ACOUSTIC AND AERODYNAMIC IMPACTS OF PREGNANCY ON THE CLASSICALLY TRAINED SOPRANO VOICE

A Dissertation

Presented to

The Faculty of the Department

of Music

University of Houston

In Partial Fulfillment

Of the Requirements for the Degree of

Doctor of Musical Arts

By

Marion K. R. Dickson

May, 2014

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ABSTRACT

Questions surrounding the unknown can often encroach on a woman's psyche as she considers how life can change when pregnancy occurs. Enquiries based on the changing body often arise; for the classical singer, whose body also serves as a keenly trained instrument, these enquiries become more specific. Questions regarding pregnancy and the professional singer include: how might the vocal range change; will the vibrato rate change, and if so, might that affect pitch accuracy; how may agility be compromised; might maximum phonation time be altered, if at all; how might the respiration process be compromised as the gestation period increases; and how may the duration of energy change when considering general vocal and physical activity in performance?

Anecdotal claims on the impact of pregnancy on the professionally trained classical singing voice may affect whether or not a professional singer chooses to bear children. Through providing additional data to the currently limited amount of information on the topic, this study hopes to aid those interested in familial life while maintaining a professional classical singing career.

The introduction will provide background information that includes a physiological overview of the process of singing. This will aid in the comprehension of the study that will follow in chapter three, and will define important physiological aspects of the respiratory and phonatory process. Beginning with respiration, discussion begins with breathing to sustain life, and continues to explore respiration in regards to the

various levels of speech, singing, and singing during pregnancy. Phonation aspects are surveyed, including laryngeal valving, subglottal pressure, and phonatory threshold pressure. The overview of acoustics includes material concerning agility, range, and perturbation values.

As the topic of singing and pregnancy has recently begun to arise as a point of investigation in professional literature, the first chapter will also include a brief survey of currently available data. To gain a more complete understanding of the function of the voice during pregnancy, a brief overview on hormonal influences on the voice during pregnancy, as well as typical physiological experiences associated with pregnancy, will first be explored. Next, to introduce pregnancy and the relationship to the voice, the article "Effect of Pregnancy on the Speaking Voice," found in the *Journal of Voice*, Volume 23, in 2009, will be surveyed. The main topics of three published case studies that focused on singers during the third trimester of pregnancy will be discussed. These studies provide an excellent point of comparison to the current study, and offer great insight to voice professionals who are interested in learning more about gravidity and its effects on the singing voice.

The current study seeks to provide additional insight about the impact of pregnancy on classical singers. After a description of the participant, followed by an exploration of the study's methods and materials, the data regarding the participant's physiological capacity throughout the third trimester and 10 weeks postpartum will be analyzed. Each of the measures, which include acoustic and aerodynamic values, will be addressed to observe what limits or effects gravidity had, if any, on the participant's performance.

ACKNOWLEDGEMENTS

To the members of my committee: Cynthia Clayton, Andrew Davis, Joseph Evans, Monica McHenry, and Melanie Sonnenberg: Thank you for your enduring support for this study and all my endeavors during my tenure at the University of Houston. Your encouragement, guidance and high standards have taught me well.

To Monica McHenry and Joseph Evans: Special thanks allotted for inspiring the scientist within, and for allowing the collaboration between Moores School of Music and Communication Sciences and Disorders for the betterment of future singers. It has been a privilege to bridge art and science in this sophisticated manner, and you are an inspiration.

To Cynthia Clayton: A special acknowledgement for the gift of continuance of song and study. I am looking forward to our work together.

To Howard Pollack: For all your help with editing and for a fabulous seminar.

To Tom Crow: For whose fabulous idea it was to do this study from the very beginning.

To my husband, Chris, and three beautiful children: Thank you for your willingness to go above and beyond as we help each other reach our goals.

To my parents: Without whom this gift of music would not have been, thank you for all you have given. A special note of thanks goes to my sister, Beth, for all her support. To my extended family: Thank you for your help and prayers for growth and success.

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THIS DOCUMENT IS DEDICATED TO MY FAMILY.

CHAPTER ONE

LITERATURE REVIEW

Singing is the result of a largely complex, yet unified, function of many parts of the body, beginning with the brain.[1] Respiration, the foundation of a healthy, efficient, and beautifully produced singing voice, is combined with efforts of the phonatory and articulatory systems in order to produce sound. [2] The unification of all systems functioning at their optimal level, through proper technique and training, is the goal of a classically trained singer. In order to understand this complicated process more deeply as it pertains to the classical singer, especially one who is experiencing gravidity, it may be helpful to regard the function of the systems pertaining to sound creation. One can gain a more complete understanding of sound production by considering the complex and cohesive collaboration of the systems of respiration, phonation (including laryngeal valving and the intricacies of vocal function), and acoustical measurements. Consequently, this chapter will examine each of these physiological systems and in what way the function of each affects the production of sound.

Let us regard the respiratory system, therefore, from the point of view of one who breathes to exist: respiration for life. The respiratory system is comprised of the pulmonary system, including the lungs and airways, and the chest-wall system, which includes the diaphragm, rib cage and abdomen. As it is controlled by the autonomic

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[1] Carol Ferrand, *Speech Science: An Integrated Approach to Theory and Clinical Practice.* (Boston, MA: Pearson, Allyn and Bacon, 2007), 355.

[2] For more comprehensive information on the science of the voice please regard: Carol Ferrand, *Speech Science: An Integrated Approach to Theory and Clinical Practice* (Boston, MA: Pearson, Allyn and Bacon, 2007); James McKinney, *The Diagnosis and Correction of Vocal Faults: a manual for teachers of singing and for choir directors* (Nashville, TN: Genevox Music Group, 1994); Richard Miller, *The Structure of Singing: System and Art in Vocal Technique* (New York: Schirmer Books, 1986); Johan Sundberg, *The Science of the Singing Voice* (Dekalb, Illinois: Northern Illinois University Press, 1987).

nervous system, the respiratory system functions without conscious effort. Rather, the body coordinates the need for breathing without our conscious thought. The rules of air pressure govern how the lungs function; they fill with air from the outside as air travels from high-pressure to low-pressure areas, and vice versa. Upon inhalation, the diaphragm contracts downward, and the abdominal muscles release forward as the viscera adjust due to the contracting diaphragm. The lungs, through pleural linkage, are connected to the diaphragm, and extend vertically as well as horizontally (due to the external intercostal muscles). The muscular action that occurs during exhalation for quiet breathing, or breathing for life, is passive; upon exhalation the recoiling action of the lungs occurs naturally and the diaphragm relaxes.

Lung volumes, or the measurements of air within the lungs at various levels of the respiratory cycle, are especially important when considering the process of speaking and singing. The amount of air that is utilized within a complete breath cycle is called tidal volume. Vital capacity is comprised of tidal volume plus the amount of air that can be inhaled beyond a "normal inhalation" as well as taking into account the amount of air that can be exhaled beyond a "typical exhalation." Therefore, vital capacity is the greatest amount of air one can inhale and exhale within one cycle. Whether used partially or completely, vital capacity can be used in a state of rest, within speech, during aerobic exercise, and while singing. Vital capacity is also the referent measure for all other respiratory measures, particularly those involved in speaking or singing. Because the absolute value of vital capacity is largely dependent on body size, it is typically reported as a percent of predicted value. For example, a typical female vital capacity is 3.0 Liters, while a typical male vital capacity is 5.0 Liters. If a woman's respiratory function testing yielded a vital capacity of 3.0 Liters, it would be reported as 100% of the predicted value for her age, height, and gender. By contrast, if a man's vital capacity were 3.0 Liters, it would be well below the predicted value for his age, height, and gender.

According to Carole Ferrand, there are four main points of comparison regarding breathing for life, or "quiet breathing," and breathing for speech:[3] the location of the air intake at either the mouth or nose; the ratio of time for completion of inhalation versus exhalation; the lung volume; and the amount of muscular activity engaged for exhalation.

Initially, quiet breathing, which is breathing during a state of inactivity, will be examined. The defined location of air intake is the nose, with 40% of the respiratory cycle time devoted to inspiration, and 60% to expiration. The internal intercostal muscles, used for exhalation, are passive as the diaphragm relaxes upwards and the natural volume of the lung decreases in relaxation. Breathing for life requires no thought and necessitates a very low volume of air, as the volume of air involved in quiet breathing is 10% of vital capacity. Therefore, this process is passive, especially when compared to information to breathing for speech.

When breathing for speech, the body needs to override the nervous system as it functions for quiet breathing so the process of phonation can be initiated and completed. Instead of breathing solely to sustain life, the body must create airflow that will be transferred into sound. Moreover, to sustain the sound for a longer period of time, based on the number of words in the sentence or phrase being spoken, the body requires physiological actions beyond the autonomic process of breathing for life.

Breathing for speech most often occurs through the mouth instead of the nose, because it is more efficient for the communicative process. Breathing through the mouth

[3] Ferrand, 88-89.

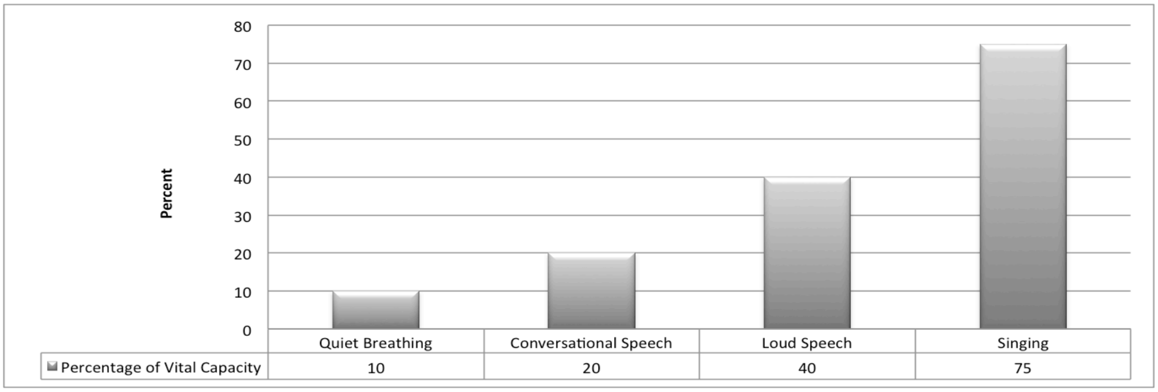
takes less time, due to less airflow resistance, and allows phonation to begin more rapidly. Although the ratio of inhalation to exhalation during speech is always characterized by a quick inhalation and prolonged expiration, it is highly variable, depending upon the length of utterance being produced.

Resting expiratory level, defined as the balance of alveolar pressure and atmospheric pressure, occurs immediately after one completes an exhalation and just before the next inhalation begins. Therefore, forces of inhalation and the forces of exhalation are at equilibrium during resting expiratory level. This can affect the use of musculature when speaking. If one continues to speak beyond resting expiratory level, for example, then the abdominal muscles become engaged to sustain the amount of needed subglottal pressure, which is the amount of air pressure below the closed vocal folds required for speech.

In summary, the muscles of inhalation are active during speech; the external intercostals are engaged with the diaphragm, when needed, to prevent the immediate recoiling of the lungs and to maintain the required amount of subglottal pressure for the type of phonation.[4] Thus, a higher level of energy is required when breathing for speech than when breathing solely to sustain life. Moreover, while conversational speech uses about 20% of one's vital capacity, loud speech can use up to 40%. Therefore, as compared to quiet breathing, breathing for loud speaking demands a significantly more active respiratory system.

[4] Ferrand, 92.

Figure 1.0: Percentage of Vital Capacity used during breathing for specific tasks[5, 6]



Hoit and Lohmeier did a specialized study on this topic in “Influence of Continuous Speaking on Ventilation,” and their results support the notion that breathing during speaking requires shorter inspirations and longer exhalations, as described previously. More sustained expiratory alveolar (i.e., within the lungs) pressure than for quiet breathing is necessary to “maintain speech loudness at a relatively constant level.”[7] Even more necessary, however, is a constant level of subglottal pressure, which is directly related to expiratory muscular engagement. The study measured ventilation levels for all their participants in both quiet breathing and speaking through acoustic signals, vital capacity measurements, measuring rib cage and abdominal muscle movements, and estimating blood-gas levels. The participants were asked to speak for a total of 10 contiguous minutes, with “This speaking task . . . designed to maximize the possibility that speaking would influence ventilation.”[8] The results of the study indicated

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5 Johan Sundberg, *The Science of the Singing Voice* (Dekalb, Illinois: Northern Illinois University Press, 1987), 33.

6 S. D. Foulds-Elliot, C.W. Thorpe, S. J. Cala and P. J. Davis, "Respiratory function in operatic singing: effects of emotional connection," *Logopedics Phoniatrics Vocology* 25 (2000): 156.

7 Jeanette D. Hoit and Heather L. Lohmeier, "Influence of Continuous Speaking on Ventilation," *Journal of Speech, Language, and Hearing Research* 43 (2000): 1240.

8 Hoit, 1246.

that each of the participants had more ventilation during speech than quiet breathing (almost twice as much as during quiet breathing), meaning that the exchange of gases moving in and out of the lungs increased during speech from the rate of gases exchanged during quiet breathing.[9]

Considering the increased complexity of the respiratory process from quiet breathing to breathing for speech, one might assume the even greater complexity of the muscular actions for breathing when singing. Shirlee Emmons, a voice pedagogue and singer who taught voice at Princeton and Columbia Universities, among others, writes of respiration and its role within singing in her article "Breathing for Singing" published in the *Journal of Voice*. Stating "the singer must be a truly 'professional breather,'"[10] Ms. Emmons mentions some of the factors singers to take into account when determining the magnitude of inhalation needed. These include the phrase length of the current phrase, as well as the overarching phrase lengths for the piece, the linguistic considerations of the text, and the rhythm, dynamics, and tessitura of the phrase.[11] The more advanced the singer, the more integrated this process should be. However, it is important to consider these elements on a conscious level even when one has advanced to the professional level of singing. Many singers revisit the technical process of respiration for singing, as the proper balance of muscular action during phonation must be maintained for the voice to function most efficiently and beautifully.

In a study published in the *Journal of Voice* in 2001 by Monica Thomasson and Johan Sundberg, professional operatic singers' inhalatory breathing patterns were

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[9] Ibid., 1245.
[10] Shirlee Emmons, "Breathing for Singers," *Journal of Voice* 2 (1988): 30.
[11] Ibid., 30.

reviewed.[12] The singers, two sopranos (one of whom was pregnant) and three baritones, were asked to sing three different and well-practiced selections in a concert situation. Each singer was asked to perform these three different selections three times, which totaled nine pieces for each singer, within one continuous performance. The measurements were taken from each singer's performance of the repeated pieces and then compared. Given this analytical process, the results of this study indicated that, for all singers' repeated performances, the rib cage movements at the same places in the music (for each performance) had a high level of consistency when lung volume was measured. However, the abdominal wall movements were not consistent; instead, they varied across performances for three of the five participants.[13] The author suggests that the abdominal wall measurements vary because of technique; perhaps those singers whose abdominal wall movements were not consistent because they maintained a technique that favored rib cage movement over abdominal wall movement as part of the inhalatory process.[14] The abdominal muscles, however, are more easily accessible for support, as the intercostal muscles are more difficult to move. When a singer is able to repeat the same physical movements of inhalatory musculature, specifically rib cage movements, for each particular phrase successive times, then this embodied muscular action speaks to its importance for the task's successful completion. Moreover, this evidence supports the implication of the inhalation in relation to consistent and efficient tone production.

When examining respiration during pregnancy, one must consider that the body is concurrently sustaining and nourishing two different beings. Pregnancy causes changes

[12] Monica Thomasson and Johan Sundberg, "Consistency of Inhalatory Breathing Patterns in Professional Operatic Singers," *Journal of Voice* 3 (2001): 373.
[13] Ibid., 375.
[14] Ibid., 382.

to the body which alter the respiratory process due to the growing fetus.[15] The second trimester finds the most significant changes in lung volumes and capacities. As the fetus grows, the body adjusts by increasing the diameter of the chest both anteriorly and posteriorly, thus counteracting the raised position of the diaphragm, whose resting position can raise by 4 cm during pregnancy.[16] This adjustment of the chest allows for the lung volume and vital capacity to remain relatively the same as during pre-pregnancy. However, expiratory reserve volume, defined as the amount of air that can be expired from the lungs after a normal exhalation, is decreased.[17] Therefore, functional residual capacity, the amount of air that is left in the airways and the lungs at the end of expiration, which includes expiratory reserve volume, is reduced 10 – 20% at the full term of the pregnancy.[18] This affects the singer, who may need to inhale more frequently because the total amount of needed air is no longer available. Furthermore, because of increased progesterone levels, the resting minute exchange of gases in respiration increases to 40-50%.[19] This means that the volumes of gases that are exchanged during one minute's time during respiration are increased, which affects the tidal volume. Tidal volume is the amount of air exchanged during a quiet sitting, and during gravidity, this volume is increased by 30 – 50%.[20]

Taking this information into account, one can surmise that singing during pregnancy would increase in difficulty based on the respiratory compensations described

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[15] Edward J. Hillman, M. D., "Otolaryngological Manifistations of Pregnancy*," Baylor College of Medicine*, (1996); http://web.archive.org/web/20060129094553/http://www.bcm.edu/oto/grand/2295.html.
[16] Bhatia Praveen and K. Bhatia. "Pregnancy and the Lungs." *Postgraduate Medical Journal* 76, (2000): 683.
[17] Hillman.
[18] Praveen, 683.
[19] Hillman.
[20] Donald Mattison, *Clinical Pharmacology during Pregnancy*, (San Diego, CA: Elsevier, Inc., 2013), Science Direct e-book: 8.

above. However, in order to gain a more comprehensive understanding of physiological implications pertaining to pregnant singers, the importance of the phonatory system and its function must also be examined.

The phonatory system, comprised of the extrinsic and intrinsic musculature of the larynx, combined with the respiratory system, is responsible for the production of sound. There are three intrinsic sets of valves in the larynx: aryepiglottic folds, true vocal folds, and false vocal folds. The most complex of these valves that regulate the amount of airflow through the vocal tract are the vocal folds.[21] The determination of the level of function of the folds and their ability to convert air into sound is termed laryngeal valving efficiency. In order to evaluate laryngeal valving efficiency, several measurements must be obtained: airflow, amplitude, and subglottal pressure, all of which are directly related to the expiratory musculature contracted during phonation.[22]

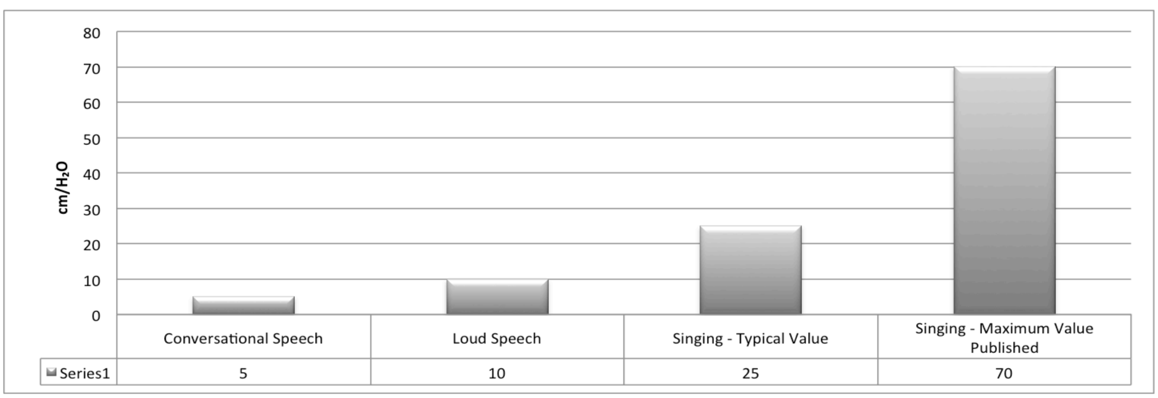
The efficiency of laryngeal function, therefore, requires appropriate subglottal pressure, which is the air pressure below the level of the vocal folds. Because lung volume for speaking and singing is generally above resting expiratory level (the state of balance between the air pressure outside the lungs and inside the lungs) the body must counteract the passive forces to achieve consistent subglottal pressure.[23] This process involves contraction of specific respiratory musculature during phonation, including the contraction of the external intercostal and abdominal muscles. Keeping in mind that the body must counteract the natural respiratory forces during speech, these muscles are contracted to maintain the needed level of subglottal pressure for consistent speech dynamic. The direct measurement of subglottal pressure, which aids in ascertaining

[21] Ferrand, 185-186.
[22] Ibid., 132.
[23] Sundberg, 29.

laryngeal health, is a difficult task, requiring needles to be inserted into the larynx during phonation. In lieu of this, one may gain a sufficient indication of subglottal pressure by measuring phonatory threshold pressure.[24]

A general indicator of vocal health, phonatory threshold pressure reveals the minimum amount of air pressure below the adducted vocal folds required to initially blow the vocal folds apart and commence vibration.[25] When the lips are closed and the glottis is open, the amount of pressure in the mouth equals the amount of subglottal pressure.[26] The following chart reveals healthy levels of subglottal pressure as measured in cm/H_2O for speaking conversationally, speaking loudly, typical measures for singing, and the most exceptional measure recorded during singing. Consequently, the amount of pressure required, for any trained singer, requires more expiratory muscular effort as compared to functions of breathing quietly or speaking.

Figure 1.1: Subglottal Pressure for varying vocal tasks[27]



[24] Ferrand, 94 - 95.
[25] Ibid., 130.
[26] Sundberg, 35.
[27] Ibid., 36.

H. K. Schutte, the author of the 1986 article entitled “Aerodynamics of Phonation,” studied laryngeal efficiency through measurements of mean airflow rate, subglottal pressure and sound intensity in 45 participants and 64 patients.[28] The study was designed to help with diagnosis of vocal pathologies, and revealed that measuring subglottal pressure was more helpful than measuring airflow rate for diagnosing pathology. This discovery was relevant for those working with patients, for if a patient has abnormally high subglottal pressure, further evaluations would be needed to discover if there may be excessive medial compression of the vocal folds, especially if the airflow rate was less than expected.[29]

According to “The Effects of Age and Gender on Laryngeal Aerodynamics,” the 1998 study by Justine Goozée, age and gender play a significant role when considering the levels of mean phonatory airflow and sound intensity, defined as loudness of sound.[30] (Interestingly, that subglottal pressure was found to be the least affected due to age and gender according to this study.) Subglottal pressure is sustained by use of the natural recoil forces of the body, as well as the muscles of expiration during phonation for both sexes, as maintained by Goozée.[31]

As noted earlier, it is important to realize that the phonatory system, located in the larynx, is complex and contains many intrinsic and extrinsic muscles, joints, cartilages, bones, and valves. The vocal folds are the most intrinsic of the three sets of valves in the larynx and are comprised of multiple layers of varying composition.[32] To understand the

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[28] H. K. Schutte, "Aerodynamics of phonation," *Acta Oto Rhino Laryngologica Belgica* 40 (1986): 344-357.

[29] Schutte, 356.

[30] Justine V. Goozee, “The Effects of Age and Gender on Laryngeal Aerodynamics,” *International Journal of Language & Communication Disorders* 33 (1998): 221.

[31] Ibid., 231.

[32] Ferrand, 123.

function of the phonatory system, one must regard the action of the vocal folds as they work through the vibratory cycle.

Vocal fold vibration is best described by the myoelastic-areodynamic theory of phonation. The comprehension of this theory is paramount; therefore, each step of the process will be examined in detail. The lateral cricoarytenoid muscles are responsible for closing the folds at the midline. As subglottal pressure is built up beneath the closed folds, phonatory threshold pressure is reached with the minimal amount of air pressure needed to separate the folds. This releases a pulse of air that is then converted to acoustic energy. With continuous vocal fold vibration, specifically by the lamina propria and the superficial layer of the vocal folds, multiple air pulses are produced. These acoustic pulses are modified by the shape of the vocal tract until they are released at the lips. The muscular elasticity returns the folds to their closed position. The cycle of vocal fold vibration continues as long as airflow continues.[33]

When considering function of the vocal folds, there are three voice characteristics that voice scientist Johan Sundberg describes as paramount: fundamental frequency, or pitch; amplitude, or loudness; and spectrum, or timbre.[34] Examining these characteristics imparts a more complete comprehension of the function of the vocal folds and the sound that results.

As has been noted, Sundberg suggests pitch, defined as the perceptual correlate of fundamental frequency, as the primary characteristic of vocal fold function. Assuming the singer is using proper breath management, pitch (fundamental frequency), is related

[33] Schutte, 334 - 345.
[34] Sundberg, 51.

directly to laryngeal musculature and longitudinal tension of the vocal folds.[35] If the vocal folds are lax (maintaining less muscular tension), then their texture will be thick; the resulting pitches sung with this composition will be low in frequency. The opposite will occur for higher pitches. The thyroarytenoid muscle, the most interior portion of the vocal fold itself, also has the ability to contract or release. During contraction, the tension of the thyroarytenoid also slightly increases pitch.[36]

There are other specific muscles responsible for both the lengthening and tensing of the vocal folds. The cricothyroid muscles, when contracted, lengthen the vocal folds by causing the thyroid cartilage to slide forward and tilt downward.[37] This increases the distance from the posterior portion of the folds, located at the arytenoid cartilages, and the anterior portion of the folds, located just inside the thyroid cartilage.[38] When the length of the vocal folds increase, their mass decreases, and longitudinal tension increases; the resulting frequency increases. In conclusion, the vocal folds will vibrate more quickly or more slowly depending on their longitudinal tension, and the resulting pitch will equal the frequency of the vocal fold vibration.[39]

Now that the musculature responsible for pitch has been examined, Sundberg's second consideration for vocal fold function can be considered.[40] Sound intensity, defined as the perceptual correlate of loudness, is mainly controlled by subglottal pressure, which is directly related to breath management as earlier described. The higher

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[35] Kimberly Steinhauer, Judith Preston Grayhack, Ann L. Smiley-Oyen, Susan Shaiman, and Malcom R. McNeil, "The Relationship Among Voice Oncet, Voice Quality, and Fundamental Frequency: A Dynamical Perspcective," *Journal of Voice* 18 (2004): 432.

[36] James McKinney, *The Diagnosis and Correction of Vocal Faults: a manual for teachers of singing and for choir directors* (Nashville, TN: Genevox Music Group, 1994), 70-71.

[37] Ferrand, 129.

[38] Sundberg, 16.

[39] Sundberg, 39.

[40] Ibid., 51.

the subglottal pressure, the louder the sound; consequently, during phonation, higher subglottal pressure results in an increase of medial compression by the adductory forces of the vocal folds.[41]

Timbre, the quality or color of the voice, is the third major consideration for vocal fold function according to Sundberg.[42] Timbre is related both to the musculature action of the folds and subglottal pressure; therefore, both characteristics that have been described above influence timbre in a significant fashion.[43] With the intention of clarifying vocal timbre as a significant vocal fold characteristic, it is beneficial to describe timbre in relation to registration.[44]

In a general sense, registers are groups of pitches that are produced with the same type of vocal fold function and which share similar quality and color.[45] For women, chest registration and middle voice overlap at approximately G4, or 400 Hz, and the middle voice and head voice registration overlap at E5, or 660 Hz.[46] Keeping in mind that a seamless vocal range is the goal of professional singers, it is important to note that negotiating through these passaggi points, or registrational transitions, is an essential skill that must be honed. Registration and timbre are affected through manipulation of vocal fold function based upon the singer's execution as related to genre, where the pitch lies within the tessitura of the phrase, or both. Moreover, this manipulation is possible because registers in the voice overlap; these pitch areas require decisions concerning which registration, or a mixture of the two, will function most ideally for the specific

[41] Johan Sundberg, Ronald Scherer, Markus Hess, Frank Müller, and Svante Granqvist, "Subglottal Pressure Oscillations Accompanying Phonation," *Journal of Voice* 27 (2013): 420.

[42] Johan Sundberg, *The Science of the Singing Voice* (Dekalb, Illinois: Northern Illinois University Press, 1987), 51.

[43] Ibid., 49

[44] Ingo Titze, "A Framework for the Study of Vocal Registers," *Journal of Voice* (1988): 191.

[45] McKinney, 93.

[46] Sundberg, 51.

pitch or pitches. Having the ability to decide what kind of mixture in registration one employs through the passaggi is an important tool, and to physiologically create that desired sound is expected of professionals who are classically trained.

Sundberg's study from 1991, "Comparisons of Pharynx, Source, Formant and Pressure Characteristics in Operatic and Musical Theatre Singing," explores the production of sound by a single, professionally trained female singer in three different types of vocal fold production (namely: classical, belt, and a combination of the two.) The differences in producing these styles of vocal production, according to Sundberg, are determined by subglottal pressure, laryngeal adjustment, and vocal tract shaping. Results of the study revealed a higher intensity and subglottal pressure in belting, as well as the highest amount of glottal adduction; the data revealed similarities to hypofunctional voice production. When regarding /ae/ sung in a sustained manner on G4, A-flat 4, and A4, in all three production styles, the data showed the Sound Pressure Level (or intensity) at 85 – 93 dB for the belt production, while the classical and mixed production values were 76 – 81 dB, and 74 – 81 dB, respectively. Data concerning subglottal pressure levels for belt production revealed a 2.4 – 3.2 P_{sub}, while the classical and mixed production revealed data from 1.6 – 1.8 P_{sub} and 1.5 – 2 P_{sub}, respectively. Therefore, data suggest that belting has the highest level of subglottal pressure, as well as the greatest amount of medial compression, when compared to operatic singing and a mixed approach of these two types of vocal production.[47]

The study "Membranous and Cartilaginous Vocal Fold Adduction in Singing," published in the *Journal of Acoustical Society of America* by Christian T. Herbst,

[47] Johann Sundberg, "Comparisons of Pharynx, Source, Formant, and Pressure Characteristics in Operatic and Musical Theatre Singing," *Department for Speech, Music and Hearing: Quarterly Progress and Status Report* 32 (1991): 61.

provides an evaluation on how the vocal folds function during different types of registration within phonation.[48] Vocal fold function in both singers and non-singers was evaluated, while the participants produced certain pitches with varying qualities of timbre within varying registrational qualities. Designated areas of their range, with specific attention focused on passaggi points, were stipulated for the provided vocalize exercises, and no mixing of registration was permitted.[49] Instead, they were asked to sing specific pitches in a breathy or pressed manner combined with either the falsetto or chest registrations. The goal was to observe whether or not the separate parts of the vocal folds, the membranous and the cartilaginous sections, functioned in an individualistic manner during phonation within different registrations.[50]

Herbst's analysis determined that both singers and non-singers are able to produce sounds resulting in different registrational qualities through separate function of the membranous and cartilaginous sections of the vocal folds. Observations were made of the cartilaginous portion of the folds, which comprises the posterior one-third of the vocal folds, by measuring the post-glottal chink dimensions during phonation. Additionally, the membranous function of the folds, comprising the anterior two-thirds of the vocal folds, was measured by the mass, or thickness, of the thyroarytenoid. The results revealed: the production of breathy (or light mechanism) falsetto employed both less cartilaginous adduction and less membranous medialization; the pressed (or heavier mechanism) integrated within falsetto production had more cartilaginous adduction and maintained less membranous medialization; the light mechanism chest phonation resulted

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[48] Christian T. Herbst, Quingjun Qiu, Harm K. Schutte, and Jan G. Svec, "Membranous and cartilaginous vocal fold adduction in singing," *Journal of the Acoustical Society of America* (2011): 2253.
[49] Herbst, 2255.
[50] Ibid., 2253.

in less cartilaginous adduction and more membranous medialization; and pressed, heavy mechanism chest production resulted in more cartilaginous adduction and more membranous medialization. In conclusion, the authors determined that the level of control the singers have on adducting the membranous and cartilaginous sections of the folds on an individual level directly affect the singer's ability to control the registrational aspects of singing.[51]

Once air has been set into vibratory motion, sound is initiated and allows for communication through speech and singing. Although the beauty of the tone is subjective for the voice, it is often considered the most important element, after vocal health. The most efficient vocal production within the complex muscular process will likely yield the most esthetically pleasing quality. Therefore, several vocal characteristics that play a significant role in revealing healthy and beautiful singing need to be examined; these characteristics include onset, agility, range, and vibrato.

These vocal characteristics, and acoustic measurements of these characteristics, are important to define because they are used in describing fundamentals of efficient sound production. The onset of a tone is the beginning of the sound. Although onset may seem like a simple level of function, the beginning of a tone is a likely indicator of the health of the instrument.[52] The voice pedagogue Richard Miller said of the onset, "The way a singer initiates vocal sound is crucial to the subsequent phrase. A good beginning to the singing tone is of prime consideration regardless of the achievement level of the singer."[53] Although singers strive for a balanced onset, both hypofunctional and hyperfunctional onsets are also possible. For example, if a singer begins a tone with

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[51] Herbst, 2260.
[52] Miller, 8.
[53] Ibid., 1.

hyperfunctional phonation, known as a glottal attack, then the vocal folds were closed before the tone was initiated, and subglottal pressure had increased to an excessively high level beneath the closed folds, prior to phonation.[54] In contrast, hypofunctional onsets have too much breath in the sound that is not being vibrated, and the vocal folds begin vibration before complete adduction is achieved. Neither of the latter types of onset is efficient, and both require corrective action in order to achieve a balanced beginning of the tone. Once onsets are balanced with vocal fold closure and subglottal pressure, the resulting phrases will subsequently be produced with efficiency, as long as breath energy and laryngeal function remain consistent.

Agility and range of the voice are prime aspects within the acoustics of singing, and both require continual maintenance and vocal exercise. These acoustic aspects of singing work together, as range is maintained, and even expanded, through vocalises that use agility as their main vehicle; alternatively, Miller suggests varying agility exercises with more sustained exercises in order to achieve the same goal.[55] One must perform all vocalises with consistent breath energy, proper vocal tract configuration, and a clear feeling of resonance in the mask, in order to exercise the vocal folds in a healthy way while extending range.

It is understood that, for a healthy vibrato rate, the long term pitch variation of the sound should stay within five to seven cycles per second (Hz), and that the alternating pitch will not be extended beyond a semi-tone of the original frequency.[56] Therefore, issues concerning vibrato include variations with the rate of vibration as well as extent of pitch variation. Oscillation that creates a ‘bleating’ sound, with the rate of long term

[54] Miller, 3.
[55] Ibid., 167.
[56] McKinney, 197.

pitch variation exceeding eight or more times per second,[57] is the result of extreme laryngeal tension and inconsistent breath energy.[58] Alternately, a 'wobble' may be described as the vibrato rate as being slower than five oscillations per second, even though the general trend over the last century is that a slower vibrato rate has become acceptable.[59]

As one can surmise, one must be vigilant to reduce tension and maintain a balance between medial compression and airflow for efficient, regular, and even vibrato.[60] "Vibrato Rate and Extent in Soprano Voice: A survey on One Century of Singing," published by Isidoro Ferrante, discusses the topic with respect to 105 different recordings of 75 artists singing the same pitch from "Vissi d'arte," from *Tosca* by Puccini.[61] The study analyzes each participant singing B-flat 5 on the word "Signor" in the aria, and in doing observes vibrato oscillation rate as well as pitch extent from these professional performances dating from 1901 – 2009. A summary of the results concludes that within the past one hundred years the rate of vibrato has slowed; moreover, the rate from the beginning of the twentieth century was seven Hz as compared to more recent recordings measuring at five Hz.[62] Over time, the same singers had a decrease in vibrato rate,[63] which substantiates McKinney's statement concerning older singers and vibratory rate: "Some professional singers who have enjoyed long and highly successful careers develop vibrato problems after many years of singing. The ocean wave or wobble is the most

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57 Miller, 182.

58 McKinney,198.

59 Isidoro Ferrante, "Vibrato rate and extent in soprano voice: A survey on one century of singing," *Journal of Acoustical Society of America*, (2011): 1683.

60 Miller, 187.

61 Ferrante, 1683-1684.

62 Ibid., 1687.

63 Ferrante, 1687.

prevalent type."[64]

One can more clearly understand the function of the vocal instrument after examining the systems of the body that work cohesively to produce sound. Studying the differences among respiratory forces required for quiet breathing, speaking, and singing helps demonstrate the increasing energy level of muscular groups required across these tasks in their given order. Understanding the function of the human voice requires studying the phonatory system, laryngeal valving, and the vibratory process of the vocal folds (including pitch, loudness and timbre), and their relationship to subglottal pressure within sound production. Vocal qualities that include balanced onset, agility, and appropriate vibrato, when produced with sufficient energy, consistent thoracic support, and with proper pharyngeal configuration, result in increased beauty and efficiency of tone. Moreover, for those experiencing pregnancy, the examination of these qualities, in addition to analyzing respiratory function, can reveal how the body adapts in these specific areas during phonation. In the final analysis, examination of the respiratory system, the phonatory system, and acoustic measures give the singer, the voice teacher, the choral conductor, and the astute audience member a comprehensive understanding of the complex act of singing.

When this study commenced, early in 2010, the proportion of literature on the participant of pregnancy and the singing voice, as compared to other aspects of vocal physiology, was close to naught. Currently, there is more research available on the topic; in comparison to other research topics in coordination with the singing voice, however, more studies need to be completed. In an effort to increase the knowledge base for singers, voice teachers, and voice scientists who are interested in the topic, this case study

[64] McKinney, 200.

was implemented.

Before the details of the current study are explored, a brief overview on hormonal influences on the voice during pregnancy, as well as typical physiological experiences associated with pregnancy, will be presented. In addition, information from three particular studies on the topic ranging from 2007 – 2012 will be examined.

Overview

According to Jean Abitbol's article "Sex Hormones and the Female Voice," as found in the Journal of Voice in 1999, hormones such as estrogens and progesterone influence not only the organs involved in reproduction, but also mucosa, the laryngeal instrument, and other tissues, including the cerebral cortex.[65] Notably, dehydration is a result when examining both cervical and vocal fold smears as influenced by progesterone.[66] Conversely, estrogens have a regenerative effect on mucosa, and have "an increase of secretions of the endocervical glandular cells."[67, 68] The laryngeal mucosa mimics the same kinds of secretions both above and below the vocal folds when estrogen is increased.[69] Additionally, in the 2008 study "Sex Hormone Effects on Body Fluid Regulation," as published in *Exercise and Sports Science Reviews*, author Nina Stachenfeld found that both estrogen and progesterone affect capillary fluid dynamics:

> Clinical reports of edema in association with sex hormone administration, the premenstrual period, and pregnancy suggest that estradiol and progesterone may play important roles in body fluid distribution. Estrogens tend to increase, whereas progesterone tends to decrease, plasma volume through effects on

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[65] Jean Abitbol, Patrick Abitbol and Beatrice Abitbol, "Sex Hormones and the Female Voice," *Journal of Voice* 13 (1999): 431.
[66] Abitbol, 433.
[67] Abitbol, 431.
[68] Ibid., 435.
[69] Ibid.

capillary fluid dynamics or Starling forces.[70]

There are varying statistics on the amount of progesterone increase during pregnancy from approximately 20 ng/mL at 10 weeks of gestation to approximately 135 ng/mL at 40 weeks of gestation,[71] and may even increase to 200 ng/mL.[72] However, estroil, the main estrogen of pregnancy,[73] ranges approximately from .5 ng/mL at 10 weeks of gestation to 12 ng/mL at 40 weeks gestation.[74] Progesterone, the more important of the two during gravidity, is responsible for successful implantation as well as preservation of the pregnancy. Therefore, due to the increased levels of this principal pregnancy hormone, it is likely that one may experience dehydration during pregnancy. This is significant to the singer because progesterone causes the epithelium to "slough off," and causes dryness of surfaces of the larynx. This can also cause a difficulty in agility with classically trained singers and may even affect phonation within different registrations.[75]

Abdul-Latif Hamdan's 2007 article "Effect of Pregnancy on the Speaking Voice," as found in the *Journal of Voice*, says the following about estrogen during the menstrual cycle, which may aid in further understanding of this hormone's effects on the voice:

> In non-pregnant women, during the maturation phase of the menstrual cycle…estrogens secreted by the ovaries result in slight thickening of the cordal mucous membrane creating greater vibratory amplitude… Estrogens also improve the permeability of the blood vessels and capillaries on the vocal folds in an attempt to increase oxygenation. This can explain the well-rounded voice described early in pregnancy. [76]

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[70] Stachenfeld, Nina S., "Sex Hormone Effects on Body Fluid Regulation," *Exercise and Sport Science Review* 36 (2008): 157.

[71] Bruce White, Ph. D., and Susan Porterfield, Ph.D., *Endocrine and Reproductive Physiology* (Philadelphia, PA: Mosby, 2013), 251.

[72] Abdul-Latif Hamdan, Lorice Mahfoud, Abla Sibai and Muheiddine Seoud, "Effect of Pregnancy on the Speaking Voice," *Journal of Voice* 23 (2007): 493.

[73] Ibid., 253.

[74] White, 251.

[75] Hamdan, 492-493.

[76] Ibid., 492.

Two medical conditions are described in a paper presented at The Baylor College of Medicine in 1995, "Otolaryngologic Manifestations of Pregnancy," by Edward J. Hillman. Laryngopathia gravidarum is described as laryngeal deviations that some pregnant women endure. These laryngeal changes, including symptoms of hoarseness, difficulty in breathing, and sore throat can be acute or chronic. Edema of the arytenoids, aryepiglottic and false focal folds often occur with this condition. The second medical condition Hillman mentions is gastro-esophageal reflux disease (GERD). GERD occurs in 30 – 50% of all pregnancies, with symptoms occurring mostly in the third trimester. Symptoms associated with reflux include hoarseness, sore throat, wheezing, cough and chest pain.[77]

According to "Effect of Pregnancy on the Speaking Voice," as published by The Voice Foundation in 2009 by Abdul-Latif Hamdan, *et al.*, all pregnant women in the study experienced gastro-esophageal reflux compared to the 14.3% of the control group who experienced GERD. This is a significant find. Interestingly, the study primarily examined vocal fatigue, hoarseness, aphonia, and maximum phonation time during the third trimester of 25 pregnant women whose mean age was 30.9 years. 28% of these women had "incidence of smoking in various forms (cigarette or Arghile);"[78] Of the women smokers, 8% experienced hoarseness and 12% reported vocal fatigue. This was compared to the control group of non-pregnant women, whose mean age was 28.3 years with a 28% of the women as smokers. 5% of the control group experienced of hoarseness, and none reported vocal fatigue. Neither group experienced aphonia. [79]

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[77] Hillman.
[78] Hamdan, 491.
[79] Ibid.

The authors mention that the symptoms the pregnant women experienced could be influenced by several factors, including GERD, as well as the respiratory condition of the women. As previously mentioned, with the diaphragm rising by 4cm during pregnancy, the diaphragmatic expansion increases 1 to 2 cm further upon inhalation. The circumference of the chest also expands by 5 – 7 cm to aid with the inhalator process.[80] However, functional residual capacity is reduced in pregnancy by 10 – 20%, and total lung capacity by 4 – 5%;[81] all which could influence the voice to experience fatigue, as well as possibly affecting maximum phonation time. Additionally, during pregnancy, the blood volume of the mother in a typical pregnancy increases from 1500 – 1600 mL and the total body water found in her body increases by 6.5 – 8.5 L in a full term pregnancy. This increase of liquid in the body may negatively influence the body through the occurrence of edema in the vocal folds.

This study found that maximum phonation time on a single inhalation was markedly less during pregnancy than post-pregnancy. The participants, who were asked to breathe deeply and to sustain /a/ for as long as they could for this measurement, experienced maximum phonation time during the third trimester as 7.52 seconds, and post delivery as 8.74 seconds (with measures taken from 12-24 hours postpartum).[82] The control group experienced maximum phonation time as 17.36 seconds. The most interesting findings of the study report an increase in vocal fatigue in third-trimester women, as well as a lower maximum phonation time for the same group, as compared to the control group.

[80] Ibid.
[81] Mattison, 8.
[82] Hamdan, 492, 490.

Three studies published in 2012 are of particular interest: “Pregnancy and the Singing Voice: Reports From a Case Study,” by Filipa Martins Baptista Lã and Johan Sundberg; “Pregnancy and Voice: Changes During the Third Trimester,” by Verónica L. Cassiraga, et.al.; and “The Impact of Pregnancy on the Singing Voice: A Case Study,” by Stephanie Adrian. Correlations between these studies will be explored and, in Chapter 2, will be compared to the study at hand.

As published in the *Journal of Voice*, Lã and Sundberg’s study “Pregnancy and the Singing Voice: Reports from a Case Study,” begins with a similar postulation to the other two studies referenced above: that pregnancy, with the cervical and vocal mucosae having similar responses to hormones, has a direct effect on vocal fold quality and vibration.[83] This assertion is based on analysis of Abitbol and Jean de Brux’s study completed in 1986.[84] Each of the three studies mentioned in the previous paragraph evaluated acoustic and aerodynamic measures during gravidity, exploring the phonatory effects of hormone levels singular to pregnancy.   The study completed by Lã and Sundberg included postpartum measurements, as well.

Participants

These three studies have a variance of the number of participants involved. Cassiraga’s study included a group of forty-four pregnant women, spanning the ages of twenty to forty years, who were in their third trimester and were patients at Hospital

[83] Lã, Filipa Martins Baptista and Johan Sundberg. "Pregnancy and the Singing Voice: Reports from a case study." *Journal of Voice* 26, no. 4 (2012): 432.

[84] Abitbol, pg. 435

Italiano in Buenos Aries.[85] The control group consisted of forty-eight women in the same age range who were not pregnant. The other two studies referenced are case studies, with a single woman as the participant with the ages of 35 and 28, respectively; and both were non-smoking, classically trained sopranos.[86, 87]

It is important to acknowledge that a case study provides both benefits and restrictions. As stated in the Lã and Sundberg article, the authors mention that benefits stem from the same participant throughout the pregnancy and the participant maintains the same physiological history throughout the study. Case studies provide "systematic and extensive data on the complex interactions between different factors that may influence the results."[88]

Data Collection

An important comparative point is the timeframe, both within pregnancy and postpartum, when the data was collected. It was enlightening to observe the choices regarding when data was collected; two of the three studies focus on the third trimester. This is of particular interest because the current study referenced in Chapter Two is also based on data during the third-trimester and postpartum. Lã and Sundberg maintain that their choice to study gravidity during the third trimester was due to the highest levels of estrogen and progesterone in the body during this time.[89] The following table demonstrates this comparative information:

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[85] Veronica L. Cassiraga, Andrea V. Castellano, Jose Abasolo, Ester N. Abin and Gustavo H. Izbizky, "Pregnancy and Voice: Changes During the Third Trimester," *Journal of Voice* 26 (2012): 584 - 585.

[86] Stephanie Adrian, "The Impact of Pregnancy on the Singing Voice: A Case Study," *Journal of Singing: The Official Journal of the National Association of Teachers of Singing* 68 (2012): 266.

[87] Lã, 432.

[88] Ibid.

[89] Lã, 432.

Table 1.0: Inter-study Comparative Data Collection Points

Author	Week during pregnancy	Week Postpartum
Adrian	Week 9, week 17, week 27, and week 35	N/A
Cassiraga	Weeks 30 – 41 for the pregnant group; non-specified past that point.	N/A
Lã and Sundberg	Weekly, from week 28 until birth. Included one measurement taken at 48 hours after birth.	Weekly, through 11 weeks postpartum

Points of Focus

Each of the studies mentioned above has similarities to the other studies, yet maintains a unique goal that sets it apart from the others. Similar points of primary focus between the three studies include both aerodynamic and acoustic measures. Acoustic measures include: fundamental frequency (sung and spoken), perturbation measures of jitter percent and shimmer percent, and noise-to-harmonic ratio. The perturbation measures of jitter and shimmer evaluate short-term variation from period-to-period in vibrato. Jitter measures the short term variation in pitch from one period to the next, and shimmer percent values indicate the amount of short-term amplification from period-to-period.[90] Noise to harmonic ratio, which gives an accurate measure of the amount of noise in the voice, is defined as the "average ration of the inharmonic spectral energy in the frequency range 70-4200 Hz to the harmonic spectral energy in the frequency range 70-4200 Hz."[91]

Aerodynamic measures explored include across the three studies include: maximum phonation time, voicing efficiency, sound pressure level, phonatory threshold

[90] KayPENTAX *Phonatory Aerodynamic System (PAS) Model 5500 Instruction Manual.* Vol. Issue D. Lincoln Park, NJ: PENTAX Medical Company, 20.

[91] KayPENTAX *Phonatory Aerodynamic System*, 22.

pressure and subglottal pressure. Contrastingly, measurements unique to a single study include: pitch range, collision threshold pressure (defined as the lowest pressure that produces vocal fold contact) and normalized amplitude quotient. According to Lã, normalized amplitude quotient, or NAQ, is defined as "the ration between peak-to-peak amplitude and the product of period time and the negative peak of the differentiated flow glottogram."[92] Additionally, Lã states that NAQ evaluates the adduction and abduction of the vocal folds, and indicates the amount of hyper-phonation or hypo-phonation.[93] Two of the three studies included journal entries by the participant, including quality of voice and vocal fatigue, breath, agility, timbre and range.[94][95] In addition, "Pregnancy and Voice: Changes during the Third Trimester," as published by the *Journal of Voice* in 2012, included an evaluation of voice quality as one of the initial tasks, monitoring the level of hoarseness, breathiness, roughness or strain in the participants.[96] One study included a recording of an art song that was evaluated by a team of ten voice teachers as well as the participant herself.

Methods

Videostroboscopy was used to observe vocal fold function and appearance in Adrian's study, and a digital laryngograph microprocessor was employed in Lã and Sundberg's study, to measure oral pressure signals, electrolaryngograph signals, flow and audio signals. [97,98] The study by Cassiraga, et al., included digital recordings made

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[92] Lã, 433.
[93] Ibid.
[94] Adrian, 266.
[95] Lã, 432.
[96] Cassiraga, 584.
[97] Adrian, 266.
[98] Adrian 2012, 266,

in a relatively quiet room with less than 40 dB of background noise, using an external sound card and microphone to optimally capture measurements for "a flat speech-range frequency response (60-10 000 Hz)."[99]

Tasks

The tasks in acquiring data were similar across the three studies. Acoustic measurements, such as fundamental frequency and perturbation (that include % jitter and % shimmer), involved reading a phonetically balanced reading segment, such as the "Rainbow Passage."[100, 101]

Aerodynamic measures, which include voicing efficiency, sound pressure level, and phonatory threshold pressure (PTP), were taken in a similar manner between the Adrian and the Lã and Sundberg studies. In Adrian's study, aerodynamic measures, such as voicing efficiency, sound pressure level, resistance, were taken from tasks that included /pa/ /pa/ /pa/ /pa/ /pa/, repeated three times into an airflow mask.[102] Sundberg and La's study included a task that consisted of /pæ/ being sung for six repetitions on pitches in different registrations (A3, E4, B4, and F5), and employing a diminuendo for each sung pitch.[103]

Maximum phonation time (MPT) was measured throughout each study, using a variety of approaches. Specifically, the Lã and Sundberg study required the singer to take one initial inhalation and record entries of counting aloud for as long as she was physically able. The study by Adrian did not specify which vocal task was used for the

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99 Cassiraga, 584.
100 Cassiraga, 584.
101 Adrian, 268.
102 Ibid.
103 Lã, 432.

MPT readings. Cassiraga's participants were asked to sustain /o/ to measure MPT.

Lã and Sundberg's study presented a task for subglottal pressure that was the same as the test used to measure phonatory threshold pressure, or PTP, and collision threshold pressure, or CTP (the lowest subglottal pressure that produces vocal fold contact). As described above, the participant was asked to record sequences of /pæ/ on four pitches: A3, E4, B4, and F5, with a diminuendo performed on each sung pitch.

The Lã and Sundberg study also included a performance of Robert Schumann's "Widmung," from *Myrthen Lieder*, Opus 25, no. 1. It was used for auditory measures that included fatigue and timbre and was evaluated by a panel of voice teachers, as well as by the participant herself.

Data

Further scholarship from the reference to each of these three studies was highly encouraged as the data included comprehensive findings, not all of which are referenced below. Any significant difference in the data results suggests further exploration into the tasks for these measurements.

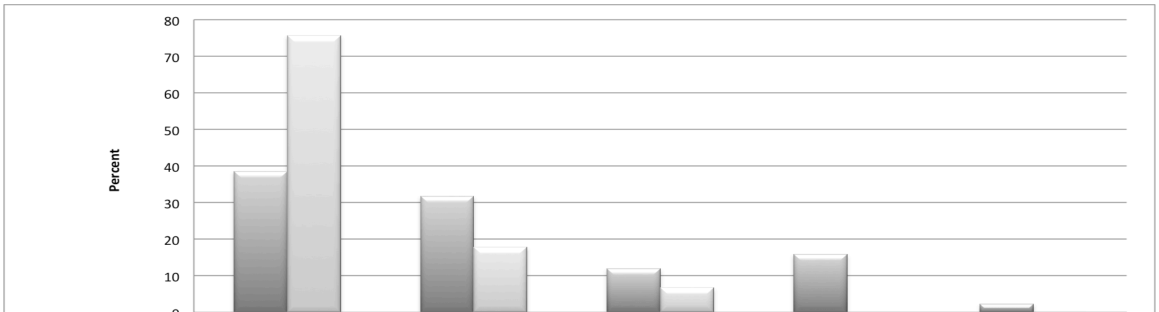
Table 1.1: Inter-study Data Chart

	MPT (sec)	SPL (dB)	PTP (cm/H_2O)	CTP (cm/H_2O)	Subglottal Pressure (cm/H_2O)	Aero-dynamic Efficiency ($dB/cm/H_2O$)	NAQ
Adrian - Mean during pregnancy	9.2 sec	91.9 dB			85.4 cm/H_2O	8.7 $dB/cm/H_2O$	
Cassiraga - Mean for pregnant women	10.3 sec	51.2 dB					
Cassiraga - Mean for non-pregnant women	14.5 sec	44.88 dB					
Lã and Sundberg - Mean during pregnancy.	19 sec		F5: 11.5 cm/H_2O	F5: 16.9 cm/H_2O	F5: 30.5 cm/H_2O		0.1.5
Lã and Sundberg - Mean postpartum	29 sec		F5: 11.0 cm/H_2O	F5: 15.3 cm/H_2O	F5: 30.0 cm/H_2O		0 .4

"Pregnancy and Voice: Changes During the Third Trimester," by Cassiraga, *et al.*, included a measure that, through the use of spectrogram analysis, quantified auditory perception.[104] Both the group of pregnant participants, as well as the control group, provided measures of hoarseness, breathiness, a combination of hoarseness and breathiness, and breathiness and asthenia (the latter is defined as the loss of physical strength). The chart that follows provides the values acquired.

[104] Cassiraga, 584.

Figure 1.2: Auditory Perception for Pregnant
and Non-pregnant Women in Cassiraga's Study



	Normal Voice Paramaters	Breathiness	Hoarseness	Hoarseness and Breathiness	Breathiness and Asthenia
Pregnant Women	38.6	31.8	12.0	15.9	2.3
Non-Pregnant Women	75.6	17.8	6.7	0	0

Significant results by study:

When regarding the significant results to the three studies as mentioned, the results all focused on findings specific to each particular study. "The Impact of Pregnancy on the Singing Voice: A Case Study," by Stephanie Adrian, found the most significant result of her study in the voicing efficiency measures of glottal resistance.[105] Both the sound pressure level and the aerodynamic resistance values were lower in weeks 17 and 27 than in week 9 and week 35, in which the latter are the bookend weeks of the study. The author surmised that the reason for the lower resistance values mid-pregnancy were possibly due to edema or tissue change (due to hormonal influence), although neither are visible by the stroboscopy.[106]

The most interesting results from the group study by Verónica Cassiraga, *et al.*, "Pregnancy and Voice: Changes During the Third Trimester," included the data concerning the auditory phonation values. The values of hoarseness could be related to

[105] Adrian, 268.
[106] Adrian, 269.

gastro-esophageal reflux (measured by self-analysis by each participant), which 52.3% of the pregnant participants recorded experiencing.[107] The high level breathiness values for the pregnant participants may be related to the increasing body mass index and the increased level of physical effort required to support the sustained tone required for the measure. The effort required to support may be overwhelming, resulting in hypofunctional phonation, or breathiness in the tone.

Finally, the case study by Lã and Sundberg, "Pregnancy and the Singing Voice," revealed detailed analytical measures, as well as more participative measures that were substantiated by the data, concerning a classically trained 28 year old semi-professional singer. The most noteworthy findings included phonatory threshold pressure and collision threshold pressure with considerably high measurements during pregnancy, which, coordinating with the low levels of normalized amplitude quotient (NAQ) during pregnancy, suggests decreased vocal fold movement.[108] Moreover, increased glottal adduction was also suggested by the data through measurements concerning alpha-ratios, all of which reached the lowest point at the week of the birth.[109]

In conclusion, each of the three studies referenced are excellent accounts of women who experienced gravidity, birth, and postpartum. One may expect, based on these references, that the body may endure changes that occur because of pregnancy, and these changes will most likely affect the voice. These changes include, but are not limited to: increased vocal fold edema may occur due to changes of sex hormones in the body; acid-reflux; increased body-mass-index may result in the shifting of the center of gravity, which can affect posture, and therefore, the support system of the body and

[107] Cassiraga, 585.
[108] Lã, 434.
[109] Ibid., 436.

voice; increased body-mass-index may also provide a challenge to contracting the abdominal muscles during phonation as pregnancy approaches full-term; and during pregnancy vocal fold efficiency will most likely decrease, and glottal adduction increase, because of the hormonal changes in the body during this time.

CHAPTER TWO

METHODS

Without knowledge of the studies referenced in the previous chapter (as they were published after the current study commenced in 2010) similar measurements were recorded. Foci for the current study included respiratory, acoustic and aerodynamic measures. The respiratory measures included vital capacity and oxygen saturation. Agility, pitch accuracy in semi-tones, vibrato rate, and perturbation measures (including jitter % and shimmer %) were included in the acoustic measures. Aerodynamic measures included voicing efficiency, laryngeal resistance, airflow, sound pressure level, and phonatory threshold pressure. Self-perceived evaluations were also recorded through use of the Voice Handicap Index and the Singing Handicap Index.

Participant

The participant of the study was thirty-five years old during the third trimester of the pregnancy and 10 weeks postpartum. A non-smoker, the participant was pregnant with her third child, gained a total of thirty-five pounds during pregnancy, and had been studying voice professionally for seventeen years. Data were acquired during the following weeks of the pregnancy: 28 weeks, 30 weeks, 34 weeks, 36 weeks, and 39 weeks. In addition, one final acquisition was obtained at 10 weeks postpartum. The pregnancy concluded with a successful vaginal delivery that did not require surgery or medicine.

Instrumentation

Aerodynamic measures of phonatory threshold pressure and laryngeal valving efficiency were recorded in a sound-attenuated booth with the Phonatory Aerodynamic System 6600 and a calibrated airflow head. The participant wore a mask over the nose and mouth to capture airflow, with a pressure sensing tube behind the lips to acquire intraoral air pressure.

Vital capacity measures were acquired with SpiroVision 3 (FutureMed), and the oxygen saturation values were recorded with a non-invasive pulse oximeter. These values were documented manually every fifteen seconds during the performance of an aria which was recorded while the participant wore a head-mounted microphone.

Samples for acoustic measures of vibrato and perturbation were recorded using the Computerized Speech Laboratory (CSL, Model 4500, KayPENTAX) and a head mounted microphone (AKG C520). Vibrato rates were calculated through the analysis of each sung pitch using the Praat software.

Protocol

The protocol for data collection followed a specific series of tasks, which were repeated in the same order each acquisition day. The participant began warming up at home to a performance-ready state before leaving for the acquisition site. Then, as a method of self-analysis, the participant completed the Vocal Handicap Index and the Singing Handicap Index.

Respiratory tasks

For vital capacity, the participant breathed in as much as possible and then exhaled as quickly and completely as possible. The participant wore an oxygen sensor over the finger, and oxygen saturation values, measuring the amount of oxygen in the hemoglobin,[110] were recorded manually every fifteen seconds during the performance of Nannetta's aria from Act III of Giuseppe Verdi's *Falstaff,* "Sul fil d'un soffio etesio."

Aerodynamic tasks

To acquire data for the phonatory threshold pressure (PTP) measure, the participant produced three sets of seven repetitions of /pi/ spoken as quietly as possible at a typical pitch at a rate of 1.5 syllables per second. To calculate laryngeal valving efficiency, the participant sang /pi/ syllable trains three times, at a dynamic level of *forte*, on one pitch. The pitch was G4 at week 28; however, after re-evaluation, this task was sung on E-flat 5 for the remainder of the seven trials to reflect a more accurate measure for the range of a soprano. Additional aerodynamic measures, including laryngeal resistance, mean airflow, mean peak air pressure, and sound pressure level during voicing were also obtained with the same task.

Acoustic tasks

To measure vibrato and perturbation, the participant recorded fifteen trials of singing /i/ at a *mezzo forte* dynamic for four seconds each, on the following pitch levels (singing each pitch level for the fifteen trials, then beginning the next pitch,

[110] Debra J. Wiegand and Lynn McHale, Ph.D., R.N., C.C.R.N., *American Association of Critical Nurses Procedure Manual for Critical Care,* (St. Louis, MO: Elsevier/Saunders, 2001): 77.

from low to high registrations): A-flat 3, A-flat 4, E-flat 5, and A-flat 5. Through analysis of each sung pitch using the Praat software, vibrato rates were calculated by counting the number of oscillations, or beats, which then were divided by the number of seconds the segment lasted. Perturbation measures of jitter and shimmer were also taken from these data, as well as Amplitude Tremor Intensity Index (ATRI) and Frequency Tremor Intensity Index (FTRI), the latter two being indices of vibrato extent in intensity and frequency.

To determine agility and pitch accuracy in semitones, the participant performed three trials of the following scale degrees, beginning on the pitches A-flat 3, D4, and B- flat 4, on /i/, as quickly as possible: 1 2 3 4 5 4 3 2 1 2 3 4 5 4 3 2 1 2 3 4 5 6 7 8 9 10 11 9 7 5 4 2 1. Because the third trial was consistently the fastest, it became the primary measurement. The last pitch level was not used in calculating data, because of the tendency of the participant to sustain the pitch longer than the others, as it was the final note in the vocalization. Pitch accuracy in semitones was analyzed in Praat.[111] Each of the twenty-four pitches in the task was analyzed and the fundamental frequency was converted to semitones. The semitone data were then compared to the target semitone for each pitch in the task, and the difference between the two was calculated.

Intra-Judge Reliability

To determine reliability, the data from week 30 of pregnancy were re-measured. There were no differences between original and repeated measures for vital capacity

[111] Paul Boersma and Weenink, David. "Praat: doing phonetics by computer." Version 5.3.71, 2014. http://www.praat.org (accessed April 15, 2014).

measures and oxygen saturation. The difference between the original and the repeated measures for aerodynamic measures were: phonatory threshold pressure = 0.0%; laryngeal valving efficiency = 3.3%; laryngeal resistance = 2.9%; mean airflow during voicing = 3.7%; mean peak air pressure = 0.1%; mean sound pressure level during voicing = 0.3%. The difference for the original and the repeated measures for acoustic measures were: ATRI, FTRI, amplitude perturbation quotient, pitch perturbation quotient, mean accuracy in semitones, and timed vibrato rate segment = 0.0%; mean agility = 1.4%; timed agility segment = 8.8%; and mean vibrato rate = 3.7%; number of oscillations = 2.0%. Data are illustrated in Table 2.0.

Table 2.0: Respiratory, Acoustic, and Aerodynamic Reliability Measures

	Initial Value at 30 weeks	Reliability Measure	Averaged Difference
Vital capacity (L)	3.1	3.1	0.0%
Oxygen saturation (%)	97.0	97.0	0.0%
PTP (cm/H_2O)	3.2	3.2	0.0%
Laryngeal valving Efficiency (ppm)	1026.0	1059.0	3.3%
Laryngeal resistance (cm/H_2O/L/s)	86.0	88.5	2.9%
Mean airflow during voicing (cm/H_2O)	270.0	260.0	3.7%
Mean peak air pressure (cm/H_2O)	24.0	23.98	0.1%
Mean sound pressure level during voicing (dB)	97.0	96.7	0.3%
ATRI (%)	9.9	9.9	0.0%
FTRI (%)	3.1	3.1	0.0%
PPQ (%)	0.3	0.3	0.0%
APQ (%)	0.6	0.6	0.0%
Mean pitch accuracy in semitones	0.5	0.5	0.0%
Mean agility (notes/sec)	7.1	7.2	1.4%
Timed agility segment (sec)	3.4	3.1	8.8%
Mean vibrato rate (oscillations/sec)	5.4	5.6	3.7%
Number of oscillations	20.5	20.9	2.0%
Timed vibrato rate segment (sec)	3.8	3.8	0.0%

CHAPTER THREE

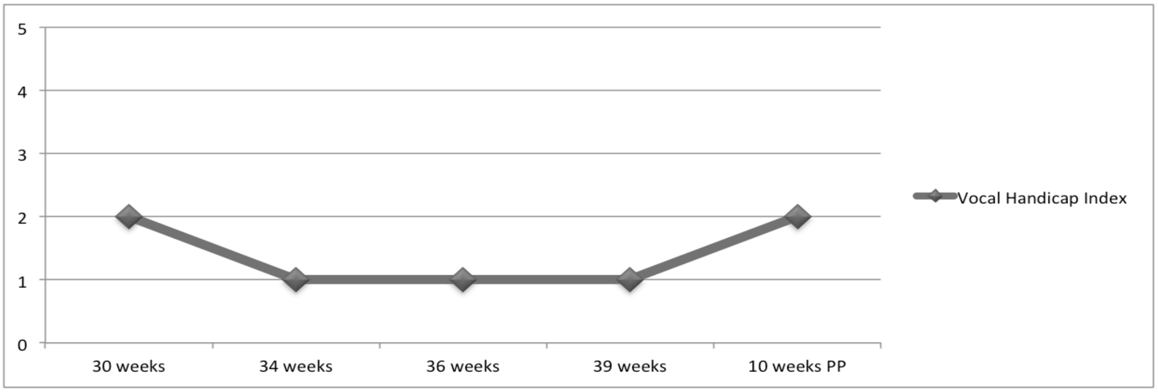
RESULTS

Self-perceived measures, the Vocal Handicap Index and Singing Handicap Index, will be discussed first, and will be followed by aerodynamic measures. The latter includes results for phonatory threshold pressure, laryngeal valving efficiency, laryngeal resistance, mean peak airflow, mean peak air pressure, and mean sound pressure level during voicing. The last results discussed are acoustic, and include vibrato rate, perturbation measures such as jitter and shimmer, and ATRI and FTRI. Pitch accuracy and mean agility in notes/second will conclude the results.

Vocal Handicap Index

The Vocal Handicap Index (VHI) has a total score ranging from zero to one hundred forty four, based on a summation of responses on a one to five scale. The VHI score was two for week 30 of pregnancy and again at week 10 postpartum. The latter weeks of pregnancy, from week 34 to week 39, show a value of one.

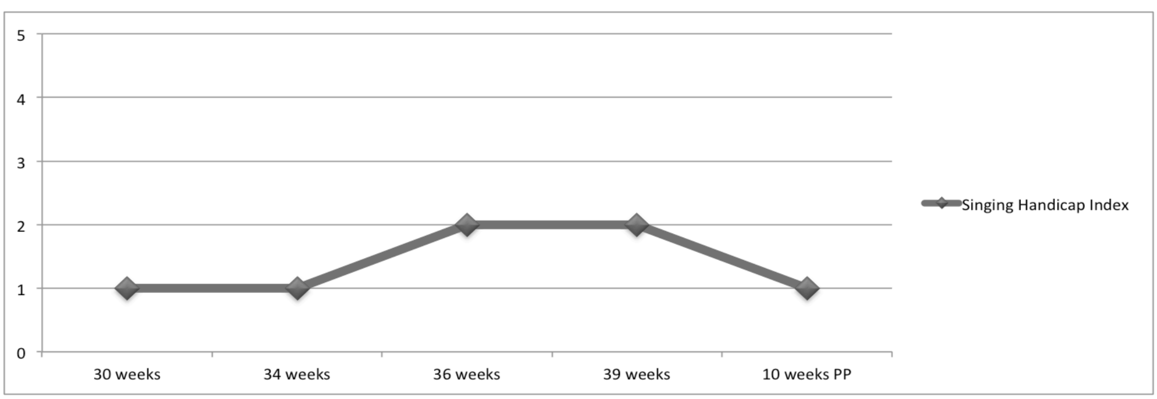
Figure 3.0: Vocal Handicap Index



Singing Handicap Index

The total score for the Singing Handicap Index (SHI) ranges from zero to one hundred twenty, based on a summation of responses on a one to five scale. Singing Handicap Index scores show an increase from one at 30 weeks, to two at weeks 36 and 39 of pregnancy. The value then decreases to one at 10 weeks postpartum.

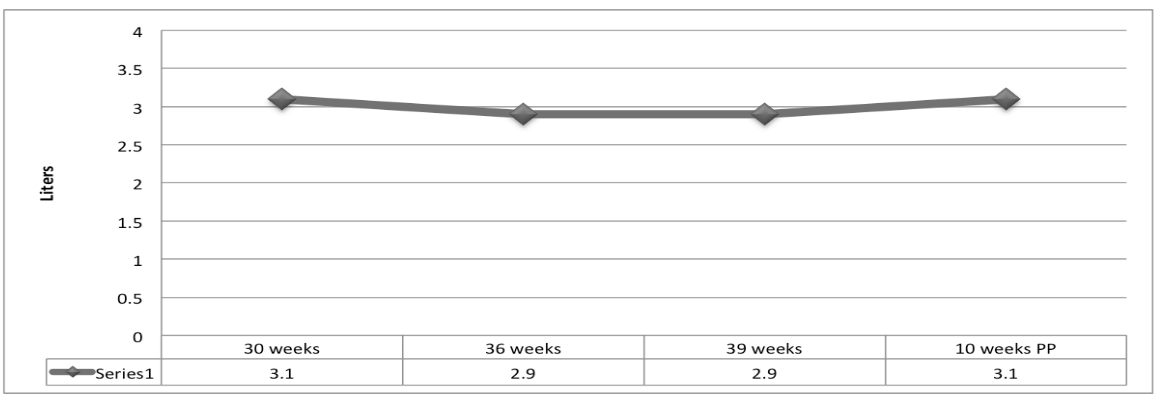
Figure 3.1: Singing Handicap Index



Respiratory Data

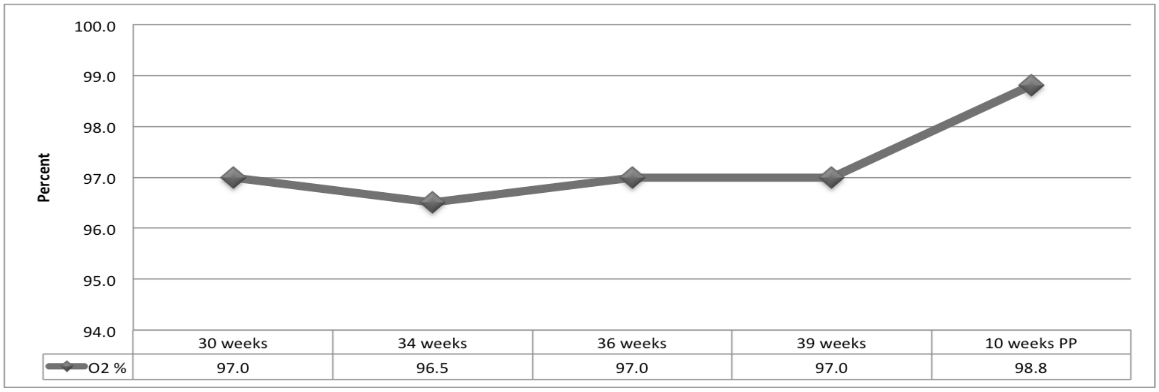
Vital capacity is the maximum amount of air that can be inhaled and exhaled in one maximal effort respiratory cycle. There were five vital capacity records available, as seen in the figure below. Vital capacity was not measured in week 28, and SpiroVision3 was not available in week 34 of pregnancy. A decline in vital capacity is evidenced from 30 weeks of pregnancy, when 3.1 liters was recorded, to 2.9 liters measured at 36 weeks; this latter measure was maintained through week 39. The measure of vital capacity postpartum was 3.1 liters for 10 weeks postpartum.

Figure 3.2: Vital Capacity



The oxygen saturation levels, lower during pregnancy than postpartum, remained at levels of 96.5% and above. During pregnancy, the oxygen saturation levels for weeks 30, 36 and 39 were 97.0%, and at week 34 the level was 96.5%. Ten weeks postpartum showed an increase from 97.0% at week 39 to 98.8%.

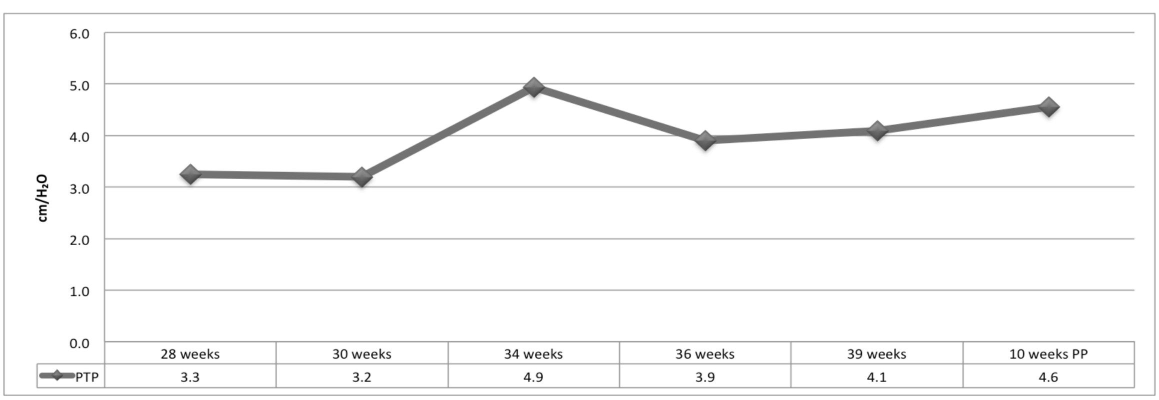
Figure 3.3: Oxygen Saturation



Aerodynamic Data

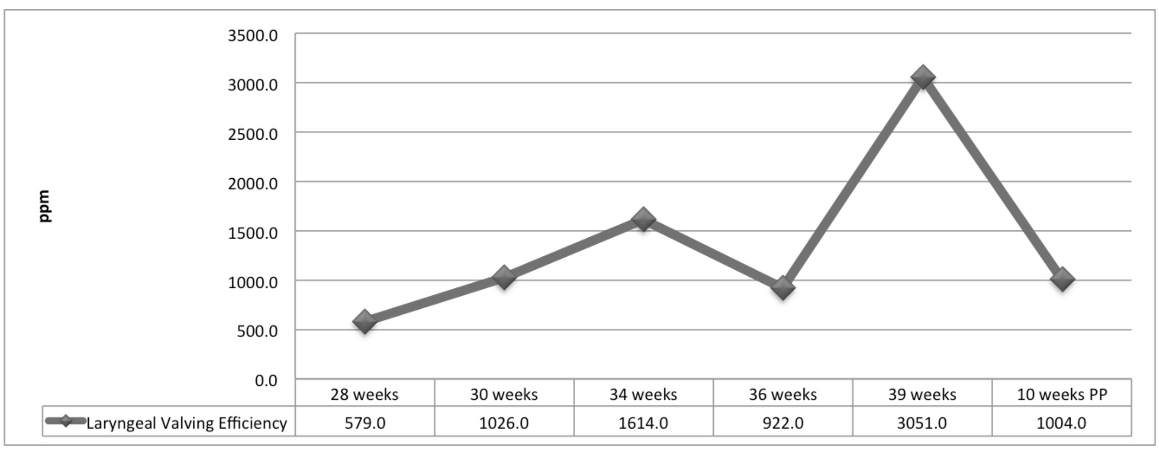
An indicator of vocal health, phonatory threshold pressure (PTP) is a measure of the minimum pressure required to initiate the first cycle of vocal fold vibration. The trend for PTP measurements during pregnancy increased from 3.3 cm/H_2O to 4.1 cm/H_2O, with the exception of the highest value at 34 weeks, 4.9 cm/H_2O. Interestingly, the 10 week postpartum measurement continued to increase from the full term value for PTP of 4.1 cm/H_2O, to a value of 4.6 cm/H_2O.

Figure 3.4: Phonatory Threshold Pressure



Calculated with an equation encompassing a number of aerodynamic measures, laryngeal valving efficiency, or vocal efficiency, is a measurement that gives an overview of laryngeal behavior.[112] Laryngeal valving efficiency increased from week 28 to week 34, with values beginning with 579.0 parts per million (ppm) to 1614.0 ppm. In week 36 there was a decreased level of efficiency, measuring at 922.0 ppm. Week 39, five days before the birth, had the highest value for efficiency, measuring at 3051.0 ppm. A marked drop was evidenced at the 10 week postpartum measurement, which was 1004.0 ppm.

Figure 3.5: Laryngeal Valving Efficiency



The aerodynamic measures that affect laryngeal valving efficiency are illustrated in the following figure. Each of the values from these measures in this figure is presented in the following figures for further explanation.

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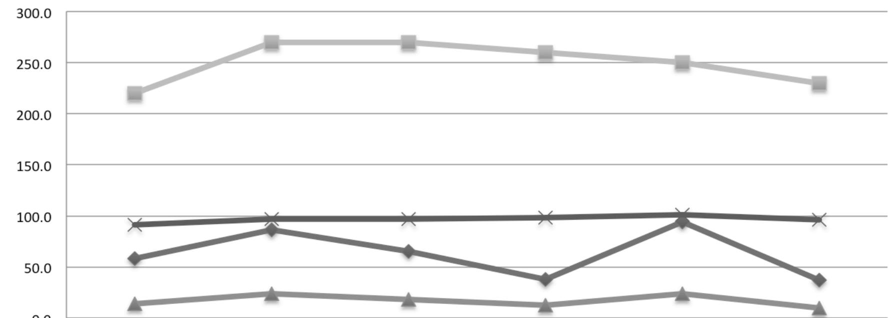
[112] KayPENTAX *Phonatory Aerodynamic System*,123.

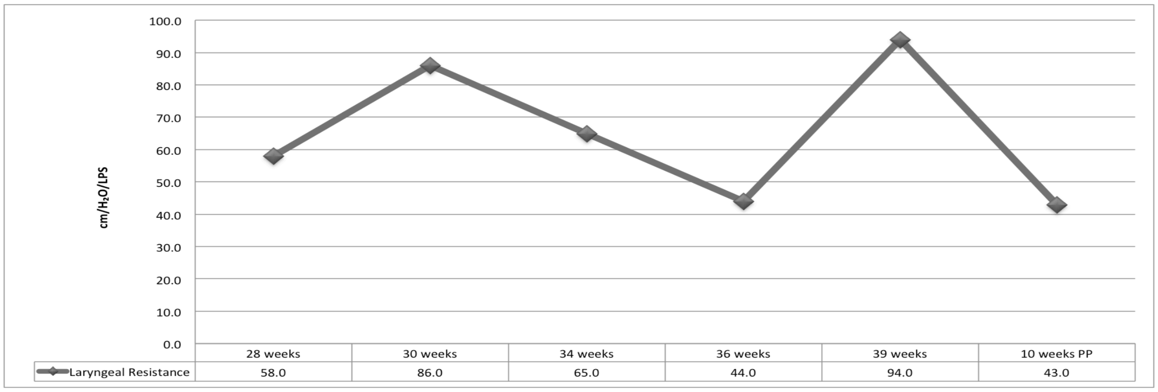
Figure 3.6: Aerodynamic Measures that affect Laryngeal Valving Efficiency



	28 weeks	30 weeks	34 weeks	36 weeks	39 weeks	10 weeks PP
Laryngeal Resistance (cm/H_2O/LPS)	58.0	86.0	65.0	38.0	94.0	37.0
Mean Airflow During Voicing (cc/sec)	220.0	270.0	270.0	260.0	250.0	230.0
Mean Peak Air Pressure (cm/H_2O)	14.0	24.0	18.0	12.21	24.0	9.82
Mean SPL During Voicing (dB SPL)	91.0	97.0	97.0	98.0	101.0	96.0

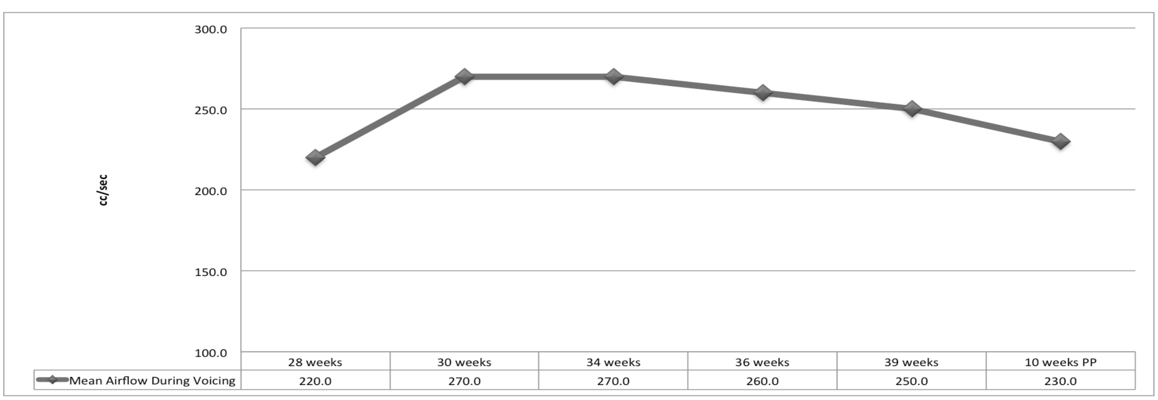
Laryngeal resistance reflects the amount of resistance to airflow generated by the larynx during phonation. Laryngeal resistance values, which were obtained through the task of sung /i/, at the dynamic of *forte*, repeated three times (on G4 for week 28, and E-flat 5 for the remaining dates), showed marked changes over time. During pregnancy, resistance increased between 28 – 30 weeks, from 58.0 cm/H_2O/LPS to 86.0 cm/H_2O/LPS. From week 30 to week 36, a decrease in laryngeal resistance occurred, from 86.0 cm/H_2O/LPS, to 44.0 cm/H_2O/LPS. During Week 39 of the pregnancy the value increased to 94.0 cm/H_2O/LPS. The postpartum reading from week 10 of postpartum decreased to 43.0 cm/H_2O/LPS, which was almost the same as week 36.

Figure 3.7: Laryngeal Resistance



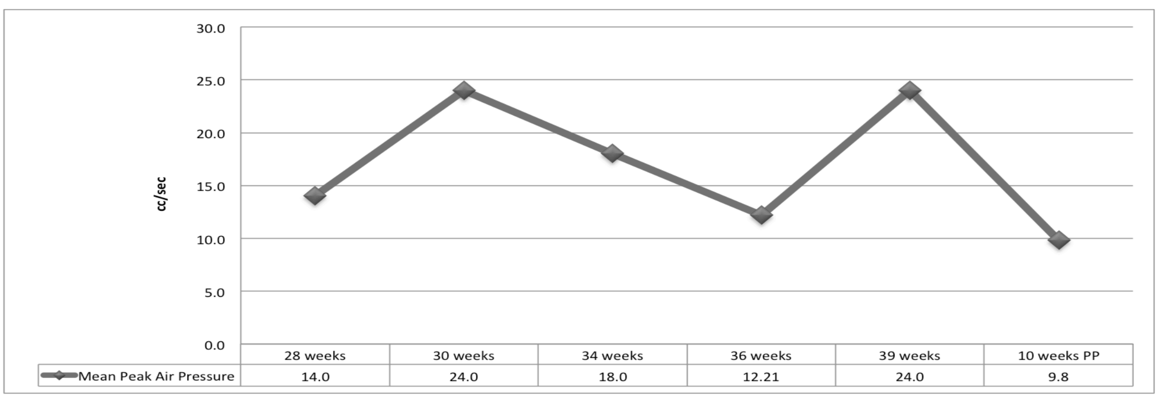
Mean airflow during voicing is defined as the average amount of airflow moving through the vocal folds during phonation. From 28 weeks through 30 weeks there was a slight increase from 220.0 cc/sec to 270.0 cc/sec; the latter value was maintained through 34 weeks. From that time forward, there was a consistent decline of mean airflow during voicing, through week 39, at 250.0 cc/sec, to 10 weeks postpartum, at 230.0 cc/sec.

Figure 3.8: Mean Airflow During Voicing



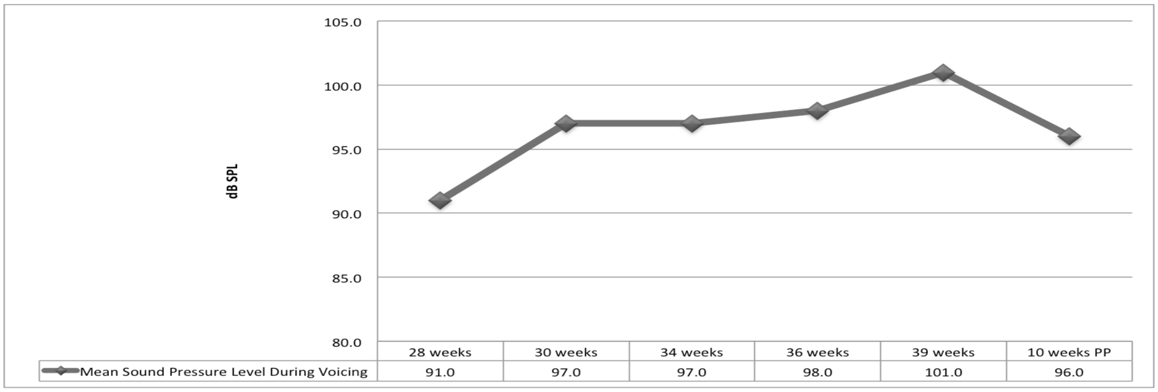
Mean Peak Air Pressure is an aerodynamic measure that averages the values of the pressure peak values, or built up oral pressure (which is taken as an estimate of subglottal pressure) recorded by the task of the sung /i/, at the dynamic of *forte*, on G4 for week 28, and E-flat 5 for the remaining weeks. The data showed a direct relationship with laryngeal resistance, with a marked rise in values at weeks 30 and week 39. From the beginning, there was an increase from week 28 to week 30, from 14.0 cm/H_2O to 24.0 cm/H_2O. A decrease occurred from week 30 through week 36, from 24.0 cm/H_2O to 12.0 cm/H_2O. Moving forward, the value of mean peak air pressure was maximal in week 36, to 24.0 cm/H_2O, while week 10 postpartum evidenced a marked decrease to 10.0 cm/H_2O.

Figure 3.9: Mean Peak Air Pressure



The Mean Sound Pressure Level (SPL) is defined as the acoustic correlate of loudness. As the figure below specifies, there was an increase in mean sound pressure level that continued from week 28 through week 39 of the pregnancy. The rise in mean SPL began with 91.0 dB at 28 weeks, and increased to 101.0 dB by week 39. The postpartum reading had a decreased value of 96.0 dB at 10 weeks postpartum.

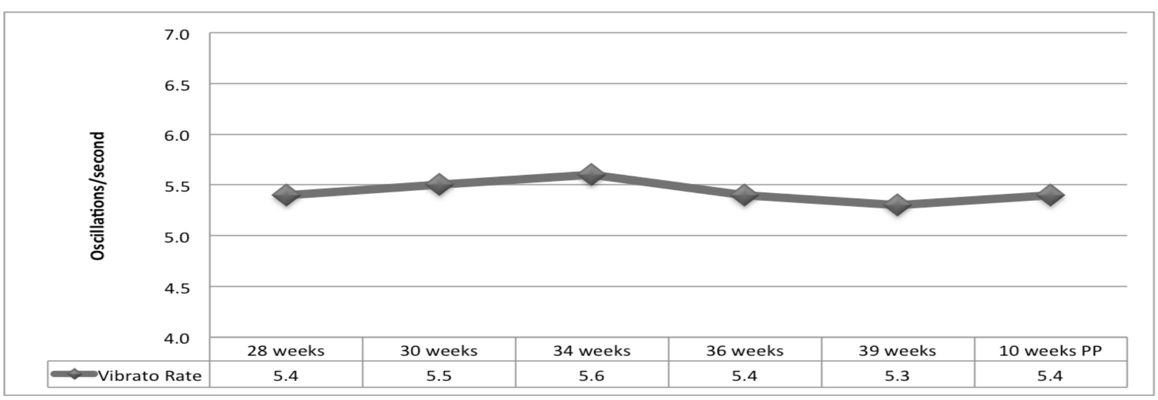
Figure 3.10: Mean Sound Pressure Level



Acoustic data

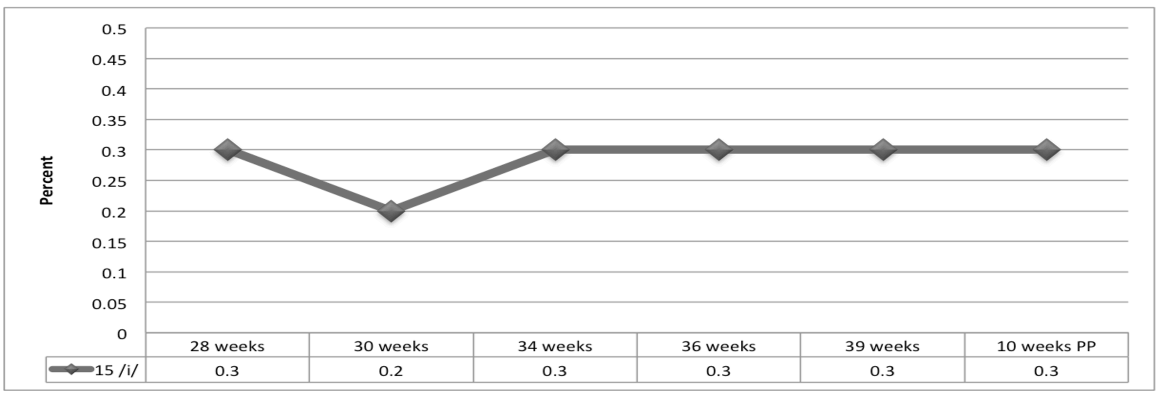
The vibrato rate measures were obtained from week 28 through week 10 postpartum. The vibrato rate stayed relatively consistent throughout pregnancy and postpartum, around 5.4 oscillations per second.

Figure 3.11: Vibrato Rate for 15 /i/'s on A-flat 5



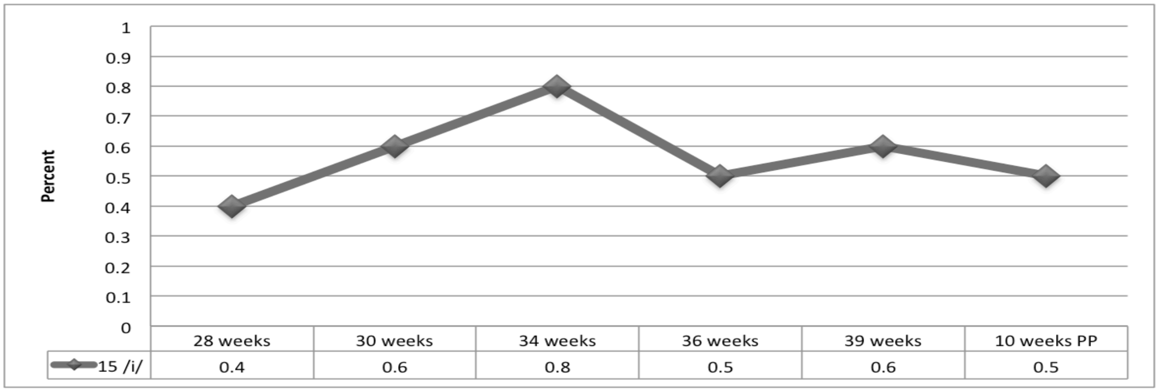
The Pitch Perturbation Quotient, or PPQ, is a measure of short-term variation in frequency, from cycle-to-cycle, and is an indicator of noise in the voice. PPQ for the pregnancy remained at 0.3% throughout the study, with the exception of week 30, where the level was 0.2%.

Figure 3.12: Pitch Perturbation Quotient for 15 /i/'s at A-flat 5



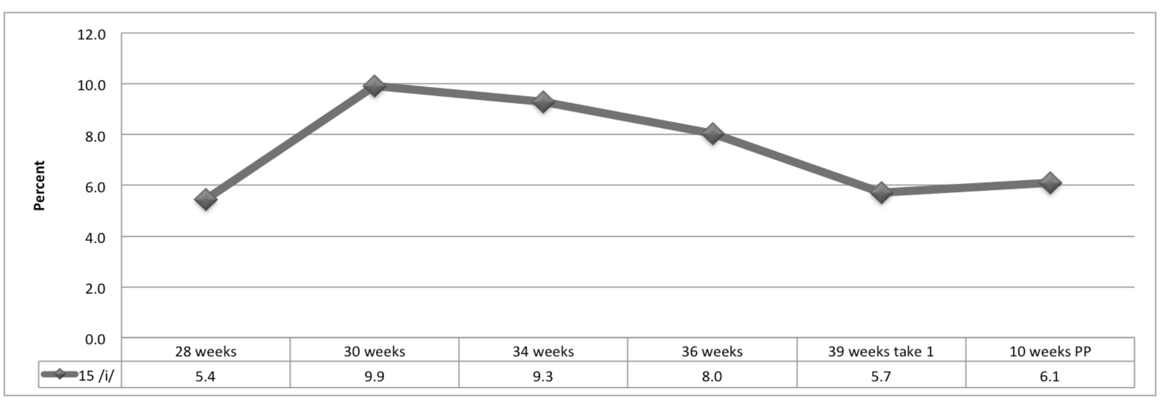
The Amplitude Perturbation Quotient, or APQ, is the measure of the short-term variation in the distance the vocal folds open from the midline, and is also an indicator of noise. The values for this measure began with a marked increase from 0.4% at 28 weeks to 0.8% in week 34. A decrease occurred in week 36, to 0.5% APQ, followed by a slight increase during week 39 to 0.6%. The postpartum value decreased to 0.5%.

Figure 3.13: Amplitude Perturbation Quotient for 15 /i/'s at A-flat 5



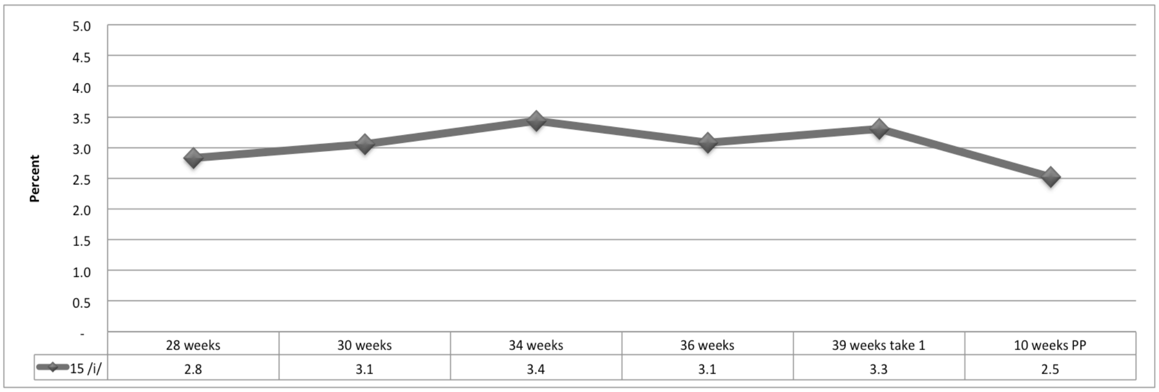
Amplitude Tremor Intensity Index, or ATRI, measures long-term amplitude, or long-term intensity variation, and is used in this study to reflect the intensity component of vibrato. ATRI values increased dramatically from the 28th week of pregnancy, from 5.4 %, to 9.9% in 30 weeks. Then a systematic decrease in values occurred from 30 weeks to 39 weeks of pregnancy, to 5.7 % in week 39 (similar to the 28th week in pregnancy value, 5.4%). The postpartum measure was also similar in weeks 28 and 39, with the latter having the value of 6.1%.

Figure 3.14: Percentage of Amplitude Tremor Intensity Index for 15 /i/'s on A-flat 5



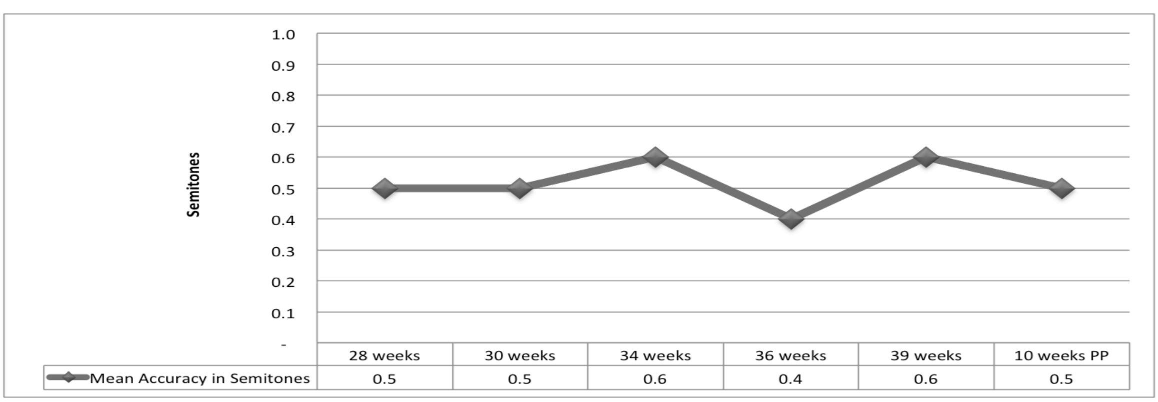
An index reflecting the frequency component of vibrato, the Frequency Tremor Intensity Index (FTRI) showed stable values during pregnancy, which centered around 3.0%. The postpartum value decreased slightly to 2.5%.

Figure 3.15: Frequency Tremor Intensity Index for 15 /i/'s at A flat 5



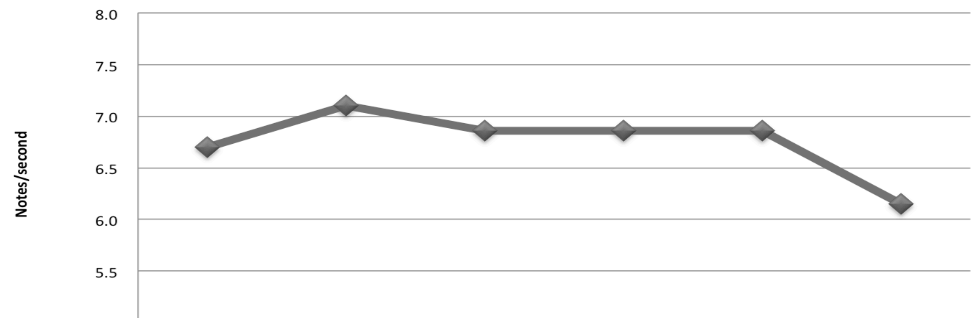
The mean accuracy values recorded throughout the study were relatively unchanged in pitch accuracy in semitones, with the highest value being .6 semitones away from the target pitch.

Figure 3.16: Mean Pitch Accuracy in Semitones



Mean agility values reflect the number of notes produced per second. During the third-trimester of pregnancy, the agility in this participant stayed relatively constant; however, at 10 weeks postpartum, the agility decreased to 6.2 notes per second.

Figure 3.17: Mean Agility in Notes/Second



	28 weeks	30 weeks	34 weeks	36 weeks	39 weeks	10 weeks PP
Mean agility in notes/second	6.7	7.1	6.9	6.9	6.9	6.2

CHAPTER FOUR

DISCUSSION

The goal of this study was to compare the acoustic and aerodynamic data reflecting physiological changes during the participant's gravidity. To provide a framework for data interpretation, participant's state of vocal health and level of function during pregnancy and postpartum must first be considered.

Self-assessments

The Vocal Handicap Index evaluates how the voice influences the life of the speaker, physically, functionally, and emotionally. The Singing Vocal Handicap Index primarily serves as a way to address "the physical, emotional, social, and economic impact of singing voice problems."[113] The highest possible self-evaluation value on the Singing Voice Handicap Index is 144, and the highest self-assessed value on the Voiced Handicap Index is 120. In either index, a high value indicates increased problems. However, this participant's overall self-assessment was healthy, never over a two for either index. Therefore, the participant's data seem to indicate she was feeling healthy, overall, because her self-assessed values were so close to zero. Although the findings for the self-assessed measures of Vocal Handicap Index (VHI) and Singing Handicap Index (SHI) did not exceed a level two for either assessment, when compared, the findings may seem counter-intuitive. One may expect values on the VHI and the SHI to coincide,

[113] Seth M. Cohen, M.D., M.P.H., Barbara H. Jacobson, Ph.D., C. Gaelyn Garrett, M.D., J. Pieter Noordzij, M.D.; Michael G. Stewart, M.D., M.P.H., Albert Attia, Robert H. Ossoff, D.M.D., M.D., and Thomas F. Cleveland, Ph.D., "Creation and Validation of the Singing Voice Handicap Index," *Annals of Otology, Rhinology & Laryngology* 116 (2007): 402.

because the same person's voice, on the same day, experiencing the same level of physiological and psychological awareness, is being evaluated. However, given the strenuous nature of professional-level singing, performers often regard their instrument with keen sensitivity. Because of her awareness of her vocal instrument, when considering function, this participant was able to evaluate each type of production separately. Therefore, this evaluation resulted in data that differed almost in parallel opposition between the two indices.

The values for the VHI show the singer was more comfortable speaking than singing during the last six weeks of pregnancy, as compared to the postpartum rating. SHI values show a shift in vocal functioning perception, as the participant was more comfortable singing at 30 weeks of gravidity, but as the pregnancy progressed to full-term, less comfort in vocal functioning during singing was evident. The values for SHI decreased at 10 weeks postpartum, which shows a shift towards higher level of comfort for singing.

These assessments reflect both psychological and physiological issues. After the birth, when a woman's body is no longer experiencing the weight and requirements of pregnancy, the participant might have felt increased "freedom" when singing, because of the return of non-pregnant physiological function, most especially in the lungs and abdominal area. However, when the daily task of speech is required, the experience of dehydration and fatigue postpartum (during lactation, especially), can allow for more immediate concerns regarding vocal function. The participant nursed on demand for the first five months, and then continued nursing 14 months postpartum. Given this fact, the first months postpartum introduced sleep deprivation and the possibility of dehydration if the participant was not drinking enough fluids. Therefore, combined factors of fatigue and insufficient hydration may be variables to consider.

It is also necessary to consider that indices of self-perception are subjective. Furthermore, the participant was aware of the purpose of the indices, which may have biased her responses.

Respiratory measures

According to literature, vital capacity does not change during pregnancy.[114] The mean vital capacity for women between 25 and 50 is between 3.6 liters and 3.9 liters.[115] This study revealed a slight decrease in vital capacity from week 30 to week 39 during pregnancy, with the values beginning at 3.1 liters, and decreasing to 2.9 liters in in weeks 36 and 39. This drop, however, is miniscule; perhaps, due to the growing fetus, there was slightly less room in the lungs, or, perhaps the participant was too fatigued to provide enough energy for the measurements to be made consistently. The postpartum vital capacity value displayed in the data increased to 3.1 liters. This leads to the consideration that the participant, who is petite, may have slightly less vital capacity than the average singer, given that both age and size are considered when calculating vital capacity.[116] Thus, these measures indicate the participant's relatively stable respiratory health.

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[114] Mattison, 8.

[115] Carole Ferrand, *Speech Science: An Integrated Approach to Theory and Clinical Practice.* (Boston, MA: Pearson, Allyn and Bacon, 2014), 244.

[116] Ferrand, 242.

The oxygen saturation results indicate normal health for the participant, although it is interesting that the data show slightly less oxygen saturation during pregnancy than postpartum. The values during pregnancy remain at 97.0%, and increase to 99.0% postpartum. According to the American Association of Critical Nurses Manual for Critical Care, 97.0% to 99.0% oxygen saturation measurements are normal for a healthy individual.[117] Interestingly, a point of information from the same reference indicates that in some people, oxygen saturation may vary based on the level of physiological activity and the level of oxygen in the tissues.[118] Perhaps the levels were not at 100.0% because the singer was performing an operatic aria during the time of measurement. Considering all facts presented for both vital capacity and oxygen saturation measurements, however, the participant is considered healthy, with little change over time in respiratory function.

Phonatory Threshold Pressure

The aerodynamic measure of Phonatory Threshold Pressure (PTP) indicates the level of vocal health of the participant. The values of PTP during gravidity increased from 3.3 cm/H_2O to 4.1 cm/H_2O, which is to be expected, due to the possible edema of the vocal folds during pregnancy related to increased hormone levels. The highest PTP value, during week 34, 4.9 cm/H_2O, may be related to fatigue or increased swelling of the vocal folds on that particular day.

Mindful that typical estimates of phonatory threshold pressure during conversational speech are found to be 3.0 cm/H_2O to 5.0 cm/H_2O, the postpartum PTP

[117] Wiegand, 77.
[118] Ibid.

data displays interesting results.[119] The task for this measure was repeated three times, and consisted of seven quietly spoken /pi/s. The 10 week postpartum PTP level was found at an increased level, from 4.1 cm/H_2O during week 39 of pregnancy to 4.6 cm/H_2O. This indicates there was more aerodynamic effort involved to initiate vocal fold vibration postpartum. This increased effort may be due to lack of sleep and possible dehydration. The participant's nursing on demand caused sleep deprivation, and lactation could affect hydration levels if not enough water was ingested during this time.

When regarding these indicators of physiological and vocal condition during gravidity and postpartum, including self-analysis, respiratory measures (including oxygen saturation and vital capacity), and vocal health measures (as measured by phonatory threshold pressure), the participant presents healthy levels of physiological and vocal function. The following discussion will highlight how the pregnancy impacted acoustic and aerodynamic vocal function. The acoustic and aerodynamic data from pregnancy will be compared to the postpartum data to demonstrate changes, if any, that are found in the participant's physiological and vocal health.

Acoustic measures

During the third trimester, both positive and negative results were shown within acoustic measures. Noticeable differences are apparent in the amplitude tremor intensity index (ATRI). A possible explanation for the systematic increase in loudness variation during vibrato from week 28 to week 30 (from 5.4 % to 9.9%) is that the participant was less fatigued, resulting in an increase of energy. It is of interest that the sound pressure

[119] Ferrand, 167.

level measure, albeit taken from another task, also showed increased values from week 28 to week 30, from 91 dB to 97 dB, substantiating this possibility. The systematic decline from week 30 to week 39 in ATRI (from 9.9% to 5.7%) is attributed to the participant approaching her due date, when an increased level of fatigue was a likely factor. Increased weight gain also could have affected breath support, which would, in turn, affect the subglottal pressure, and thus decrease the amplitude variation.

The ATRI values at 10 weeks postpartum stabilized at the same value found in week 39. This could also be due to the transition of the physical demands of late pregnancy to those of caring for a newborn baby, including the fatigue associated with full-time nursing.

The frequency tremor intensity index (FTRI) measures long-term changes in frequency that is perceived as vibrato. The third trimester FTRI values remain relatively the same, from 2.8% in week 28, to 3.3% FTRI in week 39. There is a small increase in this value during week 34, from 2.8% to 3.4%, and then a decrease to 3.1% in week 36. Concluding with the postpartum values of FTRI, a slight decrease was seen in the value of 2.5%.

According to Ferrand, in *Speech Science: an Integrated Approach to Theory and Clinical Practice*, healthy shimmer measures for speech are below 0.5 dB, and healthy jitter measures for speech are between 0.2% and 1%.[120] Based on this, the closer the jitter and shimmer percent values are to zero, the less noise in the voice. Both the jitter and shimmer percent values remained below 1.0% for the duration of the study, as the APQ data (measuring shimmer) rose slightly in the first part of the third trimester, and the PPQ values (measuring jitter) rose slightly during the second half of the third trimester. The

[120] Ferrand, 186

postpartum value of APQ declined from the 39 week value, from 0.6% to 0.5%. In conclusion, the periodicity of vocal fold vibration was not noticeably affected by gravidity.

The data for the acoustic measure of agility present a reduction in the number of notes produced per second at 10 weeks postpartum as compared to the third trimester. The values of agility during pregnancy ranged from 6.7 to 7.1 notes per second, with the 10 weeks postpartum value reducing to 6.2 notes per second. The task from which these values were determined was the 24-note chromatic task that began on B-flat 4 and was sung as quickly and accurately as possible. The decline in postpartum agility could be due to physical fatigue, or other factors that affect vocal fold vibration, such as dehydration or edema. It was during this time that the participant active both day and night, caring for the newborn, including breast-feeding exclusively. It may be concluded that that agility was not affected by pregnancy so much as it was affected by the first few months of postpartum fatigue.

Pitch accuracy in semitones, measured from the same task as agility, was not affected by pregnancy. Accuracy within 0.5 semitones at 28 weeks remained constant until 36 weeks of pregnancy, which decreased to 0.4 semitone accuracy. However, in week 39, semitone accuracy was 0.6, which decreased slightly to 0.5 semitone accuracy at 10 weeks postpartum.

Decreased values for acoustic measures in the third trimester include only vibrato rate, as it decreased by 2.0%, from 5.4 oscillations/second, to 5.3 oscillations/second. This is a positive finding, indicating that pregnancy does not affect vibrato for the professional singer. Accepted vibrato rates are 5.0 – 7.0 oscillations/second, and the results show the vibrato rate was within this range throughout the study.

Aerodynamic measures

Now that the acoustic measures have been assessed, the results of aerodynamic measures of laryngeal efficiency, and what affects this efficiency, will be examined. Laryngeal efficiency demonstrates how effectively the vocal folds valve air.

Laryngeal valving efficiency increased dramatically during the third trimester, from 579.0 ppm at 28 weeks, to 3051.0 at 39 weeks. One possible reason for the marked increase from week 36, at 922.0 ppm, to 3051.0 ppm in week 39, may be physiological preparation for birth. The participant was two cm dilated and reached her maximum weight of 158 pounds. The baby was born five days later, and hormone changes may have influenced the laryngeal configuration for increased laryngeal resistance. (Sound pressure level readings have an increasing correspondence to the increased values in laryngeal resistance, as will be discussed later.)

Postpartum values for laryngeal valving decreased, from 3051.0 ppm during week 39, to 1004.0 ppm at 10 weeks postpartum. This decrease at 10 weeks postpartum is unsurprising, given postpartum recovery was relatively rapid, due to the natural delivery that required no caesarean section. The support system rebounded quickly to pre-pregnancy function as compared to the end of the third trimester of gravidity.

Laryngeal resistance, in addition to mean peak air pressure, mean airflow during voicing, and mean sound pressure level, influences laryngeal valving efficiency. The values for laryngeal resistance are interesting, as an increase in value is found in both weeks 30 and 39. The peak at 39 weeks corresponds directly to the peak in laryngeal valving efficiency, likely making it a prime factor of influence in that value. Laryngeal resistance is the amount of resistance to the airflow which is sustained at the level of the glottis; the body was preparing to give birth five days later, and was likely experiencing increased hormonal activity (again, the participant was in the earliest stage of labor), which could affect the function of the folds due to swelling or increased dryness. Another viable consideration is that the participant was doing her best to overcome the physical challenges associated with advanced pregnancy, and increased vocal effort for the task in lieu of proper respiratory support. The 10 week postpartum value for laryngeal resistance dropped considerably, from 94.0 cm/H_2O/liter/second to 43.0 cm/H_2O/liter/second. This value suggests a return of more typical laryngeal and respiratory function postpartum.

Interestingly, the values for laryngeal resistance and the values for mean peak air pressure both show increases in weeks 30 and 39. These similarities indicate how the laryngeal resistance was being affected; the high levels of mean peak air pressure at those particular times (24.0 cm/H_2O for both dates) suggest an increase in medial compression of the vocal folds, as more pressure was required to blow the folds apart. Earlier it was surmised, based on acoustic measure of ATRI, as well as increased levels in laryngeal resistance and mean peak air pressure, that week 30 may have been a more energetic week for the participant. Therefore, perhaps this suggested level of energy was related to vocal fold closure, and therefore, increased laryngeal efficiency. As week 39 was only five days away from birth, perhaps an increase of hormonal activity in preparation for birth increased medial compression.

Mean airflow during voicing stayed relatively the same during gravidity through 10 weeks postpartum, with a slight increase from 220.0 cc/sec to 270.0 cc/sec, where it remained through week 34. Slowly, a slight decrease to 250.0 cc/sec occurred from 34 weeks to 39 weeks of gravidity. The airflow continued to drop at 10 weeks postpartum, but only slightly, to 230.0 cc/sec.

Finally, mean sound pressure level (SPL) values in this study have appeared to be associated with third trimester gravidity. The initial level of SPL during week 28 was 91 dB, and continued to an increased value of 101.0 dB in week 39. The increased SPL at week 39 corresponds directly to the laryngeal efficiency measure peak in week 39, just as the laryngeal resistance and peak airflow do. The decrease in the postpartum value for SPL at 10 weeks postpartum, 96.0 dB, is reasonable due to a decreased energy felt by the participant at this time, as discussed earlier.

Therefore, similar results of increased values between (in order of increasing percentages) mean sound pressure level during voicing, mean airflow during voicing, phonatory threshold pressure, laryngeal resistance, mean peak air pressure, and laryngeal valving efficiency, are evidenced with the aerodynamic measures during the third trimester. The smallest increase was seen in mean agility, at a 6.0% increase, and the greatest increase was demonstrated in the data for laryngeal valving efficiency, at 427.0%.

Table 4.0 displays comparative measures for self-evaluated, respiratory, acoustic, and aerodynamic measures during the third trimester of pregnancy. The measures are listed as having no change, a decrease in value, or an increase in value, and are listed in increasing order. The values reflected are the lowest and highest values obtained.

Table 4.0: Comparative Measures for Respiratory, Acoustic, And Aerodynamic Values during the Third Trimester

No change *2% or less*	**Decreased Values** *3% or more* *Listed in increasing order*	**Increased Values** *3% or more* *Listed in increasing order*
Vibrato rate 5.4 - 5.3 (beats/second) *Decreased by 2%*	Vital Capacity 2.90 - 3.09 (l) *Decrease of 7%*	Mean Agility 6.7 - 7.10 (notes/second) *Increased by 6%*
Oxygen Saturation 96.5 - 97.0 (%) *Increased by 1%*		Mean Accuracy in Semitones .50 - .55 (semitones) *Increased by 9%*
		Mean Sound Pressure Level during Voicing 91 - 101 (dB SPL) *Increased by 11%*
		FTRI 2.83 - 3.43 (%) *Increased by 21%*
		Mean Airflow during Voicing 220 - 270 (cc/sec) *Increased by 23%*
		Pitch Perturbation Quotient .25 - .32 (%) *Increased by 28%*
		Phonatory Threshold Pressure 3.3 – 4.9 (cm/H_2O) *Increased by 49%*
		Laryngeal resistance 58 - 94 (ppm) *Increased by 62%*
		Mean Peak Air Pressure 14 - 24 (cm/H_2O) *Increased by 42%*
		*ATRI 5.44 – 9.93 (%, weeks 28 -30) *Increased by 72%* 9.93 – 5.72 (%, weeks 30-39) *Decreased by 42%*
		*APQ .38 - .78 (%, weeks 28 -34) *Increased by 105%* .78 – .64 (%, weeks 34-39) *Decreased by 18%*
		Laryngeal Valving Efficiency 579 – 3051 (ppm) *Increased by 427%*

*These values indicate the measure both increased and decreased during the study.

Acknowledging this as a longitudinal study, the data between week 39 of pregnancy and 10 weeks postpartum provides another interesting comparison. Because week 39 was the last week of data acquisition before the birth, the body was at its maximum weight. The participant was 2.0 cm dilated at the week 39 recording, and her body had already begun preparing for labor. Thus, brief comparative measures between this point and 10 week postpartum is especially revealing when considering elements of vocal function between these two highly contrasting times of physiological function.

The following discussion addresses changes revealed in Table 4.1. The increased vital capacity from week 39 to week 10 postpartum is mostly likely due to more room in the thoracic area after the pregnancy. The oxygen saturation level increase, at 2.0%, is notable; however, this value does pose a question as to why the levels decreased during pregnancy. Postpartum, there was no longer a need for the body to use oxygen for sustaining two lives, so the oxygen saturation level was higher. Perhaps the increased activity level of singing an aria, as mentioned earlier, had an effect of decreased oxygen saturation in the tissue.

The increased value of 12.0% for phonatory threshold pressure postpartum may reveal increased swelling at the level of the folds, which may be related to fatigue or dehydration. The amplitude tremor intensity index shows an increase of 6.0%, meaning the long-term variations in loudness during vibrato increased. This, combined with the higher score on the Vocal Handicap Index, reveals the participant was possibly affected by increased laryngeal tension, which would affect both PTP and ATRI.

Decreased values for corresponding vocal attributes indicate that these values began at a higher level during the last week of pregnancy than their values at 10 weeks postpartum. The difference in agility measures, although decreased only by 10.0%, may be due to fatigue postpartum. Mean pitch accuracy in semitones decreased 2.0%, with fatigue, again, being the most probable factor. Laryngeal efficiency, which is influenced by laryngeal resistance, mean airflow during voicing, mean peak air pressure during voicing, and mean sound pressure level during voicing, shows a noticeable decrease from 39 weeks of pregnancy to 10 weeks postpartum. The components of this measure also decreased, with mean peak air pressure during voicing and laryngeal efficiency decreasing by over half.

These decreased aerodynamic measures possibly reflect volatility in hormonal influence, as progesterone drops considerably after birth, greatly impacting the function of the larynx by reducing hormonally influenced dehydration. The body, by 10 weeks postpartum, has begun to revert to its pre-pregnancy physiological state, including increased thoracic space for more efficient breath management. Thus, all the measurements that comprise laryngeal efficiency show signs of returning to pre-pregnancy levels following the last week of pregnancy.

Table 4.1: Comparative Measures for Respiratory, Acoustic and Aerodynamic Values Between Week 39 of Pregnancy and 10 Weeks Postpartum

No change *2% or less*	**Decreased Values** *3% or more* *Listed in increasing order*	**Increased Values** *3% or more* *Listed in increasing order*
Vibrato Rate 5.31 – 5.36 (beats/second) *Increased by 1%*	Mean Sound Pressure Level during Voicing 101.0 – 96.0 (dB SPL) *Decreased by 5%*	ATRI 5.72 – 6.09 (%) *Increased by 6%*
Oxygen Saturation 97.0 – 98.8 (%) *Increased by 2%*	Mean Airflow During Voicing 250.0 – 230.0 (cc/sec) *Decreased by 8%*	Vital Capacity 2.91 – 3.12 (l) *Increased by 7%*
Mean Pitch Accuracy in Semitones 0.55 - 0.54 (semitones) *Decreased by 2%*	Mean Agility 6.86 – 6.15 (notes/sec) *Decreased by 10%*	Phonatory Threshold Pressure 4.1 – 4.6 (cm/H_2O) *Increased by 12%*
	Pitch Perturbation Quotient 0.32 - 0.28 (%) *Decreased by 13%*	
	Amplitude Perturbation Quotient 0.64 - 0.49 *Decreased by 23%*	
	FTRI 3.3 – 2.52 (%) *Decreased by 24%*	
	Laryngeal Resistance 94.0 – 43.0 (cm/H_2O/l/sec) *Decreased by 54%*	
	Mean Peak Air Pressure 24.0 – 9.82 (cm/H_2O) *Decreased by 59%*	
	Laryngeal Valving Efficiency 3051.0-1004.0 (ppm) *Decreased by 67%*	

Comparison to previous studies on pregnancy and the voice

The data from this study provide interesting comparisons and contrasting points with data from the three studies presented in Chapter One. In "The Impact of Pregnancy on the Singing Voice: A Case Study," author Stephanie Adrian experienced variations in perturbation measures from week 27 to week 35, with jitter percent increasing 49.0%, from 0.67% to 1.0%, and shimmer percent decreasing 61%, from 3.2% to 1.2%[121]. The current study differs in that the pitch perturbation quotient remained the same, at 0.3% jitter from weeks 28 to 36. Interestingly, amplitude perturbation quotient measures for the current study also differ from Adrian's study. The current study's jitter increased 25%, from 0.4% to 0.5% from week 28 to week 36.

Considering aerodynamic findings in the Adrian study, sound pressure level increased from 81.16 dB to 91.93 dB from weeks 27 – 35, which was an increase of 13.3%.[122] The current study has comparable sound pressure level, which at 28-weeks was 91.0 dB SPL and 98.0 dB SPL at 36-weeks. This was an increase of 8.0%. The slight difference in the data between the studies most likely has to do with the difference in the tasks.

Comparisons with the study by Verónica L. Cassiraga, "Pregnancy and Voice: Changes in the Third Trimester," are less easily gleaned. Because of the different measures taken, and the lack of a classically trained soprano as a participant with no sung tasks included, there are no direct values to compare.

Comparative measures between the current study and "Pregnancy and the Singing Voice," by Filipa Martins Baptista Lã and Johan Sundberg, were the most similar; increased vocal efficiency was evidenced in both studies. The study by Lã and Sundberg came to this conclusion by interpreting increased phonatory threshold pressure and collision threshold pressure, in addition to low normalized amplitude quotient during pregnancy.[123] These measures were acquired through similar tasks for both studies. The current study came to this conclusion through the increase in aerodynamic measures,

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[121] Adrian, 268.
[122] Ibid.
[123] Lã, 435.

including laryngeal valving efficiency, as influenced by laryngeal resistance, mean peak air pressure, mean airflow during voicing, mean peak air pressure, and mean sound pressure level during voicing.

CHAPTER FIVE

CONCLUSION

The impacts of pregnancy on acoustic and aerodynamic aspects of the classically trained soprano voice were studied longitudinally. The participant was a healthy thirty-five year old throughout the study. Respiratory, acoustic, and aerodynamic data were acquired during the following weeks of pregnancy: 28 weeks, 30 weeks, 34 weeks, 36 weeks, and 39 weeks, as well as 10 weeks postpartum.   When considering the results, it is apparent that vocal efficiency increased during pregnancy, and subsequently decreased at 10 weeks postpartum.

The data for this study revealed both positive and negative changes in acoustic and aerodynamic measures during the third trimester. Positive findings indicate, for this participant, that pitch accuracy and vibrato rate were not markedly affected by pregnancy during the third trimester. However, increasing values were found for acoustic and aerodynamic measures that influence laryngeal valving efficiency, a measure that indicates laryngeal function. Although the values were within healthy levels, with no signs of physical or vocal damage, the increase of laryngeal valving efficiency suggests increasing tension, peaking in week 39 of pregnancy. This corresponds to the body's increasingly high progesterone and estrogen levels immediately prior to childbirth, as well as to the increase of the fundus, which corresponds with weight gain. These high hormonal levels have been shown to influence the body with increased vocal edema, hoarseness, and dehydration which most likely affected the professional voice in a noticeable way at the end of the third trimester.

In summary, addressing questions about vocal function may be more easily attempted with this addition to literature on pregnancy and the voice. Each singer's experience will be unique and the results will never be exactly the same. However, the association of increased laryngeal tension, as found in this study and in accordance with the Lã and Sundberg study, as well as in the data presented by Adrian and Cassiraga, seems to suggest that vocal edema and hoarseness may often be experienced by singers when pregnant.

With this awareness, therefore, it is recommended that professional singers maintain healthy vocal function throughout gravidity. This can be achieved by continuing vocalizations and repertoire that was already part of the singer's study and performance prior to conceiving. Remaining vigilant about proper hydration is important, especially due to the dehydrating effects of progesterone during pregnancy. Maintaining a balance of activity and much needed physical rest is recommended. Making appropriate physiological choices can help maintain vocal efficiency, which is paramount for sustaining vocal health both during gravidity as well as postpartum.

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