singing instruction. However, of those who rated U-VBF to be somewhat difficult to use (*n* =21), 33.3% perceived it to be moderately to very helpful, while the remaining 57.1% believed it to be slightly to somewhat helpful. A small percentage (9.5%) of those who rated U-VBF to be somewhat difficult believed it was not at all helpful in singing instruction. The majority of those who rated U-VBF to be extremely difficult (60.0%) perceived it to be slightly to somewhat helpful, while 40.0% believed it to be moderately to very helpful. Of those who chose the neutral rating of "neither easy nor difficult," the majority (46.7%) believed U-VBF to be somewhat helpful, while an equal percentage regarded it as being moderately to very helpful.

Figure 14

Crosstabulation between Participants' Ratings for Perceived Ease of Use by Perceived Usefulness of U-VFB in Singing Instruction

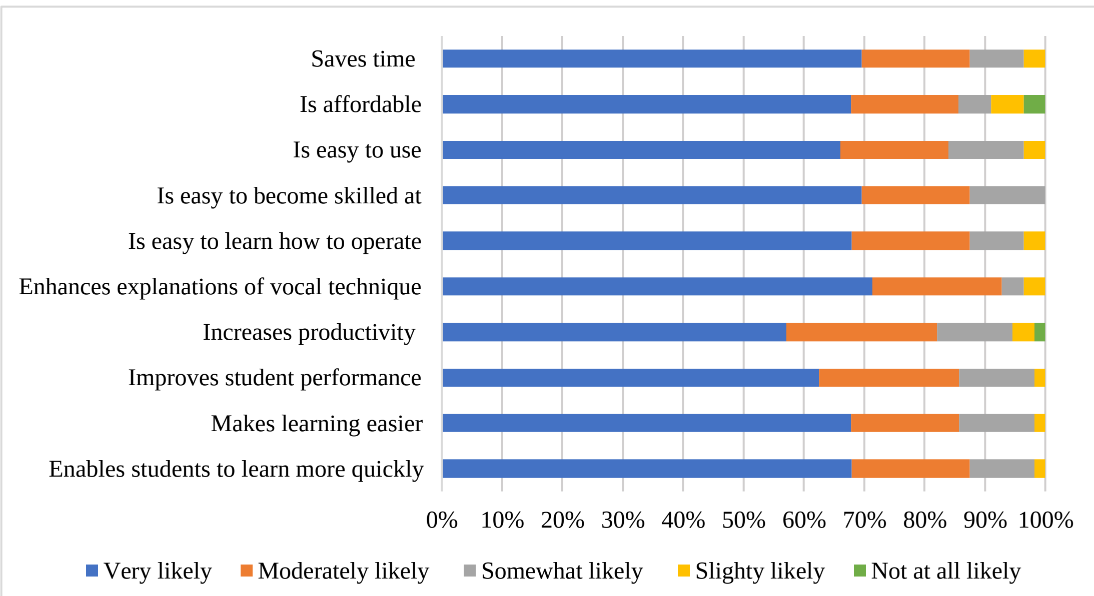


Likelihood of Using Ultrasound Visual Biofeedback (U-VBF)

In further examining likelihood of using U-VBF in singing instruction, participants were asked to rate on a 5-point Likert scale, with 1 (*not at all*) to 5 (*very*), how likely they would be to use U-VBF given the presence of specific drivers, such as making learning easier, enhancing explanations of vocal technique, easy operation, affordability, etc. Visual examination of frequency distributions showed that given potential drivers, most participants felt that they would be very likely to use U-VBF in singing instruction (see Figure 15).

Figure 15

Ratings for Drivers Regarding Likelihood of Using U-VBF

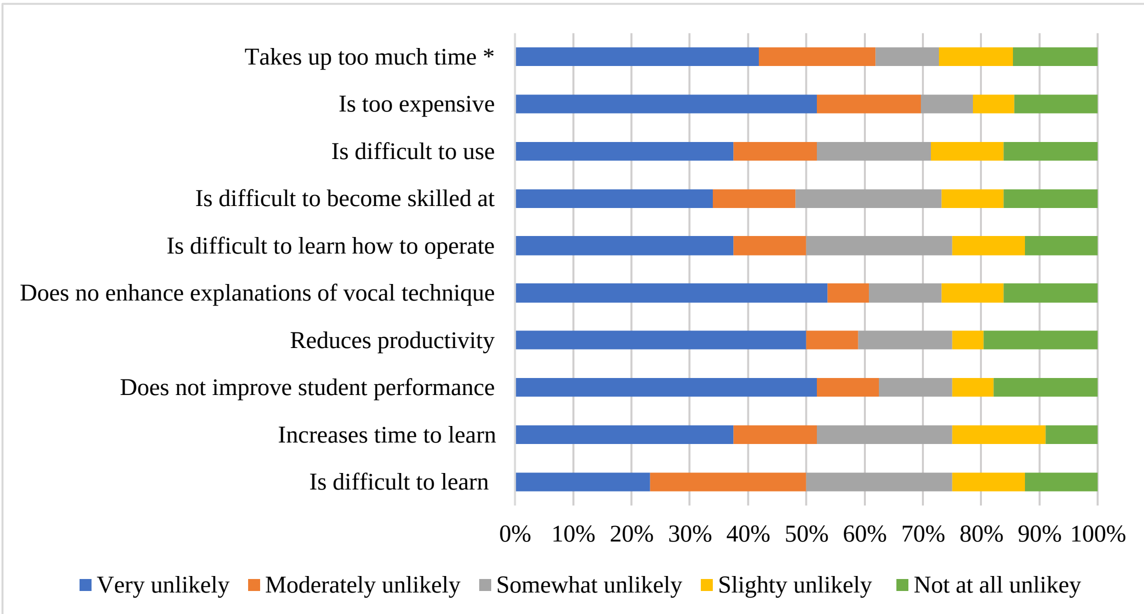


Comparison between participants' ratings and their familiarity with how ultrasound works, knowledge of U-VBF in singing instruction, and familiarity with using ultrasound to visualize lingual movements revealed similar trends regarding likelihood of using U-VBF given specific drivers, regardless of how familiar participants were with ultrasound and U-VBF. A general trended was observed with consistent higher ratings from participants (*n* = 22) who reported some degree of prior knowledge compared to those who reported not being familiar with U-VBF at all (*n* = 34).

Participants were also asked to rate how unlikely they would be to use U-VBF given the presence of potential barriers, such as difficulty in learning how to use and operate, increased time and expense, reduced productivity, etc. Using a 5-point Likert scale, participants were asked to rank, with 1 (*not at all*) to 5 (*very*), how unlikely they would be to use U-VBF if specific barriers were present. As rankings centered on the degree of how unlikely participants were to use U-VBF, interpretation of the values was reversed such that lower rankings (i.e., 1 = *not at all unlikely*) indicated that participants perceived U-VBF to be less of a barrier. Visual examination of the frequency of distributions for participants' ratings indicated that most were moderately to very unlikely to incorporate U-VBF as a teaching tool given the presence of specific barriers (see Figure 16). Specifically, over half of the sample agreed that they would be very unlikely to adopt U-VBF if it did not improve student performance (51.8%), reduced productivity (50.0%), was ineffective in enhancing explanations of vocal technique (53.6%), and if it was too expensive (51.8%).

Figure 16

Ratings for Barriers Regarding Likelihood of Using U-VBF



* Missing one data point.

Of interest, are the participants who responded with more neutral ratings, *somewhat unlikely* or *slightly unlikely*, as well as those who reported the rating *not at all unlikely* to use U-VBF given a specific barrier. Crosstabulation of variables was conducted to further examine whether participants' ratings were potentially informed by how much they knew about ultrasound and U-VBF. Examination of the resulting contingency tables showed no obvious interrelation between knowledge or familiarity. Surprisingly, participants who reported having minimal to no prior knowledge or familiarity of ultrasound and U-VBF appeared to disagree more so than those with previous experience that these specific barriers would interfere with their likelihood of using U-VBF. This finding suggests positive expectations among participants without prior knowledge or experience of what U-VBF can provide in the voice studio.

Thematic Analysis of Perceptions of Ultrasound Visual Biofeedback

Thematic analysis offers a flexible approach to analysis of qualitative data (Braun & Clarke, 2006). Following familiarization of the data, codes were developed to describe the content of participants' responses. Data were collated into groups to identify common themes.

Perceived Strengths. For the perceived strengths of U-VBF, the following four themes were identified from analysis: (a) clarifies pedagogy, (b) supports behavior recognition, (c) supports different learning styles, and (d) uncertainty (see Table 10). Most participants felt that visual biofeedback could be utilized as a new or supplemental teaching tool to objectify pedagogical concepts and promote clearer dialogue between teacher and student. Participants also commented on the immediate feedback provided by visual biofeedback and that visualization of the physical movements during a student's singing provided valuable information to the teacher in informing the next steps in instruction. Participants also felt that U-VBF could be used to clarify terminology and address misconceptions regarding specific movements of articulators, such as the role of the tongue in singing.

As a potential instructional tool, many participants felt that visual biofeedback might better support students who were visual learners by providing in real time a clear image of lingual and jaw movement during singing, allowing for the cultivation of kinesthetic awareness. One respondent felt that ultrasound might be an engaging way in which to connect with younger students who are attuned to technology. Others expressed uncertainty regarding the usefulness of U-VBF, stating that they did not yet know enough about it to make an informed decision.

Table 10

Perceived Strengths of U-VBF in Singing Instruction

Theme	Codes	Quotations
Clarifies Pedagogy	*Promotes dialogue between teacher/student*	• "…I can tailor my suggestions based on the visualization from the biofeedback technology." • "Being able to know exactly what the student is doing physically and be able to correct since we can't ever feel exactly what they are feeling when singing."
	Objectifies concepts	• "It helps make instruction a little more tangible and, in some ways, objective" • "It would help validate a teacher's auditory assessment of a student's technical strengths and weaknesses and help to inform lesson planning and teaching processes."
	Provides new teaching tool	• "An additional tool for understanding one's voice, particularly for visual/science interested students."
	Affirms learning of new skill	• "It is another mode of affirmation for students developing new skills and techniques." • "It provides an element of 'don't just take my word for it' proof that some students seem to need."

Table 10 (continued)

Theme	Codes	Quotations
Supports Behavior Recognition	*Provides clear visual reference*	• "It provides clear visualization for both my student and myself in identifying any potential muscular tension and/or physiological aspects in sound production." • "Some students' learning styles may also be well-served by this tool as another way for them to have a concrete representation of what they are doing and to connect how things feel as they sing to what they see."
	Increases self-awareness/assessment	• "Visual biofeedback might help students to develop an accurate body schema vis à vis the structure and function of the voice and a clearer understanding of the behavior of sung tone (i.e., the physical of sound)." • "In the case of ultrasound, it can be revolutionary for prompting kinesthetic awareness of tongue and jaw positioning."
	Works in real time	• "Immediately seeing tensions in the body instead of guessing." • The integration of visual biofeedback technology immediately places these sensations into focus for the student and teacher alike."

Table 10 (continued)

Theme	Codes	Quotations
Supports Different Learning Styles	*Visual learning*	• "Many students are extremely visual and would find it easier to SEE what their voice is doing as opposed to me describing it." • "Some students are visual learners, so I assume that having visual feedback for the sounds they are making would be more helpful to those students than receiving strictly auditory feedback."
	Technological affinity	• "…I think younger students are more primed for this kind of input due to the prevalence of gaming and simulation in our popular culture now."
Uncertainty	*Uncertain*	• "Can't say yet."

Perceived Limitations. Five themes were identified in participants' responses regarding the limitations of U-VBF including (a) equipment needs, (b) training requirements, (c) misuse of equipment, (d) distrust of equipment, and (e) uncertainty (see Table 11). When asked to comment on perceived limitations of U-VBF, most respondents commented on availability, cost, and quality of equipment. Others voiced the limitation of ultrasound equipment being unavailable for students during independent practice or rehearsals. Many respondents also expressed concerns regarding training requirements and the time needed not only to learn how to use ultrasound to provided visual biofeedback, but also to teach their students how to interpret and benefit from the images provided. Another concern included over-reliance of U-VBF and the lack of transfer of learned skills to singing without visual biofeedback. Another concern included the potential negative impact U-VBF may have on student's performance by placing too much focus onto a single aspect of singing technique, distracting from the overall intention of singing, reducing artistic freedom, or causing undue anxiety. Additionally, others felt that some of their students may find U-VBF more confusing than helpful or be averse to a scientific approach to voice instruction.

Table 11

Perceived Limitations of U-VBF in Singing Instruction

Theme	Codes	Quotations
Equipment Needs	*Cost/Availability*	"Resource/budgetary concerns, both from an institutional and individual perspective…accessibility will hinder instructors from utilizing this equipment if they work for institutions with a limited departmental budget or if they are private instructors with limited resources." “Also, reliance on technology when one doesn’t have access during rehearsals and performance seems like a problem.”
	Quality	“The need for good equipment.”
Training Requirements	*Training*	“I would think that it would be necessary to have a teacher to serve as an interpreter of the feedback being shown on the screen. I would image that just seeing the feedback would not be enough to provide meaningful instruction.” “If a teacher is not adequately trained in vocal pedagogy, they might very well come up with some potentially harmful work-around technique hacks in order to get the desired biofeedback results.”
	Knowledge	“This can be a limitation if the singer doesn’t have knowledge about the tool being used, how it works, if the student is not a learner, and so on.” “Acoustic software provides abstract visual evidence only, requires high degree of translation into other learning modes.”
	Time	“With some visual programs (particularly those that show spectra and acoustic information, it would take FOREVER to train entering undergraduates from woefully deficient educational backgrounds…to understand what they are seeing.” “Might take a long time to explain to students what is going on and how it relates to their singing.”

Table 11 (continued)

Theme	Codes	Quotations
Misuse of Equipment	*Over-reliance*	• "Students don't always 'transfer' the knowledge and employ it when they DON'T have the visual feedback – they don't develop the kinesthetic awareness they need to do the same thing without the visual guidance." • "It could make students dependent upon the type of feedback, and they may not develop the corresponding connections to how the singing feels as well."
	Cause bad habits	• "Also, there can be, in general and in all discussions of technical matters, a tendency for students to become overly self-analytical and abstract in their thinking and practice." • "It could also cause stress related tension in a singer if they focus on getting the feedback correct, rather than the particular technique that will lead the to the appropriate biofeedback."
	Distraction	• "Relying on science alone is limiting. There are other aspects of listening to a student and working with integration of instincts as well as using ultrasound."
Distrust of Equipment	*Loss of Artistry*	• "Students might lose the artistic aspect of singing." • "I feel sound aesthetic is still too subjective to be replaced."
	Averse to	• "Some of my students are not interested in the science behind singing and might find it too 'academic.'" • "Not every student is well-versed or willing to accept the biovisual feedback. To some, they might find the biovisual feedback confusing."
Uncertainty	*Uncertain*	• "Not familiar enough to make a statement."

Perceived Importance. Responses for perceived importance of visual biofeedback, such as U-VBF, in voice instruction were collated into codes within the themes "important" and "not important" (see Table 12). Many respondents felt that ultrasound imaging could be used as an additional teaching tool to provide a visual explanation to a pedagogical concept, assisting in acquisition of a technical skill and providing objective feedback on a student's performance. As one respondent commented, "When science supports vocal technique, it helps remove mystery from an instrument that cannot be seen with ease and regularity." In general, most respondents felt that visual biofeedback using ultrasound could be used to provide important information regarding technical components of singing and to encourage students to cultivate kinesthetic awareness. Some referenced the need for voice teachers to stay up to date with new approaches to vocal pedagogy, including incorporation of technology, such as visual biofeedback systems.

Others felt that U-VBF was unnecessary for effective voice instruction, referencing limitations due to lack of availability or no current use of other visual biofeedback systems. One respondent commented, "I think it can be useful, but fortunately not essential, as I can't imagine my institution spending any money to provide it!" Some felt that while U-VBF in singing instruction may be helpful, they voiced concerns about overreliance or diminishing of other aspects of vocal instruction. As one respondent commented "It's important that it offers a vision of what is happening inside, but you can't use it as the only way to address the student's problems." In regard to U-VBF, another participant stated, "Important to make students 'see' what they do vocally, but a rich or perfectly pitched sound is not yet good singing."

Table 12

Perceived Importance of U-VBF in Singing Instruction

Theme	Codes	Quotations
Important	*Useful teaching* tool	• "Words are limiting, especially when trying to describe processes that the student can't see. Having another sensory input to explain adjustments needed would be helpful." • "I think visual biofeedback might be quite important and useful tool in helping students to understand their vocal function clearly and accurately."
	Provides visual insight	• "I think it's important because it can provide a visual element. Almost all motor skills (i.e., walking, playing an instrument) we can learn by seeing what's happening. We don't get that advantage with voice or smaller articulatory movements. Having some form of visual feedback can assist in learning, especially at the early stages."
	Objectifies pedagogy	• "Unfortunately, the applied studio is grounded in subjectivity, both of the art form of singing itself and from the personal assumptions and bias of the instructor. Visual audio feedback would provide measurable artifacts with which to base curricular choices." • "Teaching singing can be abstract, especially since it is difficult to observe the instrument in action. Any additional tools that give a student more insight into what they are doing can help demystify the process."
	Informative	• "I believe it is important to use technology for visual biofeedback because it is possible for a teacher to miss hearing something that needs to be addressed in a singer's voice."
	Promotes self-monitoring	• "Helps some students monitor."
	Staying current	• "It is important because we are the 21st century! When we take a vocal pedagogy class, esp. at the master's level, we shouldn't continue the tradition of graduating singing teachers based on how wonderful their voices are. We should be graduating singing teachers that are worthy of the level of education they were awarded. All technology should be taught in vocal pedagogy class – not dumbed-down because most are performance majors that are only interested in teaching if they don't make it as a performer."

Table 12 (continued)

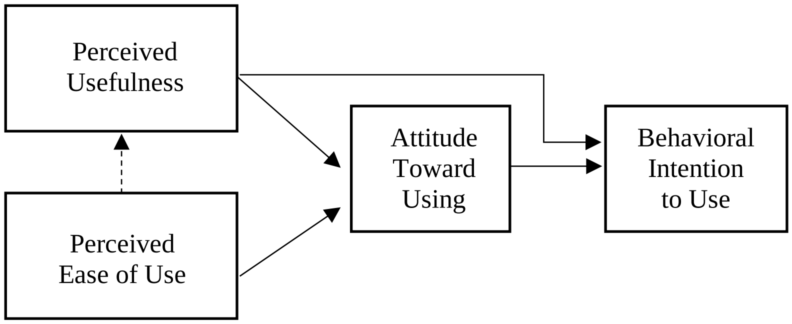
Theme	Codes	Quotations
Not Important	*Lack of accessibility*	• "This lack of availability of the technology, it is not important however would be very useful if more accessible."
	Don't currently use	• "I don't currently use acoustic or anatomic technology in my teaching. I respect it, but I guess that means I don't consider it to be important."
	Unnecessary	• "It is important in research, but not always applicable in the voice studio."
	Impedes learning	• "Depending on the student's learning style, the extra visual information could be overwhelming."

Interest Levels in Use of Ultrasound Visual Biofeedback in Voice Instruction: Hypothesis 2

The second research question addressed interest levels among voice teachers in learning about using technology, specifically U-VBF, in singing instruction. According to the TAM, behavioral intention to use or interest in using a technology system is directly influenced by attitude toward use and perceived usefulness (Davis, 1989). Following the assumptions made by the TAM, (see Figure 17), it was hypothesized that a relationship would exist between voice teachers' attitudes toward use of U-VBF and how interested they were in learning more about it, such that those who has more positive attitudes would express higher levels of interest

Figure 17

Excerpt from the Technology Acceptance Model (TAM), Predicting Behavioral Intention to Use



Note. This figure illustrates how perceived usefulness and ease of use inform attitude and behavioral intention of using a technology system. Adapted from "User Acceptance of Computer Technology: A Comparison of Two Theoretical Models," by F. D. Davis, R. P, Bagozzi, and P. R. Warshaw, 1989, *Management Sciences*, *35*(8), p. 985 (https://doi.org/10.1287/mnsc.35.8.982). Copyright 1989 by INFORMS.

Comparison of Interest in Visual Biofeedback and Ultrasound Visual Biofeedback

Respondents were asked to rank on a 5-point Likert scale their interest in using different acoustic VBF systems and U-VBF. Of the total sample (*n* = 56), the majority reported an interest in using either Voce Vista (58.9%) or U-VBF (57.1%) and 40.0% of respondents reported interest in both. Fewer respondents reported interest in the remaining systems Madde Synthesizer (22.0%); PRAAT (16.0%); Sing and See (23.0%).

Interest in Ultrasound Visual Biofeedback (U-VBF)

Participants were asked using a 5-point Likert scale to rate how interested they were in using U-VBF in their teaching if it was available. Overall, responses were largely positive (see

Table 13). Central tendency measures indicated that most participants reported being very interested in using U-VBF (*Mdn* = 4, *Mode* = 5). Of the total sample (*n* = 56), 39.3% reported being very interested in using U-VBF, while 23.2% reported being moderately interested. Of the remaining number of participants, 23.2% expressed the more neutral opinion of being somewhat interested, while 10.7% reported being slightly interested. Only two individuals (3.6% of the sample) reported being not at all interested.

Table 13

Ratings of Interest in Using U-VBF in Singing Instruction

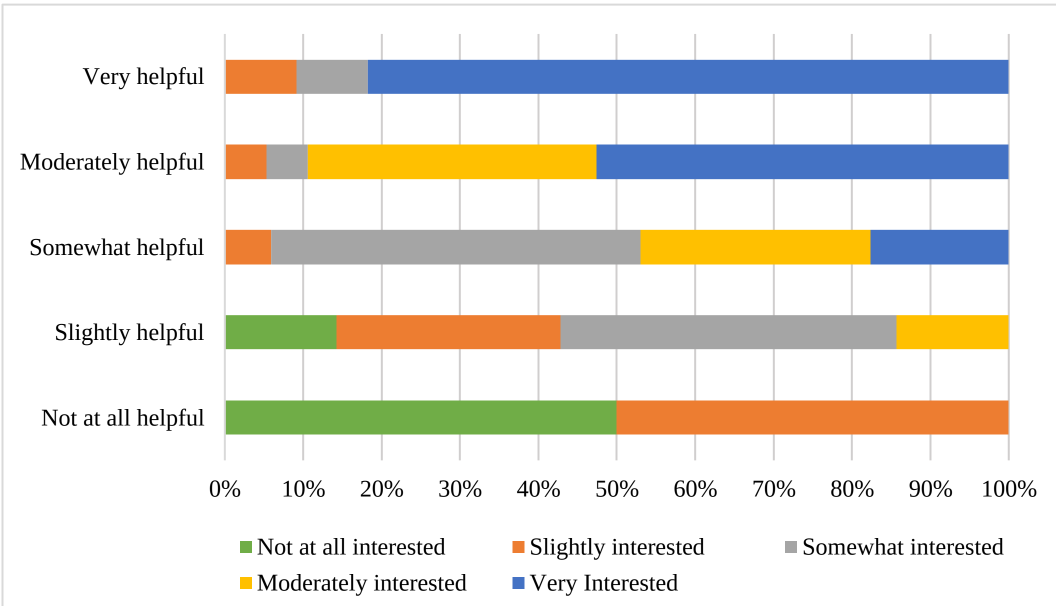
	Rating Response Frequency *n* (%)					Median	Mode
	1	2	3	4	5		
Interest in Using U-VBF in Singing Instruction	2 (3.6%)	6 (10.7%)	13 (23.2%)	13 (23.2%)	22 (39.3%)	4	5

Note. 1 = Not at all, 2 = Slightly, 3 = Somewhat, 4 = Moderately, 5 = Very

Associations between perceived usefulness of U-VBF and degree of interest in using U-VBF in singing instruction were explored by comparing participants' ratings for both variables (Figure 18). Participants who regarded U-VBF as being either moderately or very helpful in singing instruction also expressed high levels of interest in using this mode of visual biofeedback in their teaching. Of the 11 voice teachers who regarded U-VBF as being very helpful to teach vocal pedagogy in voice lessons, 81.8% also reported being very interested in using U-VBF. Nineteen participants regarded U-VBF as being moderately helpful, of which 52.6% expressed being very interested in using it, while 36.8% reported being moderately interested. Level of interest declined with decreased perceptions of usefulness. Of those who perceived U-VBF to be sightly helpful (*n* = 6), 14.3 % reported being not at all interested in using U-VBF. Two participants rated U-VBF as not at all helpful in singing instruction, one reported being uninterested in using it in their teaching, while the other expressed slight interest.

Figure 18

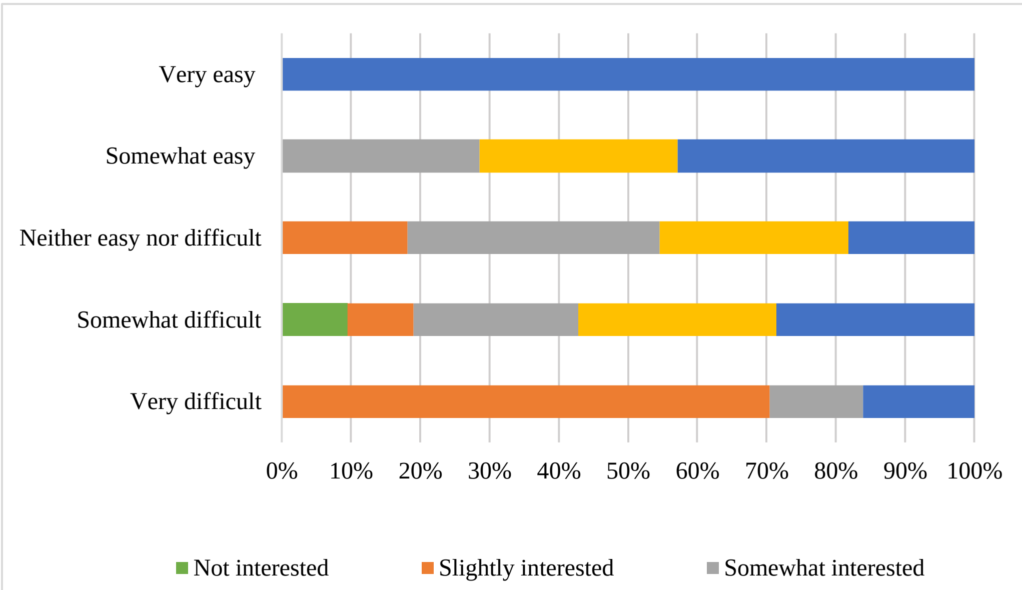
Crosstabulation Between Ratings of Usefulness of U-VBF in Singing Instruction by Ratings of Interest in Using U-VBF



Comparison between participants' opinions regarding ease of use of U-VBF and their interest in using it in their teaching showed less of a distinct relationship (see Figure 19). Those who reported being very interested in using U-VBF in their teaching (66.7%) also perceived U-VBF to be very easy to use. However, those that believed U-VBF to be difficult did not necessarily express lower levels of interest. Of those who expressed some degree of interest in using U-VBF (n = 54), 48.1% perceived U-VBF as being somewhat to very difficult to use, while 27.8% believed it to be somewhat to very easy to use. Although two participants felt that U-VBF would be very difficult to use, both expressed being very interested in learning more about and exploring the use of U-VBF in their teaching. Of the participants who rated U-VBF as being somewhat difficult to use (*n* = 21), 9.5% reported being uninterested in using U-VBF in their teaching.

Figure 19

Crosstabulation Between Ratings of Interest in Using U-VBF by Ratings of Ease of Using U-VBF in Singing Instruction

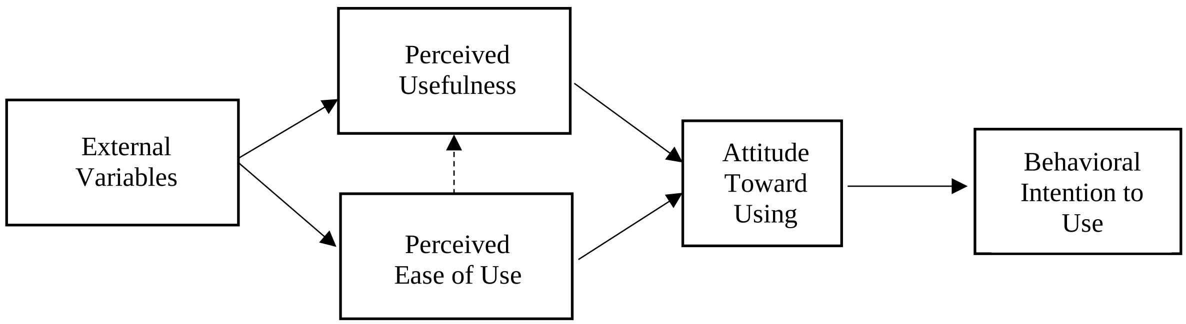


Relationships between External Variables and Attitudes of Ultrasound Visual Biofeedback: Hypothesis 3

According to the Technology Acceptance Model (TAM), acceptance of a technology system and the behavioral intention to use it are indirectly influenced by external variables that may inform perceived usefulness, ease of use, and interest in using. These include demographic, personal, and professional characteristics (see Figure 20; Davis, 1989). Regarding voice teachers' perceptions of the utility of U-VBF in singing instruction, it was hypothesized that perceptions of usefulness, ease of use, and interest would be influenced by selected external variables, such as years of teaching experience, level of education, knowledge regarding voice anatomy, physiology, and acoustics, experience using acoustic visual biofeedback systems, voice type, region, and setting as a voice teacher. The choice of these variables was purely theoretical based on their relevance to the practice of voice instruction.

Figure 20

Excerpt from the Technology Acceptance Model (TAM) Showing External Variable Influence



Note. This figure shows the influence of external variables on user perceptions of and behavioral intention to use a technology system. Adapted from "User Acceptance of Computer Technology: A Comparison of Two Theoretical Models," by F. D. Davis, R. P, Bagozzi, and P. R. Warshaw, 1989, *Management Sciences*, *35*(8), p. 985 (https://doi.org/10.1287/mnsc.35.8.982). Copyright 1989 by INFORMS.

Descriptive analysis via crosstabulation was conducted to compare participants' ratings of perceived usefulness, ease of use, interest in learning more about U-VBF, and interest in using U-VBF with the identified external variables listed above to determine the presence of potential relationships. Potential relationships were determined through examination of response frequency distributions for perceived usefulness, ease of use, and interest by the external variables of interest. Analysis of the resulting data revealed that few of the selected external variables appeared to have an influence on perceptions of usefulness of U-VBF in singing instruction, apart from region, education, years of teaching experience, and voice type. No prominent associations were found between perceived ease of use of U-VBF and the selected external variables, although a moderate trend was found for years of teaching experience. Comparison of external variables with participants' ratings for interest in learning more about U-VBF and in using it in their teaching revealed few associations, apart from participant's interest in learning about U-VBF as influenced by region and voice type.

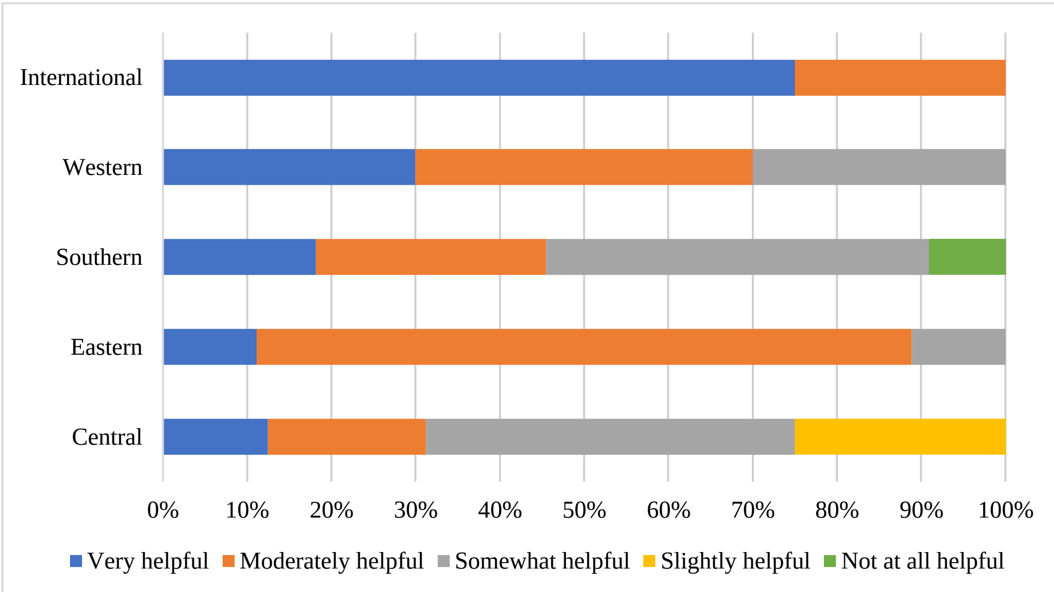
Region and Perceived Usefulness of Ultrasound Visual Biofeedback

Crosstabulation of data was conducted to examine participants' ratings of how helpful U-VBF would be in singing instruction in relation to what region they were from. As two participants listed "unknown" for region, these two data points were discarded from analysis. Visual examination of frequency distributions indicated positive opinions regarding use of U-VBF in singing instruction in relation to the Western and Eastern regions of the United States and abroad (see Figure 21). Although the number of individuals from the Eastern region (n = 9) and internationally (n = 4) was small, the majority believed U-VBF to be moderately to very useful in singing instruction. International participants were the most positive with regard to their views on the usefulness of U-VBF, with 75.0% rating it as being very useful and the remaining 25.0% rating it as being moderately useful.

Most participants from the Eastern region also believed U-VBF to be useful, with 77.8% expressing that it could be moderately helpful. Prominently positive opinions also came from the Western region (n = 14) with half rating U-VBF as being moderately to very helpful. Participants from the Southern (n = 11) and Central regions (n = 16) were the most skeptical with most choosing the neutral rating of *somewhat helpful* (3). Four participants in the Central region perceived U-VBF to be only slightly helpful, while one individual in the Southern region believed it to be not at all helpful in singing instruction.

Figure 21

Perceived Usefulness of U-VBF by Region

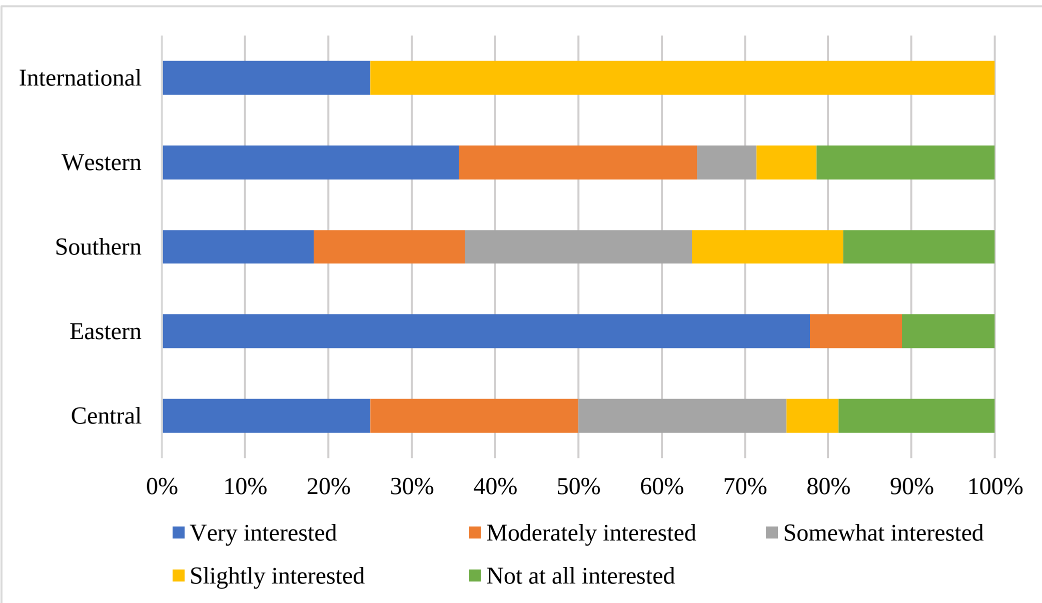


Region and Interest in Learning about Ultrasound Visual Biofeedback

A different relationship was found to exist between region and participants' interest in learning about U-VBF (see Figure 22). While the majority of international participants held positive views regarding the usefulness of U-VBF, surprisingly, most (75.0%) expressed being only slightly interested in learning more about it. Of the respondents from the Eastern region, 88.9% reported being moderately to very interested, while 64.3% from the Western region, reported the same degree of interest. Overall, these ratings of interest reflect the pattern of ratings of perceived usefulness these two regions, indicating that not only did many of the participants from the Western and Eastern regions perceive U-VBF to be helpful in singing instruction, but they also expressed high levels of interest in learning more about it. A similar pattern between ratings for perceived usefulness and interest in learning more about U-VBF is evident from data collected from the Southern and Central regions. More neutral ratings of interest (i.e., *somewhat interested*) may be attributed to the percentage of participants who expressed uncertainty regarding the usefulness of U-VBF, as indicated by their rating of it being somewhat helpful.

Figure 22

Interest in Learning U-VBF by Region

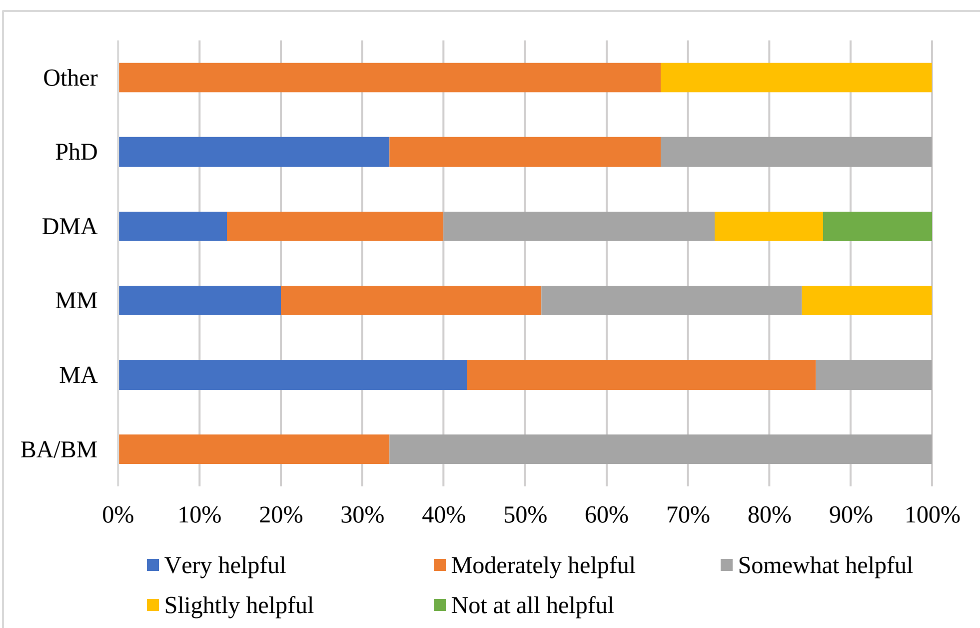


Education and Perceived Usefulness of Ultrasound Visual Biofeedback

Regarding the potential influence of education, more positive perceptions of the usefulness of U-VBF were provided by voice teachers who had completed higher degrees in formal education (see Figure 23). Of those who reported earning a master's degree, being either a MA or MM (*n* = 32), 25.0% perceived U-VBF to be very helpful in explaining vocal pedagogy concepts in singing instruction. Of those who earned a MA (*n* = 7), 42.9% rated U-VBF as being very helpful, while 20.0% of those who had earned an MM (*n* = 25) provided the same rating. One participant out those who had earned a PhD (*n* =3), believed U-VBF to be very useful. Of those who reported receiving another form of education (i.e., completion of continuing education programs, such as Estill Voice Training), opinions regarding the usefulness of U-VBF were generally positive with the two of the three participants rating U-VBF as being moderately helpful. Overall, most of the sample (64.3%) rated U-VBF as being somewhat to moderately helpful. Those who reported earning only a bachelor's degree (*n* = 3) expressed the greatest uncertainty regarding the usefulness of U-VBF with 66.7% choosing the more neutral rating of *somewhat helpful* (3). Only two participants, both who had earned a DMA, felt that U-VBF was not at all helpful to singing instruction.

Figure 23

Perceived Usefulness of U-VBF by Education

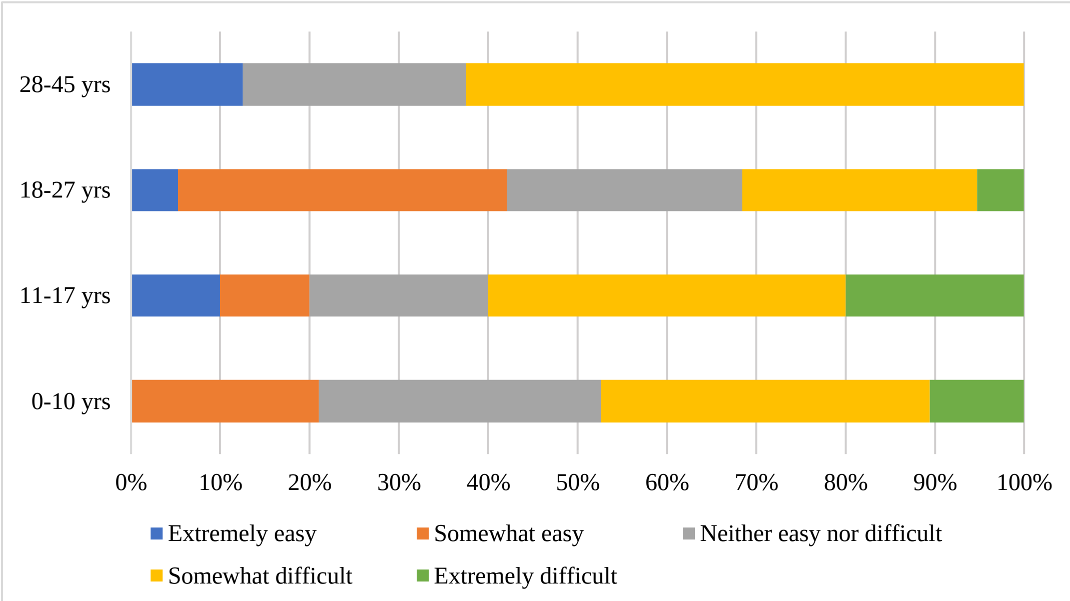


Teaching Experience and Perceived Ease of Use of Ultrasound Visual Biofeedback

Examination of participants' ratings for perceived usefulness of U-VBF in relation to their teaching experience revealed no distinct trends; however, a moderate relationship was found to exist between years of teaching and perceived ease of use of U-VBF (see Figure 24). Overall, the majority of the total sample (*n* = 56) expressed uncertainty regarding ease of use of U-VBF, with 37.5% choosing the rating of *somewhat useful*, and 26.8% choosing the neutral rating of *neither easy nor difficult* (3). However, teachers with 18-27 years of experience provided the most positive views with 42.1% rating U-VBF as being moderately to very easy to use. Those with 11-17 years of experience had the most negative opinions with 60.0% rating U-VBF as being somewhat to extremely difficult to use. The greatest amount of uncertainty was expressed on both ends of spectrum by new teachers and those who were more seasoned. Of the teachers who had taught 0-10 years, 31.6% choosing the neutral rating of *neither easy nor difficult* (3) and 36.8% chose the rating of *somewhat difficult* (2). Most voice teachers who had taught for 28-45 years believed U-VBF to be somewhat difficult to use, while 25.0% rated it as being neither easy nor difficult.

Figure 24

Perceived Ease of Use of U-VBF by Years of Teaching

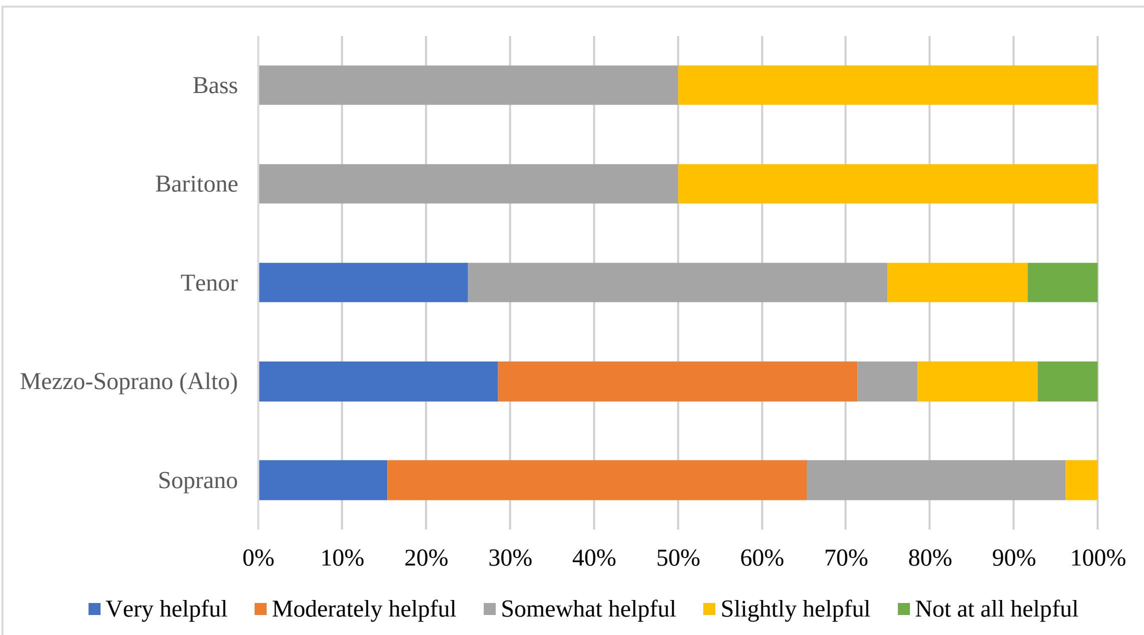


Perceived Usefulness of Ultrasound Visual Biofeedback in Relation to Voice Type

An appreciable trend was evident when comparing participants' reported voice type with their ratings of perceived usefulness of U-VBF. Examination of the data indicated that female voice types expressed more positive perceptions of the usefulness of U-VBF compared to male voice types (see Figure 25). Of the total sample, 30.4% of voice teachers who identified their voice type as Soprano, perceived U-VBF to be moderately to very helpful, while 17.9% of those whose reported their voice type as being Mezzo-Soprano (Alto) reported the same opinions. Of the total number of participants who rated U-VBF as being very helpful (*n* = 11), an equal percentage (36.4%) reported their voice types as with Soprano and Mezzo-Soprano. Among those who reported U-VBF as being moderately helpful, 68.4% were Sopranos while 32.6% were Mezzo-Sopranos. Greater uncertainty regarding the usefulness of U-VBF was observed among the male voice types, Tenor, Baritone, and Bass. Both Baritones (*n* = 2) and Basses (*n* = 2) were split evenly between the neural rating of *somewhat helpful* (3), and the slightly negative rating *slightly helpful* (2). Of the participants who reported being Tenors, half perceived U-VBF to be somewhat helpful, while 25.0% viewed it as being very helpful.

Figure 25

Perceived Usefulness of U-VBF by Voice Type

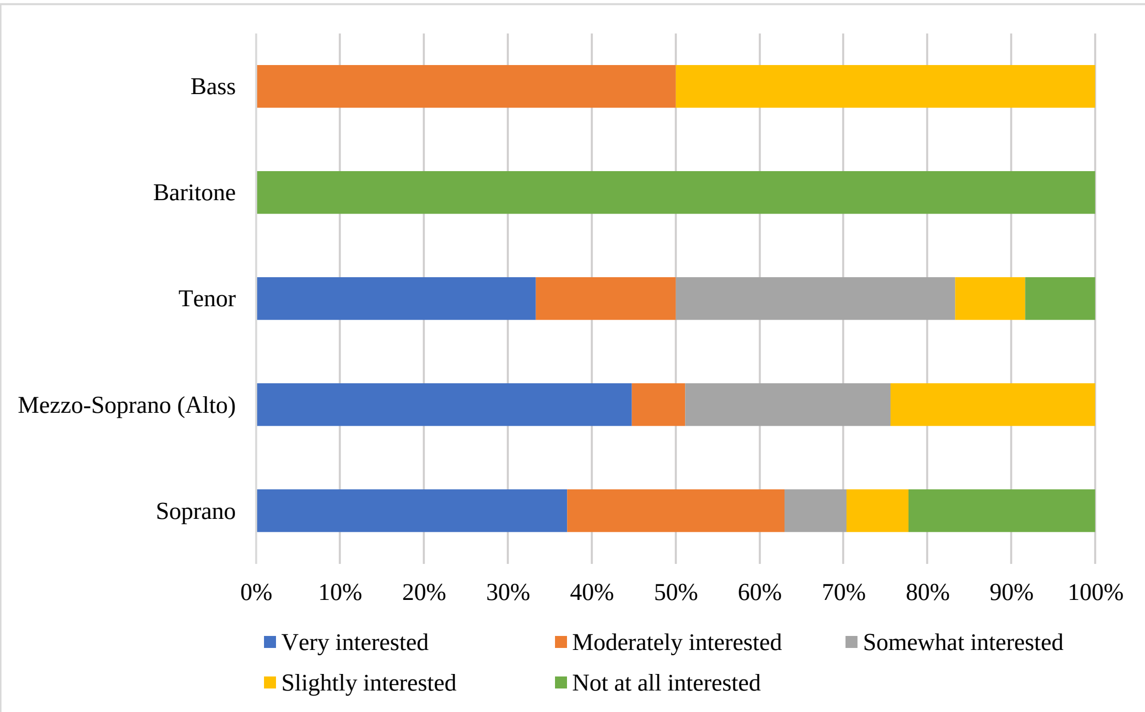


Voice Type in Relation to Interest in Learning about Ultrasound Visual Biofeedback

Similar to perceived usefulness, a larger number of voice teachers who reported being Sopranos or Mezzo-Sopranos expressed greater interest in learning more about using U-VBF in comparison to the other reported voice types (see Figure 26). Of the total sample (*n* = 56), half of those reported being moderately to very interested in learning more about U-VBF were Sopranos or Mezzo-Sopranos. Of this number, 45.5% were Sopranos. Neither of the two participants who were Baritones reported being interested, while half of Tenors (*n* = 12) expressed being somewhat interested. Degree of interest between the two participants who reported their voice type as Bass varied, with one participant expressing slight interest, while the other indicated being moderately interested.

Figure 26

Interest in Learning about U-VBF by Voice Type



Comparison of Pre-and Post-Video Survey Responses: Hypothesis 4

Training in how to use a technology system can positively inform both users' acceptance of the system, as well as their beliefs in being able to effectively use it (Nelson & Cheney, 1987). An educational video serves as a cost-effective means in which to provide training. After viewing the instructional video, it was hypothesized that voice teachers' acceptance of using U-VBF in the voice studio would increase. Additionally, positive perceptions regarding ease of use and effective use of U-VBF would also increase. Lastly, it was hypothesized that voice teachers' interest in future use of U-VBF would increase as well.

At the beginning of the post-survey, participants were asked to rate how informative they found the video to be in demonstrating the use of U-VBF in singing instruction. Overall, responses to whether the video was informative were positive with 91.0% rating content as being moderately to very informative. Participants were also asked how much the instructional video changed their opinion on using technology in the voice studio. Overall, responses varied with 25.0% reporting that the video changed their opinion by a moderate amount, while an equal percentage stated that it changed their opinion only by a little. Of the remaining participants, 5.4% reported the video changing their opinion of U-VBF by a great deal, 23.0% by a lot, and 21.0% not at all.

Comparison of Pre- and Post-Video Perceptions of Usefulness

Like the pre-survey analysis, perceived usefulness included opinions related to the helpfulness and importance of U-VFB to singing instruction, both in general, and in teaching common vocal pedagogy concepts. After viewing the instructional video, participants were asked to rate how important they felt U-VBF was for singing instruction. Approximately 54.0% of respondents reported U-VBF to be moderately to very important, while 43.0% found it to be only slightly to somewhat important. Participants were also asked whether they felt U-VBF was helpful in explaining concepts related to voice anatomy and physiology, and acoustics (see Table 14). Central tendency measures showed generally positive opinions regarding use of U-VBF to explain concepts related to voice anatomy and physiology (*Mdn* = 4, *Mode* = 5) with the majority (41.1%) believing U-VBF to be very helpful. In contrast, participants were less confident that U-

VBF was helpful in explaining concepts related to acoustics (*Mdn* = 4, *Mode* = 3) with the majority (30.4%) believing it to be only somewhat helpful.

Table 14

Post-Video Response Ratings for Perceived Usefulness of U-VBF in Teaching Acoustics and Anatomy/Physiology for Voice Instruction

	Rating Response Frequency *n* (%)					Median	Mode
	1	2	3	4	5		
Acoustics	2 (3.6%)	6 (10.7%)	17 (30.4%)	15 (26.8%)	16 (28.6%)	4	3
Anatomy & Physiology	0 (0%)	9 (16.1%)	7 (12.5%)	17 (30.4%)	23 (41.1%)	4	5

Note. 1 = Not at all, 2 = Slightly, 3 = Somewhat, 4 = Moderately, 5 = Very

Next, participants were asked to re-rank their opinions regarding perceived usefulness of U-VBF for teaching different vocal pedagogy concepts, such as diction, vowel modification, vocal timbre, vocal resonance, and for the visualizing the vocal tract. Central tendency measures revealed generally positive opinions (see Table 15). Most participants believed U-VBF to be moderately useful for teaching diction (50.0%), vocal timbre (32.1%), and vocal resonance (32.1%), and very useful for allowing students to visualize the size and shape of the vocal tract (48.2%).

Table 15

Post-Video Response Ratings for Perceived Usefulness of U-VBF in Teaching Vocal Pedagogy Concepts

	Rating Response Frequency *n* (%)					Median	Mode
	1	2	3	4	5		
Diction	4 (7.1%)	10 (17.9%)	14 (25%)	28 (50%)	0 (0%)	3.5	4
Visualization of Vocal Tract	1 (1.8%)	3 (5.4%)	14 (25%)	11 (19.6%)	27 (48.2%)	4	5
Vowel Modification*	4 (7.1%)	10 (17.9%)	9 (16.1%)	32 (57.1%)	0 (0%)	4	4
Vocal Timbre	2 (3.6%)	10 (17.9%)	12 (21.4%)	18 (32.1%)	14 (25%)	4	4
Vocal Resonance	1 (1.8%)	13 (23.2%)	12 (21.4%)	18 (32.1%)	12 (21.4%)	4	4

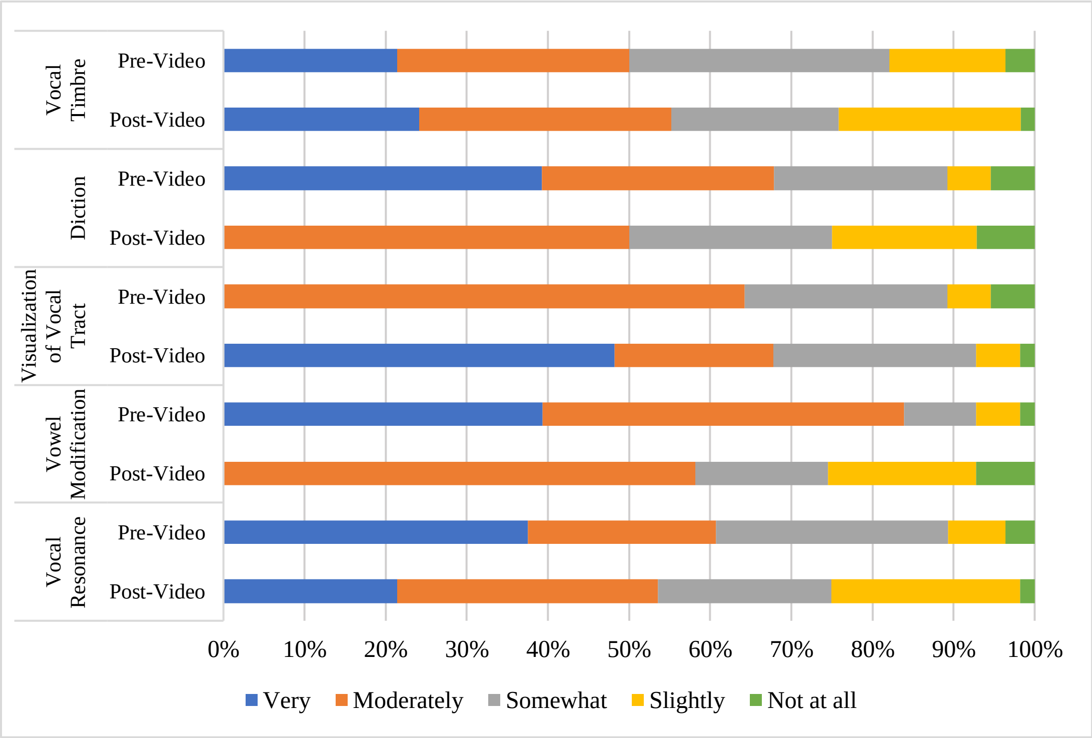
Notes. 1 = Not at all, 2 = Slightly, 3 = Somewhat, 4 = Moderately, 5 = Very.

***** Correction for one missing data point for vowel modification.

Despite the relatively positive opinions from the post-survey data regarding the usefulness of U-VBF, comparison of changes in response frequencies per rating score as shown in Figure 27, revealed a general decline in participants' perceived usefulness of U-VBF. Examination of central tendency measures showed a slight decline in frequency of positive ratings for use of U-VBF for teaching diction ($Mode_{(pre)} = 5$, $Mode_{(post)} = 4$) and vocal resonance ($Mode_{(pre)} = 5$, $Mode_{(post)} = 4$), while most participants' ratings for vowel modification stayed the same ($Mode_{(pre)} = 4$, $Mode_{(post)} = 4$). Of note, ratings increased both for teaching vocal timbre ($Mode_{(pre)} = 3$, $Mode_{(post)} = 4$) and for allowing visualization of the vocal tract ($Mode_{(pre)} = 4$, $Mode_{(post)} = 5$).

Figure 27

Comparisons Between Frequencies of Pre- and Post-Video Ratings for Usefulness of U-VBF in Teaching Vocal Pedagogy Concepts



After viewing of the video, opinions regarding the utility of U-VBF were generally positive for teaching vocal pedagogy concepts specifically related to vocal timbre, as indicated by central tendency measures (see Table 16). Participants' rating of the pedagogical concept of teaching volume changes was more guarded (*Mdn* = 2, *Mode* = 2), while opinions appeared to be mixed for teaching tone focus (*Mdn* = 3, *Mode* = 5).

Table 16

Post-Video Ratings of Usefulness of U-VBF in Teaching Vocal Pedagogy Concepts Related to Vocal Timbre

	Rating Response Frequency *n* (%)					Median	Mode
	1	2	3	4	5		
Balanced tone* (*chiaroscuro*)	4 (7.3%)	8 (14.5%)	13 (23.6%)	18 (32.7%)	12 (21.8%)	4	4
Changes in vocal tone color	2 (3.6%)	6 (10.7%)	13 (23.2%)	17 (30.4%)	18 (32.1%)	4	5
Vowel enunciation & quality	1 (1.8%)	8 (14.3%)	16 (28.6%)	31 (55.4%)	0 (0%)	4	4
Tone focus	5 (8.9%)	9 (16.1%)	15 (26.8%)	11 (19.6%)	16 (28.6%)	3	5
Volume changes	10 (17.9%)	19 (33.9%)	16 (28.6%)	8 (14.3%)	3 (5.4%)	2	2
Vocal tract adjustments for changing singing styles	12 (21.4%)	9 (16.1%)	14 (25%)	21 (37.5%)	0 (0%)	3	4
Vocal tract adjustment for high register singing*	3 (5.5%)	6 (10.9%)	12 (21.8%)	18 (32.7%)	14 (25%)	4	4
Vocal tract adjustments for passaggi points	4 (7.1%)	8 (14.3%)	12 (21.4%)	18 (32.1%)	14 (25%)	4	4

Note. 1 = Not at all, 2 = Slightly, 3 = Somewhat, 4 = Moderately, 5 = Very.

***** Correction for one missing data point for vowel modification.

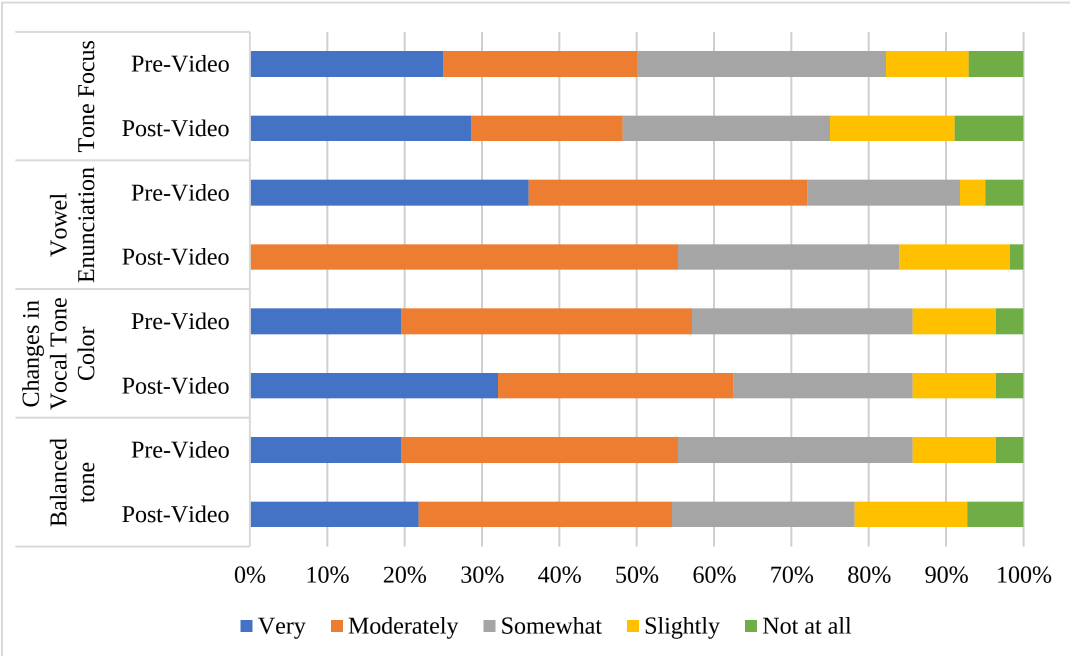
Like the decrease in ratings observed for perceived usefulness of U-VBF after viewing the video, comparison of changes in response frequencies of pre- and post-video responses for the usefulness of U-VBF to teach concepts related to vocal timbre similarly showed a general decline in opinion (see Figure 28). Examination of central tendency measures indicated a decrease in the frequency of positive ratings for use of U-VBF to teach vocal tract adjustments for changing singing style ($Mode_{(pre)}$ = 5, $Mode_{(post)}$ = 4), high register singing ($Mode_{(pre)}$ = 5, *Mode*$_{(post)}$ = 4) and navigating passaggi points (*Mode*$_{(pre)}$ = 5, *Mode*$_{(post)}$ = 4). A slight increase in the number of positive ratings was observed for perceptions regarding using U-VBF to teach changes in tone focus (*Mode*$_{(pre)}$ = 3, *Mode*$_{(post)}$ = 5). Frequency of positive ratings for using U-VBF to teach changes in vocal tone color. (*Mode*$_{(pre)}$ = 4, *Mode*$_{(post)}$ = 5) also moderately increased.

Comparison of Pre- and Post-Video Perceptions of Ease of Use

Following viewing of the instructional video, participants were asked to use a 5-point Likert scale to rate ease of use of U-VBF in singing instruction from 1 (*very difficult*) to 5 (*very easy*). Central tendency measures as shown in Table 17 indicated that opinions were largely positive (*Mdn* = 4, *Mode* = 4) with the majority (37.5%) believing U-VBF to be somewhat easy to use. In comparing participants' pre- and post-video ratings, central tendency measures indicated that after viewing the video, most participants had shifted from their original opinion that U-VBF was somewhat difficult to use to being somewhat easy to use. Further comparison of changes in response frequencies for ratings of ease of use between pre- and post-viewing of the video revealed a prominent increase in positive ratings (see Figure 29).

Figure 28

Comparisons Between Frequencies of Pre- and Post-Video Ratings for Usefulness of U-VBF in Teaching Vocal Pedagogy Concepts Related to Vocal Timbre



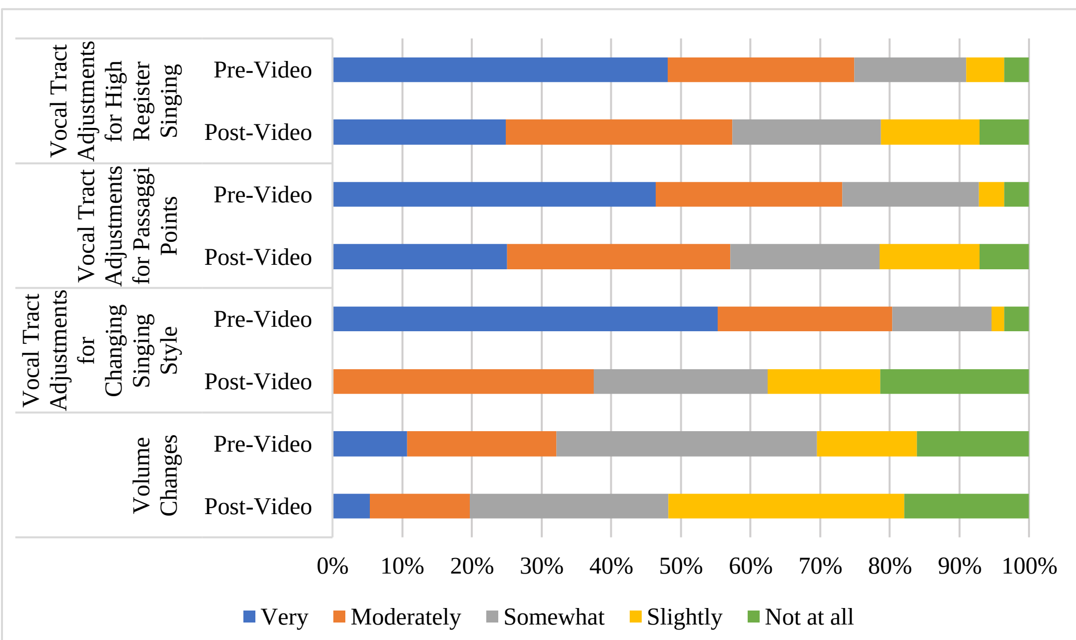


Table 17

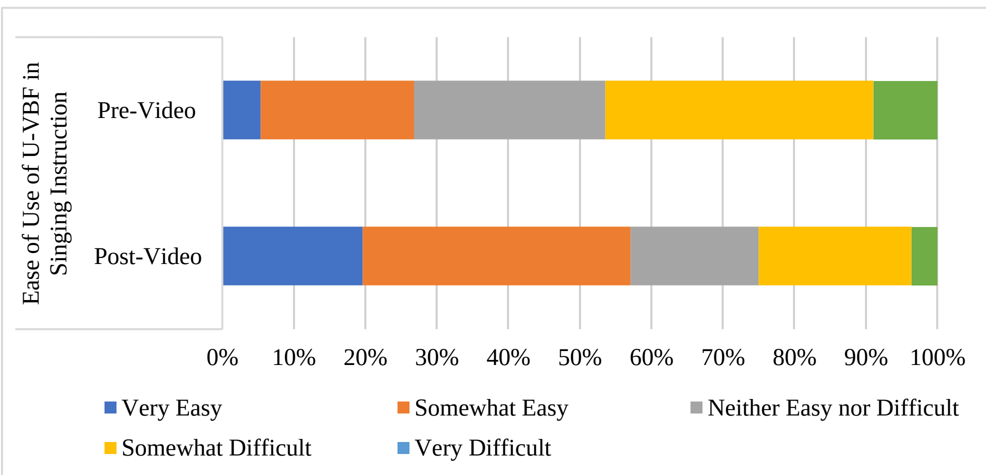
Post-Video Ratings of Perceived Ease of Use of U-VBF in Singing Instruction

	Rating Response Frequency *n* (%)					Median	Mode
	1	2	3	4	5		
Ease of Use of U-VBF in Singing Instruction	2 (3.6%)	12 (21.4%)	10 (17.9%)	21 (37.5%)	11 (19.6%)	4	4

Note. 1 = Very difficult, 2 = Somewhat difficult, 3 = Neither easy nor difficult, 4 = Somewhat easy, 5 = Very easy

Figure 29

Comparison Between Frequencies of Pre- and Post-Video Ratings for Ease of Use in U-VBF in Singing Instruction



Participants were also asked using a 5-point Likert scale how much they agreed with the statement that they could effectively use U-VBF in their teaching. Examination of central tendency measures revealed that most respondents felt they would be able to effectively use this mode of visual biofeedback (*Mdn* = 4, *Mode* = 5). Of the total sample (*n* = 56), 46.6% strongly agreed, while 37.5% somewhat agreed, and 5.4% somewhat disagreed. The remaining 10.7% neither agreed nor disagreed (see Table 18).

Table 18

Post-Video Ratings of Perceived Effective Use of U-VBF in Singing Instruction

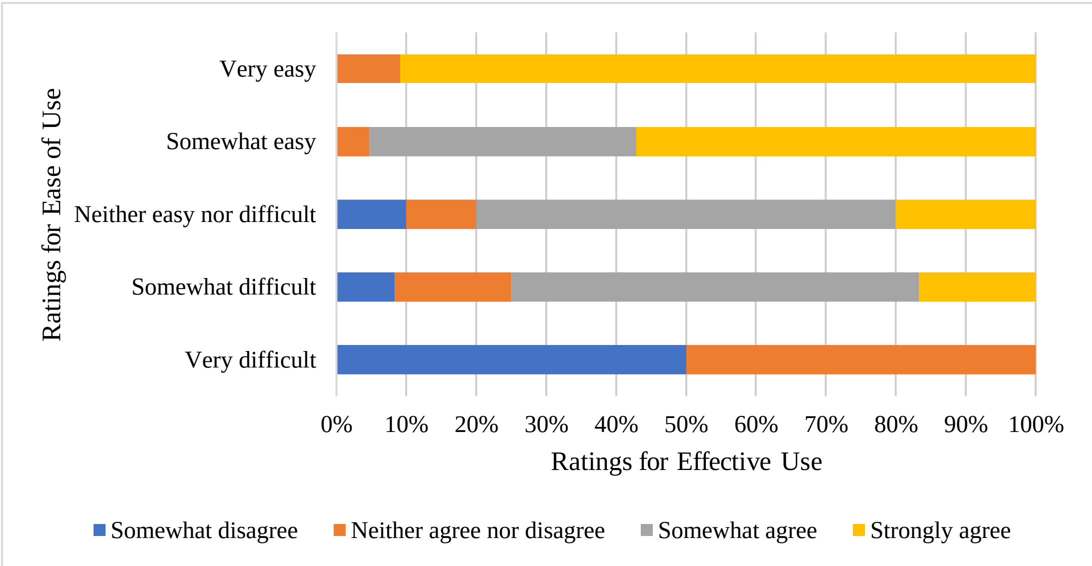
	Rating Response Frequency *n* (%)					Median	Mode
	1	2	3	4	5		
Effective Use of U-VBF in Singing Instruction	0 (0.0%)	3 (5.4%)	6 (10.7%)	21 (37.5%)	26 (46.6%)	4	5

Note. 1 = Strongly disagree, 2 = Somewhat disagree, 3 = Neither agree nor disagree, 4 = Somewhat agree, 5 = Strongly agree

According to the TAM (Davis, 1989), effective use is closely related to perceived ease of use. If a user perceives a technology system to be easy to operate, they will express higher levels of self-efficacy. Participants' ratings for ease of use and whether they agreed that they could effectively use U-VBF were compared through crosstabulation of variables (see Figure 30). Most participants who perceived U-VBF to be very easy to use, also strongly agreed that they would be effective in employing it in the voice studio. Those who expressed more neutral opinions regarding ease of use of U-VBF only somewhat agreed that they could use it effectively in their teaching.

Figure 30

Crosstabulation Between Ratings for Ease of Use by Ratings for Effective Use of U-VBF



Comparison of Pre- and Post-Video Ratings of Interest

After viewing the instructional video, participants were asked to rate their level of interest in pursuing or learning more about future use of U-VBF in singing instruction. Central tendency measures showed overall high levels of interest (*Mdn* = 4, *Mode* = 5) with 42.9% reporting being very interested. Most of the remaining responses were split evenly between being slightly interested and moderately interested, while only one participant reported being not interested at all (see Table 19).

Table 19

Post-Video Ratings of Interest in Future Use of U-VBF in Singing Instruction

	Rating Response Frequency n (%)					Median	Mode
	1	2	3	4	5		
Interest in Future Use of U-VBF	1 (1.8%)	11 (19.6%)	9 (16.1%)	11 (19.6%)	24 (42.9%)	4	5

Note. 1 = Not interested, 2 = Slightly interested, 3 = Somewhat interested, 4 = Moderately interested, 5 = Very interested

Comparison between pre- and post-video response frequencies for each rating score revealed minimal changes in opinions (see Figure 31). Although the positive rating of *very interested* (5) marginally increased between pre- and post-viewing of the instructional video from 39.3% to 42.9%, the more negative rating of *slightly interested* (2) also increased from 10.7% to 19.6%. Crosstabulation comparing participants' ratings for perceived usefulness of U-VBF with their ratings of interest showed that in general, those who perceived U-VBF to be very important expressed higher levels of interest, while those who expressed being slightly to moderately interested generally expressed more neutral opinions regarding the usefulness of U-VBF to singing instruction (see Figure 32). Of interest, one individual who reported U-VBF as being not all important to singing instruction still expressed being somewhat interested in learning more about use of U-VBF in the voice studio. Only two individuals out of the total sample (n = 56), who rated U-VBF as being slightly important, reported being not interested.

Figure 31

Comparison Between Frequencies of Pre- and Post-Video Ratings for Interest in Use of U-VBF in Singing Instruction

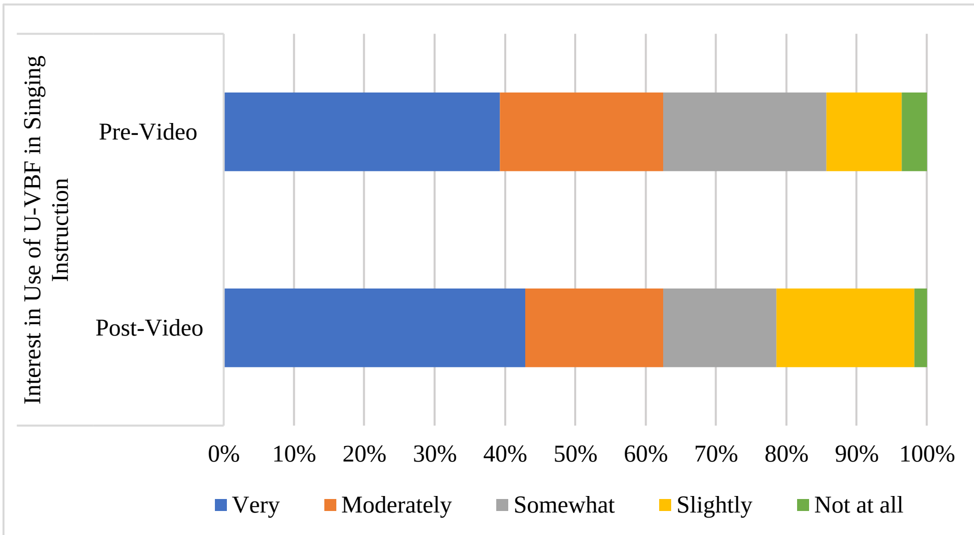
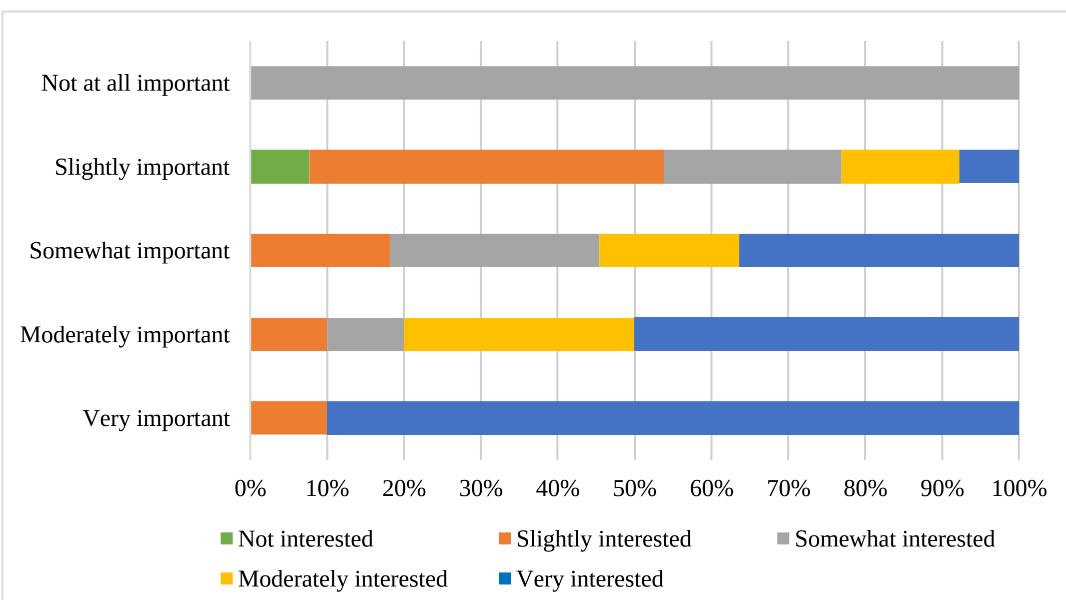


Figure 32

Crosstabulation Between Post-Video Perceptions of Usefuless and Interest for Use of U-VBF in Singing Instruction



Changes in Likelihood to Use. According to the TAM, the likelihood of using a technology system is directly informed by a user's acceptance of it and subsequent degree of interest in using it (Davis, 1989). Following this assumption, it was hypothesized that after watching the instructional video, participants who expressed higher levels of interest in learning more about U-VBF and exploring its use in the voice studio, would provide higher ratings for likelihood of future use. Examination of frequency distributions of ratings indicated overall positive intentions (see Table 20). Central tendency measures revealed that most participants reported being somewhat likely to use U-VBF in singing instruction (*Mdn* = 4, *Mode* = 4). Of the total sample, (*n* = 56), 42.9% reported being somewhat likely to use U-VBF and 30.4% reported being extremely likely, while 14.3% chose the neutral rating of *neither likely nor unlikely* (3). Of the remaining sample (*n* = 7), 7.1% reported being somewhat unlikely to use U-VBF, while 5.4% reported being extremely unlikely.

Table 20

Post-Video Ratings of Likelihood of Using U-VBF

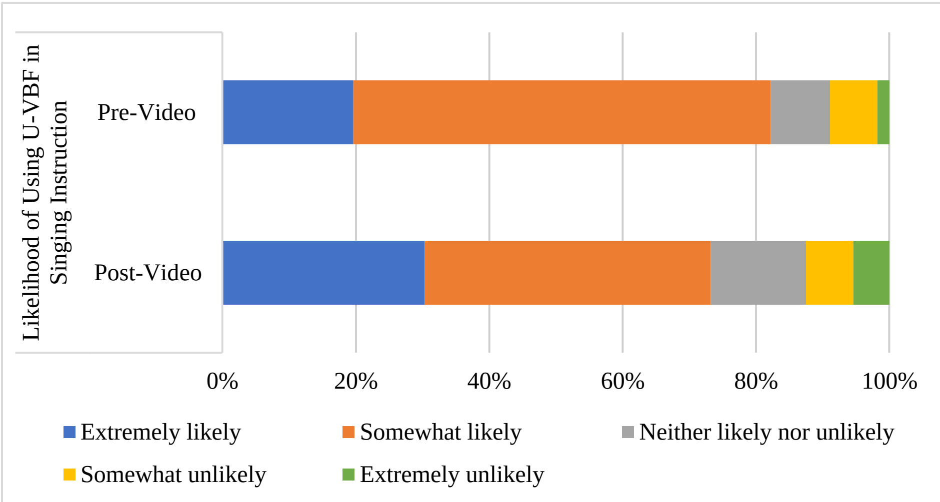
	Rating Response Frequency *n* (%)					Median	Mode
	1	2	3	4	5		
Likelihood of Using U-VBF	3 (5.4%)	4 (7.1%)	8 (14.3%)	24 (42.9%)	17 (30.4%)	4	4

Note. 1 = Extremely unlikely, 2 = Somewhat unlikely, 3 = Neither likely nor unlikely, 4 = Somewhat likely, 5 = Extremely likely

Comparison of changes in response frequencies for each rating score revealed a moderate, positive shift in opinion from pre- to post-viewing of the video (see Figure 33). Following viewing of the video, the percentage of participants who reported being extremely likely to use U-VBF increased from 19.6% to 30.4%; however, more participants also reported being uncertain or unlikely to use U-VBF in their teaching.

Figure 33

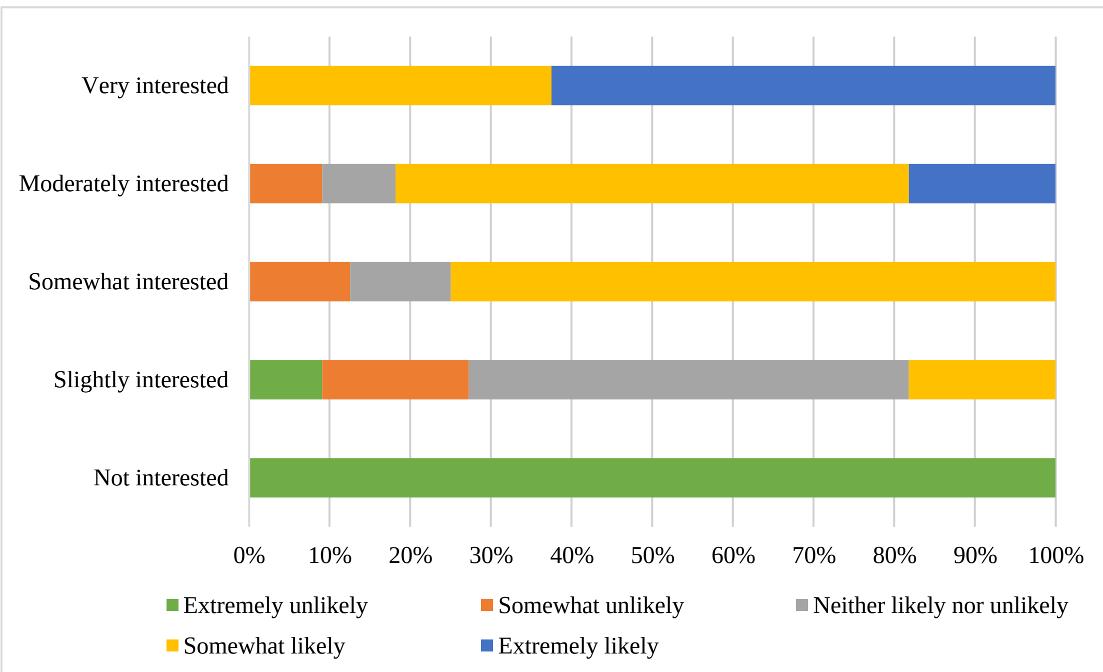
Comparison Between Frequencies of Pre- and Post-Video Ratings for Likelihood of Using U-VBF in Singing Instruction



As likelihood to use a system is often influenced by interest, crosstabulation between participants' ratings for interest in U-VBF and ratings for their likelihood of using U-VBF was conducted to further examine the relationship between these two variables (see Figure 34). Examination of the data showed that in general, participants reported being either uncertain or less likely to use U-VBF if they demonstrated a lower level of interest and vice versa. Of the 11 participants who expressed being slightly interested in U-VBF, 27.0% reported being somewhat to extremely unlikely to use it in the future, while the majority (55.0%) expressed being neither likely nor unlikely to use, and 18.0% stated being somewhat likely to use U-VBF. Of the participants who were very interested in U-VBF (n = 24), 63.0% reported being extremely likely to use U-VBF, while the remaining 38.0% reported being somewhat likely. Participants who provided the more neutral ratings of being somewhat to moderately interested in U-VBF (*n* = 20), also largely reported neutral opinions on their likelihood of using it in their teaching. Of those who expressed moderate interest in U-VBF (*n* = 11), 18.0% reported being extremely interested in future use. The one individual who was uninterested in U-VBF, also reported being extremely unlikely to use it in singing instruction.

Figure 34

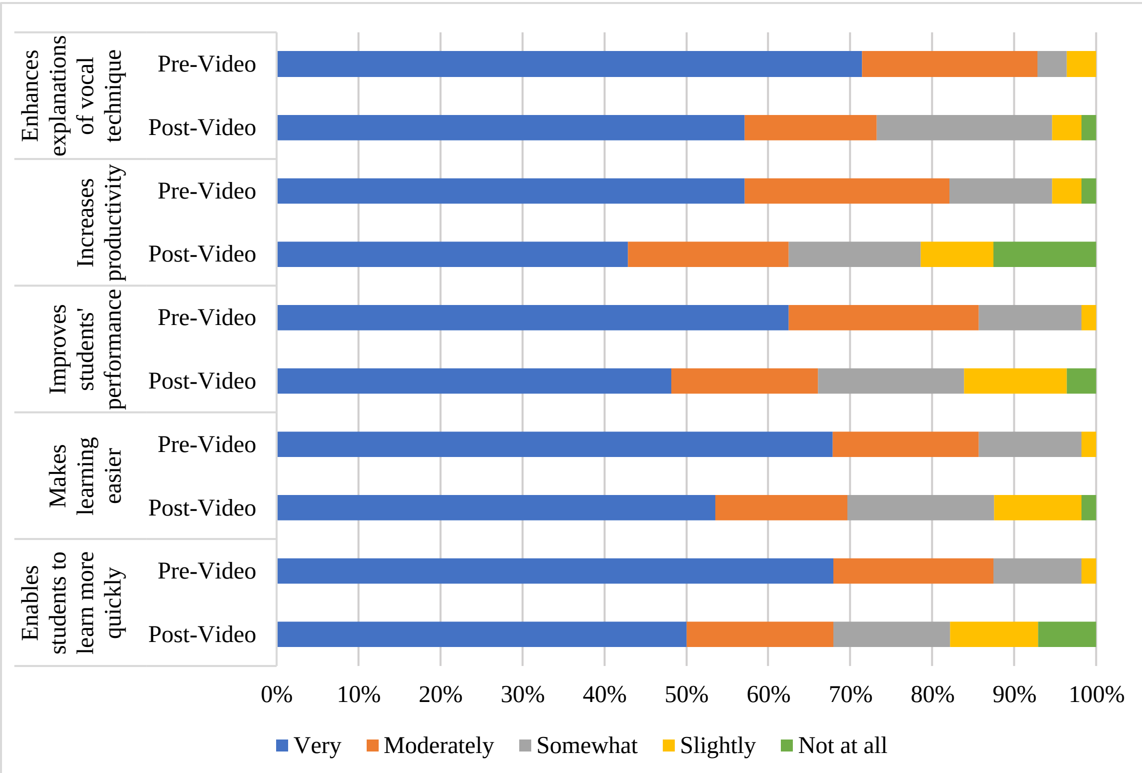
Crosstabulation between Ratings for Likelihood of Use by Interest in Use of U-VBV in Singing Instruction

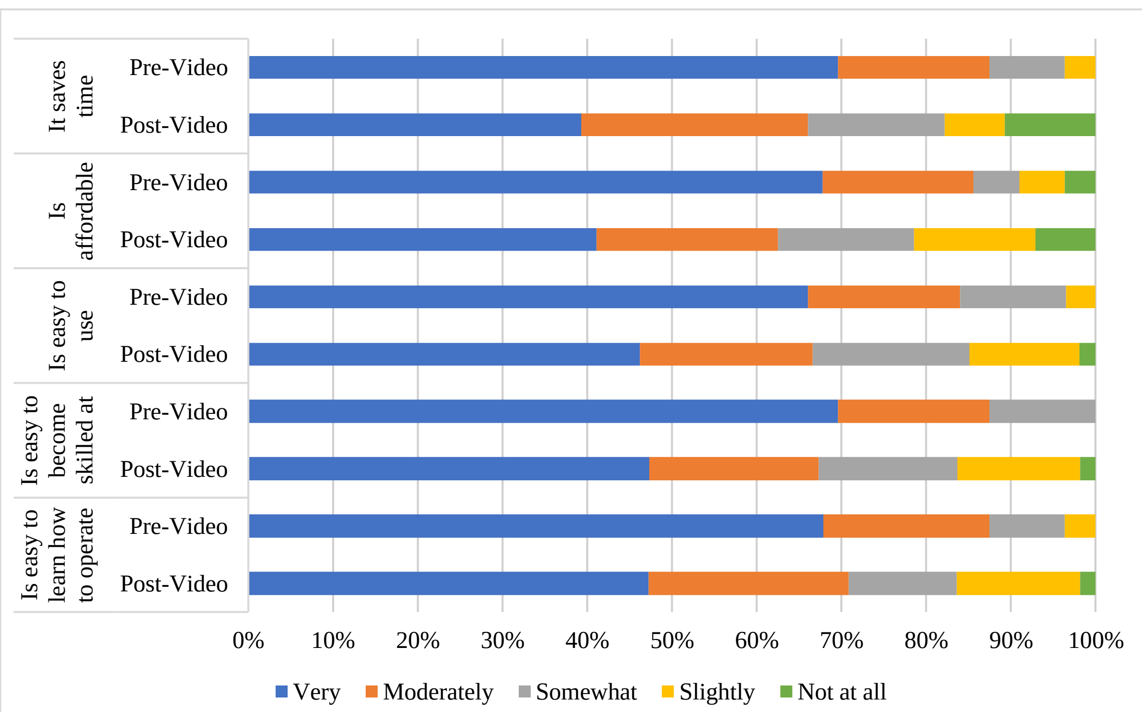


Changes in Likelihood to Use Given Drivers and Barriers. Based on the comparisons between participants' ratings of likelihood to use U-VBF pre- and post-viewing of the instructional video, it was hypothesized that participants' ratings for likelihood to use U-VBF given potential drivers would either increase or stay the same. Surprisingly, visual comparison of response frequencies revealed an overall decline in ratings (see Figure 35). After viewing the video, more participants chose *not at all* (1) when rating their likelihood to use U-VBF for all selected drivers. Further examination of central tendency measures indicated that although there was a general decline is ratings for participant's reported likelihood to use U-VBF given the presence of specific drivers ($Mdn_{(pre)} = 5$ to $Mdn_{(post)} = 4$), many participants' opinions remained the same ($Mode_{(pre)} = 5$ to $Mode_{(post)} = 5$).

Figure 35

Comparisons of Pre- and Post-Video Ratings for Drivers for Likelihood of Using U-VBF

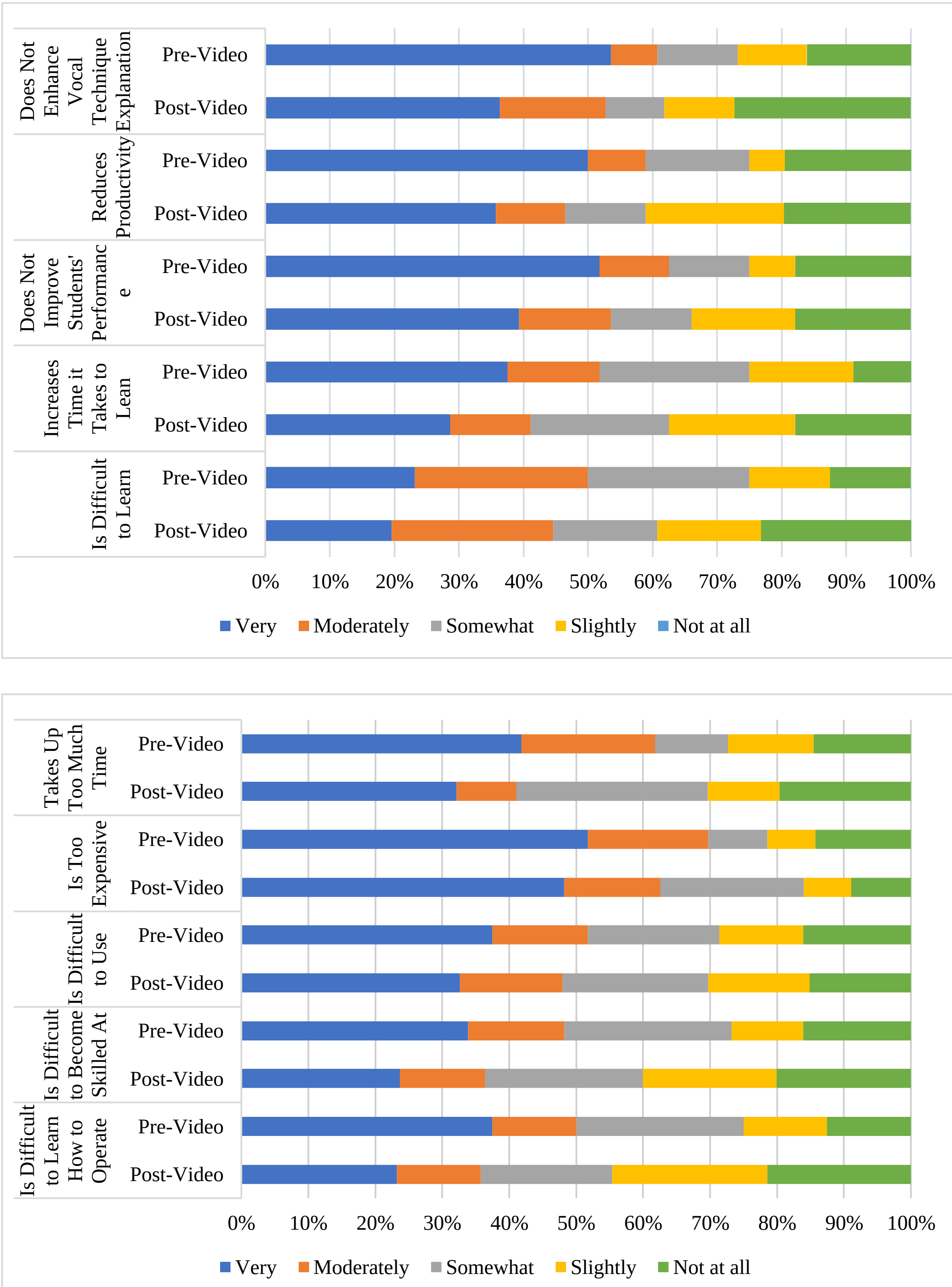




Given the general decline in positive ratings of participants' likelihood to incorporate U-VBF into their teaching following viewing of the instructional video, it was assumed that ratings for perceived barriers would increase, indicating that participants were less likely to use U-VBF. However, visual comparison of response frequencies for pre- and post-video ratings revealed a moderate decrease in ratings for all potential barriers (see Figure 36). Central tendency measures revealed that while many participants' ratings of *very unlikely* (5) to use U-VBF remained the same after viewing the video ($Mode_{(pre)}$ = 5 to $Mode_{(post)}$ = 5), others chose the ratings *moderately unlikely* (4), *slightly unlikely* (2) and *not at all unlikely* (1). This shift in opinion was reflected in further examination of the overall distribution of responses ($Mdn_{(pre)}$ =5 to $Mdn_{(post)}$ = 3). In particular, prior to viewing the video, most participants rated themselves as being *very unlikely* (5) to use U-VBF given the barrier, "is difficult to become skilled at" ($Mode_{(pre)}$ = 5). However, after viewing the video, opinions shifted with many chose the rating of *slightly unlikely* (2) to use U-VBF given this barrier ($Mode_{(post)}$ = 2), suggesting that these participants did not perceive this barrier to be a threat to likelihood of use. This assumption is supported by the findings of high levels of self-efficacy expressed by most participants following viewing of the instructional video.

Figure 36

Comparisons of Pre- and Post-Video Ratings for Barriers to Likelihood of Using U-VBF



Summary of Qualitative Data

Two open-ended questions were included in the post-survey to invite participants to explain what information provided by U-VBF they believed to be the most helpful to singing instruction and to voice any additional opinions. Thematic analysis revealed that the majority found U-VBF to be the most helpful in allowing students to visualize tongue movement during singing and in promoting kinesthetic awareness. Participants also mentioned usefulness of U-VBF in teaching concepts associated with tongue movement, such as vowel formation and modification, and diction. Others mentioned the utility of U-VBF in addressing tongue tension. Some voiced their reservations of use of U-VBF in the voice studio. As one respondent commented, “ultimately, ultrasound belongs more in the pathology lab, rather than the teaching studio.” Another voiced concern that U-VBF may promote, rather than decrease unwanted tensions during singing, stating “The most unhelpful part could be getting a student to relax and not adjust posture or breathing as they used the instrument.” In general, opinions regarding the utility of U-VBF for the pedagogical concepts of vocal timbre, resonance, and volume changes, were mixed. While some felt that U-VBF could be used to demonstrate the relationship between tongue movement and adjustment in vocal tone color, others felt that acoustic differences could be more easily heard rather than seen.

Of the total sample (n = 56), 25 respondents provided their opinions about the use of ultrasound to provide visual biofeedback in the voice studio. Many respondents voiced their reservations regarding its utility, citing barriers such as cost of equipment and set-up time. Some felt that the provided image of the oral cavity was not as clear as originally believed. As one respondent stated:

> After viewing the video, I am less likely to use this tool in the studio because I don't think the images are clear as I anticipated, and therefore, I am not sure that the tool would be as effective as I had first thought in providing the student with a visualization of what is happening while they are singing.

While some felt that it placed too much focus on tongue movement, ignoring other crucial components of good vocal technique such as breath support, others felt that use of a technology system in general detracted from the artistic expression of singing. As one respondent voiced, "Ultrasound is a fine tool for the pathologist, but the singing teacher has to take a wholistic approach, lest the technique be boiled down to a few mechanisms and become devoid of its humanity." Others expressed discomfort in using these systems with one respondent commenting:

> My only real hesitation would be, in a sense, a general aesthetic/pedagogical one: how "scientific" do we wish to render the singing studio? I think that my tendency would be to make use of visual biofeedback resources in the context of 'field trips,' taking students once and a while a facility (medical, research, or the like) to explore these methods. I'm not sure that I would wish to incorporate their use into my own studio or their machinery into my space. Since I'm no scientist, I think it would be disingenuous or pretentious for me to use these in a quotidian way.

Those with more positive perceptions toward use of U-VBF in singing instruction felt that it could serve as a useful supplement for explaining specific pedagogical concepts, such as the role of the tongue in singing. One respondent mused about the potential use of ultrasound to monitor laryngeal elevation as gauged by movement of the hyoid. Others felt that U-VBF could serve as a useful teaching tool for select students who expressed interest in this mode of instruction.

CHAPTER V

DISCUSSION AND CONCLUSION

Summary of Results

The following discussion provides a summary of the primary findings of this study, potential implications of these results, a critique of the method, and directions for future research.

Current Perceptions of Usefulness of Ultrasound Visual Biofeedback

Theoretical perspectives of technology acceptance and use, such as the Technology Acceptance Model (TAM), posit that user behavior is founded on two basic principles, perceived usefulness, and ease of use (Davis, 1989). These two principles, which determine acceptance or rejection of a technology system, are informed by knowledge and experience. Specifically, perceived usefulness is tied to a positive use-performance relationship, in which use of a system fulfills the user's expectations (Davis, 1989). This idea stems from expectancy theory originally introduced by Vroom (1964), who hypothesized that behavior was motivated by anticipated benefits or limitations to performance. The expectancy model of user behavior, which was further developed by Robey and Zeller (1978), describes user perception and attitude as being influenced by specific criteria including the value of rewards received from performance of the used system, the likelihood of rewards resulting from performance, and the likelihood that performance results from use.

In the present study, it was hypothesized that voice teachers' perceptions of usefulness of U-VBF would be related to how much they knew about it and whether they perceived U-VBF to be valuable to singing instruction. Descriptive statistical analysis of collected responses indicated that in general, those who reported prior knowledge of U-VBF tended to express more positive attitudes toward its utility in the voice studio compared to those who reported no prior knowledge or familiarity. This finding is consistent with the usefulness-usage relationship outlined by the TAM. According to Davis (1989), the more familiar an individual is with a technology system and perceives it to be valuable to the actions they need to perform, the more positive their attitude toward future use will be. However, this relationship appeared to be relatively weak, as many of the participants who expressed minimal knowledge or familiarity with U-VBF also expressed positive opinions regarding its potential usefulness in singing instruction.

Opinions regarding the usefulness of U-VBF in teaching specific vocal pedagogy concepts were also generally positive, regardless of degree of participants' knowledge or familiarity with ultrasound and U-VBF. Additionally, a similar trend in responses was apparent for perceptions regarding the usefulness of U-VBF in teaching vocal pedagogy concepts specific to vocal timbre. The lack of a strong relationship between familiarity, knowledge and perceived usefulness may be attributed to the general newness of U-VBV, high levels of interest in learning more about it, and positive expectations regarding its potential usefulness. Ultrasound has primarily been used in voice science and only recently been explored in clinical application within the field of speech-language pathology. Minimal research currently exists in voice pedagogy with only one case study by A. Nair, Schellenberg, and Gick (2015) supporting use of U-VBF in singing instruction. Of note, prior observation of U-VBF did not affect opinions regarding perceived usefulness; however, only 16.0% (*n* = 9) of the total sample (*n* = 56) reported having observed use of U-VBF in singing instruction; therefore, biasing of results cannot be entirely ruled out.

Current Perceptions of Ease of Use of
Ultrasound Visual Biofeedback

Perceptions regarding ease of use were hypothesized to be more positive for individuals who reported greater knowledge or familiarity of U-VBF. The small number of participants who reported being very familiar with ultrasound, as well as knowledgeable of its use in singing instruction consistently rated U-VBF as being easy to use, agreeing with the assumption made by the TAM that greater familiarity and knowledge inform perceptions of ease of use. However, most participants within the sample perceived use of U-VBF to be somewhat difficult, despite some degree of prior familiarity of how ultrasound works or knowledge about its use in visualizing lingual movements. For the participants who reported minimal to no familiarity or knowledge of ultrasound or U-VBF, but who perceived U-VBF to be relatively easy to use, it may be assumed that they exhibited higher levels of self-efficacy and confidence in learning how to utilize U-VBF. However, given the small size of the marginal totals and overall small size of the sample (*n* = 56), these conclusions are only speculative in nature.

According to the TAM, the amount of effort required to operate a technology system plays an influential role in perceived usefulness (Davis, 1989). While comparison of data revealed a positive relationship between perceived ease of use and perceived usefulness, some participants who regarded U-VBF as being difficult to use, still expressed positive views regarding its usefulness in singing instruction. This pattern may be attributed to the participants' positive expectations regarding U-VBF despite its perceived difficulty. Additionally, the majority of participants expressed confidence in being able to effectively learn how to use U-VBF if provided training.

Likelihood to Use Ultrasound Visual Biofeedback

To further examine perceptions regarding the utility of U-VBF, participants were asked to rate how likely or unlikely they were to use U-VBF in their teaching given the presence of specific drivers and barriers. Most participants reported being very likely to use U-VBF if drivers such as "saves time," "is affordable," or "is easy to use" were present. Ratings for drivers were mostly consistent, with the largest percentage of highest ratings being for "enhances explanations of vocal technique." From these responses, it can be concluded that prior to viewing of the instructional video, participants expressed positive expectations of U-VBF and what it could offer in singing instruction.

This assumption is supported by the trend observed in responses for participants' likelihood of using U-VBF given the presence of specific barriers. A greater percentage expressed being moderately to not at all unlikely to use U-VBF despite potential barriers such as "reduces productivity," "is difficult to use," or "is difficult to become skilled at." Additionally, the presence of ratings such as "somewhat unlikely" and "slightly likely" suggests that participants were either uncertain or did not perceive these potential barriers as disrupting their likelihood to use U-VBF in their teaching.

Current Interest in Use of Ultrasound Visual Biofeedback

Results from previous experimental and survey-based studies have indicated generally positive attitudes among voice teachers toward future use of technology in the voice studio (Barnes-Burroughs et al., 2008; Howard et al., 2005). Therefore, it was hypothesized that voice teachers would express a high level of interest in learning more about U-VBF and how to use it in the voice studio.

Overall, participants expressed moderate to high levels of interest in using U-VBF prior to viewing of the instruction video. In general, those who perceived U-VBF to be more useful in singing instruction and perceived it to be easy to use reported higher levels of interest. This finding is consistent with the both the TAM and the expectancy model, in that interest and behavioral intention to use a specific technology system is informed by the belief that the system will provide a desired outcome, which can be achieved through the least amount of effort (Davis, 1989; Robey, 1979).

Influence of External Variables

Research involving the TAM has shown that external variables influence user beliefs about using a system (Agarwal & Prasad, 1999; Burton-Jones & Hubona, 2006; Davis, 1989; Morris & Venkatesh, 2000). Burton-Jones and Hubona (2006) found that variables such as age and level of education directly influenced users' perceptions of ease of use and subsequently frequency of use of a system. For this study, it was hypothesized that selected external variables, such as years of teaching experience, level of education, knowledge regarding voice anatomy, physiology, and acoustics, experience using acoustic visual biofeedback systems, voice type, region, and setting as a voice teacher would be related to participants' responses for perceived usefulness, ease of use, and interest in learning about and using U-VBF. Overall, minimal apparent trends were observed between the selected variables and participants' attitude of U-VBF and their interest in it. However, possible patterns in responses existed between region and perceived usefulness and interest in learning about U-VBF, level of education and perceived usefulness, teaching experience and perceived ease of use, and lastly, voice type and perceived ease of use.

It was hypothesized that region would be an influential external variable given the degree of concentration of private studios and university music programs within different geographical regions. The most positive perceptions on usefulness of U-VBF came from participants who hailed from the Western and Eastern regions or internationally, while those from the Southern and Central regions expressed more guarded opinions. This finding may suggest a higher level of acceptance of incorporating visual biofeedback systems, such as U-VBF, into voice pedagogy in these three regions. A similar pattern was observed for reported interest in learning about U-VBF, except for responses from international participants. Almost all the participants from the Eastern region and over half of those from the Western region reported a high level of interest in learning to use U-VBF. While responses from this study sample suggest a relationship between region and perceptions regarding the utility of U-VBF, a true association cannot be concluded given the disproportionate number of participants for each region. Most responses came from participants residing in the Central, Western, and Southern regions with the fewest responses from the Eastern region and internationally. Consequently, this pattern may only exist within this sample.

A similar conclusion was made for the relationships seen between ratings for perceived usefulness and level of education, as well as ratings for perceived ease of use and years of teaching experience. The majority of the sample reported having earned a Master of Music (MM) with the next largest percentage reporting having earned a Doctor of Musical Arts (DMA). Only a small number of participants reported having earned a Master of Arts (MA), a bachelor's degree (BA or BM), a doctorate degree (PhD), or having completed another form of education.

Of note, among those who cited other forms of education, one of the participants had completed Estill Voice Training, a program which incorporates use of acoustic visual biofeedback and video endoscopy to promote kinesthetic awareness of voice production (Estill Voice International, 2021). Another reported being certified in Somatic Voicework™ The LoVetri Method, an approach to vocal training for Contemporary Commercial Music (CCM) styles which incorporates principles of voice science and voice therapy (Somatic Voiceworks, 2021). This background likely influenced ratings of perceived usefulness among this group.

Similarly, of the seven voice teachers who reported having earned a Master of Arts, three had completed degrees in Speech-Language Pathology. As standard curriculum for a MA in Speech-Language Pathology includes several classes on voice anatomy and physiology, acoustics, and the treatment of voice disorders, it can be assumed that these participants not only were more familiar with U-VBF, but also held more positive opinions regarding its potential usefulness in singing instruction. Opinions among participants who reported having earned a DMA and MM may have been more mixed given the lack of standardization of curriculum in voice performance programs and consequently a wider variation of knowledge regarding vocal anatomy and physiology, acoustics, and voice habilitation and rehabilitation.

Regarding perceived usefulness by voice type, it appeared that the majority of participants who regarded U-VBF as being moderately to very helpful in singing instruction were either Mezzo-Sopranos (Altos) or Sopranos. However, most respondents in the total sample were female (n = 40) with the majority (46.4%) listing soprano as their voice type. Therefore, selection bias for gender likely contributed to this association and this result should be interpreted with caution.

According to Burton-Jones and Hubona (2006), it is difficult to gauge the influence of external variables in that the effects depend on the nature of the technology system, usage measure, and external variable itself. Small sample size, as well as unequal marginal totals likely resulted in biasing of results, obscuring potential relationships that may have existed. Consequently, analysis of the data was purely exploratory in nature and focused on looking for the existence potential trends, rather than on determining the strength of these associations.

Changes in Attitude of Ultrasound Visual Biofeedback from Pre- to Post-Viewing of Video

According to the TAM, training informs a user's knowledge of a technology system, which subsequently influences behavioral intention to use the system (Davis, 1989). From this assumption, it was hypothesized that voice teachers' perceptions of the utility of U-VBF would increase after watching an instructional video, as well as their interest in future use and opinions regarding likelihood of use in the voice studio. Contrary to what was hypothesized, participants' perceived usefulness of U-VBF and opinions regarding likelihood of use decreased after viewing of the video. Ratings for usefulness for teaching different vocal pedagogy concepts also declined, apart from vocal timbre, and adjusting vocal tone color, for which ratings marginally increased. Participants' opinions regarding usefulness of U-VBF for visualization of the vocal tract also increased, which aligned with similarly high ratings of the usefulness of U-VBF to teach anatomy and physiology. These quantitative findings were supported by the qualitative data, in which participants agreed that U-VBF could be used to show changes in vocal timbre by providing visualization of tongue height and advancement but felt that teaching the aesthetics of a singing style was better taught using acoustic and verbal cues.

A similar decline was seen in participants' reported likelihood of using U-VBF in the presence of potential drivers toward use, suggesting that participants did not perceive U-VBF to be as useful as originally believed prior to viewing the instructional video. Of note, however, perceived barriers affecting likelihood of using U-VBF also decreased. This finding suggests that after watching the video, participants viewed these barriers as being less of a threat to the likelihood of using U-VBF than originally assumed. This trend in data suggests that while participants' perceptions regarding the utility of U-VBF may have moderately declined following viewing of the instructional video, they were still amendable to learning more about U-VBF. This assumption is supported by data showing a moderate increase in participant's interest levels.

Most prominently, participants perceived U-VBF to be much easier to use after watching the video. Participants also highly rated perceptions regarding effective use in the voice studio. Both findings align with assumptions made by the TAM that technology users who believe a system is easy to use, possess higher levels of self-efficacy (Davis, 1989). Perceptions regarding effective use were also related to participants' interest levels and ratings for likelihood of using U-VBF, suggesting that belief in effective use of a system is more likely to predict positive behavioral intentions for future use than either perceived ease or perceived usefulness alone. However, as clearly indicated by the TAM, these opinions are tightly interconnected. While interest and likelihood to use U-VBF were found to be significantly associated with perceptions of ease of use and effective use, overall behavioral intentions for future use were impacted by decreased perceptions of how useful U-VBF would be in singing instruction. Although the majority of participants felt that U-VBF was still important to singing instruction to varying degrees, most reported only being somewhat likely to use U-VBF in the future. This finding is notable, given the conclusion made by Davis (1989) that users are often driven to adopt a technology system more so because of its perceived benefit from the functions it performs than how easy it is to use.

Interpretation of Qualitative Data

Thematic analysis of the qualitative data sheds light on the quantitative data, specifically in voice teachers' perceptions of the strengths and limitations of U-VBF in singing instruction before and after viewing of the instructional video. The tendency to choose more neutral responses for ranked variable questions may have been influenced by the influential weight of some of the perceived barriers of U-VBF, such as cost, availability, time, and training. While many respondents thought that U-VBF could potentially serve as a useful tool in clarifying vocal pedagogy and provide a quick visual reference for students and teachers alike, they also felt that the cost of purchasing an ultrasound machine and the time it would take to train students to interpret the images detracted from is overall potential benefits. Perceived strengths and limitations largely remained the same following viewing of the video, although many participants felt that the image provided by ultrasound was not as clear as they had originally expected. While the majority agreed that U-VBF could be used to visualize tongue movement to show changes in vocal tone color, they still felt that perceptual acoustic measures or use of acoustic visual biofeedback and traditional pedagogy approaches would be more beneficial for teaching pedagogical concepts such as vocal resonance, timbre, and changes in singing style. Many additionally worried that the ultrasound image would be too difficult for their students to interpret and effectively reference.

Overall, the results indicate that while interested in learning more about U-VBF, perceptions regarding the utility of U-VBF in singing instruction from voice teachers who participated in this study was mixed. Although many expressed high levels of self-efficacy, believing that ultrasound would be relatively easy to operate in the studio, this opinion was dampened by perceived barriers such as availability, time, cost, and how useful U-VBF would be in teaching different vocal pedagogical concepts. Although perceived ease of use informs interest or behavioral intention to use, Davis (1989) found that perceived usefulness was more significantly linked to actual system use. That ease of use and interest in a technology system are not necessarily predictors of its use replicates previous findings for technology use in music learning (Barnes-Burroughs et al., 2008; Waddell & Williamon, 2019).

In summary, despite the decline in perceived usefulness from pre- to post-viewing of the instructional video, over half of the participants in this study remained interested in learning more about U-VBF. However, it should be considered that while voice teachers are open to learning more about U-VBF and how it can be used to teach vocal pedagogy concepts such as vocal timbre, actual use of this teaching tool may not be as likely due to lower perceptions of usefulness. Lastly, it is also important to note that perceptions regarding usefulness and ease of use may have been different if a larger sample size had been obtained, which was more equally representative across different demographics, such as education, voice type, region, etc.

Critique of Method

The following critique will address study strengths and limitations, and directions for future research.

Study Strengths

This was the first study to gauge voice teachers' perceptions toward the utility of ultrasound to provide visual biofeedback during singing instruction. Ultrasound has been successfully used in clinical application in speech-language pathology but has been little explored for its potential use in voice pedagogy. A. Nair, Schellenberg, and Gick (2015) explored the use of U-VBF to supplement traditional voice instruction in a small case study; however, no research has yet been conducted to assess acceptability of using U-VBF during singing instruction. This study employed the Technology Acceptance Model (TAM) developed by Davis (1989), which has been proven to have reliable and valid constructs (Chin & Todd, 1995; Doll et al., 2007), and has been validated over a wide range of systems, including technology use in music learning (Waddell & Williamon, 2019). Consequently, the TAM provided a strong theoretical basis from which to develop this study. Additional strengths of this study included cost effectiveness of adopting a survey-based design, use of an online venue, and wide sampling frame, which included a database consisting of over 2,000 voice teachers across the country formed from the NATS membership directory, as well as those who were able to access social media platforms reserved for vocal pedagogues and singing voice specialists.

Study Limitations

There are several limitations to this study including low response and completion rates resulting in a small sample size and overall methodological limitations. Originally, stratified random sampling was employed to recruit a representative sample of the general population of voice teachers throughout the United States. A low response rate, however, prompted adoption of snowball sampling by posting of a research flyer on selected social media cites for voice teachers and singing voice specialists. As a non-random sampling method, snowball sampling does not guarantee representation of the population and is susceptible to community bias, thus limiting the extent of generalizability of results. Statistical analysis of the results was further limited by the overall small size of the study (n = 56), limiting both statistical power and interpretation. Consequently, this study was exploratory in nature, and results are only suggestive of potential patterns of opinions regarding usefulness, ease of use, and interest in use of U-VBF in singing instruction.

Additional methodological limitations include unknown reliability of the survey and lack of a robust review of validity. Face validity was established through review of the surveys by two professional, licensed speech-language pathologists familiar with ultrasound and U-VBF, one professional voice teacher, who is expert in vocal pedagogy. Future research should follow a more extensive review of validity and reliability following the six-step method outlined by Collingridge and Grantt (2008) including running a pilot test, cleaning collected data, employing principal components analysis (PCA), and reviewing for internal consistency.

Low level of prior exposure to both VBF and U-VBF also may have obscured perception rankings, as well as pre- and post-changes in rankings. Additionally, as a survey-based study, there was no way to accurately predict actual system use. The TAM measures both usage behavior as mediated by predictors such as perceived usefulness and ease of use, as well as actual system use. Given the novelty of U-VBF, particularly in singing instruction, the results of this study only measured predicted intention to use or interest. According to Waddell and Williamon (2019), intention use does not necessarily predict future use. Additionally, behavioral intention to use often falls short of actual system use, and thus functions more as a moderator rather than a predictor (Waddell & Williamon, 2019). In this study, only nine out of the total number of study participants (n = 56) reported previous observation of U-VBF in singing instruction. Whether participants with prior observation of U-VBF also received hands-on experience with using ultrasound is unknown. Future research would benefit from providing hands-on experience to study participants with analysis using the TAM model to evaluate actual system use in comparison to behavioral intention to use.

Conclusions

Overall, the purpose of this study was to gauge the current knowledge, attitude, and interest among voice teachers regarding real-time visual biofeedback in the voice studio, identify potential influential external variables, and evaluate whether perceptions changed following viewing of an instructional video demonstrating use of ultrasound visual biofeedback (U-VBF) in singing instruction. Results convey a general feeling of uncertainty regarding use of ultrasound to provide visual biofeedback in the voice studio. While participants after viewing the instructional video, perceived U-VBF to have specific benefits, such as providing a visual picture of lingual movement during singing that could be viewed and interpreted by both teacher and student for learning vocal pedagogy concepts, such as vocal timbre, many continued to have reservations regarding availability, cost, and set-up time. Some felt U-VBF could not as clearly demonstrate vocal pedagogy concepts, such as teaching different singing styles, as originally perceived. Others continued to prefer more perceptual acoustic and traditional approaches to singing instruction. Although rankings of perceived usefulness of U-VBF following viewing of the instructional video generally declined, continued expression of interest in learning more about U-VBF and higher opinions regarding its ease of use in the voice studio highlights an area for future research.

Although interest in using a new technology system informs attitude toward use, it does not necessarily directly influence actual system use. Future case studies involving hands-on opportunities for use of U-VBF during singing instruction could provide further insight on the utility of this mode of visual biofeedback with comparison between behavioral intention to use, attitude as informed by perceived usefulness and ease of use, and actual system use. Additionally, this study only looked at voice teachers' perceptions of using U-VBF in singing instruction. Future research employing different research methodologies, such as the action-research framework employed by Howard et al. (2005) or a multiple-baseline design across settings could provide further insight into both voice teachers and their students' perceptions of voice instruction with and without U-VBF.

While technology by itself won't perfect an individual's vocal technique for singing, visual biofeedback, such as U-VBF, has the potential to clarify complex topics, objectify terminology, form new dialogue between voice teacher and student, and increase acquisition of a newly learned skill. Unlike the traditional mode of voice instruction, which relies on multiple repetitions of linguistic metaphors that are prone to subjectivity, U-VBF allows for some components of singing behavior to be captured and discussed in real time. However, despite the potential pedagogical benefits of U-VBF, use of a system goes only as far as its perceived benefits. Whether U-VBF is accepted and explored as a supplemental tool for singing instruction is yet to be fully determined. Continued research in this area could provide further insight into the use of U-VBF in singing instruction in relation to its perceived benefits and limitations from voice teachers and students alike.

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APPENDIX A

INSTITUTIONAL REVIEW BOARD APPROVAL

UNIVERSITY OF
NORTHERN COLORADO

Institutional Review Board

Date:	11/16/2020
Principal Investigator:	Kristen Smith
Committee Action:	**IRB EXEMPT DETERMINATION – New Protocol**
Action Date:	11/16/2020
Protocol Number:	2010012524
Protocol Title:	Investigating the utility of ultrasound visual biofeedback in voice instruction for two different singing styles
Expiration Date:	

The University of Northern Colorado Institutional Review Board has reviewed your protocol and determined your project to be exempt under 45 CFR 46.104(d)(702) for research involving

Category 2 (2018): EDUCATIONAL TESTS, SURVEYS, INTERVIEWS, OR OBSERVATIONS OF PUBLIC BEHAVIOR. Research that only includes interactions involving educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior (including visual or auditory recording) if at least one of the following criteria is met: (i) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained, directly or through identifiers linked to the subjects; (ii) Any disclosure of the human subjects' responses outside the research would not reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation; or (iii) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects can readily be ascertained, directly or through identifiers linked to the subjects, and an IRB conducts a limited IRB review to make the determination required by 45 CFR 46.111(a)(7).

You may begin conducting your research as outlined in your protocol. Your study does not require further review from the IRB, unless changes need to be made to your approved protocol.

<u>As the Principal Investigator (PI), you are still responsible for contacting the UNC IRB office if and when:</u>

UNIVERSITY OF
NORTHERN COLORADO

Institutional Review Board

- You wish to deviate from the described protocol and would like to formally submit a modification request. Prior IRB approval must be obtained before any changes can be implemented (except to eliminate an immediate hazard to research participants).
- You make changes to the research personnel working on this study (add or drop research staff on this protocol).
- At the end of the study or before you leave The University of Northern Colorado and are no longer a student or employee, to request your protocol be closed. *You cannot continue to reference UNC on any documents (including the informed consent form) or conduct the study under the auspices of UNC if you are no longer a student/employee of this university.
- You have received or have been made aware of any complaints, problems, or adverse events that are related or possibly related to participation in the research.

If you have any questions, please contact the Research Compliance Manager, Nicole Morse, at 970-351-1910 or via e-mail at nicole.morse@unco.edu. Additional information concerning the requirements for the protection of human subjects may be found at the Office of Human Research Protection website - http://hhs.gov/ohrp/ and https://www.unco.edu/research/research-integrity-and-compliance/institutional-review-board/.

Sincerely,

Nicole Morse

Nicole Morse
Research Compliance Manager

University of Northern Colorado: FWA00000784

Carter Hall 3002 I Campus Box 143 I Greeley, CO 80639 I Office 970-351-1910 I Fax 970-351-1934

APPENDIX B

REGIONS BY NUMBER OF VOICE TEACHERS AND 10% SAMPLE FOR EACH REGION

Table 21

Regions by Number of Voice Teachers and 10% Sample for Each Region

Region				Overall Region Total	Opera Sample	Musical Theater Sample
WESTERN REGIONS						
Cal-Western	North-western	West Central	Inter-mountain			
404	206	106	20	736	37	37
AZ	AK	CO	ID			
CA	OR	KS	MT			
HI	SD	NE				
NV	WA	WY				
UT						
CENTRAL REGIONS						
Central	Great Lakes	North Central				
217	263	128		608	30	30
IA	IN	ND				
IL	MI	MN				
MO	OH	WI				
SOUTHERN REGIONS						
Mid-South	South Eastern	Southern	Texoma			
95	204	51	191	541	27	27
TN	AL	AR	NM			
KY	FL	LA	OK			
	GA	MS	TX			

Table 21 (continued)

Region			Overall Region Total	Opera Sample	Musical Theater Sample
EASTERN REGIONS					
Eastern	Mid-Atlantic	New England			
375	293	226	894	45	45
DE	MD	CT			
NJ	NC	MA			
NY	SC	ME			
PA	VA	NH			
WV		RI			
		VT			
			2,779	139	139

APPENDIX C

STUDY DESCRIPTION FOR ONLINE PROMOTION WITH PROMOTIONAL FLYER

Hello,

If you are a voice teacher, singing voice specialist, or work with either of these professionals, we are currently seeking voice teachers who teach either opera or musical theater at a university or private studio to participate in a study regarding the potential utility of using ultrasound visual biofeedback as a part of voice instruction.

The research consists of two online surveys that should each take no more than 5-10 minutes to complete and a 17-minute instructional video demonstrating how ultrasound visual biofeedback can be used to teach concepts such as vowel modification or changing of vocal tone quality. Collectively, participant involvement would require between 25-35 minutes.

The goal of the study is to gather information regarding perceived usefulness and ease of use of this technology from professional voice teachers and will inform future studies regarding incorporation of different modes of technology in voice teaching.

Participants will have the opportunity to enroll in a raffle for one of two $100 gift cards following completion of both surveys. This study has been approved by the Institutional Review Board (IRB) at the University of Northern Colorado

We would also be very grateful if you could share the survey link with your friends and colleagues who are singing teachers. Please see the formal study letter for more information. The link to the surveys is here: [link]

If you have any questions, feel free to contact me or my advisors with any questions.

Kristen J. Smith: kristen.smith@unco.edu
(Primary Researcher)

Dr. Don Finan, PhD.: donald.finan@unco.edu
(Research Advisor)

Dr. Caitlin Raaz, PhD., CCC-SLP: caitlin.raaz@unco.edu
(Research Advisor)

Dr. Mary Kathryn Brewer, DA: Mary.Brewer@unco.edu
(Research Advisor)

Promotional Research Flyer

APPENDIX D

ATTITUDES OF U-VBF IN SINGING INSTRUCTION SURVEY
PRE-VIDEO QUESTIONNAIRE

ATTITUDE OF U-VBF IN SINING INSTRUCTION SURVEY
PRE-VIDEO QUESIOTNNAIRE

Thank you for agreeing to complete this questionnaire. Please note that all responses are voluntary. We are interested in learning about your experience, knowledge, and attitudes about the use of visual biofeedback technology in the voice studio as well as the use of ultrasound visual biofeedback technology.

This questionnaire will take between 5-10 minutes to complete. All information you provide will be kept confidential and only summary results will be provided.

A. Demographic Information

Please complete the following demographic information and background questions.

1. Age: ____

2. Are you a singing teacher? **Yes / No**

3. In what state do you currently teach? ______

4. What is your voice type?

   Soprano Mezzo Soprano (Alto) Tenor Baritone Bass

5. Do you have formal training as a voice teacher? **Yes / No**

6. Please indicate your level of education

   DMA PhD MM MA Other: _____

7. How many years total have you taught voice? ______

8. What singing styles do you teach?

   Musical Theater Opera/Classical Contemporary Other: _____

9. What singing style do you regard yourself as an expert in teaching?

   Musical Theater Opera/Classical Contemporary Other: _____

10. What singing style do you regard yourself as an expert in teaching?

11. In what setting do you teach voice?

    Private studio College/University Conservatory

YES/NO	Yes	No		

12. Have you ever **taken** a class that includes anatomy and physiology of the voice?

13. Have you ever **taught** a class that includes anatomy and physiology of the voice?

14. Have you ever **taken** a class that includes voice acoustics?

15. Have you ever **taught** a class that includes voice acoustics?

16. Have you ever **used** acoustic analysis software in a class (taken or taught)?

    a. What kind? *PRAAT* *Voce Vista* *Madde Synthesizer* *Sing&See* *Other: ____*

B. Knowledge and Attitudes for Visual Biofeedback Technology Use in the Voice Studio

The next set of questions ask about your experience, knowledge and attitudes about the use of visual biofeedback technology in the voice studio. In this survey**, visual biofeedback technology** is used to refer to instrumentation that captures some aspect of physiology or behavior with the purpose of guiding the learner toward a higher level of conscious control. Please give one answer that best fits your response for each question.

LIKERT SCALE RANKING	1 Not at all	2 Slightly	3 Somewhat	4 Moderately	5 Very

1. How **familiar** are you with the following software programs providing visual biofeedback?

   Voce Vista
   Madde Voice Synthesizer
   PRAAT
   Sing & See
   Other: (Please specify): ________________________

2. How **helpful** do you think technology that assists with visual biofeedback (i.e., acoustic software programs such as *Voce Vista and others*) is in singing instruction?

3. How **likely** is it that you would use visual biofeedback technology in your teaching, if it were available?

4. How **familiar** are you with ultrasound and how it works?

5. How **knowledgeable** are you on the use of ultrasound in providing visual biofeedback in singing instruction?

6. How **familiar** are you with ultrasound for offering visual biofeedback information on movements of the tongue to increase self-awareness during speaking (or singing)?

7. How **interested** would you be in using ultrasound as visual biofeedback in your teaching if it were available?

YES/NO/DON'T' KNOW	**Yes**	**No**	**Don't Know**	

8. Have you ever **observed** a voice teacher using ultrasound visual biofeedback in singing instruction?
9. What do you find to be the **strengths** of using visual biofeedback technology in the voice studio?

____

10. What do you find to be the **limitations** of using visual biofeedback technology in the voice studio?

____
____

11. Why do you think use of technology for visual feedback is **important OR not important**?

____
____

12. Please **rank** how interested you are in learning more about the following forms of visual biofeedback from 1-5 with **1 being not at all** to **5 being very**

	Rank
Voce Vista	_______
Madde Voice Synthesizer	_______
PRAAT	_______
Sing & See	_______
Ultrasound	_______

C. Perceived Usefulness & Ease of Use of U-VBF

This set of questions will focus on your perceptions on the usefulness and ease of use of **ultrasound visual biofeedback technology**. Please give one answer that best fits your response for each question.

LIKERT SCALE RANKING	1 Not at all	2 Slightly	3 Somewhat	4 Moderately	5 Very

1. How **helpful** do you think ultrasound visual biofeedback would be in teaching concepts in singing such as vocal timbre, based on your experience?

2. How **easy** you do you think it will be to use ultrasound visual biofeedback in singing instruction?

3. Please rank how **useful** you think ultrasound visual biofeedback would be in teaching the following concepts:

   Vocal Resonance
   Vocal Timbre (Tone quality)
   Vowel Modification
   Visualization of Vocal Tract Size and Shape
   Diction & Articulation

4. In relation to <u>vocal timbre</u>, please rank how **useful** you think ultrasound visual biofeedback would be in teaching the following concepts?

   Balanced tone (chiaroscuro)
   Changes in vocal tone color
   Tone focus/Placement of the Voice
   Vowel enunciation/Vowel quality
   Volume changes
   Vocal tract adjustments for changing singing styles *(i.e., classical to belting)*
   Vocal tract adjustments for passaggi points
   Vocal tract adjustments for high register singing
   Other: (Please specify): ________________________

5. If readily available, how **likely** would you be to use visual biofeedback, such as U-VBF, if it:

Enables students to learn more quickly
Makes learning easier
Improves students' performance
Increases productivity
Enhances explanations of vocal technique
Is easy to learn how to operate
Is easy to become skilled at
Is easy to use
Is affordable
It saves time

6. How **unlikely** are you to use visual biofeedback, such as U-VBF if it:

Is difficult to learn
Increases the time it takes to learn
Does not improve students' performance
Reduces productivity
Does not enhance explanations of vocal technique
Is difficult to learn how to operate
Is difficult to become skilled at
Is difficult to use
Is too expensive
Takes up too much time

YES/NO/DON'T' KNOW	**Yes**	**No**	**Don't Know**	

7. If provided training, do you think you could easily learn how to use ultrasound visual biofeedback?

APPENDIX E

ATTITUDES OF U-VBF IN SINGING INSTRUCTION SURVEY
POST-VIDEO QUESTIONNAIRE

ATTITUDES OF UVBF IN SINGING INSTRUCTION SURVEY
POST-VIDEO QUESTIONNAIRE

Thank you for taking the time to watch the video and complete this follow-up questionnaire. Please note that all responses are voluntary. We are interested in learning about your perceptions and attitudes after viewing a demonstration video about the use of ultrasound visual biofeedback technology in the voice studio.

This questionnaire will take between 5-10 minutes to complete. All information you provide will be kept confidential and only summary results will be provided.

A. Perceptions & Attitudes for U-VBF Demonstration Video

LIKERT SCALE RANKING	1 Not at all	2 Slightly	3 Somewhat	4 Moderately	5 Very

1. How **informative** did you find the video demonstrating use of ultrasound visual biofeedback during singing?

2. How **helpful** did you find the video demonstrating use of ultrasound visual biofeedback during singing to be in clarifying the following concepts related to voice physiology and acoustics?

   Vocal Resonance
   Vocal Timbre
   Formant Frequencies
   Relationship between Harmonics & Formants
   Movement of the Tongue & Tone Color
   Movement of the Tongue & Vowels
   Formant Frequencies and Vowels
   Formant tuning / Formant tracking

3. How **much** did the video demonstrating use of ultrasound visual biofeedback during singing **change** your opinion on using technology in the voice studio?

B. Perceptions & Attitudes for Ultrasound Visual Biofeedback in Singing Instruction

The next set of questions ask about your attitudes about usefulness and ease of use of **ultrasound visual biofeedback in singing instruction** and interest and likelihood of **using it in the voice studio**. Please give one answer that best fits your response for each question.

LIKERT SCALE RANKING	1 Not at all	2 Slightly	3 Somewhat	4 Moderately	5 Very

1. How **helpful** do you think that ultrasound visual biofeedback will be in explaining concepts related to voice anatomy and physiology during singing?

2. How **helpful** do you think that ultrasound visual biofeedback will help in explaining concepts related to voice acoustics during singing?

3. How **important** do you believe use of visual biofeedback, such as through ultrasound, is to singing instruction?

LIKERT SCALE RANKING	1 Not at all	2 Slightly	3 Somewhat	4 Moderately	5 Very

4. Please rank how useful you think ultrasound biofeedback would be in teaching the following concepts.

   Vocal Resonance
   Vocal Timbre (Tone quality)
   Vowel Modification
   Visualization of Size and Shape of the Vocal Tract
   Diction & Articulation

5. In relation to vocal timbre, please rank how useful you think ultrasound biofeedback would be in teaching the following concepts?

   Balanced tone (chiaroscuro)
   Changes in vocal tone color
   Vowel enunciation / Vowel quality
   Tone focus / Placement of the Voice
   Volume changes
   Vocal tract adjustments for changing singing styles (i.e., classical to belting)
   Vocal tract adjustments for passaggi points
   Vocal tract adjustments for high register singing
   Other (Specify): ________________________

6. How easy you do you think it will be to use ultrasound visual biofeedback in singing instruction?

7. If ultrasound visual biofeedback were available to you, do you think you could use it effectively in singing instruction?

8. How interested are you in pursuing or learning more about future use of ultrasound visual biofeedback in singing instruction?

9. How likely would you be to use visual biofeedback technology when singing in the future?

10. If readily available, how likely are you to use visual biofeedback such as U-VBF because it…

    Enables students to learn more quickly
    Makes learning easier
    Improves students' performance
    Increases productivity
    Enhances explanations of vocal technique
    Is easy to learn how to operate
    Is easy to become skilled at
    Is easy to use
    Is affordable
    It saves time

11. If readily available, how **unlikely** are you to use visual biofeedback, such as U-VBF because it…

    Is difficult to learn
    Increases the time it takes to learn
    Does not improve students' performance
    Reduces productivity
    Does not enhance explanations of vocal technique
    Is difficult to learn how to operate
    Is difficult to become skilled at
    Is difficult to use
    Is too expensive
    Takes up too much time

12. Do you agree that the information provided by ultrasound biofeedback is helpful to teaching vocal technique for different singing styles (i.e., musical theater, classical)?

LIKERT SCALE RANKING	1 Not at all	2 Slightly	3 Somewhat	4 Moderately	5 Very

13. In your opinion, what specific information provided by ultrasound visual biofeedback do you think is most helpful (unhelpful) to singing instruction?

____

____

14. Do you have any additional comments or opinions about the use of ultrasound as visual biofeedback in the voice studio?

____

____

Thank you for your participation in this research. Would you like to enter a raffle for the chance to win a prize? **Yes / No**