Assignment Submission Form / Ffurflen Cyflwyno Aseiniad

WIWBL Copy
Student Number: __1807590_____

Student's Name: __Colin David Reed___

Tutor Name: __Debbie Winter____

Assignment Title: **A study into the phenomenon of vocal registers, and their application in teaching voice.**

Module Code: ___BMPF7013___

Submission Date: __15/01/2021_____

Your work will not be marked unless it is accompanied by this statement.
I confirm that this is my original work and that I have adhered to the University's policy on plagiarism.
Student's Name: __Colin Reed_____Signature___

WIWBL Staff only
Received by:_____Date submitted:_____

Student Receipt
Student Number: ___1807590_____

Student's Name: __Colin David Reed_____

Tutor Name: ____Debbie Winter_____

Assignment Title: **A study into the phenomenon of vocal registers, and their application in teaching voice.**
_____

Module Code: _____BMPF7013_____

Submission Date: ____15/01/2021_____

WIWBL Staff only
Received by:_____Date submitted:_____

A study into the phenomenon of vocal registers, and their application in teaching voice.

1) The portfolio

Introduction and rationale

I have been a singing teacher for more than eleven years, with a growing practice that covers a diverse range of genres, ages, and abilities. My students range in age from seven years to seventy-five, from beginners to professional singers, and covers classical singers, music theatre, pop, folk, jazz, soul, and rock. My own vocal training was focussed on classical singing, and followed an approach that might be described as viewing the voice as a black box (Herbst, 2020), being more focussed on inputs and outputs rather than the internal workings of the voice itself. I have had instances of students from different vocal backgrounds to mine coming to my studio and using a wider range of register terminology than I am familiar with from my own voice training. Therefore, in order to be able to discuss registers across different genres that have their own terminology, I propose to undertake a review of literature regarding the phenomenon of vocal registers.

It has been recognised that register definition has often been contentious, and so attempts were made in the late 1970s to agree upon a set of register definitions. An international organisation, including speech therapist Harry Hollien, agreed upon a number of points regarding the existence of registers (Henrich, 2006) and proposed four different modes of voice production:

"Register 1: The very lowest of registers, probably used only in speaking (old terms: *pulse, vocal fry, creak*).

Register 2: That (low) register, which is used by most for speaking and singing (old terms: *modal*, *chest*, *normal* and *heavy*).

Register 3: A high register used primarily in singing (old terms: *falsetto*, *light*, *head*).

Register 4: A very high register found in some women and children and particularly relevant to the coloratura soprano (old terms: *flute*, *whistle*).” (Brown, 1996, 51).

The immediate response to this seemed to be a disagreement as to whether registers should depend solely on a laryngeal action, or whether the vocal tract should be accepted as part of the definition of registers (Henrich, 2006), and that an additional register should be considered, called 2A, representing a middle register between chest and falsetto, possibly known as *classical head voice* (Brown, 1996, 51-52; Henrich, 2006). Clearly, agreeing upon strict definitions of registers is a difficult task. Indeed, in the early 1970s Hollien had already proposed how the concept of registers was a source of controversy (Hollien, 1974).

As a teacher of singing, rather than a voice scientist, my focus is always upon gaining knowledge that will help my students acquire better vocal skills. For the most part, my students are armed only with their own ears, sense of proprioception and interoception, and perhaps an ability to record themselves. To be of use to my students, most of the knowledge of registers should be something that they can perceive themselves, without ready recourse to expensive instrumentation such as electro-glottography.

Giovanni Battista Lamperti stated that the vocal organs may be described briefly as a “pipe with double reed, blown by means of diaphragm and lungs” (Lamperti, 1905, 5). Given this simple starting model, it is clear that it has similarities to certain other instruments. The oboe, cor anglais, and bassoon are all common double reed instruments powered by breath. The oboe and bassoon typically have ranges described as from two and a half to three octaves (Yandell, 2008, 76). The range of the oboe corresponds mostly with Cornelius Reid’s description of the range of female voices, with the bassoon corresponding with the respective male voice range (Reid, 1950, 89). Reid describes a break between registers of both male and female voices, and shows that there are some notes that can be sung in either upper or lower register (Reid, 1950, 86). Woodwind instruments similarly have a break between “octave” registers, but some notes can be played at the top of the lower register (short fingering) or the bottom of the upper register (long fingering)

(Wolfe, no date). There is a clear textural and acoustic difference between the upper notes of the lower octave and the lower notes of the upper octave creating both audio and somatosensory feedback to the player. As a woodwind player myself, much of my practise time is taken up trying to smooth over this register transition, similar to that process described by classical singers in trying to even out the passaggio (Miller, 1996, 115). How acoustics may affect the singer's perception of registration is something that I would like to explore, looking at the similarities and differences between the voice and other wind instruments.

Planned programme of study

Aims

- To increase my knowledge of different ideas of vocal registers
- To investigate which ideas of vocal registers will be of practical application in my teaching practice

Objectives

- To study the historical development of the concept of vocal registers
- To compare more modern research into laryngeal registers with historical descriptions
- To study the concept of acoustic registers, and to compare the acoustic behaviour of the vocal tract with that of wind instruments, particularly the saxophone.

The proposed timeline for the project is given below.

Task	October				November				December				January			
Topic to agree with tutor																
Aims and objectives to be decided and written																
Book and journal search and review																

Main writing																
Draft submission																
Revision and final submission																

Literature Review Process

Cooper's taxonomy (classification) of literature reviews categorises reviews by their focus, goal, perspective, coverage, organisation, and audience (Randolph, 2009; Torraco, 2016). Looking at these categories in the context of vocal registers, and following Randolph's (2009) advice to formulate questions at the beginning of the research process, it became quickly apparent that my review of the literature regarding vocal registers was going to involve more than one choice in each of Cooper's categories. For example, in the first category of focus, I will be looking both at theories and practice – two of the suggested foci in Cooper's taxonomy (Randolph, 2009). The review will also be looking at aspects that may be considered a mature topic, namely the historical classification and theories of registers, whilst also reviewing emerging topics such as acoustic registers and more recent investigations of laryngeal physiology involved in different registers. Torraco (2005, 2016) suggests an integrative literature review for this type of review, especially when the principal goal may be to either synthesise new knowledge by weaving together from existing literature, or to re-conceptualise a potentially out of date or problematic conception of a topic.

Given the aims and objectives stated above, and following Randolph's (2009) advice, I formulated the following research questions.

1. Where and/or when did the concept of vocal registers originate? How did the idea of registers and their use in teaching singing develop prior to the middle of the twentieth century?

2. To what extent does laryngeal physiological research from the mid-twentieth century onwards support or contradict the more historical models of registers?

3. What influences do acoustics have on vocal fold vibration? Is this the source of the concept of acoustic registers, or is that a separate register event that is not affected by the vibration of the vocal folds?

These questions will be helpful to determine the structure of the review (Torraco, 2016). The structure will be mainly thematic, although there will be a certain temporal or historical structure to answer the first of my research questions above.

Following the formulation of research questions, the next stage is that of data collection. My aim is that the literature will be drawn from a range of primary sources, including voice science, voice pedagogy, physics, mathematics, and other musical instrument research, found in journals, books, websites, and PhD research. I will also be placing emphasis on secondary sources of published pedagogues, most notably Manuel Garcia (1857), Giovanni Battista Lamperti (1905), Oren Brown (1996), Cornelius Reid (1950, 1972, 1975), Richard Miller (1996), James Stark (2008), and Thomas Hemsley (1998), as their experience as successful practitioners displays their own reflection on action (Ghaye, 2010).

The structure of the review will be mainly thematic (Torraco, 2005, 2016), and narrative (Rhoades, 2011). Due to the potential volume of literature available on the subject of registers, and the allied sciences, a systematic review of all of the literature would not be possible in a study of this size. A narrative review will allow for a purposive sampling of the pivotal works in the field (Randolph, 2009). Moreover, I predict that some of the concepts dealing with vibration of the vocal folds will include the use of mathematics that, although I have used in my previous academic studies in physical chemistry, will be challenging. A smaller number of literature sources with a better level of analysis will be more focussed than taking a superficial view of too many articles.

The starting point for this literature review is the use of register terminology in several of my existing teaching texts. Cornelius Reid, Oren Brown, and Richard Miller all use register terminology in their texts. Cornelius Reid also gives a good historical introduction in his book Bel Canto: Principles and Practices (Reid, 1950), as does James Stark (2008). Following the citations from these sources finds some common names from the bel canto period, namely Pier Francesco Tosi (1743) and Giambattista Mancini (1912), although it should be noted that these are in later and differing quality translations. Additional common names that come out of historical reviews of pedagogy, and registers in particular, are Francesco Lamperti, his son Giovanni Battista Lamperti, and Manuel Garcia. Although these again are available in translations of differing quality, they are of particular interest in the historical development of register theory since they are contemporary with the development of higher voiced male singers “covering” the tone rather than switching to falsetto for higher notes (Stark, 2008, 85) and this is the usual method for classical singing that has been adopted since that time (Miller, 1996, 121; Hemsley, 1998, 79).

The next stage in the data collection is selecting more recent studies and articles of pivotal importance. Since I claim no great knowledge of research into laryngeal registers or acoustics of the voice, I have sought advice from other teachers within my professional associations. Two papers with particular connections to my topic of study were recommended to me to read, namely “Mechanics of human voice production and control” (Zhang, 2016), and “Registers: The Snake Pit of Voice Pedagogy” (Herbst, 2020). Reading these papers as starting points led me to realise that this is a particularly challenging and academically dense area. Referencing Coopers Taxonomy of literature reviews once more, the sixth category to be decided in a review is that of the audience (Torraco, 2016). It seems clear that the audience for Zhang’s article is other academics with an interest in vocal acoustics and physiology. My own audience for this review is that of the voice teacher/practitioner, and more specifically to increase my own understanding of the subject for use in my teaching practice. Therefore, rather than delve into further studies, it seems more useful for my target audience that I attempt to distil the details of these papers into more practical concepts for the voice practitioner. There are terminologies used in both of these papers that are not always clearly defined for the non-academic reader, and were not familiar to me on first reading. The next

stage in the data collection is therefore finding supporting materials that perhaps fill in some of the gaps. Electronic library searches using specific keywords are particularly useful in this instance. Hart (1998, 6) warns of the vast amounts of information that can be found via this method, and undoubtedly that amount has grown enormously since Hart wrote this twenty-two years ago. However, many of the keywords that I am using are very specific and quickly yield a more focussed selection of results. Hart does write of the importance of keeping accurate records and being able to manage the material. For this process, the desktop version of Mendeley (www.mendeley.com) has proved invaluable. All of the sourced literature is uploaded and stored in Mendeley, which then allows for multiple searching on common keywords, authors, themes, and it also allows for annotations and cataloguing according to user supplied keywords. This allows themes to emerge, often supplying new keywords that can be used for further searches. This process is similar to that described by Rhoades (2011) in identifying criteria and keywords.

Certain keywords were key to finding correlations between vocal acoustics and woodwind instrument acoustics, most notably “acoustic impedance.” Searching on this term brought me to the writings of J. Wolfe, Professor of Physics at the University of New South Wales, who has a particular interest in the acoustics of the voice and of various families of musical instruments. Alongside his published works, his explainer pages at the university website were an invaluable aid in gaining a practical understanding of some of the newer and more challenging concepts in acoustic theory.

Mendeley also allows for searching based on number of citations. Selecting literature purely based on citations should not be the sole basis for a review, however the number of citations of a paper can aid in the assessment of a work being considered important or pivotal (Randolph, 2009).

Critical Reflection

In reflecting on the learning process during this assignment, I will be using the six stages of Gibbs’ Reflective Cycle as adapted by Tate (Bulman and Schutz, 2013, 90-92). This model uses Kolb’s principles of learning through experience, but builds upon them by creating an iterative cycle, allowing improvements to be made based upon the reflection and analysis of a learning process (Bulman and Schutz, 2013, 124). In this way it takes Schön’s principle of reflection-in-action and

links it to reflection-on-action (Ghaye, 2010, 25), beginning the drawing of a map out of what Schön described as the “swampy lowlands” of professional practice (Bolton, 2014, 4).

1. Description

The principal reason behind me choosing this topic of study was to fill in a perceived gap in my knowledge. Beyond some very basic descriptions used by singing teachers in every day practice, I had little knowledge of vocal registers beyond the proprioceptive experience of my own voice, and the psychoacoustic experience of my students’ voices during teaching (Herbst, 2020). Earlier in 2020 I had conversations with other members of my cohort who were increasing their own knowledge of acoustic strategies used by classical singers. I decided that I should at least learn more about the descriptive language used in acoustics for singing, and so purchased Ken Bozeman’s *Practical Vocal Acoustics (2013)* with a view to filling this knowledge gap. In just reading the introduction I was struck that Bozeman’s approach to acoustics was intimately tied up with the notion of registers and the passaggio.

2. Recording feelings

This particular study started from a quite detached position. Registers are not a phenomenon that I particularly concentrate on in teaching, and I didn’t start from a position of having any strong opinions on what is right or wrong. I felt that this would be an easier study from this standpoint as I would be far less susceptible to confirmation bias, which I recognise can lead to a skewed processing of information (Frost *et al.*, 2015). The idea that, for this particular study, I would not be an insider researcher was quite appealing, although I recognise that defining who is an insider researcher can be more complex than might at first be imagined (Mercer, 2007).

Once I started reading papers that looked in detail at the vibrational modes of the vocal folds I did feel that this was a very challenging topic, and was slightly daunted by some of the material. The mathematical basis for a lot of vibrational theory is not particularly simple. Although I have previously studied mathematics to a level that nothing was completely new, mathematics is often seen as a skill that must be practised to maintain ability, and it has been a long time since I

practised mathematics at this level. Moreover, mathematical knowledge is gained by doing, by working through problems as an iterative process (Rittle-Johnson, Siegler and Alibali, 2001). To gain as much understanding as possible would require a certain amount of mathematical practise, and this would add pressure to my schedule.

As I worked through some of the more detailed papers, I became increasingly frustrated by the lack of clear explanations of many of the terms used. Both Herbst and Zhang refer to x-10 and x-11 eigenmodes without giving any explanation of what an eigenmode is, or where the nomenclature x-10 comes from, or to what it refers. I have, reluctantly, used the same nomenclature in this paper for the sake of consistency.

The lack of consistency in much of the literature added to my frustration with this work. Many authors introduce their writings about registers by decrying the vagueness of terms such as head voice and chest voice, claiming they are not specific enough or universally agreed upon. To then replace them with ill-defined terms that are not used consistently does not make sense to me. Zhang, in the course of one paper (Zhang, 2016), interchangeably refers to the lowest frequency of a pitch as either the fundamental, F0, or the first harmonic, H1. These are usually considered different naming schemes, both preferably superseded by the use of f_o, $2f_o$ as terms for the first two harmonics (Titze and City, 2016). Similarly, acoustic impedance has a specific definition that relates acoustic pressure to acoustic flow. It is used in the design of wind instruments (Wolfe, 2018), and is an important concept in medical ultrasound imaging (Murphy and Morgan, no date). In many uses of impedance in voice science and pedagogy papers, the concepts of acoustic pressure and acoustic flow seem to get interchanged with air pressure and air flow, leading to confusion between impedance and simple air resistance (Titze, 2021).

Beyond these feelings of frustration the strongest feeling that I noted in my reading was one of sadness and a certain amount of distaste at Chhetri's work (Chhetri, Neubauer and Berry, 2012; Chhetri *et al.*, 2014). I have referenced it in my paper, but I cannot really justify to myself why a desire to understand muscular interaction in vocalisation should lead to animal experimentation of

this type. It has been noted that John Stuart Mill urged social scientists to adopt an objectivist stance similar to the hard sciences of physics and chemistry, in order to lend a greater authority to a young discipline (Guba and Lincoln, 1994). I find myself wondering if a similar approach is being taken in some voice science studies, and struggle to find a link to teaching practice.

3. Evaluating the experience

My feelings of frustration at the lack of clear explanations used by many authors had a tendency to lead me off on paths away from my proposed structure and timeline. I found that I wanted to understand in more detail why an author had used a particular term, or to find a better explanation of it. The main consequence of this on my work was that I spent more time than originally planned in the reading stage, and in my own attempts to make sense of much of the material, and found I was short of time in the actual writing stage. Once I was writing, I then found I needed further explanation of concepts, most notably impedance and inertance. However, it was clear that I would have neither the time, nor the available word count, to do this comprehensively. For the sake of brevity I used Herbst's brief explanation of negative damping as inertance, and Wolfe's simplified view of the application of acoustic impedance. Attempting to illustrate the concepts behind laryngeal mechanisms became far too deep, and resulted in less time and space being dedicated to the questions of acoustics. Laryngeal mechanisms on their own could clearly form the basis of a literature review much larger than this assignment.

The reading of material regarding woodwind instruments was very rewarding, especially in that it led me to answering one of my initial objectives regarding the similarities between vocal tract acoustics and wind instrument acoustics. The conclusion that I rapidly arrived at is that they are not really similar at all, and that acoustic registers in the voice are quite a separate phenomenon than those in wind instruments.

4. Analysis of the experience

Pedro de Alcantara wrote "You can't perform an act correctly until you've had the experience of performing it, and you can't have the experience without performing the act" (Alcantara, 2013, 39).

He described this vicious circle as being one of the great stumbling blocks of musical pedagogy. I feel that the same idea could be applied to academic reviews. You won't know if the topic is easy or challenging until you actually do it. In the case of this study, once I had discovered how challenging the background to laryngeal vibrational modes was, I could have decided to limit the scope to those and to refrain from looking into the acoustical side of registers. I decided against this, because then it would not have given me the chance to look at the overall components of vocal registers as we produce and perceive them, and would have limited its relevance to my teaching practice. Although the comparisons with wind instruments ultimately led to the conclusion that the acoustics of those instruments and the voice are very different, I did find that the more consistent use of terminology and concepts by the authors of the woodwind acoustics papers was helpful in understanding them in vocal studies.

5. Conclusion about the experience

The ninety-ninety rule, a humorous aphorism used in computer science, states that the first ninety percent of the code accounts for the first ninety percent of the development time, and the remaining ten percent of the code accounts for the other ninety percent of the development time (Bentley, 1985). Certainly, when looking at a new topic with a challenging technical content, it did seem as if every stage produced more reading and need for understanding. Referring back to the research questions regularly helped to maintain a certain path, but it was a challenge to resist being diverted down many of the side roads that appeared among the way when trying to draw this particular map (Bolton, 2014, 3).

One major conclusion, or perhaps opinion would be a better term, that I formed from this process is that there is a danger for a gap to grow between voice science and its pedagogical application in voice teaching. The intellectual challenge in wrestling with difficult concepts can be rewarding in itself, however it is not necessarily immediately translated into better teaching in the voice studio. This diverging of the direction of science away from the needs of voice teaching has been noted by others. Thomas Hemsley, himself a physicist, stated that rather than truly understand the basis for the voice, many resort to substituting "half digested scientific jargon" in its place (Hemsley, 1998,

9). Cornelius Reid came to the conclusion that voice science had failed because it could not explain an “operative principle capable of demonstrating how the vocal mechanism can be induced to function more efficiently” (Reid, 2005). I do think that voice science can help provide some of the knowledge for effective voice teaching but there is a level of understanding that should be translatable from one to the other. Bloom’s Taxonomy of Education Objectives is a good framework for establishing the level of understanding of a topic. It ranges from knowledge of, for example, terminology, through comprehension, application, analysis, synthesis, and evaluation (Krathwohl, 2002). In stage two, comprehension, Bloom includes translation and interpretation. Before being able to apply, analyse, and even synthesize new knowledge, we should be able to explain it in different ways. To use another example from computer science, “If you can’t write it down in English, you can’t code it” (Bentley, 1985).

Although there is very little resulting from this study that would make an immediate change in any of my teaching practice, it has led me to re-discover some of the tools I had used mainly in my former scientific career. I feel that some of these tools will have use in further interpretation of studies in voice science in the future, and this learning is never wasted.

6. Action plan

Due to the challenging concepts of some of this study, I feel that I need to refresh my skills in three areas of mathematics. Simple periodic vibrations can be described mathematically by *simple harmonic motion* (SHM). This describes an oscillation where the restoring force is related to the displacement from rest position, and is normally written as

$$a = -\omega^2 x$$

where a is the restoring acceleration, ω is the angular frequency, and x is the displacement from the resting position (*Physics - simple harmonic motion - University of Birmingham*, no date). SHM is a topic I have studied, and as a foundation of the concepts of vibration and harmonics it will be useful for me to revise.

Individual wave vibrations are described as being *in-phase* or *out-of-phase* with others. The mathematical way of representing these is by using real numbers for in-phase, and imaginary numbers for out-of-phase. Imaginary numbers are those that contain multiples of the square root of

minus 1. This again is a topic that I have previously studied, and revision of it will help me greatly in my understanding of concepts used in this area, and in the area of semi occluded vocal tract exercises; most notably impedance and inertance.

Finally, individual wave components are combined using *matrices,* which gives rise to particular nomenclature. I suspect that this is the source of the labels x-10 and x-11 in papers by Zhang and Herbst, cited in this study. Matrix combination mathematics is again a topic that I have studied in the past.

These topics may not have an immediate impact on my teaching practice but it is clear that their application is used in many publications regarding vibration, whether that is the vibration of the vocal folds, the vibration of the air, or the way in which they interact with each other. Revising and practising these skills will aid in my future reading and critical analysis of literature.

2. Assignment

A study into the phenomenon of vocal registers, and their application in teaching voice

A Historical Development

The first comprehensive description of vocal registers was given by Zacconi in 1592 (Stark, 2008, 58). Zacconi introduced the terms chest voice and head voice, and remarked that the chest voice was more vibrant and gave more delight than dull and boring head voices. Little changed in this approach in the following two centuries. Tosi noted that the voice is divided into di Testo (chest) and di Petto (head) voice, and that the singer must learn to unite the registers otherwise the voice would lose its beauty (Tosi, 1743). Tosi also noted that chest voice was more powerful and vibrant, but could be lost ‘for want of strength.’ Mancini states a similar opinion, that the voice ordinarily divides into chest voice and head voice, although he describes singers that seem able to sing their entire range in chest voice (Mancini, 1912, 58). It should be noted that both Mancini and Tosi would have been almost exclusively describing male singers. Like Tosi, Mancini held the view that chest

voice required more strength. Mancini did offer more direct suggestions in how to unite the registers, primarily by holding back some of the weight of chest voice whilst gradually strengthening the notes in the lower range of head voice (Stark, 2008, 62).

This two-register theory predominantly held sway for the following century, although a few authors began to propose that female voices had three registers, with Mengozzi even proposing that altos and mezzo sopranos have two registers but sopranos have three (Stark, 2008, 67). The main change in the debate regarding registers came when Manuel Garcia published his *traité* in 1841. Garcia proposed a definition of a register as being a series of homogeneous sounds produced by the same mechanical means (Garcia, 1857, 6), and proposed three registers for each voice; chest, falsetto, and head, with falsetto lying between chest and head and covering the same pitch range for both male and female voices. This positioning of falsetto, especially in female voices, may seem strange to modern views. Hermann Klein noted that Garcia's use of the term for the female middle voice came about due to a similarity in mechanism to the male falsetto, but then the term stopped being used for female voices by the end of Garcia's life (Garcia, 1982, 8). The main new view that Garcia introduced was that of different modes of vibration, with the vocal folds vibrating in their full length and depth in chest voice, and in falsetto/head voice only the inner margins of the folds vibrating (Stark, 2008, 69). The additional component introduced by Garcia was the role of glottal closure. He differentiated head voice from falsetto mainly by stating that head voice had a more complete glottal closure than falsetto, leading to more brilliance of tone and more efficient use of breath (Garcia, 1857, 7, 1982, 8). He did agree with Tosi and Mancini before him in his preference for the use of chest voice in male singers, stating that the head voice was merely a hold over from the treble voice pre-puberty (Garcia, 1857, 7). Although some of his own students, notably Marchesi (1970), disagreed with Garcia's notion that all voices had three registers, Garcia's work seems to have become the dominant view into the twentieth century, possibly due do its evidential basis as Garcia was the first to successfully use the laryngoscope in exploring vocalisation (Henrich, 2006). Giovanni Battista Lamperti deviated slightly from Garcia by suggesting that the medium register (earlier referred to as falsetto by Garcia) was separate from a mixed register, that Lamperti claimed was incorrectly labelled falsetto (Lamperti, 1905, 25). His claim that the losing of this register was why there were so few accomplished tenors may have

been his reaction to the heavier, chest voiced production of tenors after Gilbert Duprez (Stark, 2008, 80). Subsequently there were proposals of as many as five registers, when considering varying timbral effects (Henrich, 2006; Stark, 2008, 78) although some teachers saw this as overcomplicating something that had been so clearly explained by Garcia (Reid, 1972, 33).

A Modern View

Christian Herbst describes registers as the “snake-pit” of voice pedagogy (Herbst, 2020). His main reasoning for this description is that there is still no universally accepted definition of a register – a point already noted in the historical overview of registers above. Herbst provides a quick snapshot of registers described as anything from two registers to five registers, noting that one of the more recent classifications of registers commonly used divides the voice into four distinct laryngeal vibratory modes (Roubeau, Henrich and Castellengo, 2009). These four modes or mechanisms are defined as follows:

M0 – vocal fry, pulse, Strohbass, Voix de Contrebasse

M1 – modal, normal, chest, heavy, thick, Voix mixte (male), mixed (male), voce finta (male), operatic head (male)

M2 – falsetto, head (female), loft, light, thin, Voix mixte (female), mixed (female)

M3 – whistle, flageolet, flute, Sifflet

It is clear that these working definitions, although encompassing many different voice quality descriptions, mainly fall within those definitions drawn up in the late 1970s, labelled as registers 1 through to 4 (Brown, 1996, 51; Henrich, 2006). However, there are some apparent contradictions. Strohbass is a register used for reaching extremely low pitches, such as in some eastern liturgical choirs (Miller, 1996, 126). This is included within M0, that elsewhere is described purely as vocal fry, a vocal production without any discernible pitch (Smith *et al.*, 2011). Within M1 we have descriptions of both chest voice and male operatic head voice. Practical descriptions have often described these as being different registers, that the head voice should be accessed without recourse to falsetto to avoid high notes being yelled in chest voice (Hemsley, 1998, 52). It is perhaps for this reason that a fifth register, or perhaps sub-register, was proposed to sit between

registers 2 and 3. Labelled as register 2A, it was suggested as a distinct, non-falsetto head register (Brown, 1996, 51-52; Henrich, 2006). If two registers so distinctly experienced by the singer as chest voice and head voice both occur within the same laryngeal mechanism M1, then it suggests that there is more than simply the vibratory mode of the vocal folds in describing a register. Herbst proposes looking at the phenomenon of registers from five different perspectives; 1) proprioception, 2) psychoacoustic perception, 3) laryngeal mechanisms, 4) vocal tract effects, and 5) individual didactic systems. The first two of these perspectives are probably the easiest to comprehend by the average singer without a background in voice science. The description of two registers as *voce di petto* (chest voice) and *voce di testa* (head voice) (Stark, 2008, 58) depended purely on the sensation of the singer. Vibrations caused by singing in a low register can be felt by the singer in the chest, whereas in a higher register they are felt more clearly in the head. Lodovico Zacconi, who proposed these terms, maintained that they were not purely his personal views but represented the general understanding of his colleagues at the time (Stark, 2008, 58). Herbst recognises that these sensations are widely and consistently observed, although they serve mainly as feedback to the singer and do not contribute to the acoustic output. He also suggests that these changing sensations may be purely proportional to the pitch/frequency rather than being the result of any vocal registration change, although he does note that the pitch limit at which vibrations are felt in the chest, 300 Hz (D4) corresponds with the zona di passaggio. Further proprioceptive differences, especially in the neck and face, can be felt on different vowels, which Herbst ascribes to changes in the supraglottal standing wave. Due to small anatomical differences between different vocal tracts, Herbst suggests that these placement sensations may not be entirely comparable across singers, and that concepts of “voice placement”, should not be treated as absolute truth. In this he is in agreement with many other teachers and singers. Giovanni Battista Lamperti described voice placing as a misnomer, stating that “voice finding” is a better term (Brown, 1931, 74), whereas Cornelius Reid suggested that any sensation is the result of the vocal organs and registration having adjusted themselves to meet the conditions of pitch, vowel, and intensity (Reid, 1972, 35). Likewise tenor Kurt Baum described any sensation of mask placement as being the result of pumping air through the pipe (Hines, 1982, 38), and tenor Franco Corelli likewise maintained that any sensation of the voice striking the mask was due to a coordinated use

of the vocal folds and the breath rather than any conscious placement (Hines, 1982, 64). When applied to teaching, it appears that Herbst would not advocate deliberate voice placement directives such as “direct the sound into the mask”, but rather allow the student to find their own sensations by doing.

Herbst follows on from the proprioceptive perception of register by considering the psychoacoustic perception. By this, he means the perception of the sound of the voice without considering the underlying physiological mechanisms. By considering this perception of registers, as perceived by the listener rather than the singer, he is closer to Manuel Garcia’s description of a register being a series of consistent and homogeneous sounds, although Garcia did also state that these were produced by the same mechanical means (Garcia, 1857, 6).

Herbst points out what he considers a deficiency of this type of perception in an example of a classical mezzo soprano singing a G major scale, with two audible transitions. When this recording has been played to several audiences by Herbst, and the audiences asked to pinpoint the register transition, singing teachers and voice therapists about equally chose either transition, but very few noted that there were in fact two transitions present. Others have questioned why we might want to draw attention to something that is so difficult to perceive. Lilli Lehman, quoted by Herbst, stated that registers will always exist as long as the term “register” is retained. Herbst states that there is a limitation in treating the voice as a “black box”, and only concentrating on its output – ie the sound – rather than using knowledge of its inner workings. Whereas Oren Brown agreed that knowledge of the workings of the voice can help, he did stress that what was needed of the student was to think what they wanted to sing, and let the voice sing it for them (Brown, 1996, 180). Likewise Cornelius Reid believed that the only elements truly under the control of the singer are pitch, vowel, and intensity (Reid, 1972, 35). In this they may have the support of neurological arguments that the only inputs into our voice production are proprioceptive and auditory (Jürgens, 2002), and that in primates there is no direct connection between the motor cortex and laryngeal motoneurons (Jürgens, 2009). This would suggest that focussing on the intention to make sound, rather than the mechanics of the inner workings, is the better approach. The implications for practice are mainly that knowing the name and function of a certain part of the vocal anatomy does

not allow the student to access it directly (Milner, 2010), and the teacher may need to find better emotional, sensory, or imagery based directions for the student.

Laryngeal mechanisms

In the next section of Herbst's (2020) paper he considers laryngeal mechanisms. This is a subject that Herbst states is challenging and involves concepts that go deeper than most texts aimed at singing teachers. Although the discussions of the mechanisms M0 and M3 are interesting, they are of less importance to my teaching practice as I do not specialise in any singing styles that make great use of these. Due to the scope of the study, I will limit myself to discussions of M1 and M2 mechanisms, as these are the two that are most commonly used in classical singing and legit music theatre styles.

In describing a self sustaining vibration of the vocal folds, Herbst states that they require two degrees of freedom. A degree of freedom may be described as each coordinate of movement of the mass (Blake, 2001, 19). For example, a particle that can move left to right (x-coordinate), up and down (y-coordinate), and away and towards (z-coordinate) would be described as having three degrees of freedom. The first degree of freedom of the vocal folds is described as the medio-lateral movement of the vocal folds, or what I might more simply call the horizontal opening and closing of the folds. Herbst claims that were this the only degree of freedom then the folds would simply be separated by the airflow and maintain that separation. Zhang (2016) disagrees with this point. He claims that the Bernoulli effect, which for simplicity can be described as varying pressure due to airflow, can create conditions for self sustaining vibration when an asymmetry in the pressure between opening and closing can be caused by an external mechanism, described as negative damping. One such case can be provided in humans by an inertive vocal tract. Zhang provides examples where the vibration of vocal folds with a single degree of freedom can be achieved where the frequency is close to a strong acoustic resonance frequency (Zhang, Neubauer and Berry, 2006). Although this is possible, it would limit the vibrations of the vocal folds to natural resonances of the vocal tract. This would mean that only pitches of the harmonic series of these resonances would be possible, much like in a bugle or natural horn. Although the resonances of

the soft and pliable vocal tract are less sharply defined than those of a hard metal brass instrument (Bozeman, 2013), we know that the human voice can readily access all pitches within its range and so this model is not the sole accurate description of vocal fold vibration. Further, excised larynges are able to vibrate without any vocal tract, and so this effect of a coupled resonating chamber cannot be the primary cause of self sustaining vocal fold vibration (Zhang, 2016). Herbst (2020) suggests a second degree of freedom as a rotational degree of freedom of the vocal folds. If the vocal folds have a measurable thickness this can lead to the bottom (inferior) edges of the vocal folds meeting before the upper (superior) edges. If an imaginary point is drawn midway between the inferior and superior edges, then we can visualise this acting as a fulcrum about which the edge of the vocal fold can rotate – see Figure 1.

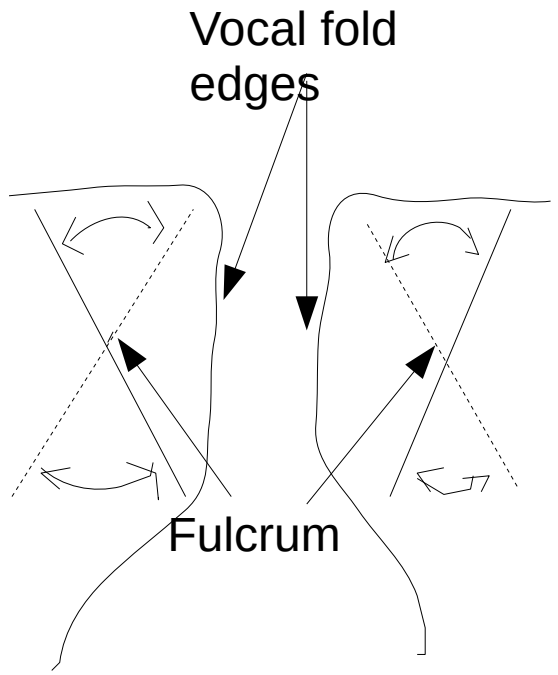

Figure 1. Rotational degree of freedom

This is probably a simplified model of the action, since the vocal folds are not constituted of a homogeneous mass with uniform mechanical properties (Zhang, 2016), but it is recognised as a basis for introductory mathematical modelling (Cveticanin, 2012). During this action, the inferior and superior edges are each at a different phase of their vibratory cycle, and so it is described as a *vertical phase difference*. The mucosal layer of the vocal folds is pliable and allows contact between different parts of the vertical thickness at any stage. The subsequent vibration has the appearance of a wave travelling through this layer and so this is also described as a *mucosal wave* (Herbst *et al.*, 2011; Zhang, 2016; Herbst, 2020). Herbst describes the medio-lateral vibrational mode as an eigenmode (a vibration where all components have the same frequency) of type x-10. This describes a mode where the glottal opening and closing is in phase with the output wave (Zhang, Neubauer and Berry, 2006). The rotational action is described as an x-11 type eigenmode, or one where the motion along the medial surface is out of phase (Zhang, Neubauer and Berry, 2006; Herbst, 2020). Herbst argues that the harmonic output of the x-11 type eigenmode is one of the recognised qualities of chest voice, or M1. An increase in the activity of the cricothyroid muscle, which acts to elongate, thin, and increase tension within the vocal fold mass, will reduce the vertical height and therefore either eliminate the rotational mode or reduce it to a smaller proportion of the surface of the vocal folds. This increases the proportion of harmonic output from the x-10 lateral vibration mode, which Herbst associates with a falsetto sound, or M2 (Herbst, 2020). Zhang, Neubauer and Berry (2006) find that when creating conditions for aerodynamically driven modes of vibration, the rotational mode must be present. When the rotational mode is reduced, or is not present, there must be a degree of acoustic coupling with a resonating tract to allow vibration to take place. This suggests that chest voice, or M1, is less dependent on the acoustics of the vocal tract and more dependent on properties of the vocal folds themselves. For the teacher this could explain why some inexperienced singers are wary of exploring M2 at first. Not only are they less familiar with its timbre and proprioceptive sensation, but there may be a feeling that it is less under their control and more susceptible to the whims of acoustics and airflow.

The description of laryngeal registers as being dominated by one muscle set over another is quite common, M1 being when the thyroarytenoid (TA) muscle is dominant, thickening and stiffening the

vocal folds, and M2 when the cricothyroid (CT) is dominant, elongating and thinning the folds (Miller, 1996, 133; Herbst, 2020). This is possibly an oversimplification, since the TA is innervated by the same nerve as the interarytenoids (IA), and the lateral cricoarytenoids (LCA), they tend to work as a group, and so thickening the vocal folds is often accompanied by a stronger adduction of the folds (Zhang, 2016). If an attempt is made to increase pitch by switching dominance to the CT, then the corresponding relaxation of TA/IA/LCA would lead to a weak and breathy falsetto production (Zhang, 2016). A more complex model, balancing the interaction of these two muscle sets, is needed to explain how a strong, non-breathy voice can be produced in M2. Studies using in-vivo canine larynges show that the maximum pitch achieved by action of the CT only occurred when coupled with a moderate action of the TA. Greater activation of the TA allowed for higher pitches with lower action of the LCA/IA or closing muscles, but too high action of the TA did not allow higher pitches to be produced (Chhetri *et al.*, 2014). However, when TA activity was reduced to a very low level, the highest pitches could not be accessed, and without an increasing action of the closing muscles, no phonation occurred at all in some regions. Other studies have also shown four distinct glottal configurations in producing different voice qualities within classical singing (Herbst, Ternström and Švec, 2009). The four qualities of the baritone voice, described here as “naïve singer’s falsetto”, “Counter-tenor falsetto”, “lyrical style”, and “full chest.” Although these four qualities can be divided into two versions of M2 falsetto and two versions of M1 chest, the perceived and acoustically measurable differences between them, due principally to differences in posterior glottal closure, demonstrate that there is more variation in laryngeal registration than the simple TA dominant or CT dominant model. This could lead to the idea of a “mixed” register. Herbst states that there are certain conditions, especially in the passaggio, that allow the vocal folds to vibrate in both chest voice and falsetto registers (Herbst, 2021). He notes that when an excised human larynx was used to produce phonation across varying pitches, there was a spontaneous change from chest to falsetto when ascending in pitch, but the voice remained in falsetto for longer when descending through the same pitch range. This corresponds with my own experience in teaching, where students often delay the change into head voice or falsetto when ascending, but are able to stay in their higher register for longer when descending. Herbst recommends exercises based on descending rather than ascending vocalisation to improve this mixing region, noting that

many pedagogues employ upwards moving exercises. The “top down” approach is, however, well established amongst pedagogues and was strongly endorsed by Oren Brown in particular (1996, 39).

Acoustic influences

Herbst states that the ability of the vocal folds to sustain vibration requires two degrees of freedom, and that the second degree of freedom can be produced by a rotational mucosal wave in the vocal folds, or alternatively by a delayed response of the supraglottal air column caused by the inertial mass of the air molecules. This allows the intra-glottal pressure to drop at the end of the open phase, enabling vocal fold closure (Herbst, 2020). He describes this as the action of an inertive vocal tract, and terms it negative damping. Inertance is a measure of the pressure difference in a fluid required to cause a unit change in the rate of change of volumetric flow-rate (Massey, 1989). It is inversely proportional to the cross sectional area of the pipe. Therefore a narrower pipe – or in this case, vocal tract – will have a higher inertance, potentially increasing the possibility of negative damping. Earlier I suggested that increased negative damping may be more necessary when singing in M2, or even with thinned vocal folds, due to the reduced vertical phase difference. Herbst notes that a pedagogical implication of his review of laryngeal mechanisms is that it is better to sing in M1 to produce strong harmonics (Herbst, 2020). He also notes that it is necessary to access M2 in order to not limit the pitch range accessible to the voice. In order to give the voice a “boost”, especially when singing acoustically, it has been known for singers to exploit a phenomenon known as the singer’s formant (Sundberg, 1987, 121; Miller, 1996, 55). This clustering of formant frequencies in the area of 2.5 kHz to 3.2 kHz is particularly helpful to the singer as there is little competition from acoustic orchestral instruments in this frequency range (Sundberg, 1987, 122). Sundberg describes the process for boosting these frequencies as involving lowering the vertical laryngeal position. However, several other authors state that these frequencies can be boosted by narrowing the epilaryngeal tube, or the part of the vocal tract immediately above the vocal folds (Bozeman, 2013; Echternach *et al.*, 2017; Aura *et al.*, 2020). Perhaps the narrowing of the epilaryngeal tube is also helping vocal fold vibration by increasing

negative damping. Bozeman also notes that the singer's formant cluster is particularly good for perception as the human ear canal has a natural resonance in the range of 3 kHz.

Acoustic registers - the voice as a wind instrument

If vocal fold vibration were sustained purely by the horizontal degree of freedom coupled with negative damping, then pitches would be restricted to natural resonances within the vocal tract. This has been described as an acoustically driven mode of vibration (Zhang, Neubauer and Berry, 2006). Clearly, the voice is not limited to this method of production as it can access a continuous range of pitches on a variety of phonemes. A mixture of aerodynamic vibration modes and the physiology of the vocal folds themselves allow the vocal folds to drive the acoustic waves in the vocal tract (Wolfe and Smith, 2008). In contrast, lip-reed musical instruments, generally brass instruments, have resonances that create standing waves in the bore of the instrument and drive the players lips. The lips will only vibrate at frequencies close to the resonances of the bore. For a reed instrument, such as the saxophone, similar coupled oscillations between the reed and standing waves in the bore of the instrument are essential in the creation of tone (Chen, Smith and Wolfe, 2009). In order to change pitch, the natural resonances of the bore must be changed. With the saxophone this is achieved by altering the tube length by opening or closing tone holes in the instrument. With the voice it is certainly possible to alter tube length, by either extending or withdrawing the lips, or by raising or lowering the larynx. However, it is considered desirable to maintain a more or less consistent tube length to maintain timbral depth and consistency of the voice character, or fach (Bozeman, 2013). An instrument that is closed at one end and open at the other can be described as a quarter wave resonator (Titze, 2006; Bozeman, 2013; Herbst, 2017). This means that a standing wave created in the bore of the instrument has a wavelength of four times the tube length. As tone holes are opened on a saxophone, by lifting keys, the quarter wavelength is shortened, thus raising the pitch/frequency. Once the shortest tube has been obtained (all keys lifted) an octave key is pressed and the next register is accessed with all keys pressed down once again. I had long assumed that this higher register was in fact a half wave resonator, which would create a doubling of the frequency and therefore a fundamental pitch sounding an octave higher. This is a simplistic, but essentially accurate description. However, the

method of accessing the higher register depends on the acoustic impedance spectrum. Acoustic impedance is defined as the ratio of acoustic pressure to acoustic volume flow. In practical terms it can be simply thought of as the acoustic response of the instrument to all possible frequencies (Wolfe, no date). Opening of small tone holes towards the closed end of the instrument creates conditions that destabilise the first harmonic of the impedance spectra, allowing the second harmonic to determine the pitch (Chen, Smith and Wolfe, 2009). This causes a coupling with the reed, and a significant physical feedback to the player, from my own experience. This seems a distinctly different register event than any so far described for the voice.

Unlike wind and brass instruments, the human vocal tract does not have a primary resonance at the pitch range typically used for speech (Wolfe, Garnier and Smith, 2009). The first resonance of the vocal tract is typically from about 300 Hz to 1000 Hz, or D4 to B5, overlapping much with the classical soprano range (Smith *et al.*, 2011). For a male voice, possibly speaking around A2, or 110 Hz, only harmonics from the third at 330 Hz and upwards could correspond with vocal tract resonances. The second resonance ranges typically from 800 Hz to 2200 Hz, overlapping only slightly with the range used by high sopranos (Smith *et al.*, 2011). Rather than resonate the fundamental pitch, this range would normally correspond to higher harmonics. This pair of resonances, in both speech and song, gives rise to *formants* (Smith *et al.*, 2011), where the relative frequencies of the two formants change the vocal quality and it is perceived as a vowel. There are theoretically many more resonances and formants, but the relative frequencies of the first two formants are considered most important in vowel production (Bozeman, 2013).

Earlier in this paper I wrote that Herbst had frequently played a recording of a mezzo soprano singing a G major scale that had two clear register transitions, although most listeners would only pick one of the two as a principal register break. Herbst notes that for one of these transitions there was a significant amplitude boost in the third harmonic of the sung pitch, corresponding to that harmonic matching a vocal resonance (Herbst, 2021). Although there was no change in the electroglottography output, suggesting no change in laryngeal vibratory mode, there was a distinct register “shift”. Herbst refers to this as a linear source-filter effect, where a clear acoustic effect is perceived by a change in the acoustic filter but this has no effect on the larynx, the sound source itself. Bozeman notes that such a transition happens in the tenor passaggio and that the position of

the “turning over” of the voice is heavily influenced by the vowel being sung. He notes especially that in the region of the tenor passaggio the first formant of the vowel corresponds to the second harmonic of the pitch, and that the passing of the second harmonic from below to above the first formant constitutes a register change. Since closed vowels, such as /**i**/ and /**u**/, are characterised by a low first formant, then this transition in the voice happens at a lower pitch when singing on more closed vowels (Bozeman, 2013). Bozeman notes that a challenge for students is to maintain a vowel when ascending in pitch. There is a temptation to open the vowel, thus keeping the first formant above the second harmonic and avoiding the register change. This makes the voice tends towards a yell timbre rather than a full head-voice. A widely known concept for combating this is one of vowel modification, or *cover*, where vowels take on a darker quality as pitch rises. The main difference of opinion seems to be between those who believe this should be an active adjustment on the part of the singer (Miller, 1996, 150) and those who view it as a passive response of the voice (Reid, 1972, 90). More striking, perhaps, is Bozeman’s observation that these vowel adjustments can be heard when produced by a synthesised tenor voice ‘singing’ an F major scale on the vowel /**ɑ**/ despite there being no change to the input formant frequencies. In other words, the change could be perceived aurally, but there was no vowel modification being made. This implies that vowel modification, or aggiustamento, is unnecessary. It may, however, still be employed to avoid the tendency to raise the first vowel formant when ascending in pitch, and could also lead to a quicker transition by lowering the first vowel formant as soon as the second harmonic has reached the same pitch.

Discussion

It is clear that the subject of registers is very wide ranging, depending not only upon the physiology and acoustics of sound production, but also upon proprioceptive and psychoacoustic perception of the produced sound. From the position of a teaching practitioner, I can draw parallels between some of the most recent descriptions of vibrational modes and the two-register theory first proposed by Zacconi, where chest voice is equivalent to M1 and the vocal folds exhibit a greater vertical phase difference. This was described by Garcia as the folds vibrating along their full length and depth. Head voice in the two-register theory would be equivalent to M2, having a lesser

vertical phase difference. The four distinct glottal configurations described by Herbst (Herbst, Ternström and Švec, 2009) can be compared to Garcia's description of falsetto and head voice, where two registers share the same vibrational mode but have a different degree of fold closure (Garcia, 1857, 7). Garcia also described a manner for the male voice of singing in the range of the head voice, but in chest voice configuration with a darkened tone. This seemed to be his response to the "chest voice" high C of tenor Gilbert Duprez (Stark, 2008, 75), and bears clear similarities to Bozeman's description of the second harmonic passing the first vowel formant (Bozeman, 2013). New research will always help to add detail to our understanding, but I find I am in agreement with Stark when he states that Garcia provided such a good foundation for our understanding of registers, and Bozeman's opinion that the historical empirical approach has clearly had success (Bozeman, 2013)

Appendix 1 – Gibbs' reflective cycle (Bulman and Schutz, 2013, 232)

References

Alcantara, P. de (2013) *Indirect Procedures*. 2nd edn. New York: Oxford University Press.

Aura, M. *et al.* (2020) 'A Nasoendoscopic Study of " Head Resonance " and " Imposto " in Classical Singing', *Journal of Voice*. doi: 10.1016/j.jvoice.2020.04.013.

Bentley, J. (1985) 'Programmimg Pearls', *Commun. ACM*. New York, NY, USA: Association for Computing Machinery, 28(9), pp. 896–901. doi: 10.1145/4284.315122.

Blake, R. E. (2001) 'Basic vibration theory', in Harris, C. M. and Piersol, A. G. (eds) *Harris' Shock and Vibration Handbook*. 5th edn. New York, NY: McGraw-HIll, pp. 49–78. doi: 10.1016/b978-075065079-3/50003-6.

Bolton, G. (2014) 'Reflective Practice - Writing and Professional Development'. London: Sage Publications Ltd.

Bozeman, K. W. (2013) *Practical Vocal Acoustics. Pedagogic Applications for Teachers and Singers*, *Vox Musicae: The Voice, Vocal Pedagogy, and Song Series*. Hillsdale, NY: Pendragon Press.

Brown, O. L. (1996) *Discover Your Voice*. San Diego: Singulair Publishing Group, Inc.

Brown, W. E. (1931) *Vocal Wisdom*. Marlboro, NJ: Taplinger Publishing Company, Inc.

Bulman, C. and Schutz, S. (eds) (2013) *Reflective Practice in Nursing*. 5th edn, *Reflective Practice in Nursing*. 5th edn. Chichester: John Wiley & Sons, Ltd. doi: 10.2307/466183.

Chen, J. M., Smith, J. and Wolfe, J. (2009) 'Saxophone acoustics: Introducing a compendium of impedance and sound spectra', *Acoustics Australia*.

Chhetri, D. K. *et al.* (2014) 'Influence and interactions of laryngeal adductors and cricothyroid muscles on fundamental frequency and glottal posture control', *The Journal of the Acoustical Society of America*, 135(4), pp. 2052–2064. doi: 10.1121/1.4865918.

Chhetri, D. K., Neubauer, J. and Berry, D. A. (2012) 'Neuromuscular control of fundamental frequency and glottal posture at phonation onset', *The Journal of the Acoustical Society of America*, 131(2), pp. 1401–1412. doi: 10.1121/1.3672686.

Cveticanin, L. (2012) 'Review on mathematical and mechanical models of the vocal cord', *Journal of Applied Mathematics*, 2012. doi: 10.1155/2012/928591.

Echternach, M. *et al.* (2017) 'Oscillatory Characteristics of the Vocal Folds Across the Tenor Passaggio', *Journal of Voice*. Mosby Inc., 31(3), pp. 381.e5-381.e14. doi: 10.1016/j.jvoice.2016.06.015.

Frost, P. *et al.* (2015) 'The Influence of Confirmation Bias on Memory and Source Monitoring', *Journal of General Psychology*, 142(4), pp. 238–252. doi: 10.1080/00221309.2015.1084987.

Garcia, M. (1857) *Garcia's New Treatise on the Art of Singing*. Boston, MA: Oliver Ditson Company.

Garcia, M. (1982) *Hints on Singing*. 2nd edn. Edited by H. Klein. New York, NY: Joseph Patelson Music House.

Ghaye, T. (2010) 'Being a Reflective Practitioner', in *Teaching and Learning through Reflective Practice: Guide for Positive Action*.

Guba, E. G. and Lincoln, Yvonna S. (1994) 'Competing Paradigms in Qualitative Research', in Denzin, N. K. and Lincoln, Y. S. (eds) *Handbook of qualitative research*. Thousand Oaks, CA: Sage Publications Inc., pp. 105–117.

Hart, C. (1998) 'Doing a Literature Review: Releasing the social science imagination', *Doing a Literature Review*. London: SAGE Publications, pp. 1–25.

Hemsley, T. (1998) *Singing And Imagination: A human approach to a great musical tradition*. Oxford: Oxford University Press.

Henrich, N. (2006) 'Mirroring the voice from Garcia to the present day: some insights into singing voice registers.', *Logopedics, phoniatrics, vocology*, 31(1), pp. 3–14. doi: 10.1080/14015430500344844.

Herbst, C. T. *et al.* (2011) 'Membranous and cartilaginous vocal fold adduction in singing', *The Journal of the Acoustical Society of America*, 129(4), pp. 2253–2262. doi: 10.1121/1.3552874.

Herbst, C. T. (2017) ‘A Review of Singing Voice Subsystem Interactions—Toward an Extended Physiological Model of “Support”’, *Journal of Voice*. Elsevier Inc., 31(2), pp. 249.e13-249.e19. doi: 10.1016/j.jvoice.2016.07.019.

Herbst, C. T. (2020) ‘Registers - The Snake Pit of Voice Pedagogy’, *Journal of Singing*, 77(2), pp. 175–190.

Herbst, C. T. (2021) ‘Registers — The Snake Pit of Voice Pedagogy’, *Journal of Singing*, 77(3), pp. 345–358.

Herbst, C. T., Ternström, S. and Švec, J. G. (2009) ‘Investigation of four distinct glottal configurations in classical singing—A pilot study’, *The Journal of the Acoustical Society of America*, 125(3), pp. EL104–EL109. doi: 10.1121/1.3057860.

Hines, J. (1982) *Great Singers on Great Singing*. Garden City, NY: Doubleday & Company, Inc.

Hollien, H. (1974) ‘On vocal registers’, *Journal of Phonetics*. Elsevier Masson SAS, 2(2), pp. 125–143. doi: 10.1016/s0095-4470(19)31188-x.

Jürgens, U. (2002) ‘Neural pathways underlying vocal control’, *Neuroscience and Biobehavioral Reviews*, 26(2), pp. 235–258. doi: 10.1016/S0149-7634(01)00068-9.

Jürgens, U. (2009) ‘The Neural Control of Vocalization in Mammals: A Review’, *Journal of Voice*. doi: 10.1016/j.jvoice.2007.07.005.

Krathwohl, D. R. (2002) ‘A Revision of Bloom’s Taxonomy: An Overwiew’, *Theory into Practice*, 41(4), pp. 212–218. doi: 10.1080/00131726509339406.

Lamperti, G. B. (1905) *The Technics of Bel Canto*. New York: G. Schirmer.

Mancini, G. (1912) *Practical Reflections on the figurative art of singing*. Boston: The Gorham Press.

Marchesi, M. (1970) *Bel Canto: A Theoretical & Practical Vocal Method*. Mineola, NY: Dover Publications, Inc.

Massey, B. S. (1989) *Mechanics of Fluids*. Springer US.

Mercer, J. (2007) ‘The Challenges of Insider Research in Educational Institutions: Wielding a double-edged sword and resolving delicate dilemmas By Dr. Justine Mercer, Centre for Educational Leadership and Management, University of Leicester.’, *Oxford Review of Education*, 33(1), pp. 1–32. doi: http://dx.doi.org/10.1080/03054980601094651.

Miller, R. (1996) *The Structure of Singing*. New York: Schirmer Books.

Milner, H. (2010) *Feelings, language, and the unconscious in learning to sing*, *Abstract of workshop delivered at BVA conference*. Available at: https://www.colinreed.co.uk/howardmilner.com/page28.html (Accessed: 27 June 2020).

Murphy, A. and Morgan, M. A. (no date) *Acoustic impedance | Radiology Reference Article | Radiopaedia.org*. Available at: https://radiopaedia.org/articles/acoustic-impedance?lang=gb (Accessed: 11 January 2021).

Physics - simple harmonic motion - University of Birmingham (no date). Available at: https://www.birmingham.ac.uk/teachers/study-resources/stem/physics/harmonic-motion.aspx (Accessed: 14 January 2021).

Randolph, J. J. (2009) ‘A guide to writing the dissertation literature review in software engineering’, *Practical Assessment, Research & Evaluation*, 14(13), pp. 1–13.

Reid, C. L. (1950) *Bel Canto: Principles and Practices*. New York: The Joseph Patelson Music House.

Reid, C. L. (1972) *The Free Voice: A Guide to Natural Singing*. New York: The Joseph Patelson Music House.

Reid, C. L. (1975) *Voice: Psyche and Soma*. New York: Joseph Patelson Music House.

Reid, C. L. (2005) ‘Voice science – an evaluation’, *Australian Voice*, 11.

Rhoades, E. A. (2011) ‘Literature Reviews’, *The Volta Review*, 3(1), pp. 61–71.

Rittle-Johnson, B., Siegler, R. S. and Alibali, M. W. (2001) ‘Developing conceptual understanding and procedural skill in mathematics: An iterative process’, *Journal of Educational Psychology*, 93(2), pp. 346–362. doi: 10.1037/0022-0663.93.2.346.

Roubeau, B., Henrich, N. and Castellengo, M. (2009) ‘Laryngeal Vibratory Mechanisms: The Notion of Vocal Register Revisited’, *Journal of Voice*, 23(4), pp. 425–438. doi: 10.1016/j.jvoice.2007.10.014.

Smith, J. *et al.* (2011) ‘The acoustics of registers and resonances in singing’, in *Australian Acoustical SocietyConference 2011, Acoustics 2011: Breaking New Ground*.

Stark, J. A. (2008) *Bel Canto: A History of Vocal Pedagogy*. Toronto: University of Toronto Press.

Sundberg, J. (1987) *The Science of the Singing Voice*. DeKalb, Illinois: Northern Illinois University Press.

Titze, I. R. (2006) ‘Voice Training and Therapy With a’, *Journal of Speech Language and Hearing ResearchHearing Research*, 49(April), pp. 448–460. doi: 10.1044/1092-4388(2006/035).

Titze, I. R. (2021) ‘The Concept of Impedance’, *Journal of Singing*, 77(3), pp. 1–24.

Titze, I. R. and City, I. (2016) ‘Some Consensus has been Reached on the Labeling of Harmonics , Formants , and Resonances’, *Journal of Voice*. Elsevier, 30(2), p. 129. doi: 10.1016/j.jvoice.2015.09.014.

Torraco, R. J. (2005) ‘Writing Integrative Literature Reviews: Guidelines and Examples’, *Human Resource Development Review*, 4(3), pp. 356–367. doi: 10.1177/1534484305278283.

Torraco, R. J. (2016) ‘Writing Integrative Literature Reviews: Using the Past and Present to Explore the Future’, *Human Resource Development Review*, 15(4), pp. 404–428. doi: 10.1177/1534484316671606.

Tosi, P. F. (1743) *Observations on the Florid Song; or, Sentiments on the Ancient and Modern Singers*. Edited by J. E. Galliard. London: J. Wilcox.

Wolfe, J. (2018) ‘The Acoustics of Woodwind Musical Instruments’, *Acoustics Today*, 14(1).

Wolfe, J. (no date) *What is Acoustic Impedance and Why is it Important*, *University of New South Wales School of Physics*. Available at: http://newt.phys.unsw.edu.au/jw/z.html (Accessed: 20 December 2020).

Wolfe, J., Garnier, M. and Smith, J. (2009) ‘Vocal tract resonances in speech, singing, and playing musical instruments’, *HFSP Journal*. doi: 10.2976/1.2998482.

Wolfe, J. and Smith, J. (2008) ‘Acoustical coupling between lip valves and vocal folds’, *Acoustics Australia*.

Zhang, Z. (2016) ‘Mechanics of human voice production and control’, *The Journal of the Acoustical Society of America*, 140, pp. 2614–2635. doi: 10.1121/1.4964509.

Zhang, Z., Neubauer, J. and Berry, D. A. (2006) ‘Aerodynamically and acoustically driven modes of vibration in a physical model of the vocal folds’, *The Journal of the Acoustical Society of America*, 120(5), pp. 2841–2849. doi: 10.1121/1.2354025.