THE EFFECT OF VOCAL WARM-UP ON VOICE QUALITY OF UNTRAINED FEMALE SINGERS IN MALAYSIA

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THE EFFECT OF VOCAL WARM-UP ON VOICE QUALITY OF UNTRAINED FEMALE SINGERS IN MALAYSIA

ABSTRACT

Professional singers and singing teachers regard vocal warm-up as vital. However, very few studies have evaluated this effect quantitatively. This study aimed to evaluate the effect of the vocal warm-up on the singing voice quality through acoustic parameters of Jitter, Shimmer and harmonics-to-noise ratio (HNR) and to assess whether scientific evidence supports the warm-up procedure, whether an untrained singer can benefit from singing vocal warm-up exercises in a similar way as a trained singer and whether the vocal warm-up should be encouraged or bypassed. 40 untrained female singers were recorded twice while uttering the vowel /a/, /o/ and /i/ in two different pitches: Low- A3 (220.0 Hz) and High- C5 (523.2 Hz) for at least five seconds. The recordings were collected before and after a 20 minutes vocal warm-up session. Results showed significant variations in the average values of the parameters measured. A decrease was detected in comparison with the average value of Jitter and Shimmer before and after the vocal warm-up, whereas HNR increased. The results of this study provide valid support for the advantageous effect of vocal warm-up on the voice quality of untrained female singers and present acoustic analysis as a valuable and sensitive tool for quantifying this effect. The positive effects of the findings indicated that the vocal warm-up should be encouraged and not bypassed. As for the vowel effect, per cent jitter, per cent shimmer and harmonics-to-noise ratio (HNR) may not be useful for the description of acoustic differences between vowels.

Keywords: vocal warm-up, voice quality, acoustic parameters

KEBERKESANAN PEMANASAN SUARA TERHADAP KUALITI VOKAL PENYANYI TIDAK TERLATIH DI MALAYSIA

ABSTRAK

Pemanasan vokal adalah sangat penting bagi penyanyi profesional and guru vokal untuk mengekalkan kesihatan suara mereka. Namun, masih terdapat kurang kajian yang dijalankan secara kuantitatif dalam bidang ini. Kajian ini bertujuan untuk menyelidik keberkesanan pemanasan suara terhadap kualiti vokal dengan menggunakan parameter akustik *Jitter, Shimmer and harmonics-to-noise ratio (HNR)*. Selain itu, kajian ini dijalankan untuk menilai sama ada bukti saintifik menyokong prosedur pemanasan vokal, menilai sama ada penyanyi yang tidak terlatih boleh mendapat manfaat daripada menyanyi latihan pemanasan vokal dengan cara yang sama seperti penyanyi terlatih dan menilai sama ada pemanasan vokal harus digalakkan atau dilangkau. 40 penyanyi wanita yang tidak terlatih direkodkan dua kali sambil mengucapkan vokal /a/, /o/ dan /i/ dalam dua nada: Nada rendah-A3 (220.0 Hz) dan Nada tinggi-C5 (523.2 Hz) untuk sekurang-kurangnya lima saat. Rakaman telah dikumpulkan sebelum dan selepas sesi pemanasan vokal selama 20 minit. Keputusan menunjukkan variasi ketara dalam nilai purata parameter akustik yang diukur. Penurunan nilai purata *Jitter* dan *Shimmer* dikesan dengan perbandingan sebelum dan selepas pemanasan suara, sedangkan *HNR* meningkat. Hasil kajian ini memberikan sokongan yang sah mengenai kebaikan dan kepentingan pemanasan vokal terhadap kualiti suara penyanyi wanita yang tidak terlatih dan membuktikan analisis akustik sebagai alat yang berharga dan sensitif untuk mengukur kesan ini. Kesan positif penemuan dalam kajian ini menunjukkan bahawa pemanasan suara harus digalakkan dan tidak dilangkau. Keputusan kajian ini mencadangkan peratus *Jitter* dan *Shimmer s*erta *harmonics-to-noise ratio (HNR)* mungkin tidak berguna untuk perihalan perbezaan akustik antara vokal.

Kata Kunci: pemanasan vokal, kualiti vokal, parameter akustik

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LIST OF SYMBOLS AND ABBREVIATIONS

HNR : Harmonics-to-noise ratio

PTP : Phonation Threshold Pressure

SPSS : Statistical Package for the Social Sciences

SPR : Singing Power Ratio

TA : Paired Thyroarytenoid

PCA : Posterior Cricoarytenoid

LCA : Lateral Cricoarytenoid

IA : Interarytenoid

CT : Cricothyroid

MHC : Myosin Heavy Chain

ATP : Adenosine Triphosphate

STF : Slow Tonic Muscle Fibres

VFE : Dr. Joseph Stemple's Vocal Function Exercises

MANOVA : Multivariate Analysis of Variance

ANOVA : Analysis of Variance

MPFR : Maximum Phonation Frequency Range

PPE : Perceived Phonatory Effort

MRI : Magnetic Resonance Imaging

LPC : Linear Predictive Code

F1 : First Formant

F2 : Second Formant

F3 : Third Formant

RAP : Relative Average Perturbation

L3 : Third Formant

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CHAPTER 1

INTRODUCTION

1.1 Background of the study

The human voice is a result of motor activity, which is determined by genetic, social, cultural, and linguistic factors. The production involves complicated aerodynamics and biomechanism that requires the three anatomical systems, namely respiratory, laryngeal, and surgical systems, be neurophysiologically coordinated. The respiratory system, together with the larynx, generates the subglottal air pressures necessary to initiate and maintain voicing (Morrison & Rammage, 1994; Titze, 1994; Verdolini, 1998). The laryngeal system is the vocalisation source, and the supralaryngeal system modulates the source-generated energy into an acoustic output perceived by the listener. Speaking and singing utilised these systems; however, singing voice requires the maximisation of vocal output by increasing respiration, phonation, and resonance coordination (Morrison & Rammage, 1994; Titze, 1994; Verdolini, 1998). Good singing may seem an effortless act, but most singers engage in training since singing is an athletic activity that requires a good condition and a coordinated interaction of various physical functions (Sataloff, 2015).

Singing voices vary from speaking voices in a variety of acoustic, physical, and perceptual ways, and many researchers have quantified these differences. The singing voice has three major units: the lungs, which act as a power supply; the vocal folds, which is an oscillator; and the vocal tract, which acts as a resonator (Sundberg, 1977; Zhang, 2016). These elements work together to create the voice that is heard in both speech and singing, but it is the manipulation of the vocal instrument that occurs in singing that sets the singing and speaking voices apart, for example, during singing, singers learn to execute a series of resonatory and phonatory adjustments that non-singers don't learn (McCrea & Morris, 2007). According to Sundberg (1977), the shape and length of the vocal folds determine the frequencies created by the vocal folds including the amount of air pressure moving through them. There are muscles stretching and thinning the vocal folds. When this happens, the frequency will be higher and when they are in the opposite shape, the frequency is lower. Singers develop control over their frequency range, which allows them to sing a larger range or several octaves of frequencies and vocal warm-up allows them to practice the precision of those vocal instrument adjustments (Sundberg, 1977).

Voice pedagogues, voice therapists, singers and scientists alike devote tremendous time and energy to designing and validating vocal exercises to enhance the voice quality of a performer. In voice pedagogy, the term "voice quality" refers to the distinctive characteristics which characterize the singing voice. In an evaluative context, the same word is often used to denote to what degree a specific vocal production meets professional quality expectations. Acoustic measures are instrumental in describing voice qualities (Teixeira & Fernandes, 2014; Sascha & Pascal, 2019).

Standard acoustic measures that are widely used to measure vocal quality are jitter, shimmer, and Harmonics-to-noise ratio (HNR) (Bausar, Bohlender, Mehta, 2018; Teixeira & Fernandes, 2014; Sascha & Pascal, 2019). For this study, the independent variable was vocal warm-up instructions. The acoustic parameters of jitter, shimmer and harmonics-to-noise ratio (HNR) were the dependent variables. In the description of normal and dysphonic speakers, the acoustic parameters, jitter and shimmer, have proven to be useful in measuring the production of sustained vowels, vocal characteristics related to roughness and hoarseness respectively. These perturbation measures were used to track and record frequency variability and instability in the signal. The measure of fundamental frequency cycle-to-cycle variation which is known as the vocal perturbation is referred to Jitter (De Felippe, Grillo & Grechi, 2006; Teixeira, Oliveira, & Lopes, 2013). Jitter measures were studied by the following authors: Brown et al. (1990) studied sustained vowel in female subjects; Sabol et al. (1995) collected values for sustained vowels, and Brown, Rothman, and Sapienza (2000) studied values for sung and spoken vowel.

Shimmer, also known as amplitude perturbation, quantifies the cycle-to-cycle variability in waveform amplitude (Teixeira, Oliveira, & Lopes, 2013; James & John, 2007). Shimmer measures were studied by the following authors: Brown et al. (2000) studied sustained vowel /i/ from speaking and singing tasks between male and female singers and non-singer groups, and Amir, Amir, and Michaeli (2005) investigated sustained vowels in classical voices. The perturbation measures provide valuable voice and vocal health information. Jitter (roughness) has been reported mainly due to insufficient control of vocal fold vibrations. Patients with vocal fold pathologies have a higher percentage of reported jitter. With reduced vocal fold lesions and glottal resistance, Shimmer improves. The presence of noise at emission and breathiness is associated with Shimmer. The hoarseness and breathiness of voice normally execute vocal quality changes due to deterioration of voice and laryngeal diseases (Teixeira, Oliveira, & Lopes, 2013; James & John, 2007; Mezzedimi et al., 2018).

The noise-related measure which is the harmonics-to-noise ratio (HNR), captures the relative contributions of all periodic to aperiodic energy in the speech signal. Harmonics-to noise ratios (HNR) is an objective and quantitative evaluation of the degree of hoarseness (De Felippe, Grillo & Grechi, 2006; Teixeira, Oliveira, & Lopes, 2013). Shimmer measures were studied by the following authors: Brown et al. (2000) studied sustained vowel /i/ from speaking and singing tasks between male and female singers and non-singer groups, and Amir, Amir, and Michaeli (2005) investigated sustained vowels in classical voices. Normal voices have low additive noise in the voice and characterized by a high HNR (Yumoto & Gould, 1982; Teixeira, Oliveira, & Lopes, 2013). Greater harmonic energy or greater signal in the voice represents more effective vocal fold vibration and hence better voice quality. Thus, increased noise energy within the signal suggests abnormal vocal function. Harmonics-to-noise ratio (HNR) measures the number of voice signals and a higher measure of HNR which is associated with decreased noise energy represents better vocal quality (Christian, 2007; Teixeira, Oliveira, & Lopes, 2013; Yumoto & Gould, 1982). Reduced measurements of perturbation associated with reduced variability in the signal and, therefore, better vocal quality.

There is very little information as to how vocal warm-up affects the acoustics parameter of the singing voice although the vocal warm-up is widespread and comprehensive in the singing community (Amir, Amir, & Michaeli, 2005). The goal of the present study was to use acoustic measures to evaluate the effect of vocal warm-up on the voice quality of untrained female singers in Malaysia.

1.2 Statement of the Problem

The computerized acoustic analysis was presented in previous years as a reliable and successful tool to assess subtle changes in voice quality and stability. The potential benefit of this tool is to reliably record, calculate and quantify minor variations that are otherwise difficult to identify (Teixeira & Fernandes, 2014; Sascha & Pascal, 2019). Standard acoustic measures that are widely used to measure vocal quality are jitter, shimmer, and Harmonics-to-noise ratio (HNR) (Bausar, Bohlender, Mehta, 2018; Teixeira & Fernandes, 2014; Sascha & Pascal, 2019). However, conflicting evidence exists that these acoustic measures can thoroughly evaluate vocal characteristics. Although the changes in acoustic values were statistically significant, it did not always indicate clinically significant improvements in vocal performance. For example, the singing voice has lower shimmer and noise-to-harmonic ratio than the speaking voice, according to Lundy et al. (2000). However, no significant differences were found in a different study using these voice quality parameters between singers and untrained speakers. From the literature, therefore, it is unclear if such acoustic parameters will contribute to the vocal quality of untrained female singers after the intervention of vocal warm-up.

Besides that, a major drawback of earlier research is that the vocal warm-up procedures used differently between the studies. Some research permitted participants to utilize a personalized warm-up regimen (Amir, Amir & Michaeli, 2005) while others utilized structured warm-up procedures (Motel, Fisher, & Leydon, 2002; Elliot, Sundberg & Gramming, 1995). In previous studies, the duration of warm-up procedures differed greatly between 7 and 30 minutes (Amir, Amir & Michaeli, 2005; Elliot, Sundberg & Gramming, 1995; Motel, Fisher, & Leydon, 2002). This lack of consistency may lead to conflicting results between studies. Thus, this research aimed to assess the impact of vocal warm-up on voice quality of untrained female singers using acoustic measures in two-pitch conditions, A3 (chest register) and C5 (head register) before and after vocal warmup. A standardized warm-up protocol with a duration of 20-minutes was carried out in this study. Hypothetically, one can assume that per cent jitter and shimmer will decrease while harmonics-to-noise ratio (HNR) will increase following a vocal warm-up.

1.3 Research Objectives

1. To evaluate the effect of vocal warm-up on the voice quality of untrained female singers through the acoustic parameter – Jitter.

2. To evaluate the effect of vocal warm-up on the voice quality of untrained female singers through the acoustic parameter – Shimmer.

3. To evaluate the effect of vocal warm-up on the voice quality of untrained female singers through the acoustic parameter – Harmonics-to-noise ratio (HNR).

4. To study whether acoustic parameters (Jitter, Shimmer and Harmonics-to-noise ratio (HNR)) differ with vowel type (/a/, /o/, /i/) at different pitch level – Low predetermined tone (frequencies) - A3 (220.0 Hz).

5. To study whether acoustic parameters (Jitter, Shimmer and Harmonics-to-noise ratio (HNR)) differ with vowel type (/a/, /o/, /i/) at different pitch level – High predetermined tone (frequencies) - C5 (523.2 Hz).

1.4 Purpose of the Study

The goal of the study was (1) to establish whether vocal warm-up immediately affects the vocal quality of untrained female singers using acoustic analysis, both before and after vocal warm-up in two pitch conditions, A3 (chest register) and C5 (head register), (2) to assess whether scientific evidence supports the warm-up procedure, and (3) whether it should be encouraged or bypassed. Although it is well recognised and practised by professional, warm-ups are sometimes bypassed and neglected by singers and voice teachers (Amir, Amir & Michaeli, 2005). The null hypothesis of this investigation is that there will be no difference in vocal quality between the experimental conditions as measured by dependent variables of acoustic parameters of Jitter, Shimmer, and Harmonics-to-noise ratio (HNR). The alternative hypothesis is that there will be differences in these acoustic measurements as a function of vocal warm-up.

1.5 Significance of the Study

Singers are called “vocal athletes” because the demands placed on the singer’s voice are immense. Singers are different from non-singers as singers have higher stamina, strength and phonatory agility. This enables them to perform complex laryngeal manoeuvers to fulfil their vocal demands during singing, according to Zeitels, Hillman, Desloge, Mauri & Doyle (2002). The benefit of singing vocal warm-ups has long been documented, and untrained singers could apply the techniques used by trained singers to enhance their singing voices. Nevertheless, minimal empirical evidence is available to validate the effect of vocal warm-up on the singing voice quality of untrained female singers in Malaysia. Most of the research focused heavily on trained singers (Amir, Amir, and Michaeli, 2005; Thorpe et al., 2001; Griffin, Woo, Colton, Casper & Brewer, 1995). Therefore, there is a need to gain a greater understanding of what is happening to the voice quantitatively as a result of warm-up and which parameters are affected in the voices of untrained singers.

This research seeks to determine whether an untrained singer can benefit from singing vocal warm-up exercises in a similar way as a trained singer, perhaps proving that anyone can improve their singing with some training. A strong foundation of supportive research about vocal warm-ups could assist in establishing the need for vocal training and education of solo voice educators. Understanding the pedagogical results of vocal warm-ups could benefit voice teachers in implementing best practice in rehearsals.

1.6 Definition of Terms

For the present study, the following terms are operationally defined as follows:

Voice Quality

The distinctive characteristics which characterize the singing voice. It involves both phonatory and resonatory characteristics (McCrea & Morris, 2007). Some of the descriptions of voice quality are roughness, breathiness, hoarseness and nasality (Teixeira, Oliveira, & Lopes, 2013; James & John, 2007). Acoustic measures are instrumental in describing voice qualities (Teixeira & Fernandes, 2014; Lathadevi & Suresh, 2008). Acoustic analysis is a part of computerized voice laboratories and it is useful in supplementing the assessment of voice quality and speech analysis (Sascha & Pascal, 2019).

Jitter

Jitter is a measure of fundamental frequency cycle-to-cycle variations. It is also known as the vocal perturbation. A decrease in Jitter indicates that there is an improvement in vocal roughness (Teixeira & Fernandes, 2014; Lathadevi & Suresh, 2008).

Shimmer

Also known as amplitude perturbation, quantifies the cycle-to-cycle variability in waveform amplitude. A decrease in Shimmer indicates that there is an improvement in vocal breathiness (Teixeira & Fernandes, 2014; Lathadevi & Suresh, 2008).

Harmonics-to-noise ratio (HNR)

An assessment of the ratio that captures the relative contributions of all periodic to aperiodic energy in the speech signal. An increase in HNR indicates that there is an improvement in vocal hoarseness (Teixeira & Fernandes, 2014; Lathadevi & Suresh, 2008).

Untrained Singers

Individuals who enjoy singing as a hobby but never had any previous vocal training.

Two pitch-conditions

Low-A3 (220.0 Hz) and High-C5 (523.2 Hz). The low pitch was produced in the chest register and the high note in the head register (Lee, Kwon, Choi, Lee, Lee & Jin, 2008).

1.7 Conceptual Framework

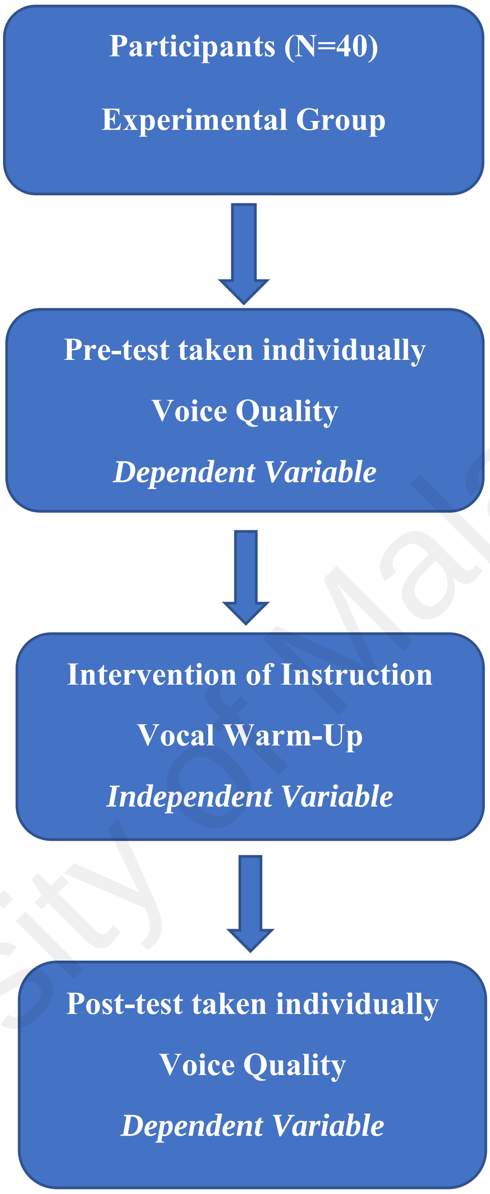


Figure 1: Conceptual Framework

The Effect of Vocal Warm-up on Voice Quality of Untrained Female Singers in Malaysia

1.8 Research Questions:

The following research questions guided this investigation:

1. Does vocal warm-up significantly alter the acoustic parameter - Jitter of the untrained singing voice?

2. Does vocal warm-up significantly alter the acoustic parameter - Shimmer of the untrained singing voice?

3. Does vocal warm-up significantly alter the acoustic parameter - Harmonics-to-noise ratio (HNR) of the untrained singing voice?

4. Do acoustic parameters (Jitter, Shimmer and Harmonics-to-noise ratio (HNR)) differ with vowel type (/a/, /o/, /i/) at different pitch level – Low predetermined tone (frequencies) - A3 (220.0 Hz)?

5. Do acoustic parameters (Jitter, Shimmer and Harmonics-to-noise ratio (HNR)) differ with vowel type (/a/, /o/, /i/) at different pitch level – High predetermined tone (frequencies) - C5 (523.2 Hz)?

1.9 Delimitations of the Study

While a rigorous design was used in this study, there were still limitations. Caution should be taken when making generalizations based on the research results presented, partly because of the following possible factors:

1. The study was only open to untrained female singers.
2. A small sample size of the present study.
3. Only fixed six vocal warm-up exercises for this study.
4. Only fixed three vowels for this study.
5. A control group was not used in this study.

1.10 Organization of the Study

In summary, the research questions in this study concentrate on the effect of vocal warm-up on the voice quality of untrained female singers. This research is structured as follows, to find answers to the interrelated central questions. Chapter one introduces the background of the study on vocal warm-up and the acoustic measures of the singing voice. Chapter two elaborates on laryngeal biomechanics; laryngeal biomechanics; acoustic analysis of voice - perturbation measures (Jitter, Shimmer and Harmonics-to-noise ratio (HNR)); acoustic voice analysis using Praat software; the physiological effects of vocal warm-up; vocal tract tuning, resonance, and acoustics; singer's formant; measurement of the singer's formant; disordered voices; and the effectiveness of vocal warm-up was completed indicated by the literature review. Chapter three elaborates on the research method and the data collection procedures. Chapter four elaborates on the results and analysis after the data is calculated with Praat software and the Statistical Package for the Social Sciences (SPSS) Version 25. Chapter five concludes with a summary, conclusion and recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review documented fundamental discussions of voice science and vocal pedagogy to provide untrained singers with anatomical knowledge of the voice and the mechanics of vocal mechanics (Ronald, Thomas & Frederick, 2011 Chhetri, Neubauer & Berry, 2014; Palaparthi et al., 2019; Poletto, Verdun, Stominger & Ludlow, 2004). This review benefits untrained vocal singers and vocal coaches who seek ways to teach vocal techniques, as this provides a unique and concise way to answer questions about fundamental issues of vocal pedagogy, and understand the benefits of singing a vocal warm-up through the acoustic analysis.

This chapter begins with a review of the studies regarding the production of voice and laryngeal biomechanics which relate large muscle performance and recovery processes to that of the intrinsic muscles of the larynx (Chhetri, Neubauer & Berry, 2014; Palaparthi et al., 2019; Poletto, Verdun, Stominger & Ludlow, 2004). If one is to make comparisons between the large muscles of the body and the small, intrinsic muscles of the larynx, background information regarding laryngeal muscle physiology is necessary. This studies presented in this section focus on the muscle fibre types of the human thyroarytenoid muscle (TA). Of interest is the fatigability of this primary vocal fold adductor. Vocal fatigue or voice disorder is a phenomenon reported by both amateur and professional voice users alike. Vocal pedagogy touts warming up the voice as a means to improve vocal performance as well as reduce injury and fatigue. Studies on the effectiveness of vocal warm-up are presented, using perturbation measures to analyze voice quality in the singing voice.

A comprehensive literature review has been done on the voice production; laryngeal biomechanics; laryngeal biomechanics; acoustic analysis of voice - perturbation measures (Jitter, Shimmer and Harmonics-to-noise ratio (HNR)); acoustic voice analysis using Praat software; the physiological effects of vocal warm-up; vocal tract tuning, resonance, and acoustics; singer's formant; measurement of the singer's formant; disordered voices; and the effectiveness of vocal warm-up was completed. The literature involved normal voices, trained singing voices, and disordered voices as well as vocal warm-up exercises.

In the published literature some variations between the voices of singers and non-singers were identified. Differences have been reported in jitter, shimmer and harmonics-to-noise ratio (HNR) (Milenkovic, 1987; Brown, Rothman, and Sapienza, 2000), phonation threshold pressure (Elliot, Sundberg, & Gramming, 1995; McHenry et al., 2009), and singing power ratio (SPR) (Amir, Amir, and Michaeli, 2005).

2.2 Production of Voice

Phonation is the production of voiced sound through vocal fold vibrations. The sound waves production is a pressure disturbance distributed across time and space (Zhang, 2016). The larynx is a hollow, tubular structure connected to the top of the trachea which consists of the intrinsic laryngeal muscles, membranes, cartilages, and ligaments (Ronald, Thomas & Frederick, 2011). Vocal folds are tissue folds in the throat that are key to creating sounds through vocalization. They comprised of twin folds of mucous membrane extending horizontally from back to front across the larynx (Maria, 2007). The opening space between the vocal folds is referred to the glottis. Vocal fold abduction involves the movement of a vocal fold away from the glottis due to muscular contraction within the larynx. Posterior cricoarytenoid (PCA), paired thyroarytenoid (TA), and lateral cricoarytenoid (LCA), inter arytenoid (IA), and cricothyroid (CT) form part of the intrinsic laryngeal muscles (Chhetri, Neubauer & Berry, 2014; Palaparthi et al., 2019; Poletto, Verdun, Stominger & Ludlow, 2004). The intrinsic laryngeal muscles control the fine motor actions of the larynx. The muscles of the paired thyroarytenoid (TA) form the majority of the vocal fold body. The paired thyroarytenoid (TA) muscles shorten, thicken and stiffen the vocal folds upon contraction. Contraction of the CT muscles causes the vocal folds to lengthen. Contraction of LCA muscles causes vocal fold adduction. The contraction of the PCA muscles abducts the vocal folds and lowers resistance. The muscle of the IA (interarytenoid) holds the vocal cords in a closed position after they are joined together by the LCA muscles. It closes the glottis and seals the posterior glottis (Chhetri, Neubauer & Berry, 2014; Palaparthi et al., 2019; Poletto, Verdun, Stominger & Ludlow, 2004). Vocal fold vibration is caused by air pressure below the adducted vocal folds (Sataloff, 2017). The vocal folds sustain self-oscillation and the oscillation produces a sound (Titze, 1988). For the oscillation of the vocal fold, the activation of intrinsic laryngeal muscles is important as both small and large oscillations of the amplitude need approximation of the vocal folds. Vocal morphology and the stress distribution in the tissue are affected by intrinsic laryngeal muscle activation (Palaparthi et al., 2019).

Production of the sound in singing involves a proper positioning of the larynx and a shaping of the vocal tract with special attention to the placement of the articulators. The tongue is to remain free of tension to allow for the vocal tract to remain as open as possible to create an “open throat” perception. By shaping the tip of the tongue to the bottom of the lower front teeth, a separation of the hyoid bone from the top of the larynx is accomplished, again aiding in the low larynx position to optimize vocal tract resonance (DeCaro & Donato, 2006). Another advantage of a low larynx position was that the distance of the intraglottal tissue decreases as the distance between the hyoid bone and thyroid cartilage increases, which means that the vocal folds can vibrate more freely, the mechanical stress on the vocal folds is lessened, and therefore voice output is enhanced by expanding the laryngeal ventricle and enhancing the energy of the singer’s formant (Vurma & Ross, 2003). The biomechanics of the larynx should, therefore, be understood to explain vocal productions and how they are affected by the warm-up.

2.3 Laryngeal Biomechanics

It is essential to understand how the laryngeal muscles can be affected by a vocal warm-up. This section aims to address the role of the laryngeal muscles in healthy vocal production and how vocal quality can be enhanced.

Biomechanics concepts can be applied to much of the movement of the laryngeal muscles, which consist of vocal folds that function mechanically (Cooper, Patridge, & Alipour-Haghighi, 1993). The laryngeal biomechanics is a complex interaction of solid mechanics, fluid mechanics, and acoustics (Titze, 2000). Solid mechanics is the study of rigid bodies, while fluid mechanics is the study of the movement of liquids and gases. Solids, liquids, and gases are made of tiny particles, and the bulk movement of a large particle system can be described by mechanical principles. The aggregated particles may deform, translate, or rotate (Titze, 2000). When the intrinsic, extrinsic, and supplemental muscles contract, the active forces in the larynx arise, which are then spread across the vocal fold tissues (Titze, 2000).

Paired thyroarytenoid (TA) muscles and cricothyroid (CT) muscles are the most prominent intrinsic laryngeal muscles. They are the primary muscles regulating vocal pitch. Lengthening the vocal folds is mainly achieved by using the CT muscles. It moves the thyroid cartilage forward and thereby stretches the vocal folds, increases stress, and raises the vocal pitch. The TA resides within the vocal folds, which makes them shorter and stiffer and has a nonlinear effect on the vocal pitch. The body layer of the vocal folds is formed by TA muscles, while CT muscles control the tension in the vocal fold membranes (Deguchi et al., 2011; Poletto, Verdun, Stominger & Ludlow, 2004). The TA muscle is responsible for the muscle actions during a speech while the CT muscle plays with higher fundamental frequencies, for example, singing in the head register and transition of registers (Watson, 2009; Poletto, Verdun, Stominger & Ludlow, 2004).

The vocal warm-up can be measured in numerous ways, for example, what will happen to the vocal fold tissues after warm-up. According to McHenry, Johnson & Foshea (2009), the vocal warm-up is a submaximal exercise that is known to have similar warm-up effects for physical activity. Physical activity warm-up is designed to reduce the risk of injury, improve skeletal muscle dynamics, and increase athlete performance (Woods, Bishop & Jones, 2007). The possibilities of physiological improvements during physical exercise warm-up include: (1) Increased skeletal muscle speed, strength, and relaxation through faster metabolism; (2) Reduced internal viscosity of active skeletal muscles led to increased movement efficiency and smoother contractions; (3) Facilitated release of haemoglobin oxygen at high temperatures of the skeletal muscle tissue to allow more oxygen release to the working muscles; (4) Higher temperature promotes faster dissociation of haemoglobin and oxygen, a mechanism that helps to provide more oxygen to active tissues; (5) Enhanced secondary nerve transmission, which could lead to increased contraction speed and reduced reaction time at higher tissue temperatures; and (6) increased blood flow through active tissue due to vasodilatation (Hoffman, 2002; Woods et al., 2007). Increased skeletal muscle temperature and increased blood flow are the main physiological changes due to warm-up, according to McHenry et al. (2009).

Most research has concentrated primarily on the physiologic characteristics of the human skeletal muscles. There is a lack of studies that examine the characteristics of laryngeal muscles in humans; therefore it remains unclear (Hoh, 2005). Skeletal muscle fibre forms of laryngeal muscles have been observed in both human and animal models. The presence of myosin heavy chain (MHC) isoforms characterizes skeletal muscle fibres which regulates the speed of contraction (Barany, 1967). While various forms of skeletal muscle fibre and hybrid combinations of different fibre types are likely to exist, the classification will be summarized as follows for this discussion: Type I fibres are highly resistant to fatigue and contract slowly; Type II is the most fatigable but fastest-contracting fibre types. Both types of muscle fibres vary concerning the bioenergetics pathway used to form adenosine triphosphate (ATP). As an energy substrate, Type I fibres rely on oxygen for the continuous supply of ATP. ATP is the usable energy form of the body needed to initiate, sustain and stop muscle contraction. The fast-twitch fibres can be further classified into three main subtypes: Type IIa, Type IIx, and Type IIb. Such fibres mainly contribute to muscle speed and strength and differ in fatigability. For the generation of ATP, immediate energy (phosphocreatine) systems and glycolysis at different levels are provided by type IIx and IIb fibres (Hoh, 2005).

The laryngeal muscles of three healthy humans were examined by Teig, Dahl and Thorkelsen (1978). The researchers stained the frozen portion of each muscle and microscopically examined the fibres. The researchers concluded that the laryngeal muscles consist of a combination of type I and type II muscle fibres. The research showed that the Paired thyroarytenoid (TA) muscle has faster fibre type profiles than the Posterior cricoarytenoid (PCA) muscle, which has faster fibres than the cricothyroid (CT) muscle (Hoh, 2005). The PCA muscle is the main vocal cord abductor while the cricothyroid (CT) muscle is the only tensor muscle of the larynx aiding with phonation (Deguchi et al., 2011; Poletto, Verdun, Stominger & Ludlow, 2004). The variability in the distribution of muscle fibre type in both skeletal limb muscle and laryngeal muscle differ from person to person due to genetic predisposition. According to Hoh (2005), muscle endurance may change to adapt to changes in function and hormonal stimuli, but the distribution of the fibre type remains constant in a person.

A study by Brandon et al. (2003) found TA specimens to have types I, IIa, and some had type IIx with more abundant type II (fast-twitch) fibres. Additionally, a few rare fibres for both α-cardiac and type I were found. No muscle spindles were identified throughout the TA, which is in contradiction to a study by Han et al (1999). The investigators suggest it is possible that, like extraocular muscles, human laryngeal muscles use specialized spindle-like receptors and afferents (evolved specialized, non-weight bearing movements). These receptors may provide feedback as to vocal fold length and position as highly adapted kinesthetic receptors (Brandon et al., 2003b).

Kersing and Jennekens (2003) found almost equal proportions of muscle fibre types I and II, and they acknowledged reports that the glycolytic and oxidative capacity of the type II fibres (type IIa) indicate that the majority have the aerobic capacity, like type I fibres. Therefore, both are “rich” in mitochondria. Like the Brandon study, no muscle spindles were identified. A human TA research by Han et al. (1999) explored the presence and distribution of slow tonic tone muscle fibres (STFs), the tonic of the contractile properties of which differ significantly from slow as well as fast-twitch fibres. Immunofluorescence microscopy revealed STF in the human TA.

The investigators found the STF to be localized in the middle of the vocalis (anterior-posterior orientation). Additionally, these fibres were found interspersed singularly or in small groups among twitch muscle fibres. The authors hypothesize that such arrangements allow the STF to influence vocal fold vibration either directly or by interaction with twitch fibres. These tonic fibres are thought to “exert a filtering effect on the harmonics produced by vocal fold vibration (p.155)”. STF was also found interspersed with muscle spindles. Together, these fibres may play a key role in proprioception (e.g., perception of position, length and tension). The authors conclude that “the presence of many STF, or STF at certain locations within the TA, maybe one of the reasons that certain individuals can sing professionally just as other genetic physical attributes allow some people to be star athletes (p. 155)”. While the TA is comprised mostly of fibres of oxidative metabolism, making it generally fatigue-resistant, it appears that there is considerable variation among individuals as to the proportion of types I and II and hybrid muscle fibres. The current understanding of the effects of ageing on the TA as compared to skeletal limb muscles was reviewed by Thomas, Harrison and Stemple (2008). The authors conclude that the TA may be characterized as rapidly contracting and largely fatigue resistant. This combination is unusual for limb skeletal muscle. Additionally, the TA muscle differs from limb skeletal muscles in terms of its innervation, architecture, mitochondrial content, contractile protein profile, and ageing patterns (Thomas et al., 2008). The authors warn that the research concerning the typical skeletal muscle cannot be easily generalized to the laryngeal musculature because of these variations. However, generalized laryngeal fatigue remains debilitating for many averages, as well as, professional voice users. Laryngeal fatigue is characterized by physical sensations similar to that of skeletal muscles. Singers and speakers complain of muscle ache, soreness, and tension, as well as, the need for increased effort to continue vocalizing. The physiological and biomechanical phenomena associated with laryngeal fatigue remain under investigation (Welham & Maclagan, 2003). As the skeletal muscles composition of the vocal fold is being established, it is important to understand how the laryngeal muscles can be affected by a vocal warm-up. Although it is difficult to directly quantify the impact of vocal warm-up on the individual intrinsic laryngeal muscles, a well-established standardized acoustic analysis tool can indirectly measure the collective influence of warm-up (Milenkovic, 1987; Brown et al., 1990; Brown, Rothman, and Sapienza 2000). The following section discussed the perturbation measures used in most research studies to quantify the vocal quality.

2.4 Perturbation Measures – Jitter, Shimmer & Harmonics-to-noise ratio (HNR)

Vocal perturbation measures quantify the average variability of the voice (Baken, 1990). Vocal perturbation measures are used typically to quantify vocal quality in the speaking voice. Three vocal perturbation measures used by Milenkovic to quantify vocal quality are jitter, shimmer, and signal-to-noise ratio (Milenkovic, 1987). Jitter is defined as cycle-to-cycle variations in pitch. It is also known as the frequency perturbation or modulation frequency. Shimmer, also known as amplitude perturbation or modulation extent, refers to cycle-to-cycle variations in intensity. The Harmonics-to-noise ratio captures the relative contributions of all periodic to aperiodic energy in the speech signal (Teixeira, Oliveira, & Lopes, 2013; Bausar, Bohlender, Mehta, 2018).

Brown et al. (1990) compared jitter ratios of elderly female singers (63-85 years) with young female non-singers (20-32 years) and elderly female non-singers (75-90 years). All subjects produced sustained phonation of the vowel /a/. No significant differences were found. However, the elderly singers exhibited the lowest mean jitter ratio values (0.22), compared with the young (0.27) and elderly non-singer groups (0.32). Elderly singers and young non-singers had a standard deviation of 0.21 and elderly non-singers 0.38.

The effects of isometric-isotonic vocal exercises practised daily for four weeks in 20 voice major graduate students (age range of 21-43 years) was studied by Sabol et al. (1995). The experimental group and the control group was used in this study. The subjects were randomly assigned to the two groups. The researchers decided to divide the groups based upon the participants' experience, level of singing, age, and sex (three males and seven females in each group). The experimental group was taught how to properly perform Dr. Joseph Stemple's Vocal Function Exercises (VFEs), and the exercises were added into their practice sessions, two times a day and twice per session. As previously completed, the control group continued their current practice sessions. All the participants in both groups were required to continue their voice lessons and training and were told to avoid verbal aggression (e.g., yelling) (Sabol et al., 1995).

Experimental and control subjects sustained the vowel /a/, /i/, /u/ at three pitch levels. Pre-and post-test measures differed significantly at both high and low pitch levels. For the experimental group, the mean jitter increased from 0.24 to 0.31 at the comfortable pitch, while for the control group, the jitter decreased from 0.25 to 0.18. The jitter of the experimental group increased at the low pitch from 0.26 to 0.32, while the control group lowered by 0.01. These findings are surprising, and in contradiction with the previous studies. One would expect that with vocal exercise the irregularities found in vocal fold function due to variation of mass, tension, muscle or neural activity would be reduced.

Sabol et al (1995) evaluated the effects of Dr. Joseph Stemple's Vocal Function Exercises (VFEs) on vocal measures when they were integrated into singers' everyday practice. It was a pre-test and post-test group control design. Acoustic measures (jitter, frequency range and fundamental rate), aerodynamic measures (phonation volume, maximum phonation time and flow rate) and video stroboscopic measures were evaluated.

Sabol et al. (1995) obtained acoustic and aerodynamic analysis data using a Visi-Pitch (Kay Electrometrics model 6097) and a Nagashima Phonatory Function Analyzer (PS 77H model). Additionally, data were collected through questionnaires and case histories that revealed the participants' extracurricular activities, voice type, medical history, and schedule of singing. Similar to Stemple et al. (1994), the researchers conducted the study for 4 weeks, collecting data 28 days apart for pretest and posttest data collection.

Sabol et al. (1995) completed a statistical analysis of the data by utilizing a multivariate analysis of variance (MANOVA) and an ANOVA to assess for significance through a p-value. Significant variations between pre- and post-test findings in phonation volumes, lower airflow rates, and higher phonation times was found in this study. This study revealed higher phonation volumes to that of Stemple et al. (1994) with non-trained singers and required further investigation as to an explanation. In regards to the decreased airflow rates, it was suspected that VFEs assisted in the enhancement of vocal fold adduction, adequate phonation, and subglottic pressure. For maximum phonation time, it was thought to have increased due to an easy onset of phonation with proper glottal closure at low lung volumes resulting in an increase of phonation time (Sabol et al., 1995).

Sabol et al. (1995) demonstrated that vocal function exercises (VFEs) had a beneficial effect on trained singers without a voice disorder. These authors concluded that further research is needed to evaluate VFEs on younger singers who are in their undergraduate program and who are not as advanced as graduate trained singers are. This study showed, however, that even advanced trained singers benefited from the use of VFEs and that they could use them as a long term, practice regimen.

Later on, Brown, Rothman, and Sapienza (2000) compared jitter percentages produced by 20 professional singers and 20 non-singers during spoken and sung vowels. Subjects sustained the spoken and sung /i/ vowels of the word “sea” of “America the Beautiful”. The group consisted of 10 men (22 to 62 years) and 10 women (21 to 61 years of age). The age-matched group of non-singers consisted of 10 males and 10 females, both ranging from 22-63 years. Jitter percentages for the spoken /i/ were significantly higher for the male non-singers than the male singers. The female singers had a higher mean jitter than the non-singers did, but no significant differences were found. Overall, jitter percentages for the sung /i/ were higher for non-singers than singers.

Mendes et al. (2004) found that singing warm-ups and training had an important impact on singing, especially in raising both the fundamental frequency and intensity of the phonation range. They studied 14 professional singers over four college semesters to measure the effects of singing training. Subjects were recorded after briefly warming-up their voices by performing dynamic range exercises to expand and stretch their vocal range. They then sustained vowels and read the "Rainbow Passage" while being recorded. At the end of the study, jitter and shimmer measures slightly decreased, and phonation range increased. The measure of phonation range is also referred to as maximum phonation frequency range (MPFR), and it is defined as the range of frequencies of both the modal and falsetto registers from the lowest sustainable tone to the highest (Mendes et al., 2003). In studies that have compared singers to non-singers, singers typically have a larger MPFR and are, therefore, able to sing a larger range of tones and can stretch their voice between multiple octaves (Mendes et al., 2003). Thus, vocalization exercises can extend the vocal range the same way as stretching before a physical exercise (McHenry et al., 2009).

Shimmer, or cycle-to-cycle amplitude variation, is another perturbation measure. As was the case for the measurement of frequency perturbation, the amplitude of each glottal cycle is measured, subtracted from the previous or following period, and averaged over all differences. This is called the shimmer ratio (Horii, 1980; Lathadevi & Suresh, 2008).

Brown et al. (2000) studied shimmer measurements from speaking and singing tasks between male and female singers and non-singer groups. Each group had 10 subjects with ages ranging between 21 to 63 years. The singer group are comprised of ten males (22-62 years) and ten females (21-61 years). The age-matched non-singer group comprised of ten males and ten females both ranging in age from 22-63 years. Subjects sustained the spoken and the sung /i/ vowels of the word “sea” from the song “America the Beautiful” for five seconds each. Shimmer values for the/i/ spoken showed no major variations between singers and non-singers. For the sung /i/, the shimmer values of non-singers were significantly higher than those of the singers. Harmonics-to-noise ratio (HNR) is the noise-related measure which is just like a ratio or expressed in dB. The voice is a quasiperiodic instrument with two components: quasiperiodic waves and random noise. The harmonics-to-noise ratio (HNR) is the mean amplitude of the average divided by the mean amplitude of the isolated wave noise components (Baken, 1987; Narasimhan & Nataraja, 2019).

Comparative studies of HNR with the singing population, as for shimmer, are rare. Brown et al. (2000) compared the same singer and non-singer subjects during the sustained spoken and sung /i/ vowels for HNR. The authors reported no significant differences between singers and non-singers for the speaking sample. For the sung /i/ sample, male singers showed a significant larger HNR than the non-singer group. No differences were found in the female group.

Similar research was carried out by Tay et al. (2012) to investigate the impact of VFEs on vocal function measurements. It was a prospective experimental design which comprised of 22 ageing choral singers. The vocal measures evaluated were acoustic parameters (jitter, shimmer, phonation frequency range, and noise-to-harmonic ratio (NHR)), maximum phonation time and auditory-perceptual voice features such as breathiness, roughness, and strain. There were two groups, which are the experimental vocal function exercises (VFEs) or the control group, in this study and the subjects were assigned into both groups randomly, each of which contained eleven participants. To ensure that vocal function exercises (VFEs) was correctly conducted during the study, the control group had to meet the researcher twice. During the seven weeks, the experimental group participants had to attend four sessions with the researcher. Both experimental and control groups had to record their singing hours and practice times.

Tay et al. (2012) used the Mann Whitney U test and a paired t-test to complete statistical data analysis. No statistical difference was found between the two groups. Nevertheless, the results of the Mann-Whitney-U test revealed that the control group sang more hours than the experimental group during the study. With regards to the breathiness, roughness and strain, only roughness showed a statistically significant decrease for the experimental group. It is suspected that this was due to the improvement of the vibration of the vocal folds since performing vocal function exercises (VFEs). The results showed increased phonation frequency range in the experimental group and decreased jitter, shimmer, and HNR in both groups. It was probably because more singing hours were recorded by the control group than by the experimental group. Furthermore, it was believed that an increased frequency range of phonation and a decrease in jitter and shimmer showed that these exercises improved vocal fold adduction and increased vibration. Tay et al. (2012) gave a self-evaluation consisting of a scale of 0 to 6, 0 represented strongly disagreed and 6 represented strongly agree. The subjects were told to determine if their voice had improved after the study if their voice had changed as VFEs were utilized and whether they would continue the vocal function exercises (VFEs) on their own. Results of the self-assessment showed that the participants in the experimental group reported that their voices fatigued less and that they could sing longer after performing VFEs. Overall, the study concluded that the experimental group's use of VFEs improved overall voice quality.

2.5 Acoustic Voice Analysis Using Praat Software

Praat is a powerful acoustic analysis software written by Paul Boersma and David Weenik of the University of Amsterdam (Paul & Vincent, 2001). It is a freeware available for download via the Internet, and has research literature validating its use for acoustic analyses (Lathadevi & Suresh, 2008; Bausar, Bohlender & Mehta, 2018).

Lathadevi & Suresh (2008) used Praat software to analyze objective acoustic analysis determine whether objective acoustic analysis is useful in differentiating abnormal and normal voices. They found that abnormal voice parameters such as jitter (ddp), shimmer (dda), average pitch and measurement of HNR were different from normal voices. Significant differences were found in jitter males and shimmer females but HNR has shown no significance. They concluded that the acoustic parameters allow clinicians to characterize their voice into either normal or abnormal voices. Nonetheless, a standard local or regional normal voice database is important for comparison.

Bausar, Bohlender & Mehta (2018) examined the impact of voice sound pressure level (SPL) on acoustic parameters in 58 female voice-disordered adults and a control group of 58 vocal health women. Praat software was used to compute acoustic voice SPL, jitter, shimmer, and HNR. The increased voice SPL was significantly associated with decreased jitter and shimmer ($P < 0.001$) and increased HNR in both patient and normative control groups. Professional voice use level had a significant effect ($P < 0.05$) on jitter, shimmer, and HNR. They concluded that as voice intensity increased, acoustic perturbation improved, with jitter and shimmer decreasing, and HNR increasing.

2.6 Physiological Effects of Vocal Warm-up

Phonation threshold pressure (PTP) is an indirect measure of vocal fold function. It can be used to determine how vocal warm-up can affect the physiological characteristics of the vocal folds. According to Titze (1988 & 1992), PTP represents the minimum subglottal pressure required for vocal fold oscillation. PTP is a measure of ease of perception and phonation efficacy that is directly related to the viscosity of the vocal fold mucosa (Titze, 1988; Chan & Titze, 1998). When vocal warm-up enhances the vocal fold conditions physiologically, PTP is decreased (Milbrath & Solomon, 2003). A handful of studies have observed the relationship between a warm-up condition and phonation threshold pressure as a variable (e.g. Motel, Fisher, & Leydon, 2003; Elliot, Sundberg, & Gramming, 1995). Theoretically, the vocal warm-up will increase blood flow in muscles, decrease viscosity in the vocal folds and thus lead to a lower phonation threshold pressure (Milbrath & Solomon, 2003).

McHenry et al. examined the impact of a typical vocal warm-up versus one coupled with an aerobic routine to determine if changes in laryngeal muscle viscosity could be increased when coupled with aerobics. They examined 20 participants, both male and female, and discovered that aerobic routine did not necessarily affect the vocal folds directly. They were all familiar with the vocal warm-up. However, both warm-up activities created a general perception of less effort. Females also show that phonation threshold pressure decreases significantly following a warm-up in this study.

Another benefit to a vocal warm-up is a decrease in overall tension. According to Elliot, Sundberg, and Gramming (1995), the temperature of the muscle is increased after a warm-up, and thus muscle viscosity is reduced. It is reasonable to assume that vocal warm-up will have the same effect on the laryngeal muscles. Koufman, Radomski, Joharji, Russell, and Pillsbury (1996) studied the patterns of laryngeal tension on the singing voice in 100 healthy singers via transnasal fiberoptic laryngoscopy and found that both trained female professional singers and classical singers had very low muscle tension scores. The significance of this finding is that excess muscle tension may be the cause of phonotrauma and other voice disorders so that an increased training in vocal therapy and warm-up activities before singing can only benefit individuals by reducing laryngeal tension (Stemple et al., 2010)

The phonation threshold pressure (PTP) effects of soprano singers in a 10-minute vocal warm-up were measured by Motel et al. (2003). In this study, PTP was obtained at 10 per cent, 20 per cent, and 80 per cent of the total frequency ranges of ten pre- and post-conditions female voice majors: vocal warm-up and vocal rest. It lasted for 10 minutes and the exercise was selected to resemble the traditional warm-up procedure at the start of a daily voice lesson. Audio recording, including the accompaniment of the piano, guided the participants. Findings showed that at the 80 per cent frequency, vocal warm-up increased PTP. Higher PTP is associated with increased effort. PTP increased following a vocal warm-up is a result of muscular force production (Titze 1988). As it was reported that the TA muscle is fast-fatigable (Teig et al., 1978), the chances were high that 10 minutes of vocal warm-up led to increasing in PTP due to TA muscle fatigued. Nevertheless, the participants' perception results showed that some participants were pleased with the warm-up and one of them indicated that they felt ready for performance (Motel et al., 2003). In another research investigated by Elliot et al. (1995), phonation threshold pressure was obtained from ten amateur singers, before and after a warm-up. The warm-up of approximately 30 minutes. The singers sang/mu/ on a descending scale followed by other pitch-changing exercises with various vowels and different levels of vocal loudness. All the participants were informed not to sing extremely loud during the warm-up. All participants reported verbally that they felt they had better voices after the warm-up. They indicated that singing was easier, especially at high pitches, and they felt like having more control over their voices while singing. This research was conducted to compare the participant's subglottal pressure the fundamental frequency curve with Titze curve (1992) indicates the decreased thickness of the vocal fold correlated with an increase in fundamental frequency. The male participant curves were fairly close to the theoretical curves. Phonation threshold pressure (PTP) seemed consistently pitch-dependent for male participants, but there was no similar pattern in female participants. No consistent results have been found. There was no post-warm-up trend in PTP, with some of the participants showed increasing PTP, some decreasing PTP, and some not significantly changing PTP.

Milbrath et al. (2003) studied the effect of vocal warm-ups on phonation threshold pressure (PTP) on eight female non-singers who have voice fatigue complaints. The researchers investigated the vocal warm-up effect on perceived phonatory effort (PPE). PTP and PPE data were collected before and after two “vocal-preparation” conditions: (1) 20-minute vocal rest and general relaxation, and (2) 15-20 vocal warm-up routines created by researchers. This warm-up exercise involved stretching legs, neck, back, mandible and tongue, and then deep breathing while seated with a well-aligned posture. After that, the focus was on resonance as participants held pitches for one to two seconds while concentrating on “feeling the upper lip or nose buzz”. The participants were finally instructed to perform vocal exercises consisting of upward and downward pitch glides. PTP and PPE were measured after a vocal loading task of one hour (loud reading) and again after a vocal recovery time of 30 minutes following the vocal preparation conditions. For each of these conditions, there were no significant differences between PTP and PPE. The researchers found that PTP and PPE are not sensitive to determining vocal function changes in people with chronic vocal fatigue.

As measured by phonation threshold pressure (PTP) and perceived phonatory effort (PPE), performing warm-up as a method to avoid fatigue or minimize effort resulted in inconsistent results. Empirical findings suggest that after vocal loading, vocal warm-up exercises do not seem to have a positive impact on PTP or PPE and there is a possibility that PTP rising following a 10-30 minute vocal warm-up (Motel et al., 2003; Elliot et al., 1995). Given the conceptual effects of increasing PTP, increased effort in strictly controlled intensity and frequency, PTP increased after vocal warm-up (Motel et al., 2003; Elliot et al., 1995). According to Motel et al. (2003), phonation ease following the vocal warm-up was reported as the phonation threshold pressure increases. There are two plausible reasons. One explanation is that increased PTP at high pitches is correlated with positive phonatory changes due to an ischemic effect that prevents high-frequency vascular damage or loss of mucosal fluid. Another reason is that increased water efflux from vocal warm-up regimens in the vocal fold may help to facilitate phonation. Milbrath and Solomon (2003) also found little evidence for warm-up benefit through PTP. The researchers carried out experiments on warm-up exercises and loud reading but results indicated that the experiments were not sensitive enough to vocal-function changes. Elliot et al. (1995) propose that phonation threshold pressure variation may be due to complex properties of the vocal folds or individual differences following the vocal warm-up.

2.7 Vocal Tract Tuning, Resonance and Acoustic

Vocal warm-up is also important for vocal tract tuning. It can affect the changes in supraglottal and glottal settings and therefore changes the vocal quality. Optimal resonance can be achieved through vocal warm-up. Laukkannen, Horacek, and Havlik (2012) conducted a study whereby they used magnetic resonance imaging (MRI) to examine a male and a female to determine post-warm-up vocal tract changes. The participants were recorded twice, before and after a “some minutes” personalized vocal warm-up. Each participant was instructed to sustain each vowel, /a/, /i/ and /u/ for 20 seconds. To describe vocal tract size and shape, Midsagittal MRI images were analyzed. In particular, the pharyngeal inlet over the epilaryngeal outlet ratio was determined (Aph / Ae). The main change in males was that the larynx decreased from fifth to sixth vertebrae after warm-up. No vertical shift was found in the female larynx following the vocal warm-up. There was only a marginal rise in vowel /u/. A certain opening of the jaw was observed when the participants sang /a/. The tongue was frontal and curved, and the pharynx became wider after the warm-up. Aph / Ae increased in both groups by up to 27 per cent in males and up to 28 per cent in females for all the three vowels. Despite the small sample size, this research indicates that supraglottal changes can be observed after the vocal warm-up. The sound produced by vocal folds, which can be interpreted as a filter characteristic, is generated by supraglottal structures (Fant, 1970). Resonance occurs during vowel production when sound waves passed through the vocal tract. The vocal tract is a natural cavity resonator. Resonance is defined as the reinforced, natural oscillation of the object (Titze, 2000). The harmonic spectrum frequencies are modified by the resonance of the vocal tract. In the supraglottal structures, specific frequencies from the harmonic spectrum resonate, while others are damped by soft tissue. Formants are frequency peaks in the spectrum which have a high degree of energy (Fant, 1970).

The spectral envelope is a smooth curve that surrounds the amplitude spectrum (Fant, 1970). The specific frequencies of formants are placed on the spectral envelope using linear prediction code (LPC) assessment (Hixon et al., 2008). F-patterns, named F1 (first formant), F2 (second formant), and F3 (third formant) are the first three peaks in the spectral envelope (Fant, 1970). The F-patterns can infer the articulation or filter shape. The F1 (first formant) typically increases with decreased tongue height, the second formant, F2 increases with increased advancement of the tongue and as the opening of the mouth increases in size and become less rounded, the third formant F3 increases (Naderifar et al., 2017). The vocal warm-up, as well as the modifications to the vocal tract, can determine the resulting acoustic qualities (Laukkanen, Horacek, & Havlik, 2012). Laukkanen, Horacek, and Havlik (2012) considered the ratio of pharynx inlet and epilarynx outlet region is important in the formant production, which improves the acoustic voice qualities. The singer perceives the sound during singing and warm-up through both the vibratory sensations in the head, neck and chest and the auditory system, which are felt when the singer manipulates their instrument to achieve maximum resonance (Vurma & Ross, 2003). This practice of resonant voice has been found to have a production that feels easy and adequately loud, while also being felt vibrating within the facial tissues (Ziegler, Gillespie & Verdolini Abbott, 2010). The singer can physically feel the vibration of resonance as they warm-up and sing. The vocal tract has four or five major resonances or formants. The shape of the vocal tract determines the formant frequencies. Trained singers learn to manipulate these formants by manipulating the hypopharynx and the epilarynx (Sundberg, 1977). By lowering the larynx, the lowest part of the pharynx is expanded, as is the laryngeal ventricle, the space between the true and false vocal folds (Sundberg, 1977). Increasing the width and shape of the vocal tract leads to changes in resonator or vocal tract structure, and these variations in resonance are the most noticeable differences in the singing voice as compared to the speaking voice. The increases in width and length of the vocal tract result in an increase of resonant energy between 2500Hz and 3000Hz, which is also known as the “singer’s formant” (McCrea & Morris, 2007). The singer’s formant corresponds to the “ringing” quality of the singer’s voice and this is often referred to as “getting resonance,” as a resonant voice creates changes in the vocal tract, which create a maximum transfer of power through the vocal tract and out to the listener (Titze, 2004). Resonance can also be increased by widening the pharynx during singing while also lowering the larynx, a sensation that is similar to yawning. As the throat is “opened” by these actions, this yawning sensation can aid in stretching the vocal muscles, readying them for optimum resonance and phonation (Sundberg, 1977). Warm-up exercises are generated by resonance effects and enhancing the resonance of the vocal tract, which therefore reduces any need for extra laryngeal effort, helping the singer to achieve maximum sound and intensity without having to generate extra pressure (Sundberg, 1977).

Warm-up exercises often focus on the idea of the forward focus resonance to ensure that vowels are “placed” correctly and to reduce the excessive muscle tension that can be found with a “backward” voice, which often diminishes the effective use of the resonators (Vurma & Ross, 2003). In accomplishing forward focus, optimal resonance can be achieved which may also enhance the singer’s formant or the ringing quality of the singing voice.

Many types of vocal therapy exercise also touch upon this type of “warm-up,” which focuses on the benefit to resonance and proper projection of resonance for optimal voice output. The vocal function exercises of Stemple aim to balance the voice production subsystem and demand coordination of the respiration, laryngeal movement, and resonance so that a maximal voice output is achieved with minimal effort (Stemple et al., 2010). Opera singers, natural voice speakers and voice condition teachers have been studied and it has proved effective to improve and enhance their voice function (Stemple et al. 2010). Resonant voice therapy is similar in its conceptualization. This therapeutic warm-up “forward focus” which was derived from performing arts training, is described as voice production involving the vibratory sensations in the oral cavity and face in the context of easy phonation. By enhancing these vibratory sensations while also practising easy phonation, the goal becomes achieving the strongest possible voice with minimal effort and vocal fold impact. Resonant voice tends to be associated with vocal folds that barely touch, which optimizes the relationship between a large voice output volume and very little vocal fold impact (Ziegler, Gillespie & Verdolini Abbott, 2010).

Miller, Sulter, Schutte, and Wolf (1997) found through magnetic resonance imaging (MRI) of a singer’s vocal mechanism during various types of singing, that certain postures of the vocal tract were adjusted, which enhanced elements of the singing voice, such as resonance, and the singer’s formant. Trained singers often sing better than non-singers because those trained singers have learned a series of phonatory, articulatory, and resonatory adjustments that non-singers do not use. The ability to have a skill in some sort of performance is often attributed to talent. The natural ability to produce musical changes in the voice, where frequencies are in tune with one another and sound melodic is defined as singing talent (McCrea & Watts, 2007).

2.8 The Singer’s Formant

This section discusses the importance of vocal warm-up to increase the intensity of the singer’s formant. The singer’s formant indicates prominent sound energy near 3 kHz, mainly found in the voice of classical and operatic singers (Sundberg, 1974; Sundberg, 1998). In female voices, higher frequency spectral reinforcement is much less established, therefore the singer's formant is usually found in male voices (Morris & Weiss, 1997). Studies of classically trained singers and especially males showed a clear and strong formant of approximately 3000 Hz (between 2800 and 3400 Hz) which is absent in the voices of untrained singers. The singer’s formant is more prominent in solo singing than choral singing (Sundberg, 1998). This formant reflects the frequency spectrum of trained classical singers and the resonant frequency has been designated as wide-spread as 2600 to 4000 Hz (Morris &Weiss, 1997). The presence of the singer’s formant is to support the voice and make singers heard and understood through a full orchestra (Sundberg, 1998).

A formant cluster happens when the formant amplitudes increase and the third, fourth and fifth formants approach each other in a frequency (Sundberg, 1974; Sundberg, 1998), a formant is generated. A cluster of formants was not found in female voices. Only strong upper-frequency reinforcement was observed in female voices (Morris & Weiss, 1997). Sundberg suggested that since the partials of higher frequencies are well above the strongest orchestral sounds, the risk of masking by an orchestra is slight, therefore singer’s formant cluster in female voices is not necessary (Sundberg, 1974). The articulatory formation of the singer’s formant comprises specific parts of the vocal tract (Sundberg 1974). The way to modify vowels such as by movement of the tongue, lips and adjustments in laryngeal height, either enhances or inhibits the sound. The tweaking of vowel colour associated with adjustments in F1 and F2 (referred to as “formant tuning” or “vowel tuning”) is a big part of how singers can learn to optimize the resonance. When the larynx is lowered, increased formant density usually occurs (Sundberg, 1974; Morris & Weiss, 1997; Sundberg, 1998). Sundberg (1974) claimed that the lowering of larynx leads to the singer’s formant. There is the widening of the laryngeal ventricle and pyriform sinuses. Next, by lowering the larynx, the vocal tract’s length is raised. It is essential to lower the larynx to make separate but complementary adjustments of the pharynx and epilarynx tube pharynx to form the singer’s formant.

The epilarynx tube is small, about 2 cm in length, situated above the vocal folds (Sundberg, 1974). The larynx is located directly above the pharynx, a larger tube above the epilarynx tube that forms the rest of the throat (Sundberg, 1974). The narrowing of the epilarynx tube and reducing the epilarynx tube opening to less than 1:6 was thought to be connected to the articulatory basis for the singer's formant (Sundberg, 1974). The pharynx expands as the epilarynx tube narrows to help achieve this ratio (Sundberg, 1974; Titze, 2012). The exercises that facilitate the widening of the pharynx (Titze, 2012) and lowering of the larynx (Weiss, Brown & Morris, 2001) are important training to develop the singer's formant (Titze, 2012). The singer's formant is typically found in classically trained male singers (Sundberg, 1998; Morris & Weiss, 1997; Sundberg, 2001). Morris & Weiss (1997) claimed that without proper training, the singer’s formant can hardly emerge, although most vocal coaches consider this to be the by-product of good singing. Besides, if the frequencies are very high, the singer’s formant can hardly be produced, for instance over a C5, the presence of the formant is infrequent. High-frequency harmonics are further separated and peaks often hard to detect, especially where a partial near-formant frequent is not available (Sundberg, 1998). Therefore, in male voices, it is more accurate and more discernible to observe and measure the singer's formant than in female voices.

Warm-up exercises have been found to increase the intensity of the singer's formant, resulting in a greater 'ring' to the singing voice. A "ringing" quality in the voice is the perceptual result of these vocal tract adjustments (Omori, Kacker, Carroll, Riley, & Blaugrund, 1996; Elkholm, Papagiannis, & Chagnon, 1998). Vinturri et al. (2001) studied the influence of vocal warm-up on the singing voice. Individuals were selected randomly in the study. The subjects were all non-singers who had not gone through formal voice training or voice therapy. They found that after a warmup, the spectral energy in the singer's formant region between 2500 Hz and 3000 Hz increased significantly in all tested pitches among the female subjects. Their participants also noted that after a warm-up they felt their voice was easier to use and felt smoother in both singing and speech. In this study, the impact of vocal warm-up on non-singers was explored, their warm-up strategies were focused on intensity changes, rather than a more general vocal warm-up, and thus these results are limited in their ability to predict the effect on non-singers.

2.9 Measurement of Singer's Formant

According to Sundberg (1995), when the intensity of the formant is “exceptionally high” near 3 kHz, the absence or existence of the singer's formant can be established. The method used to calculate the exceptionally high-intensity level (the level for Sundberg) is to compare the level of the third formant (L3) to the predicted level of L3 based on the equations of Fant (1970), to estimate the level of the formant. The existence of the formant of the singer is indicated by the difference between the observed and the predicted L3 being greater or equal to 6 dB. Vowels influence the relative L3 when this method is used, and therefore the singer's formant level varies with the vowel (Sundberg 1995).

Another method of measuring harmonic peaks at the upper frequency is the singing power ratio (SPR). SPR is used to objectively differentiate trained singers from untrained singers (Omori et al., 1996; Amir, Amir, & Michaeli, 2005; Watts, Barnes-Burroughs, Estis, & Blanton, 2006). The ratio of the highest intensity peaks between 2-4 kHz and 0-2kHz range, is expressed in dB, is known as the Singing Power Ratio (SPR) (Omori et al., 1996). Singing power ratio provides an implicit finding that vocal warm-ups can affect the harmonic tuning in the vocal tract (Laukkanen, Horacek & Havlik, 2012; Watts et al., 2006).

Amir, Amir, and Michaeli (2005) studied 20 female classical singers' pre-and-post- vocal warm-up. While the singers sustained vowels at 20%, 50%, and 80% of their frequency range, the authors performed acoustic measures on their vocal samples. They found that all frequency and amplitude perturbation measures, noise-to-harmonics ratio, and singer's formant measures improved significantly after warm-up. Jitter, relative average perturbation (RAP), and shimmer all decreased significantly after warm-up. Noise-to-harmonics ratio also decreased significantly, although still within normal limits, from 0.101 to 0.096 after warm-up. They also found that singing power ratio (SPR) decreased significantly, from -29.25 to -27.82 following warm-up. Singing power ratio (SPR) correlates directly to the singer’s formant intensity. The resonant tuning is measured in the vocal tract and the SPR shows its acoustic characteristics (Omori, Kacker, Carroll, Riley, and Blaugrund, 1996). SPR is determined by measuring the peak strength ratio between 2-4 kHz and 0-2kHz as sustained vowels or vocal segments. The lower the measurement of the SPR, the more energy that has been shown in higher harmonics corresponds to the perception of a “ring” in the singing voice. Omori et al. (1996) found that the SPR of a singer's sample was significantly lower compared to non-singer, suggesting that singing efficiency can be quantified by calculating SPR.

2.10 Disordered Voices

Blaylock (1999) stated vocal warm-ups are essential to maintain a healthy voice of speech and singing, and users could benefit from structured vocal warm-up routine based on physiology of voices. A variety of problems can arise for both speakers and singers if the vocal mechanism is functioning inadequately. Singers can be greatly affected if they sing professionally as a career. Singers with all levels of training are often more sensitive to tiny changes in their voice (Cohen, Noordzij, Garrett & Ossoff, 2008).

Cohen et al. (2008) created a singer's voice handicap index that modified elements of the Voice Handicap Index (Jacobson, Johnson, Grywalski, Silbergleit, Jacobson, Benninger & Newman, 1997) to create a questionnaire that focused more on areas that may affect a singer. Singers are often at a higher risk for vocal problems and also perceive impairment much sooner and differently than a non-singer (Cohen et al., 2008). Singers will notice small changes in their voice and will often seek medical care more quickly, especially if they sing professionally. They often have lower Voice Handicap Index scores, showing less voice handicap than non-singers (Cohen et al., 2008). For singers having vocal difficulty in the form of nodules or other voice disorders, the positive benefits of vocal therapy for various voice disorders has been broadly researched. However, the use of singing is not typically involved in these techniques. Thus, the need for a positive therapy technique that is more dedicated to the small changes in the singing voice, such as a vocal warm-up, could benefit these individuals (Cohen et al., 2008).

Beyond its function for singers, the clinical relevance of vocal warm-up is substantial as it can potentially benefit not only professional singers and non-professional singers who wish to improve their voice quality, but also the non-singing voice disordered population. The vocal warm-up is a beneficial means of therapy in individuals with voice disorders (Chernobelsky, 2007). Blaylock (1999) closely studied 4 subjects with voice disorders, all of whom had a vocal pathology, such as nodules or hoarseness that had shown no major improvement with voice therapy or medical intervention. He taught them a systematized vocal warm-up after they had stopped voice therapy and asked them that they practice it once per day. The warm-up consisted of a sequence of vocal exercises that adjusted tempo, vowels, range, volume, and intensity that worked to increase coordination, flexibility, and increased strength of the vocal musculature. He assessed the subjects every three weeks after a warm-up and asked them to sing, sustain vowels, and speak. His results showed improvement. The more the participants performed a vocal warm-up, the better their voice improved over time. Blaylock (1999) examined the levels of increased intensity and waveform consistency, as well as the enhancement in harmonic information through the analysis of waveforms, sonograms and spectrograms, all of which showed improvements in the subject's voice samples over time. Singing teachers were also instructed to rank the samples based on their subjective experiences to reflect what they considered an increase in overall voice quality and these rankings also showed improvement in perceived voice quality. Lastly, subjects also provided subjective reports of their feelings about their voice quality. They reported their voice quality improved following the vocal warm-up, and good voice quality lasted longer as they continued their vocal warm-up exercises.

Voice therapy with professional singers and non-singers with voice disorders has also been shown to be an effective tool to reduce vocal nodules, which often affect singers (Chernobelsky, 2007). Therefore, having seen the positive benefits of a singing warm-up, individuals may benefit from its use in all areas of voice use, from the disordered population to improve deficits, to singers enhancing their craft, and to non-singers who have a passion to sing and also want to improve their singing abilities.

2.11 Vocal warm-up

According to Motel et al. (2003), the vocal warm-up is considered as necessary for optimal voice. Warm-ups are used to address specific vocal issues and repertoire problems, and to address the fundamental elements of good vocal technique (Hylton, 1995). The singers reported more comfort when singing following the vocal warm-up, but little is found regarding the impact of warm-up in voice production (Amir et al., 2005; McHenry et al., 2009; Elliot et al., 1995; DeFatta et al., 2012, & Vinturri et al., 2001).

Vocal warm-ups have also been shown to help reduce the thickness of the vocal folds, change the velocity of the surface waves and modify the width of the glottis before phonation. These changes affect many characteristics of the vocal mechanism, which then affect voice production (Amir, Amir, & Michaeli, 2005). In principle, vocal warm-up could improve vocal tract performances (Laukkanen, Horacek, & Havlik, 2012), prevent vocal fold muscle fatigue (Milbrath & Solomon, 2003; Motel et al., 2003), physically warm-up the vocal folds (McHenry et al., 2009), or improve vocal efficiency (Laukkanen, Horacek, Krupa & Svec, 2012). There was no evidence of vocal warm-up causing physiologic changes to vocal folds (Milbrath & Solomon, 2003; Cooper & Titze 1985; Motel et al., 2003; Elliot et al., 1995) but vocal tract and subsequent vocal acoustic changes were found in research studies (Laukkanen, Horacek, Krupa & Svec, 2012). Physical warm-up exercises can range from passive warm-ups, such as massage, to general warm-ups, such as jogging, to specific warm-ups involving actual activity movements (McArdle et al., 1996). The content and duration of vocal warm-up routines among singers and professionals varied, too (Sims and McWhorter, 2012; Gish, Kunduk, Milbrath and Solomon, 2003), though most are "variations of a few key topics" (Titze, 2001). Singing teachers are facing challenges like how to warm up (Barr, 2009). The warm-up time varies considerably in particular between the vocalists (Gish et al., 2012). For instance, a 20-minutes vocal warm-up was suggested by Miller, (1990). Nonetheless, in some studies, warm-up protocols lasted from 7 to 30 minutes (Gish et al., 2012). Most vocal warm-up exercises lasted from 5 to 10 minutes reported by a study by Gish et al. (2012). According to Elliot et al. (1995), an ideal vocal warm-up time duration ranging from 10 to 30 minutes enhances voice performance for most singers. Miller (1990), however, warns that singing for more than 30 minutes will affect the voice production quality. In designing a proper definition of vocal warm-up, both of these opinions were taken into consideration: traditional vocal warm-up and semi-occluded vocal tract warm-up.

2.11.1 Traditional Vocal Warm-up & Semi-Occluded Vocal Tract Warm-up

The research detailing vocal warm-up routines provides various exercises and sometimes conflicting evidence (Gish et al., 2012; Milbrath & Solomon, 2003 & Barr, 2009). Vocal warm-up began with exercises designed to stretch, loosen and helped ease the specific muscles involved in singing was proposed by Hylton (1995). Before vocal warm-up, a brief aerobic exercise was also suggested by (Miller, 1990) with the idea of the voice is a full-body instrument (Shear, 2008). The differential effect of "combined" warm-up and specified vocal warm-up was investigated by McHenry et al (2009). Researchers have found that aerobic exercises had a stronger impact than a specific vocal warm-up on the core body's temperature. The vocal fold composition, the unanticipated differences in physical activity levels, or hyaluronic acid difference in the vocal folds were attributed hypothetically to differences in results between men and women. Evidence indicated that, among women of average fitness, physical activity coupled with a 20-minute vocal warm-up resulted in a greater decrease in post-warm-up PTP (McHenry et al., 2009). The decline in PTP measured shows a lower viscosity and thickness of the female vocal folds, which made the initiation of the phonation easier (Titze, 1988).

Following light physical exercise or diaphragmatic breathing exercises, graduated tasks starting with gentle brief onsets and offsets were recommended for a combined warm-up (Miller, 1990). Next would be agility patterns and then tasks aimed at smooth transition in vocal registers (Miller 1990). Vocal register exercises involved ascending and descending glides, arpeggios and scales. Vocalization from top to bottom of the singer's vocalizing range is a recommended practice for maintaining the same tone across the entire range (Hylton, 1995). Additionally, when the singer sings the upward and downward scales, glissandi (gliding across a wide range) and, arpeggios, the vocal folds would be extended. All exercises except glissandi aim at endurance and vocal flexibility while at the same time enabling the voice to function without pressure (Gish et al., 2012; Hylton, 1995). A maximal stretch of vocal folds is achieved by using two-octave pitch glides on /i/ or /u/. Such exercises both separately and together work the muscles of the cricothyroid and thyroarytenoids and obtain the basic frequency over the first formant for specific acoustic loads (Titze, 2001).

Another common feature to most vocal warm-ups and therapy regimens is the concept of using the entire body as a musical instrument when singing. This is done through exercises that enhance psychological and physical awareness of one's breathing and abdominal support. Most vocal coaches emphasized the importance of abdominal or diaphragm muscle support, which helps the singer to have better control over the way they breathe. Having more control over one's breathing influences tone quality, phonation range capabilities, dynamics and intensity of the voice, and especially sound projection (Thorpe, Cala, Chapman & Davis, 2001). It is necessary for singing that breath be contained "low," to seem as though one is singing "without breath," by not quickly expending one's air intake, as this allows the singer to take in more breath and also to sustain breath throughout singing activities (DeCaro & Donato, 2006). In practising low breath, the singer does not expend excess air and, when coupled with enhanced resonance control, a stronger voice can be produced with less effort (Stemple et al., 2010). Due to the necessity for breath support, it is then obvious that good posture is also a necessity for optimal breathing and voice production as the abdominal muscles support the singing voice (DeCaro & Donato, 2006). According to Mendes et al. (2003), effective vocal training and warm-up activities include maintaining the correct posture, articulatory precision and vocal function exercises, strengthening the abdominal muscles with breathing exercises. Vocal warm-ups thus have a strong psychological component, as well as helping to facilitate relaxation and mental readiness for performing (McHenry et al., 2009).

Singers and non-singers alike have found that vocal warm-ups positively enhance the vocal mechanism physically and acoustically. Warm-up encourages improved breath support, thereby allowing singers to become conscious of the low breath, as well as singing “without breath” to avoid laryngeal tension to be able to better sustain passages (Donato & DeCaro, 2006). Thorpe et al. (2001) studied five professional singers by recording their singing with and without breath support while examining their breathing patterns with sensors attached to their skin at the abdominal and chest area. Their results showed that when singers used a supported voice, glottal quotient was lower. The glottal quotient is defined as the part of the glottal cycle in which the glottis is openly divided by the amount of time in which it is closed. The more open glottal quotient is typically a negative quality and is usually seen as an indicator of breathiness and is often a symptom of a voice disorder (Henrich, d’Alessandro, Doval & Castellengo, 2005). Thorpe et al. (2001) also found that the singer's formant increased by around 3 kHz and that the average flow rate decreased significantly, indicating that breaths terminated at higher volumes of the lungs. Having breaths terminate at higher lung volumes was interpreted to show that with a supported voice, the singer was able to have enough lung volume remaining to prepare for the next phrase, allowing for less tension throughout their singing. Breath support exercises are a staple of the singer’s warm-up for the reasons Thorpe et al. (2001) demonstrated.

A survey in 1989 of nationally accredited singing teachers, reported 93 different directions that singing teachers felt were most important for teaching breath support in singing. The highest-ranked directions all dealt with proper body posture and abdominal breathing (Griffin, Woo, Colton, Casper & Brewer, 1995). Griffin et al. (1995) also conducted a study in which they surveyed 8 classically trained singers about their concepts of the characteristics of the supported singing voice and how it is produced. The subjects in their study also confirmed that a singing voice with good breath support has better tone quality and ease of management that an unsupported singing voice does not have. They defined this better quality as being more resonant, clear, and manageable across their ranges.

By this definition, a warm-up that requires singing with the adjustments required for a supported voice can create a voice with optimal breath, resonance, and posture support in any individual who makes those adjustments. According to Elliot, Sundberg, and Gramming (1995), vocal warm-up has been shown to decrease muscle tension and enhance overall laryngeal ability. This reduction in laryngeal tension, the enhancement of breath support, and the increase 'forward' vocal resonance should support the non-singer's voice and also aid in the prevention of the development of voice disorders (Vurma & Ross, 2003).

The warm-up exercise, according to Miller (1990), should end with fast arpeggios and scale covering the entire vocal range. Singing arpeggiated passages or rapid-scale facilitates lower jaw and throat muscle relaxation. It is a sign of excessive vocal stress when a singer finds it difficult to sing rapid scales or arpeggios. Titze (2001) proposes to perform staccato arpeggios to establish a dominant mode of vocal fold vibration. It also exercises the muscles of the adductors and abductors in tandem with the tensor muscles during the shift in pitch (Titze, 2001).

The common semi-occluded vocal tract warm-up component is humming or sustained nasal consonants (Titze, 2001 & Gish et al., 2012). To develop a clean on-gliding and off-gliding in sung vowels, vocal exercises aimed at resonance balancing are important (Miller, 1986). Resonance balancing refers to the balanced combination between nasal and oral cavity resonances of the vowels, after any of the nasal consonants, /m/,/n/ or /al/ (Miller, 1986). In the vocal warm-up, the application of nasal consonants and vocal consonants is designed to enhance overall vocal quality and to ensure maximum vocal economy through resonance (Verdolini, Druker, Palmer, & Samawi, 1998). The maximized ratio between voice output (dB) and intraglottal impact stress (kPa) under constant subglottal pressure and frequency conditions is the vocal economy, or "Ev-max" (Verdolini et al., 1998). When the intraglottal pressure is decreased, voice output is optimally maximized. In theory, nasal consonants & vowels also facilitate a sustained oscillation of the vocal folds with an optimal glottal width (Milbrath & Solomon, 2003). A reduction in PTP suggests phonatory ease (Titze, 1988) and a reduced pre-phonatory glottal width is correlated with a decrease in PTP (Lucero, 1998). One of the voice building technique is humming. It enables the singer to create a clear tone and a flow phonation with minimal effort (Gregg, 1996). It also "projects the voice to the vocal mask" (Shear, 2008). Some people warn against the frequent use of nasal consonants in the music community. Nasal consonants can lead to undesired muscular habits such as tongue stiffening, larynx rising, and soft palates to be reduced chronically (Gregg, 1996; Nix, 1999). The lip trill, a semi-occlusive exercise, is a proposed alternative warm-up phoneme (Nix, 1999).

2.12 Summary

The aforementioned research has shown that vocal warm-up can make significant improvements in the singing voice of singers. Vocal warm-up might also enhance the singing voice of non-singers, yet little research exists in this area (Vinturri et al., 2001). Non-singers often are used as the control to demonstrate the benefits and differences found in the singing population, but little information exists as to the effect of a singing warm-up on non-singers alone (Vinturri et al., 2001). Many of the elements of singing involve adjustments to the vocal mechanism, lowering the larynx, adjusting the articulators, and projecting resonance to a more 'forward' placement (DeCaro & Donato, 2006; Sundberg, 1974). Because describable physical adjustments are occurring during singing, the non-singer could likely learn these concepts and adjustments to enhance their singing voice.

Common warm-up exercises and their underlying physiological contributions to vocal tract tuning were identified. Such routines and exercises differ in order and duration among voice teachers and vocalists but the basic concept of warm-up within the singing community is consistent. Due to the individual complex properties of the different tissue layers of the vocal folds, attempts to quantify changes during phonation threshold pressure (PTP) warm-up have produced mixed results. Nevertheless, it is also unclear whether the larynx's intrinsic musculature, when warmed-up or subsequently exercised, functions as the skeletal muscle. Changes in vocal tract configuration caused by a vocal warm-up may improve the voice's resonant characteristics. Semi-occlusive vocal warm-ups could make it easier, more efficient and more economical for the singer to phonate after the exercise (Cielo et al., 2013; Kapsner-Smith et al., 2015). The crucial thing is to understand how two different types of warm-up affect the vocal tract structure and the corresponding acoustic measures of a trained voice: traditional vocal warm-up and semi-occluded vocal tract warm-up (Duke et al., 2015). Such knowledge in future will serve as an important vocal training guide and in the management of voice therapy.

Standard acoustic measures for singing voice quality include perturbation measures of shimmer and jitter, noise-to-harmonics ratio (NHR), Singing Power Ratio (SPR), and relative accuracy of production (Amir et al., 2005). Such measures have been used to distinguish the speaking voice from the singing voice, where the singing voice has been found to have lower shimmer and NHR values as compared to the speaking voice (Lundy et al., 2000). It stands to reason that trained singers would have lower jitter values and more accurate pitch matching, as accurate tone production is a distinguishable feature of singers versus non-singers (Murry, 1990; Amir et al., 2005).

In summary, the benefit of singing vocal warm-ups has been documented, and non-singers could apply the techniques used by trained singers to enhance their singing voices. However, few studies documented the impact of the singing warm-up on the voice quality of the non-singer. Therefore, in this study, the acoustic measures of the untrained female singer's singing voice will be documented before and after a singing warm-up. Individuals who have not had any previous vocal training will participate in a singing vocal warm-up consisting of breathe support, resonant singing, and vocal tract shaping exercises to stretch their range and enhance their voice and body awareness. It is hypothesized that, like trained singers, untrained singers will also benefit positively from a singing warm-up. A lack of research exists regarding the singing voices of untrained singers and this study seeks to determine whether an untrained-singer can benefit from a vocal singing warm-up in the same way as a singer.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Research Design

This research aims to obtain information and draw conclusions about the impact of vocal warm-up on the voice quality of untrained female singers. This chapter provides information on the sample of the study; research design; instruments for data measurement and collection; pilot study; and data analysis procedures. This is quasi-experimental research conducted in a one-group pretest-posttest design. The dependent variable is assessed once before and once after the treatment is applied (Sage, 2019).

One group Pre-test, Post-test

Pre-test	Treatment	Post-test
O	X	O

Figure 2: One group Pretest - Posttest design (Sage, 2019)

3.2 Subjects

40 females between the ages of 21 and 35, who enjoyed singing as a hobby but never had any previous vocal training were included in this study. The reason for choosing untrained singers in this study was that in such subjects the vocal warm-up had a greater effect on the voice than in professional singers who were constantly warmed up because of the regular use of their professional voice. All participants were in good health and have no history of voice or hearing problems. On the days of the experiment, the participants were instructed to maintain their normal dietary and sleep patterns, and they were told not to sing before the experiment. All participants were instructed to fill in the

participant questionnaire (Appendix A). 40 participants were divided into eight groups (five participants per group). The experiment for the eight groups were carried out in eight different days. Research ethics application was filed in and was approved by The University of Malaya Research Ethics Committee (UMREC) (Reference Number: UM.TNC2/UMREC – 812).

3.3 Recording procedure and instrumentation

According to Richard (2004), a comfortable amount of warm-up time for a beginner is between 10 and 20 minutes before feeling fatigued. Richard (2004) stated that it may take 30 minutes for an advanced singer to touch all technical areas. Therefore, a 20-minute vocal warm-up has been chosen for the untrained female singers in this study. Subjects were recorded before and immediately after a 20-minute vocal warm-up. To ensure the validity of the measurements, participants were told not to sing or warm up their voices before the recording. Each subject was recorded individually in a quiet room while sustaining the vowels /a/, /o/ and /i/ in two different pitches: Low- A3 (220.0 Hz) and High- C5 (523.2 Hz). The low pitch was produced in the chest register and the high note in the head register. The singer was guided by each reference tone presented by the piano recording, and the singer was instructed to sustain the produced vowels (target tones) as accurate as possible for 5 seconds. The test was recorded twice based on the above criteria, taking into account the best voice production. The signal was recorded through a Neumann TLM102 microphone situated approximately 30cm from the participant's mouth, using a digital recording program, Studio One 4 Professional with a frequency response of 44100 Hz with a 16-bit sound card and high-quality speakers. The signal was pre-amplified with an Art Pro MPA-II amplifier.

The subjects were instructed to warm-up their voices following a specific protocol created by the author (Appendix B) after the first recording ("pre-warm-up" condition). The warm-up consists of phonation and positioning using a collection of syllables sung at different levels, registers and amplitude in different pitches. It also consists of breathing exercises, scales, and triads, range extension exercises, and body posture and relaxation tasks.

These exercises were based on activities established by several sources for the implementation of the vocal warm-up procedure: Vocal warm-up for child choristers (Falcão, Masson, Oliveira & Behlau, 2014), Vocal warm-up and fatigue (Milbrath & Solomon, 2003), Vocal warm-up and cool-down: a systematic review (Ribeiro, Frigo, Bastilha & Cielo, 2016). The exercises consist of general and specific vocal warm-ups as detailed in Appendix B. Warm-ups started with general exercises that consist of stretching and respiratory exercises, where participants have to follow presented instructions before phonation. Breathing exercises consist of low focused abdominal breathing as well as further stretching of the arms over the head and down to expand and stretch the ribcage (Miller, 1990). The goal of these exercises was to improve the preparation and mental concentration of the musical activity and to provide guidance for airflows and air output controls. These are important conditions for singing and producing a richer sound.

Specific exercise such as humming, aimed at mobilizing and relaxing the mucosa was then performed to improve glottal closure (Andrade, Cielo, Schwarz & Ribeiro, 2016). Exercises of bilabial nasal sound emission /m/ for a full second before moving into the /a/ were performed for the vocal projection (Falcão, Masson, Oliveira & Behlau, 2014). To have a greater vocal extension and enhance sound modulation, ascending and descending exercises were carried out (Gish et al., 2012; Hylton, 1995). Subjects were instructed to sing arpeggios scales of single-syllable words while focusing on breath and posture support, as they extend up and down their phonation range.

The experimenter was present during the warm-ups to assist and coach subjects and to ensure optimal understanding of the exercise. To minimize the effect of the time of day on the participant's voice quality, all recording sessions took place in the evening, performing the same tasks before and after the warm-up.

3.4 Acoustic Analysis

Each recorded data was analyzed using Praat, a software program that provides a quantitative acoustic analysis of voice quality. For these analyses, only the central 3 seconds of the vowels /a/, /o/ and /i/ were taken into account. The initial attack phase and the final release phase were avoided when major signal variations occur. The acoustic parameters measured for each vowel were jitter, shimmer and harmonics-to-noise ratio (HNR).

3.5 Statistical Analysis

The collected data were analyzed by the basic descriptive statistics, namely the mean and standard deviation of the quantitative variables for each measurement period. The normality distribution hypothesis was verified by the Shapiro-Wilk test for the variables Jitter (per cent), Shimmer (per cent), and HNR (dB). All the variables were normally distributed. A Paired-Samples T-test was performed independently for each of three acoustic parameters. The statistical analysis was performed using the Statistical Product and Service Solutions (SPSS) Version 25 to compare the differences found before and after a vocal warm-up for the acoustical analyses and the level of significance was set at 5% ($p < 0.05$).

3.6 Pilot Study

To establish test reliability for the acoustic parameters that were used in this study, a pilot study was conducted from September to October in the year 2019. Ten untrained female singers between the ages of 21 and 35 were included in this pilot study. The vocal acoustic analysis was performed using Praat Software.

3.7 Reliability

Reliability was established by using the Praat program to gather the data. According to the Praat, “It is the most complete program available (it contains much more than could be discussed here), or because it is distributed for free, but also because it comes with the ®nest algorithms. The pitch analysis algorithm is the most accurate in the world; the articulatory synthesis is the only one that can handle dynamic length changes (ejectives), non-glottal myo-elastics (trills), and sucking effects (clicks, implosives); and the gradual learning algorithm is the only linguistically-oriented learning algorithm that can handle free variation” (Paul & Vincent, 2001). Besides, the microphone attached to the Praat was placed at an appropriate distance from the participant during measurements, and the distance was consistently maintained throughout subsequent sessions. Also, background noise was limited by ensuring the door to the treatment room was closed for all measurements.

3.8 Data Analysis Procedure

The data collected were analyzed using quantitative measures. The data were evaluated using Statistical Product and Service Solutions (SPSS) Version 25, utilizing descriptive statistics and a Paired-Samples T-Test.

3.8.1 Research Question One

Does vocal warm-up significantly alter the acoustic parameter – Jitter - of the untrained singing voice?

Mean values and standard deviations of the Jitter parameter were computed for all of the three vowels /a/, /o/ and /i/ in both the Two Pitch-Conditions, Low-A3 (220.0 Hz) and High-C5 (523.2 Hz), pre and post vocal warm-up. Paired-Samples T-Test was conducted to explore the relationships between the independent variables and dependent variables.

3.8.2 Research Question Two

Does vocal warm-up significantly alter the acoustic parameter – Shimmer - of the untrained singing voice?

Mean values and standard deviations of the Shimmer parameter were computed for all of the three vowels /a/, /o/ and /i/ in both the Two Pitch-Conditions, Low-A3 (220.0 Hz) and High-C5 (523.2 Hz), pre and post vocal warm-up. Paired-Samples T-Test was conducted to explore the relationships between the independent variables and dependent variables.

3.8.3 Research Question Three

Does vocal warm-up significantly alter the acoustic parameter - Harmonics-to-noise ratio (HNR) - of the untrained singing voice?

Mean Harmonics-to-noise ratio parameter values and standard deviations were determined for all three vowels/a/, /o/ and/i/ in both Two Pitch-Conditions, Low-A3 (220.0 Hz) and High-C5 (523.2 Hz), pre and post vocal warm-up. Paired-Samples T-Test was conducted to explore the relationships between the independent variables and dependent variables.

3.8.4 Research Question Four

Do acoustic parameters (Jitter, Shimmer and Harmonics-to-noise ratio (HNR)) differ with vowel type (/a/, /o/, /i/) at different pitch level – Low predetermined tone (frequencies) - A3 (220.0 Hz)?

In low pitch-condition, A3 (220.0 Hz), pre and post vocal warm-up, the mean values and standard deviations of Jitter, Shimmer and Harmonics-to-Noise ratio parameters were measured for each of the vowels. Paired-Samples T-Test was conducted to explore the relationships between the independent variables and dependent variables.

3.8.5 Research Question Five

Do acoustic parameters (Jitter, Shimmer and Harmonics-to-noise ratio (HNR)) differ with vowel type (/a/, /o/, /i/) at different pitch level – High predetermined tone (frequencies) - C5 (523.2 Hz)?

Mean values and standard deviations of the Jitter, Shimmer and Harmonics-to-noise ratio parameters were computed for each of the vowels /a/, /o/ and /i/ in the High Pitch-Condition, C5 (523.2 Hz), pre and post vocal warm-up. Paired-Samples T-Test was conducted to explore the relationships between the independent variables and dependent variables.

CHAPTER 4

RESULTS

This study investigated the effects of vocal warm-up on the voice quality of untrained female singers in Malaysia. This chapter reports the findings and describes the investigation.

1. Does vocal warm-up significantly alter the acoustic parameter - Jitter of the untrained singing voice?

2. Does vocal warm-up significantly alter the acoustic parameter - Shimmer of the untrained singing voice?

3. Does vocal warm-up significantly alter the acoustic parameter - Harmonics-to-noise ratio (HNR) of the untrained singing voice?

4. Do acoustic parameters (Jitter, Shimmer and Harmonics-to-noise ratio (HNR)) differ with vowel type (/a/, /o/, /i/) at different pitch level – Low predetermined tone (frequencies) - A3 (220.0 Hz)?

5. Do acoustic parameters (Jitter, Shimmer and Harmonics-to-noise ratio (HNR)) differ with vowel type (/a/, /o/, /i/) at different pitch level – High predetermined tone (frequencies) - C5 (523.2 Hz)?

Data collected from the study were analysed using Praat Software and Paired-Samples T-Test using the Statistical Package for the Social Science (SPSS) Version 25. In summary, the findings indicated that jitter and shimmer significantly decrease while the harmonics-to-noise ratio (HNR) significantly increase after a 20-minute structured vocal warm-up. The Jitter and Shimmer decrease indicates that there is an improvement in vocal roughness and vocal breathiness respectively. The HNR increase indicates that there is an improvement in vocal hoarseness.

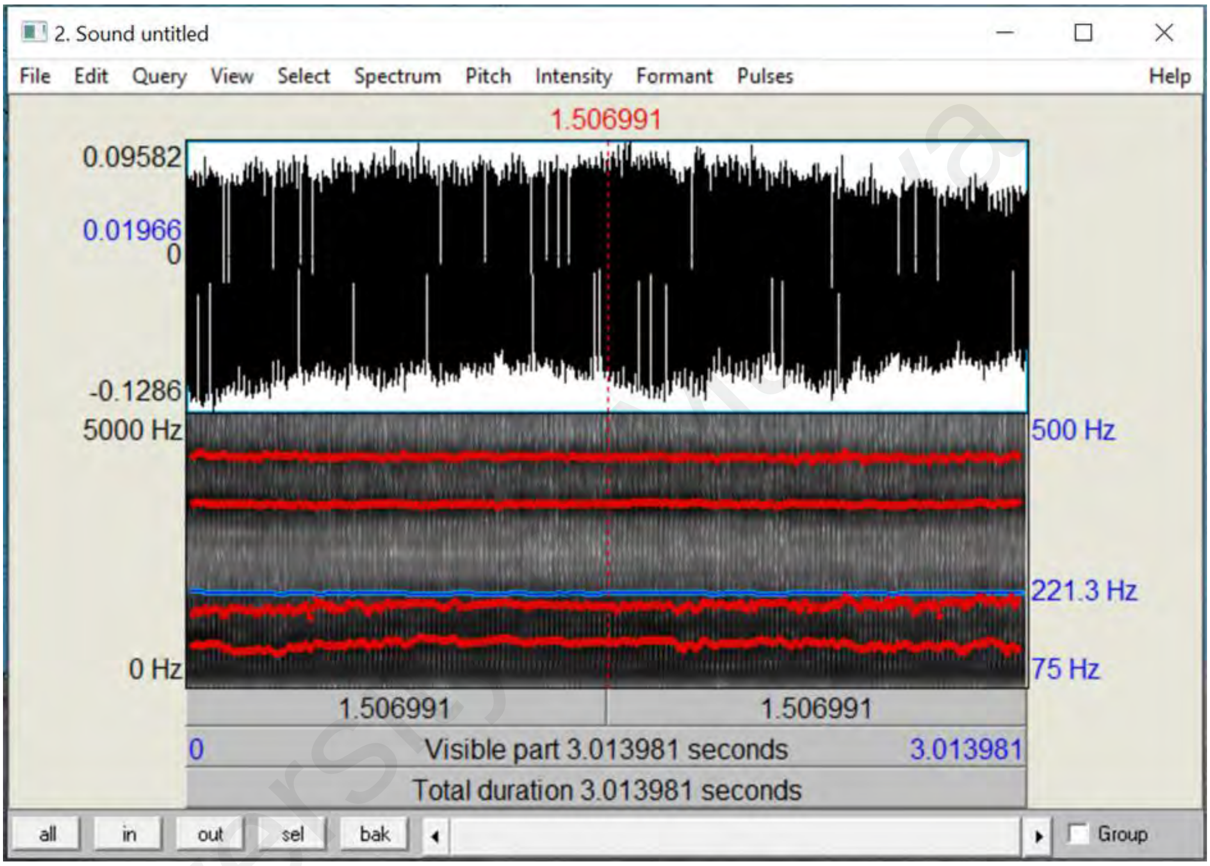
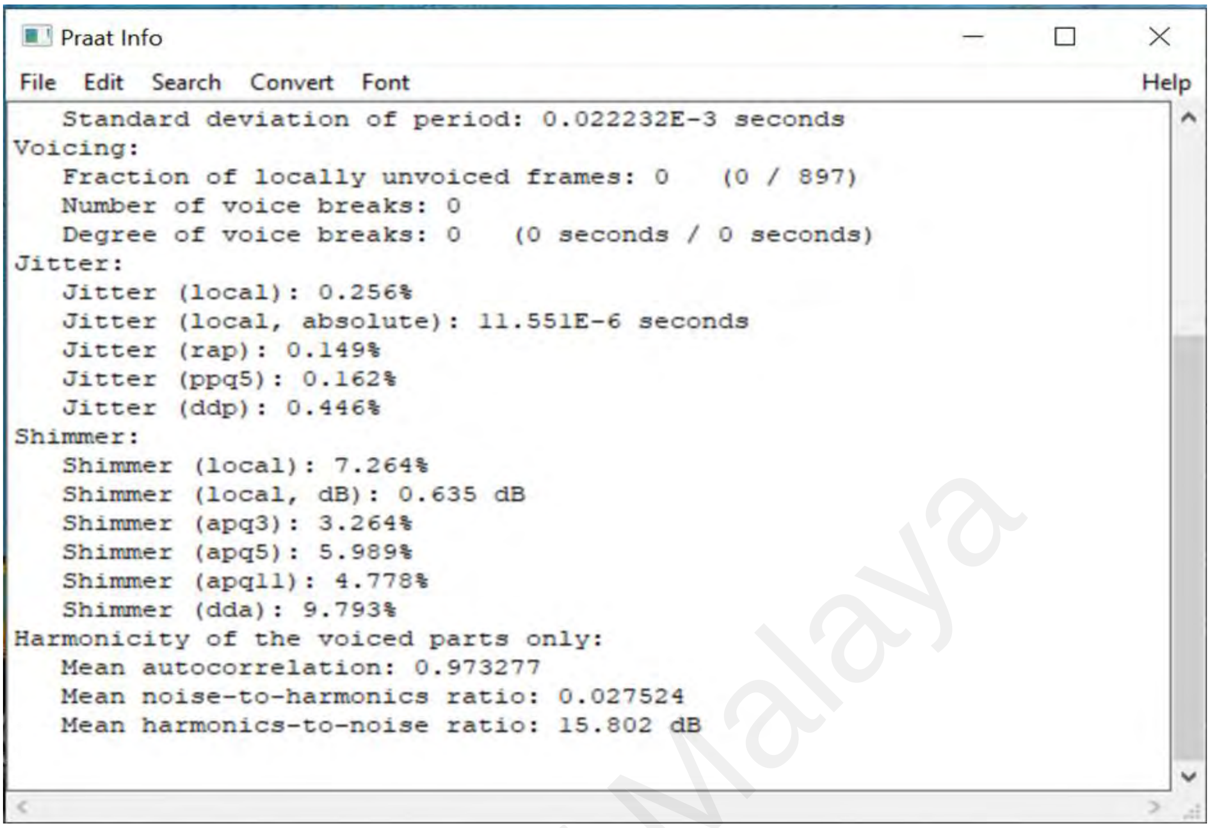


Figure 3: Example of Vocal Acoustic Analysis by Praat



```
   Standard deviation of period: 0.022232E-3 seconds
Voicing:
   Fraction of locally unvoiced frames: 0   (0 / 897)
   Number of voice breaks: 0
   Degree of voice breaks: 0   (0 seconds / 0 seconds)
Jitter:
   Jitter (local): 0.256%
   Jitter (local, absolute): 11.551E-6 seconds
   Jitter (rap): 0.149%
   Jitter (ppq5): 0.162%
   Jitter (ddp): 0.446%
Shimmer:
   Shimmer (local): 7.264%
   Shimmer (local, dB): 0.635 dB
   Shimmer (apq3): 3.264%
   Shimmer (apq5): 5.989%
   Shimmer (apq11): 4.778%
   Shimmer (dda): 9.793%
Harmonicity of the voiced parts only:
   Mean autocorrelation: 0.973277
   Mean noise-to-harmonics ratio: 0.027524
   Mean harmonics-to-noise ratio: 15.802 dB
```

Figure 4: Jitter, Shimmer and HNR parameters determined using Praat

4.1 Research Question One

Does vocal warm-up significantly alter the acoustic parameter - Jitter of the untrained singing voice?

The results of the statistical test showed a significant difference of the mean values of the acoustic parameter – Jitter, measure before and after the vocal warm-up (Table 1) which could be explained by the comparison tests.

Table 1

Mean Values and Standard Deviations (in Parentheses) of Jitter parameter for all the Vowels /a/, /o/ and /i/ in the Two Pitch-Conditions, Low- A3 (220.0 Hz) and High- C5 (523.2 Hz), before and after Vocal Warm-Up

Subject	**Jitter (%)**
Before	0.31 (0.11)
After	0.22 (0.07)

Table 2

Paired T-test Results of the Jitter parameter for all the Vowels /a/, /o/ and /i/ in the Two Pitch-Conditions, Low- A3 (220.0 Hz) and High- C5 (523.2 Hz), before and after Vocal Warm-Up

Paired Samples Test

		Paired Differences					
		Mean	SD	SE	t	df	Sig (2-tailed)
Pair 1	Pretest - Posttest	0.09	0.09	0.006	15.09	239	0.00

Table 1 demonstrated the mean values and standard deviations (in parentheses) of Jitter parameter for all the Vowels /a/, /o/ and /i/ in the Two Pitch-Conditions, Low-A3 (220.0 Hz) and High-C5 (523.2 Hz), pre and post vocal warm-up. Table 2 demonstrated the Paired T-test results of the Jitter parameter for all the Vowels /a/, /o/ and /i/ in the Two Pitch-Conditions, Low-A3 (220.0 Hz) and High-C5 (523.2 Hz), before and after vocal warm-up. The overall Jitter parameter, which was determined after warm-up, was less ($p<0.00$) than the value before warm-up, for all the vowels in the two pitch conditions (Low-A3 (220.0 Hz) and High-C5 (523.2 Hz). The value decreased from 0.31% to 0.22%. A paired-sample t-test was performed to compare Jitter parameter Vowels /a/, /o/ and /i/ pre-warm-up and post-warm-up of both low (A3) and high pitch (C5) conditions. There was a significant difference in the pre warm-up ($M=0.31$, $SD=0.11$) and post warm-up ($M=0.22$, $SD=0.07$) conditions; $t(239)=15.09$, $p=0.00$. The null hypothesis of equal Jitter pre and post-warm-up means was rejected, since $p<0.05$. Thus, the post-warm-up Jitter mean was statistically significantly lower than the pre-warm-up Jitter mean.

4.2 Research Question Two

Does vocal warm-up significantly alter the acoustic parameter - Shimmer of the untrained singing voice?

The results of the statistical test showed a significant difference of the mean values of the acoustic parameter – Shimmer, measure before and after the vocal warm-up (Table 3) which could be explained by the comparison tests.

Table 3

Mean Values and Standard Deviations (in Parentheses) of Shimmer parameter for all the Vowels /a/, /o/ and /i/ in the Two Pitch-Conditions, Low-A3 (220.0 Hz) and High-C5 (523.2 Hz), before and after Vocal Warm-Up

Subject	**Shimmer (%)**
Before	4.76 (3.30)
After	2.93 (1.66)

Table 4

Paired T-test Results of the Shimmer parameter for all the Vowels /a/, /o/ and /i/ in the Two Pitch-Conditions, Low-A3 (220.0 Hz) and High-C5 (523.2 Hz), before and after Vocal Warm-Up

Paired Samples Test

		Paired Differences					
		Mean	SD	SE	t	df	Sig (2-tailed)
Pair 1	Pretest - Posttest	1.83	2.27	0.15	12.52	239	0.00

Table 3 demonstrated the mean values and standard deviations (in parentheses) of Shimmer parameter for all the Vowels /a/, /o/ and /i/ in the Two Pitch-Conditions, Low-A3 (220.0 Hz) and High-C5 (523.2 Hz), pre and post vocal warm-up. Table 4 demonstrated the Paired T-test results of the Shimmer parameter for all the Vowels /a/, /o/ and /i/ in the Two Pitch-Conditions, Low-A3 (220.0 Hz) and High-C5 (523.2 Hz), before and after vocal warm-up. The overall Shimmer parameter was less than (p<0.00) the value before the warm-up for all three vowels in the Two Pitch Conditions, the Low-A3 (220.0 Hz) and the High C5 (523.2 Hz). The figure decreased from 4.76% to 2.93%. A paired-sample t-test was performed to compare Shimmer parameter Vowels /a/, /o/ and /i/ pre-warm-up and post-warm-up low (A3) and high pitch (C5) conditions. There was a significant difference in the pre warm-up (M=4.76, SD=3.30) and post warm-up (M=2.93, SD=1.66) conditions; t(239)=12.52, p=0.00. The null hypothesis of equal Shimmer pre and post-warm-up means was rejected, since p<0.05. Thus, the post-warm-up Shimmer mean was statistically significantly lower than the pre-warm-up Shimmer mean.

4.3 Research Question Three

Does vocal warm-up significantly alter the acoustic parameter - Harmonics-to-noise ratio (HNR) of the untrained singing voice?

The results of the statistical test showed a significant difference of the mean values of the acoustic parameter – Harmonics-to-noise ratio (HNR), measure before and after the vocal warm-up (Table 5) which could be explained by the comparison tests.

Table 5

Mean Values and Standard Deviations (in Parentheses) of Harmonics-to-noise ratio (HNR) parameter for all the Vowels /a/, /o/ and /i/ in the Two Pitch-Conditions, Low-A3 (220.0 Hz) and High-C5 (523.2 Hz), before and after Vocal Warm-Up

Subject	**HNR (%)**
Before	21.20 (5.02)
After	24.54 (4.56)

Table 6

Paired T-test Results of the Harmonics-to-noise ratio (HNR) parameter for all the Vowels /a/, /o/ and /i/ in the Two Pitch-Conditions, Low-A3 (220.0 Hz) and High-C5 (523.2 Hz), before and after Vocal Warm-Up

Paired Samples Test

		Paired Differences					
		Mean	SD	SE	t	df	Sig (2-tailed)
Pair 1	Pretest - Posttest	-3.33	3.20	0.21	-16.14	239	0.00

Table 5 demonstrated the mean values and standard deviations (in parentheses) of Harmonics-to-noise ratio (HNR) parameter for all the Vowels /a/, /o/ and /i/ in the Two Pitch-Conditions, Low-A3 (220.0 Hz) and High-C5 (523.2 Hz), pre and post vocal warm-up. Table 6 demonstrated the Paired T-test results of the HNR parameter for all the Vowels /a/, /o/ and /i/ in the Two Pitch-Conditions, Low-A3 (220.0 Hz) and High-C5 (523.2 Hz), before and after Vocal Warm-Up. The average HNR parameter was higher after the warm-up ($p<0.00$) than the value before warm-up for all the three vowels in the two pitch conditions, Low-A3 (220.0 Hz) and high-C5 (523.1 Hz). The value has increased from 21.20dB to 24.54dB. A paired-sample t-test was performed to compare HNR parameter Vowels /a/, /o/ and /i/pre-warm-up and post-warm-up for both low (A3) and high pitch (C5) conditions. There was a significant difference in the pre warm-up ($M=21.20$, $SD=5.02$) and post warm-up ($M=24.54$, $SD=4.56$) conditions; $t(239)=-14.14$, $p=0.00$. The null hypothesis of equal HNR pre and post-warm-up means was rejected, since $p<0.05$. Thus, the post-warm-up HNR mean was statistically significantly higher than the pre-warm-up HNR mean.

4.4 Research Question Four

Do acoustic parameters (Jitter, Shimmer and Harmonics-to-noise ratio (HNR)) differ with vowel type (/a/, /o/, /i/) at different pitch level – Low predetermined tone (frequencies) - A3 (220.0 Hz)?

4.4.1 Jitter

Table 7

Mean Values and Standard Deviations (in Parentheses) of Jitter for the Vowels /a/, /o/ and /i/ in the Low Pitch-Condition, A3 (220.0 Hz), before and after Vocal Warm-Up

		Vowel /a/	Vowel /o/	Vowel /i/
Variable	**Warmup**	**A3**	**A3**	**A3**
Jitter	**Before**	0.37 (0.07)	0.36 (0.10)	0.37 (0.09)
	After	0.25 (0.07)	0.25 (0.09)	0.25 (0.06)

Table 8

Paired T-test Results of the Jitter parameter classified by vowels

	A3
Subject	**Jitter**
a	t=10.82 p=0.00
o	t=6.29 p=0.00
i	t=7.97 p=0.00

After the vocal warm-up, the average vowel/a/ jitter parameter in low pitch condition (A3) was lower ($p<0.00$) than the value before warm-up which decreased from 0.37 to 0.25 per cent. A paired-sample t-test was performed to compare Jitter parameter Vowel /a/ pre-warm-up and post-warm-up low pitch (A3) conditions. There was a significant difference in the pre warm-up ($M=0.37$, $SD=0.07$) and post warm-up ($M=0.25$, $SD=0.07$) conditions; $t(39)=10.82$, $p=0.00$. The null hypothesis of equal Jitter pre and post-warm-up means was rejected, since $p<0.05$. Thus, the post-warm-up Jitter mean was statistically significantly lower than the pre-warm-up Jitter mean.

The average vowel /o/ Jitter parameter in low pitch condition (A3) calculated after the vocal warm-up was lower ($p<0.00$) than the pre-warm-up value, which decreased from 0.36 to 0.25 per cent. A paired-sample t-test was performed to compare Jitter parameter Vowel /o/ pre-warm-up and post-warm-up low pitch (A3) conditions. There was a significant difference in the pre warm-up ($M=0.36$, $SD=0.10$) and post warm-up ($M=0.25$, $SD=0.09$) conditions; $t(39)=6.29$, $p=0.00$. The null hypothesis of equal Jitter pre and post-warm-up means was rejected, since $p<0.05$. Thus, the post-warm-up Jitter mean was statistically significantly lower than the pre-warm-up Jitter mean.

The average vowel /i/ Jitter parameter in low pitch condition (A3) calculated after the vocal warm-up was lower ($p<0.00$) than the pre-warm-up value, decreasing from 0.37 to 0.25 per cent. A paired-sample t-test was performed to compare Jitter parameter Vowel /i/ pre-warm-up and post-warm-up low pitch (A3) conditions. There was a significant difference in the pre warm-up ($M=0.37$, $SD=0.09$) and post warm-up ($M=0.25$, $SD=0.06$) conditions; $t(39)=7.97$, $p=0.00$. The null hypothesis of equal Jitter pre and post-warm-up means was rejected, since $p<0.05$. Thus, the post-warm-up Jitter mean was statistically significantly lower than the pre-warm-up Jitter mean.

The difference between the three vowels was evident in the Jitter parameter. Table 7 indicated that the Jitter values are higher for the /a/ and/i/ vowels than the non-high vowel /o/ before the vocal warm-up. The findings after vocal warm-up indicated that all three vowels have the same Jitter values.

Figure 5 illustrated the average Jitter values measured pre and post vocal warm-up and their standard deviations at the low pitch level (A3).

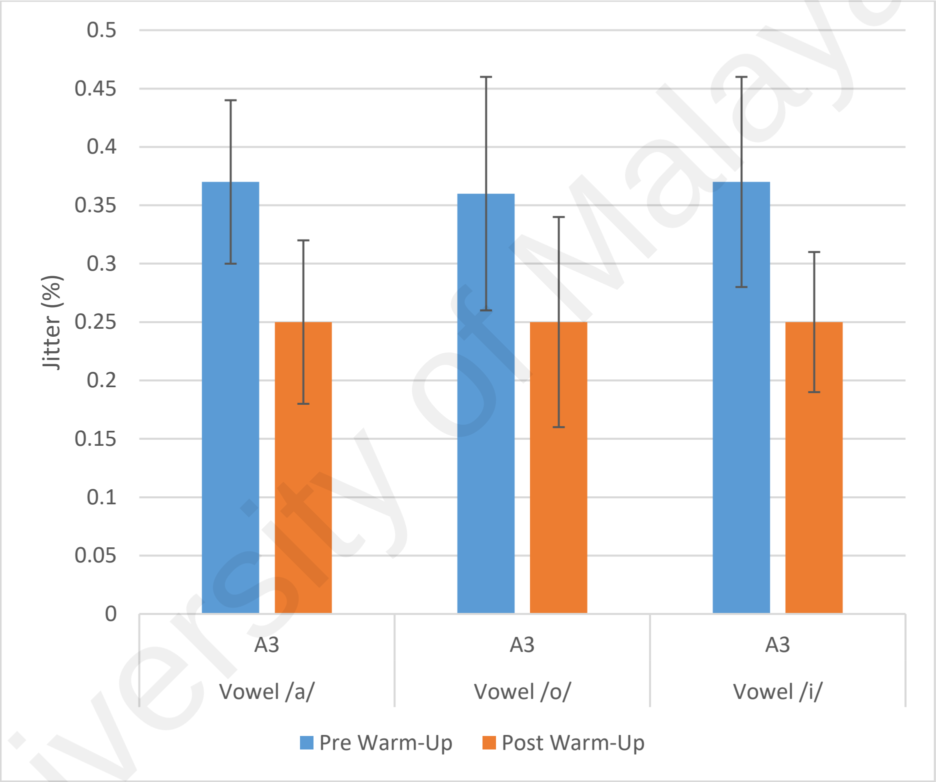


Figure 5: Group mean values and standard deviations for the Jitter parameter at Low pitch level (A3), pre and post vocal warm-up

4.4.2 Shimmer

Table 9

Mean Values and Standard Deviations (in Parentheses) of Shimmer for the Vowels /a/, /o/ and /i/ in the Low Pitch-Condition, A3 (220.0 Hz), before and after Vocal Warm-Up

		Vowel /a/	**Vowel /o/**	**Vowel /i/**
Variable	**Warmup**	**A3**	**A3**	**A3**
Shimmer	**Before**	5.61	6.30	8.97
		(1.98)	(2.47)	(4.18)
	After	2.96	3.79	5.30
		(0.90)	(1.40)	(2.36)

Table 10

Paired T-test Results of the Shimmer parameter classified by vowels

	A3
Subject	**Shimmer**
a	t=9.04
	p=0.00
o	t=8.81
	p=0.00
i	t=6.70
	p=0.00

The average vowel /a/ Shimmer parameter in low pitch condition (A3) calculated following the vocal warm-up was lower ($p<0.00$) than the value before the warm-up, decreasing from 5.61 to 2.96 per cent. A paired-sample t-test was performed to compare Shimmer parameter Vowel /a/ pre-warm-up and post-warm-up low pitch (A3) conditions. There was a significant difference in the pre warm-up ($M=5.61$, $SD=1.98$) and post warm-up ($M=2.96$, $SD=0.90$) conditions; $t(39)=9.04$, $p=0.00$. The null hypothesis of equal Shimmer pre and post-warm-up means was rejected, since $p<0.05$. Thus, the post-warm-up Shimmer mean was statistically significantly lower than the pre-warm-up Shimmer mean.

The average vowel /o/ Shimmer parameter in low pitch condition (A3) calculated following the vocal warm-up was lower ($p<0.00$) than the value before the warm-up, decreasing from 6.30 to 3.79 per cent. A paired-sample t-test was performed to compare Shimmer parameter Vowel /o/ pre-warm-up and post-warm-up low pitch (A3) conditions. There was a significant difference in the pre warm-up ($M=6.30$, $SD=2.47$) and post warm-up ($M=3.79$, $SD=1.40$) conditions; $t(39)=8.81$, $p=0.00$. The null hypothesis of equal Shimmer pre and post-warm-up means was rejected, since $p<0.05$. Thus, the post-warm-up Shimmer mean was statistically significantly lower than the pre-warm-up Shimmer mean.

The average vowel /i/ Shimmer parameter in low pitch condition (A3) calculated following the vocal warm-up was lower ($p<0.00$) than the value before the warm-up, decreasing from 8.97 to 5.30 per cent. A paired-sample t-test was performed to compare Shimmer parameter Vowel /i/ pre-warm-up and post-warm-up low pitch (A3) conditions. There was a significant difference in the pre-warm-up ($M=8.97$, $SD=4.18$) and post-warm-up ($M=5.30$, $SD=2.36$) conditions; $t(39)=6.83$, $p=0.000$. The null hypothesis of equal Shimmer pre and post-warm-up means was rejected, since $p<0.05$. Thus, the post-warm-up Shimmer mean was statistically significantly lower than the pre-warm-up Shimmer mean.

The difference between the three vowels was evident in the Shimmer parameter. Table 9 indicated that the Shimmer values are higher for the vowel /i/ than the non-high vowels /a/ and /o/ pre and post vocal warm-up.

Figure 6 illustrated the average Shimmer values measured pre and post vocal warm-up and their standard deviations at the low pitch level (A3).

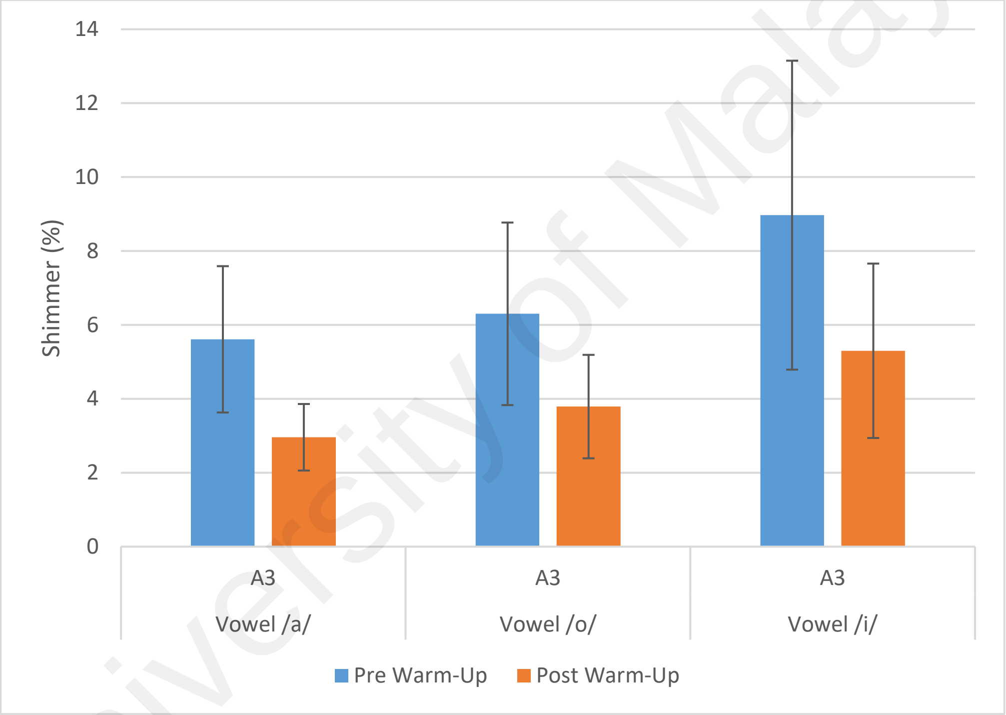


Figure 6: Group mean values and standard deviations for the Shimmer parameter at Low pitch level (A3), pre and post vocal warm-up

4.4.3 Harmonics-to-noise ratio

Table 11

Mean Values and Standard Deviations (in Parentheses) of Harmonics-to-noise ratio for the Vowels /a/, /o/ and /i/ in the Low Pitch-Condition, A3 (220.0 Hz), before and after Vocal Warm-Up

		Vowel /a/	Vowel /o/	Vowel /i/
Variable	**Warmup**	**A3**	**A3**	**A3**
HNR	**Before**	16.36	18.68	17.57
		(3.15)	(3.35)	(3.27)
	After	21.55	22.78	20.47
		(2.96)	(3.09)	(3.14)

Table 12

Paired T-test Results of the Shimmer parameter classified by vowels

	A3
Subject	**HNR**
a	t= -11.33
	p= 0.00
o	t= -9.48
	p= 0.00
i	t= -6.24
	p= 0.00

The average Harmonics-to-Noise ratio (HNR) of the low-pitch condition (A3) vowel /a/ measured in warm-up conditions was higher ($p<0.00$) than before the warm-up session, increasing from 16.36 to 21.55 dB. A paired-sample t-test was performed to compare HNR parameter Vowel /a/ pre-warm-up and post-warm-up low pitch (A3) conditions. There was a significant difference in the pre warm-up ($M=16.36$, $SD=3.15$) and post warm-up ($M=21.55$, $SD=2.96$) conditions; $t(39)=-11.33$, $p=0.00$. The null hypothesis of equal HNR pre and post-warm-up means was rejected, since $p<0.05$. Thus, the post-warm-up HNR mean was statistically significantly higher than the pre-warm-up HNR mean.

The average Harmonics-to-Noise ratio (HNR) of the low-pitch condition (A3) vowel /o/ measured in warm-up conditions was higher ($p<0.00$) than before the warm-up session, increasing from 18.68 to 22.78 dB. A paired-sample t-test was performed to compare HNR parameter Vowel /o/ pre-warm-up and post-warm-up low pitch (A3) conditions. There was a significant difference in the pre warm-up ($M=16.68$, $SD=3.35$) and post warm-up ($M=22.78$, $SD=3.09$) conditions; $t(39)=-9.48$, $p=0.00$. The null hypothesis of equal HNR pre and post-warm-up means was rejected, since $p<0.05$. Thus, the post-warm-up HNR mean was statistically significantly higher than the pre-warm-up HNR mean.

The average Harmonics-to-Noise ratio (HNR) of the low-pitch condition (A3) vowel /i/ measured in warm-up conditions was higher ($p<0.00$) than before the warm-up session, increasing from 17.57 to 20.47 dB. A paired-sample t-test was performed to compare HNR parameter Vowel /i/ pre-warm-up and post-warm-up low pitch (A3) conditions. There was a significant difference in the pre warm-up ($M=17.57$, $SD=3.27$) and post warm-up ($M=20.47$, $SD=3.14$) conditions; $t(39)=-6.241$, $p=0.00$. The null hypothesis of equal HNR pre and post-warm-up means was rejected, since $p<0.05$. Thus, the post-warm-up HNR mean was statistically significantly higher than the pre-warm-up HNR mean.

The difference between the three vowels was evident in the HNR parameter. Table 11 indicated that the HNR values are higher for the non-high vowel /o/ than the high vowel /i/ before the vocal warm-up. The findings after vocal warm-up indicated that the non-high vowels /a/ and /o/ had higher values of HNR than the high vowel /i/.

Figure 7 illustrated the average Harmonics-to-noise ratio (HNR) values measured pre and post vocal warm-up and their standard deviations at a low pitch level (A3).

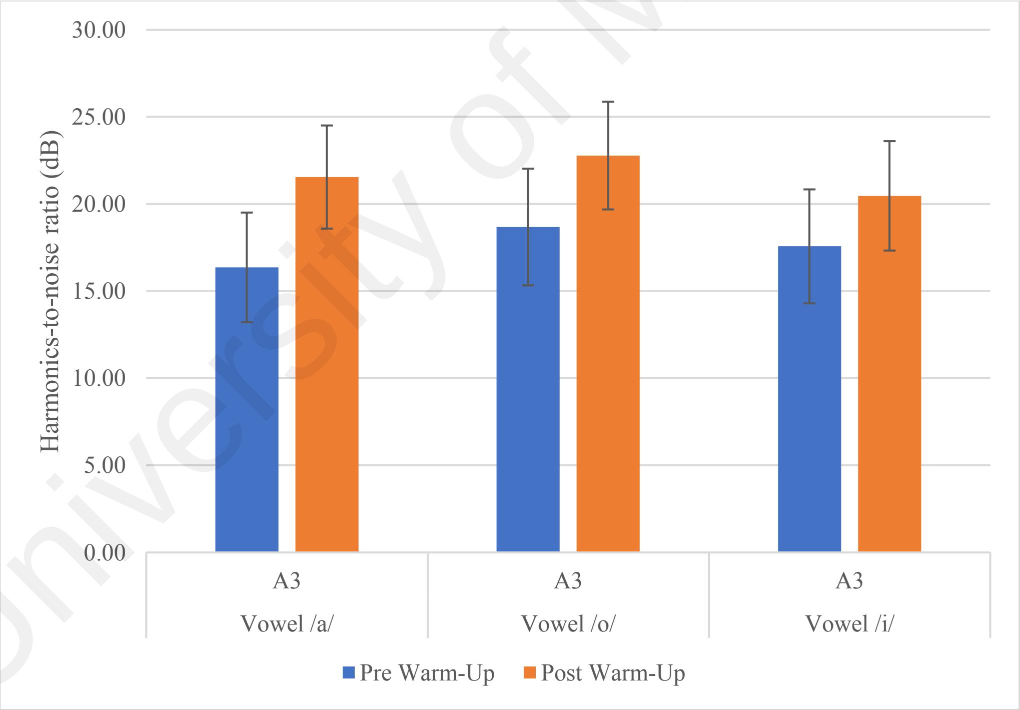


Figure 7: Group mean values and standard deviations for the Harmonics-to-noise ratio (HNR) parameter at Low pitch level (A3), pre and post vocal warm-up

4.5 Research Question Five

Do acoustic parameters (Jitter, Shimmer and Harmonics-to-noise ratio (HNR)) differ with vowel type (/a/, /o/, /i/) at different pitch level – High predetermined tone (frequencies) - C5 (523.2 Hz)?

4.5.1 Jitter

Table 13

Mean Values and Standard Deviations (in Parentheses) of Jitter for the Vowels /a/, /o/ and /i/ in the High Pitch-Condition, C5 (523.2 Hz), before and after Vocal Warm-Up

		Vowel /a/	**Vowel /o/**	**Vowel /i/**
Variable	**Warmup**	**C5**	**C5**	**C5**
Jitter	**Before**	0.27 (0.11)	0.25 (0.09)	0.26 (0.07)
	After	0.21 (0.07)	0.18 (0.07)	0.21 (0.06)

Table 14

Paired T-test Results of the Jitter parameter classified by vowels

	C5
Subject	**Jitter**
a	t=3.60 p=0.001
o	t=5.97 p=0.00
i	t=5.271 p=0.00

The average vowel /a/ Jitter parameter in high pitch condition (C5) calculated following the vocal warm-up was lower ($p<0.001$) than the value before the warm-up, decreasing from 0.27 to 0.21 per cent. A paired-sample t-test was performed to compare Jitter parameter Vowel /a/ pre-warm-up and post-warm-up high pitch (C5) conditions. There was a significant difference in the pre warm-up ($M=0.27$, $SD=0.11$) and post warm-up ($M=0.21$, $SD=0.07$) conditions; $t\ (39)=3.60$, $p=0.001$. The null hypothesis of equal Jitter pre and post-warm-up means was rejected, since $p<0.05$. Thus, the post-warm-up Jitter mean was statistically significantly lower than the pre-warm-up Jitter mean.

The average vowel /o/ Jitter parameter in high pitch condition (C5) calculated following the vocal warm-up was lower ($p<0.00$) than the value before the warm-up, decreasing from 0.25 to 0.18 per cent. A paired-sample t-test was performed to compare Jitter parameter Vowel /o/ pre-warm-up and post-warm-up high pitch (C5) conditions. There was a significant difference in the pre warm-up ($M=0.25$, $SD=0.09$) and post warm-up ($M=0.18$, $SD=0.07$) conditions; $t\ (39)=5.97$, $p=0.00$. The null hypothesis of equal Jitter pre and post-warm-up means was rejected, since $p<0.05$. Thus, the post-warm-up Jitter mean was statistically significantly lower than the pre-warm-up Jitter mean.

The average vowel /i/ Jitter parameter in high pitch condition (C5) calculated following the vocal warm-up was lower ($p<0.00$) than the value before the warm-up, decreasing from 0.26 to 0.21 per cent. A paired-sample t-test was performed to compare Jitter parameter Vowel /i/ pre-warm-up and post-warm-up high pitch (C5) conditions. There was a significant difference in the pre warm-up ($M=0.26$, $SD=0.07$) and post warm-up ($M=0.21$, $SD=0.06$) conditions; $t\ (39)=5.271$, $p=0.00$. The null hypothesis of equal Jitter pre and post-warm-up means was rejected, since $p<0.05$. Thus, the post-warm-up Jitter mean was statistically significantly lower than the pre-warm-up Jitter mean.

The difference between the three vowels was evident in the Jitter parameter. Table 13 indicated that the Jitter values are higher for the non-high vowel /a/ and the high-vowel /i/ than the non- high vowel /o/ before the vocal warm-up. The findings after vocal warm-up indicated that the high vowel /i/ and the non-high vowels /a/ had higher values of Jitter than the non-high vowel /o/.

Figure 8 illustrated the average Jitter values measured pre and post vocal warm-up and their standard deviations at high pitch level (C5).

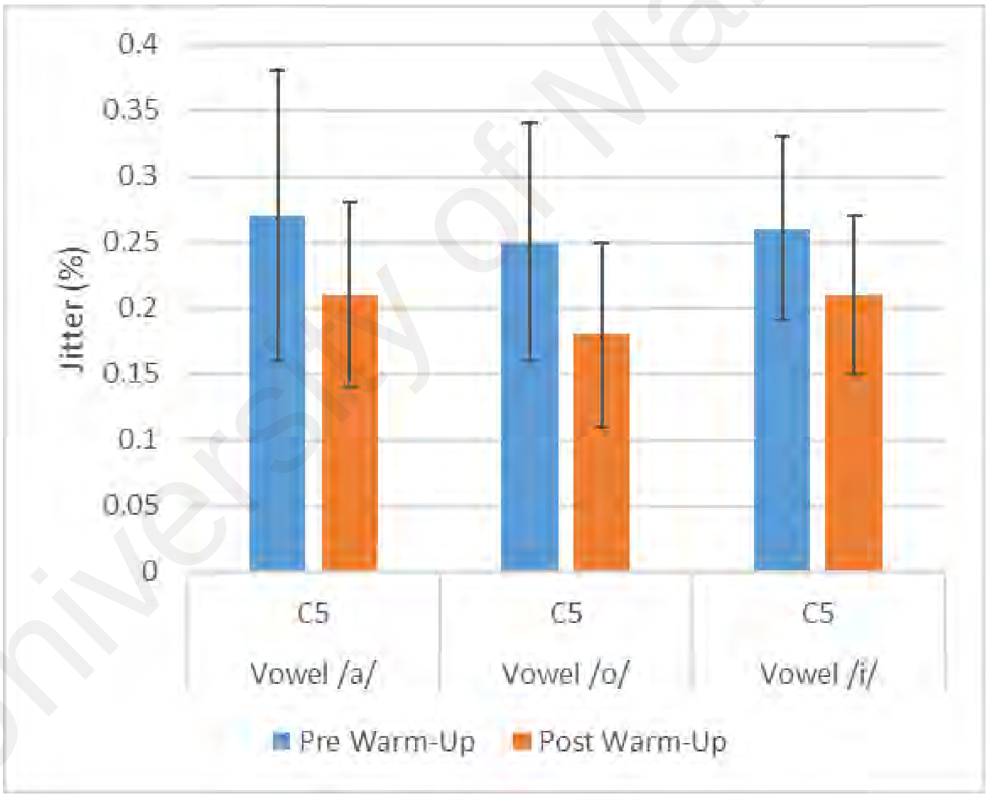


Figure 8: Group mean values and standard deviations for the Jitter parameter at High pitch level (C5), pre and post vocal warm-up

4.5.2 Shimmer

Table 15

Mean Values and Standard Deviations (in Parentheses) of Shimmer for the Vowels /a/, /o/ and /i/ in the High Pitch-Condition, C5 (523.2 Hz), before and after Vocal Warm-Up

		Vowel /a/	**Vowel /o/**	**Vowel /i/**
Variable	**Warmup**	**C5**	**C5**	**C5**
Shimmer	**Before**	2.66	2.30	2.19
		(0.88)	(0.76)	(0.69)
	After	2.16	1.70	1.68
		(0.84)	(0.53)	(0.49)

Table 16

Paired T-test Results of the Shimmer parameter classified by vowels

	C5
Subject	**Shimmer**
a	t=3.98
	p=0.00
o	t=4.75
	p=0.00
i	t=7.09
	p=0.00

The average vowel /a/ Shimmer parameter in high pitch condition (C5) calculated following the vocal warm-up was lower ($p<0.00$) than the value before the warm-up, decreasing from 2.66 to 2.16 per cent. A paired-sample t-test was performed to compare Shimmer parameter Vowel /a/ pre-warm-up and post-warm-up high pitch (C5) conditions. There was a significant difference in the pre warm-up ($M=2.66$, $SD=0.88$) and post warm-up ($M=2.16$, $SD=0.84$) conditions; $t(39)=3.98$, $p=0.00$. The null hypothesis of equal Shimmer pre and post-warm-up means was rejected, since $p<0.05$. Thus, the post-warm-up Shimmer mean was statistically significantly lower than the pre-warm-up Shimmer mean.

The average vowel /o/ Shimmer parameter in high pitch condition (C5) calculated following the vocal warm-up was lower ($p<0.00$) than the value before the warm-up, decreasing from 2.30 to 1.70 per cent. A paired-sample t-test was performed to compare Shimmer parameter Vowel /o/ pre-warm-up and post-warm-up high pitch (C5) conditions. There was a significant difference in the pre warm-up ($M=2.30$, $SD=0.76$) and post warm-up ($M=1.70$, $SD=0.53$) conditions; $t(39)=4.75$, $p=0.00$. The null hypothesis of equal Shimmer pre and post-warm-up means was rejected, since $p<0.05$. Thus, the post-warm-up Shimmer mean was statistically significantly lower than the pre-warm-up Shimmer mean.

The average vowel /i/ Shimmer parameter in high pitch condition (C5) calculated following the vocal warm-up was lower ($p<0.00$) than the value before the warm-up, decreasing from 2.19 to 1.68 per cent. A paired-sample t-test was performed to compare Shimmer parameter Vowel /i/ pre-warm-up and post-warm-up high pitch (C5) conditions. There was a significant difference in the pre warm-up ($M=2.19$, $SD=0.69$) and post warm-up ($M=1.68$, $SD=0.49$) conditions; $t(39)=7.09$, $p=0.00$. The null hypothesis of equal Shimmer pre and post-warm-up means was rejected, since $p<0.05$. Thus, the post-warm-up Shimmer mean was statistically significantly lower than the pre-warm-up Shimmer mean. Figure 9 demonstrated the graphs of Shimmer mean values and their standard deviation at high pitch level (C5) measured before and after vocal warm-up.

The difference between the three vowels was evident in the Shimmer parameter. Table 15 indicated that the Shimmer values are higher for the non-high vowel /a/ than the vowel /i/ and /o/ before the vocal warm-up. The findings after vocal warm-up indicated that non-high vowels /a/ had higher values of Shimmer than the high vowel /i/ and non-high vowel /o/.

Figure 9 illustrated the average Shimmer values measured pre and post vocal warm-up and their standard deviations at high pitch level (C5).

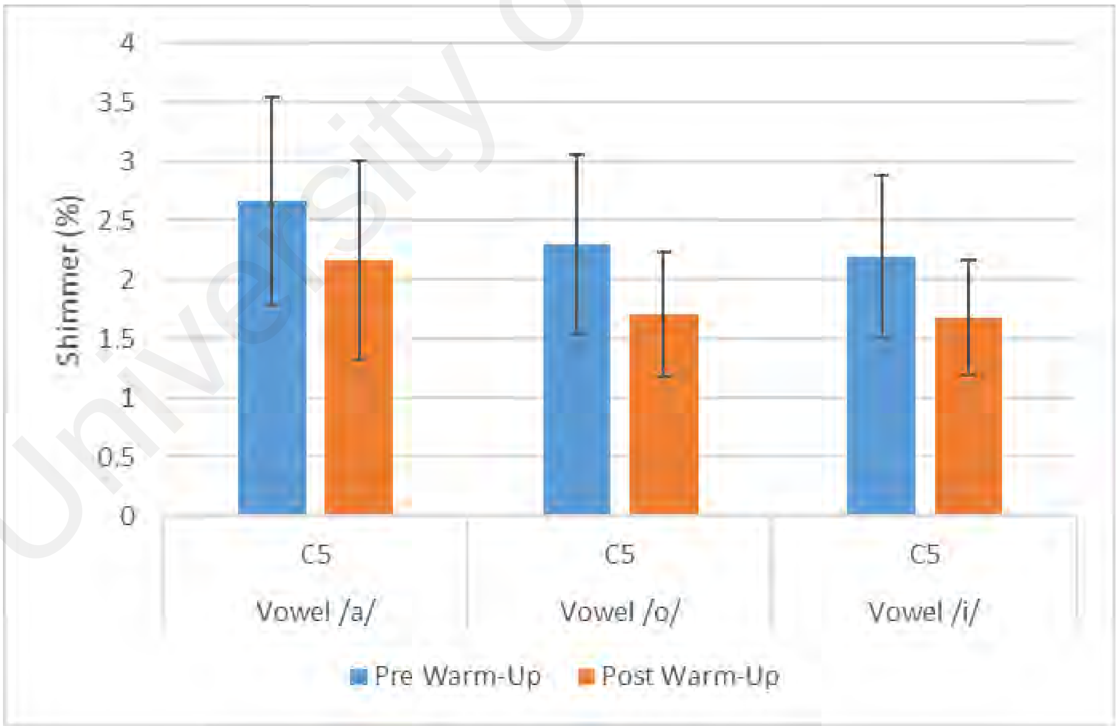


Figure 9: Group mean values and standard deviations for the Shimmer parameter at High pitch level (C5), pre and post vocal warm-up

4.5.3 Harmonics-to-noise ratio

Table 17

Mean Values and Standard Deviations (in Parentheses) of Harmonics-to-noise ratio (HNR) for the Vowels /a/, /o/ and /i/ in the High Pitch-Condition, C5 (523.2 Hz), before and after Vocal Warm-Up

		Vowel /a/	**Vowel /o/**	**Vowel /i/**
Variable	**Warmup**	**C5**	**C5**	**C5**
HNR	**Before**	23.67	25.93	25.02
		(3.10)	(2.94)	(3.97)
	After	26.83	28.98	26.64
		(3.23)	(3.67)	(4.00)

Table 18

Paired T-test Results of the Harmonics-to-noise ratio (HNR) parameter classified by vowels

	C5
Subject	**HNR**
a	t= -7.09
	p= 0.00
o	t= -6.10
	p= 0.00
i	t= -2.855
	p= 0.007

The average Harmonics-to-Noise ratio (HNR) of the high-pitch condition (C5) vowel /a/ measured in warm-up conditions was higher ($p<0.00$) than before the warm-up session, increasing from 23.67 to 26.83 dB. A paired-sample t-test was performed to compare HNR parameter Vowel /a /pre-warm-up and post-warm-up high pitch (C5) conditions. There was a significant difference in the pre warm-up ($M=23.67$, $SD=3.10$) and post warm-up ($M=26.83$, $SD=3.23$) conditions; $t(39)= -7.09$, $p=0.00$. The null hypothesis of equal HNR pre and post-warm-up means was rejected, since $p<0.05$. Thus, the post-warm-up HNR mean was statistically significantly higher than the pre-warm-up HNR mean.

The average Harmonics-to-Noise ratio (HNR) of the high-pitch condition (C5) vowel /o/ measured in warm-up conditions was higher ($p<0.00$) than before the warm-up session, increasing from 25.93 to 28.98 dB. A paired-sample t-test was performed to compare HNR parameter Vowel /o/ pre-warm-up and post-warm-up high pitch (C5) conditions. There was a significant difference in the pre warm-up ($M=25.93$, $SD=2.94$) and post warm-up ($M=28.98$, $SD=3.67$) conditions; $t(39)= -6.10$, $p=0.00$. The null hypothesis of equal HNR pre and post-warm-up means was rejected, since $p<0.05$. Thus, the post-warm-up HNR mean was statistically significantly higher than the pre-warm-up HNR mean.

The average Harmonics-to-Noise ratio (HNR) of the high-pitch condition (C5) vowel /i/ measured in warm-up conditions was higher ($p<0.007$) than before the warm-up session, increasing from 25.02 to 26.64 dB. A paired-sample t-test was performed to compare HNR parameter Vowel /i/ pre-warm-up and post-warm-up high pitch (C5) conditions. There was a significant difference in the pre warm-up ($M=25.02$, $SD=3.97$) and post warm-up ($M=26.64$, $SD=4.00$) conditions; $t(39)= -2.85$, $p=0.007$. The null hypothesis of equal HNR pre and post-warm-up means was rejected, since $p<0.05$. Thus, the post-warm-up HNR mean was statistically significantly higher than the pre-warm-up HNR mean.

The difference between the three vowels was evident in the HNR parameter. Table 17 indicated that the HNR values are higher for the non-high vowel /o/ than the high vowel /i/ and non-high vowel /a/ pre vocal warm-up. The findings after vocal warm-up indicated that the non-high vowel /a/ had higher values of HNR than the high vowel /i/ and non-high vowel /o/.

Figure 10 illustrated the average Harmonics-to-noise ratio (HNR) values measured pre and post vocal warm-up and their standard deviations at high pitch level (C5).

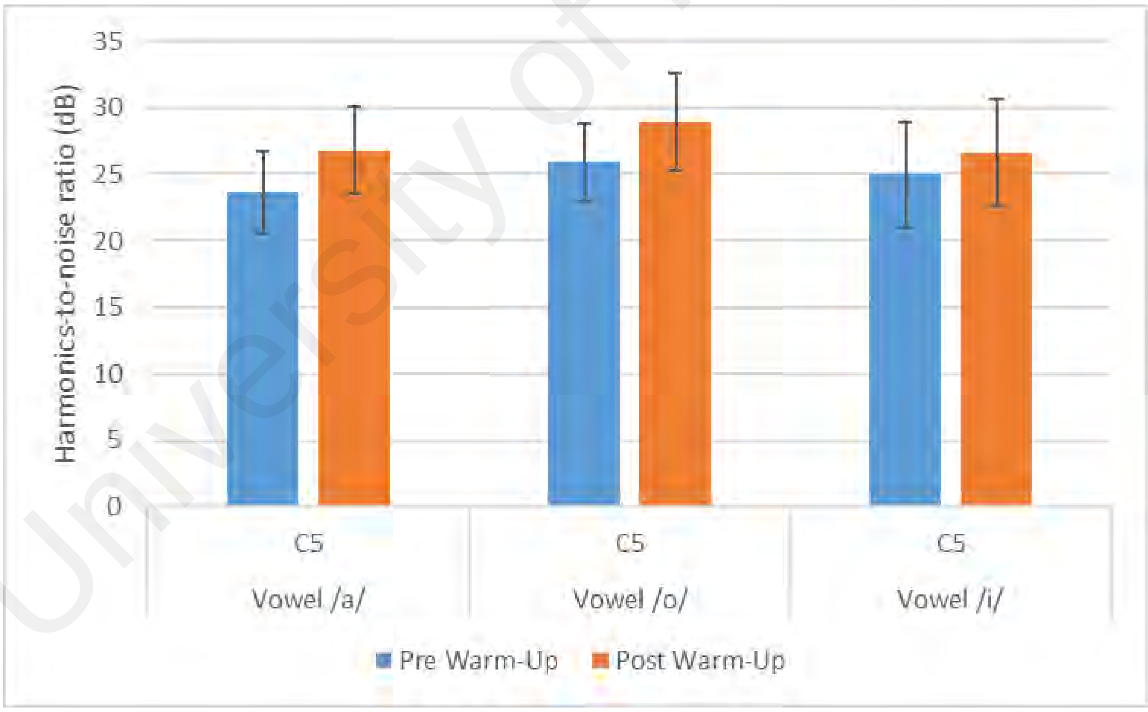


Figure 10: Group mean values and standard deviations for the Harmonics-to-noise ratio (HNR) parameter at High pitch level (C5), pre and post vocal warm-up

CHAPTER 5

DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

This research aimed to determine the effect of vocal warm-up on the voice quality of 40 untrained female singers in Malaysia. In this study, vocal acoustic parameters were measured pre and post-warm-up session, with an intervention of phonatory activity, and significant effects on all acoustic parameters were identified.

This study reflects the impact of vocal warm-up on the three acoustic parameters: jitter and shimmer decrease while the harmonics-to-noise ratio (HNR) increase after a 20-minute structured vocal warm-up. The Jitter and Shimmer decrease indicates that there is an improvement in vocal roughness and vocal breathiness respectively. The HNR increase indicates that there is an improvement in vocal hoarseness. The benefit of singing vocal warm-ups has been documented, and untrained singers could apply the techniques used by trained singers to enhance their singing voices.

5.2 Discussions of the Research Questions

This section will discuss each research question posed for this study. Each research question will be discussed individually.

5.2.1 Research Question One

Does vocal warm-up significantly alter the acoustic parameter - Jitter of the untrained singing voice?

Table 1 demonstrated a significant decrease in Jitter values after vocal warm-up. The vocal folds display fundamental frequency and amplitude variations during sustained vibration. The Jitter reflects the "frequency perturbation". Jitter demonstrates the variation in vocal fold vibration and is related to the perception of vocal roughness. The Jitter increases in patients with vocal fold disorders. The decrease shown suggests that the vocal warm-up influences the vibration cycle in the vocal fold and also decreases perturbations in normophonic subjects. It also indicates that the vibration adjustment of the vocal folds has improved, allowing for better use of the voice during the performance. The lack of control of the vocal fold vibration mainly affects Jitter (De Felippe, Grillo & Grechi, 2006; Teixeira, Oliveira, & Lopes, 2013; Mezzedimi et al., 2018).

5.2.2 Research Question Two

Does vocal warm-up significantly alter the acoustic parameter - Shimmer of the untrained singing voice?

Table 3 demonstrated a significant decrease in Shimmer values after vocal warm-up. The "amplitude perturbation" is represented by Shimmer. The shimmer is related to sound wave amplitude or vocal emission intensity. This is primarily caused by the reduction of glottis resistance and mass lesions in the vocal folds, which are associated with noise at emission and breathiness. The Shimmer also shows disturbances of short-term amplitude that are often minimally present in normophonic subjects. The relationship between subglottic pressure and glottis resistance is particularly affected by Shimmer. The decrease we observed indicates that the vocal warm-up affected the mechanisms underlying the phonatory effort, reducing the amplitude changes shown by the shimmer (Teixeira, Oliveira, & Lopes, 2013; James & John, 2007; Mezzedimi et al., 2018).

5.2.3 Research Question Three

Does vocal warm-up significantly alter the acoustic parameter - Harmonics-to-noise ratio (HNR) of the untrained singing voice?

Table 5 demonstrated a significant increase of HNR values after vocal warm-up. The Harmonics-to-noise ratio (HNR) is defined as the quantity and harmonic energy of the fundamental frequency (F0), divided by noise energy frequencies. HNR is related to the perception of vocal roughness and breathiness. Disordered voices have a high level of noise and low HNR. A decrease in HNR can indicate either increased additive disturbance noise associated with impaired glottis closure (breathiness) or increased jitter (roughness) (Teixeira, Oliveira, & Lopes, 2013; James & John, 2007). The increase in the results of this study indicates that the amount of periodic vocal signals is higher after vocal warm-up than before. Besides, this can also be correlated with a corresponding decline in aperiodicity in the signal (Yumoto & Gould, 1982; De Felippe, Grillo & Grechi, 2006; Teixeira, Oliveira, & Lopes, 2013; Mezzedimi et al., 2018).

5.2.4 Research Question Four

Do acoustic parameters (Jitter, Shimmer and Harmonics-to-noise ratio (HNR)) differ with vowel type (/a/, /o/, /i/) at different pitch level – Low predetermined tone (frequencies) - A3 (220.0 Hz)?

Table 7 demonstrated a significant decrease of Jitter values for all three vowels /a/, /o/ and /i/ at low pitch level (A3) which was produced in the chest register. As for the vowel effect, according to Table 7, it can be seen that the non-high vowel /a/ and high vowel /i/ had higher values of Jitter than the non-high vowel /o/ pre vocal warm-up. In this study, pre vocal warm-up result is similar to Orlikoff's study. In most acoustic studies using multiple vowels, Orlikoff (1995) recorded low disturbance of high vowels and higher disturbance of low vowels with several conflicting findings. However, in this study, post vocal warm-up results showed that all three vowels have the same values of Jitter. Therefore, the results could not be compared.

Table 9 demonstrated a significant decrease of Shimmer values for all three vowels /a/, /o/ and /i/ at low pitch level (A3) which was produced in the chest register. Shimmer results indicated that the high vowel /i/ had the highest values, intermediate for low vowel /o/ and lowest for vowel /a/ for pre and post vocal warm-up. In a recent study, the contrary results of the lowest shimmer for / i/, the intermediate for /a/ and the highest for /u/ were reported by Akif et al. (2004). Vowels effect have less noticeable results in terms of measuring jitter and shimmer. From these contradictory findings, it is clear that the effects of vowels on the study of perturbation are inconclusive.

Table 11 demonstrated a significant increase of HNR values for all three vowels /a/, /o/ and /i/ at low pitch level (A3) which was produced in the chest register. As for the vowel effect, Table 11 demonstrated HNR highest values for vowel /o/, intermediate for vowel /i/ and lowest for vowel /a/ pre vocal warm-up. The SNR findings by MacCallum et al. (2011) found similar vowel effects in females. SNR was highest for /i/, intermediate for /u/, and lowest for /a/. In this study, post-warm-up HNR results showed the highest values for vowel /o/, intermediate for the vowel /a/ and lowest for vowel /i/. The findings of this study are inconsistent with the results of MacCallum et al. (2011).

5.2.5 Research Question Five

Do acoustic parameters (Jitter, Shimmer and Harmonics-to-noise ratio (HNR)) differ with vowel type (/a/, /o/, /i/) at different pitch level – High predetermined tone (frequencies) - C5 (523.2 Hz)?

Table 13 demonstrated a significant decrease of Jitter values for all three vowels /a/, /o/ and /i/ at high pitch level (C5) which was produced in the head register. As for the vowel effect, according to Table 13, it can be seen that the vowels /a/ and /i/ had higher values of Jitter than the vowel /o/ pre vocal warm-up. Post vocal warm-up results showed that the high vowel /i/ and non-high vowel /a/ had higher values of Jitter than the non-high vowels /o/. Vowel /i/ and vowel /o/ had the same values, the results did not distinguish high from low vowels. Therefore, the results were also not comparable.

Table 15 demonstrated a significant decrease of Shimmer values for all three vowels /a/, /o/ and /i/ at high pitch level (C5) which was produced in the head register. Shimmer results indicated that the high vowel /a/ had the highest values, intermediate for the low vowel /i/ and lowest for vowel /o/ for pre and post vocal warm-up. The findings in this study are in line with some researchers who have found Shimmer to be the lowest for the vowel /u/, intermediate for vowel /i/, and highest for vowel /a/ (Horii, 1980; Ramig, 1983; Sorensen & Horii, 1983).

Table 17 demonstrated a significant increase of HNR values for all three vowels /a/, /o/ and /i/ at high pitch level (C5) which was produced in the head register. HNR results for pre vocal warm-up indicated that the non-high vowel /o/ had the highest values, intermediate for the high vowel /i/ and lowest for vowel /a/. A few studies showed that findings of the SNR analysis indicated that the production of low vowels, such as /a/, is carried out in a lower vibration rate of vocal fold and induces greater signal noise levels than high vowel production. This is known as the intrinsic pitch of vowels and is often attributed to mechanical coupling resulting in anterior positioning of the hyoid bone and forward tilting of the thyroid cartilage, creating an anterior pull on the vocal folds and increasing fold tension for high vowels such as /i/ and /u/ (Higgins et al., 1998; Sapir, 1989). In this study, HNR results for post vocal warm-up indicated that the non-high vowel /o/ had the highest values, intermediate for the non-high vowel /a/ and lowest for the high vowel /i/. The results of this study are inconsistent with the results of MacCallum et al. (2011). The low vowel /a/ had lesser harmonic activity in its signals, as indicated by its lowest SNR values, and the slowest vibratory frequencies, as indicated by F0 values. Conversely, the high vowels /i/ and /u/ had greater harmonic activity and higher vocal fold vibratory frequencies and demonstrated less complexity.

5.3 Implications of the Study

The significant reduction in jitter and shimmer and increase in HNR observed after the vocal warm-up confirmed the positive effect and demonstrated the importance of this practice. The findings in this study indicated that untrained singers could benefit from vocal warm-up and it should be encouraged and not bypassed. Therefore, professional singers or untrained singers should develop a vocal warm-up routine to enhance their vocal qualities and prevent future voice problems. This study's findings could benefit voice teachers in implementing best practice in rehearsals. Future research may investigate whether singing with various vowels and consonants has different effects on the vocal mechanism and on the vocal acoustic parameters. It is also important to compare the effects of vocal warm-up procedures of various duration and types in future studies. Such research may establish the best procedure for vocal warm-up to improve voice quality and prevent vocal injury in singers.

The findings of this study also seem to reinforce further suggestions of the acoustic analysis as a valuable tool for assessing and measuring the impact of voice warm-up on voice production (Teixeira & Fernandes, 2014; Sascha & Pascal, 2019; Bausar, Bohlender, Mehta, 2018). Audio-visual feedback displays, such as those provided in the Praat software version 6.1.03, might be useful tools in successfully developing a means of warming up which is not only not damaging to the voice but beneficial in facilitating an optimal vocal quality (Paul & Vincent, 2001). Using these objective measures of vocal quality, one could develop a warm-up technique to establish an enhanced tone and increased projection with minimal effort. One could also develop a warm-up technique to establish a vocal quality with minimal vocal perturbation (i.e., pure tone quality) and minimal variation in vocal perturbation (i.e., even vibrato), through the use of measures of vocal perturbation (Sataloff, 2017; Sataloff, 2017).

5.4 Conclusions

This study investigated the effects of vocal warm-in improving voice quality of untrained female singers in two pitch-conditions, A3 (Chest register) & C5 (Head register). The results demonstrated that after 20 minutes of vocal warm-up, all of the 40 participants' voice qualities improved by decreasing Jitters and Shimmers, and increasing Harmonics-to-noise ratio (HNR), which was consistent with other research studies (Amir et al., 2005; Tay et al. 2012). The results show that acoustic analysis is a valuable tool for assessing and measuring the impact of voice warm-up on voice production (Teixeira & Fernandes, 2014; Sascha & Pascal, 2019; Bausar, Bohlender, Mehta, 2018). Such results also support the importance of including different exercises in the warm-up routine which are aimed not only at laryngeal muscles but also at breathing posture and relaxation. The increase in amplitude perturbation measures after warm-up suggests that warm-up, in addition to vocal fold control, also increases the regulation of the breathing mechanism that has a significant role in amplitude variation.

The reduction in Jitter demonstrates that vocal warm-up affects the vibration cycle of the vocal fold, which minimizes disturbances and enhances voice quality. The decline in Shimmer indicates that it also affected the underlying mechanisms of the phonatory effect, reducing the variations in amplitude. The Jitter and Shimmer decrease indicates that there is an improvement in vocal roughness and vocal breathiness respectively. The HNR increase indicates that there is an improvement in vocal hoarseness. Therefore, the findings in this study indicated that untrained singers could benefit from vocal warm-up and it should be encouraged and not bypassed (De Felippe, Grillo & Grechi, 2006; Teixeira, Oliveira, & Lopes, 2013; Christian, 2007; Yumoto & Gould, 1982).

As for the vowel effect, the results indicated that vowel effects on perturbation analysis are inconsistent among this and previous studies (Akif et al., 2004; MacCallum et al., 2011). Perturbation parameters have proved to be unpredictable as a result of vowel effects in this analysis. After the vocal warm-up, all three vowels have the same values of Jitter for the low pitch condition (A3). The results were not comparable. For per cent Jitter in high pitch condition (C5), post-vocal warm-up findings indicated that the high vowel /i/ and non-high vowel /a/ had higher values of Jitter than the non-high vowels /o/. Vowel /i/ and vowel /o/ had the same values, the results did not distinguish high from low vowels. Therefore, the results were also not comparable.

For per cent Shimmer in low pitch condition (A3), shimmer results indicated that the high vowel /i/ had the highest values, intermediate for low vowel /o/ and lowest for the vowel /a/ for pre and post vocal warm-up. The findings were not in line with the study of Akif et al. (2004). Akif et al. (2004) found conflicting results including the opposite findings of lowest shimmer for /i/, intermediate for /a/, and highest for /u/. For per cent Shimmer in high pitch condition (C5), the results indicated that the high vowel /a/ had the highest values, intermediate for the low vowel /i/ and lowest for vowel /o/ for pre and post vocal warm-up. The results in this study are in line with some researchers who have found Shimmer to be the lowest for the vowel /u/, intermediate for vowel /i/, and highest for vowel /a/ (Horii, 1980; Ramig, 1983; Sorensen & Horii, 1983).

Overall, the results indicated that vowel effects on perturbation analysis are inconsistent among this and previous studies. In recent years, it has been suggested that the algorithms employed to calculate perturbation parameters may only be useful for nearly periodic voice signals and may not reliably analyse strongly aperiodic signals (Titze, 1995; Karnell, Chang, Smith & Hoffman, 1997). Besides, some recording and analysis conditions including microphone type and placement (Titze & Winholtz, 1993), analysis systems (Karnell, Scherer & Fischer, 1991; Bielamowicz, Kreiman, Gerratt, Dauer & Berke, 1996), and environmental noise (Carson, Ingrisano & Eggleston, 2003; Deliyski, Shaw & Evans, 2005) have found to affect jitter and shimmer.

For Harmonics-to-noise ratio (HNR) in low pitch condition (A3), post-warm-up HNR results showed the highest values for vowel /o/, intermediate for the vowel /a/ and lowest for vowel /i/. The results of this study are inconsistent with the results of MacCallum et al. (2011). He found that SNR was highest for /i/, intermediate for /u/, and lowest for /a/. For Harmonics-to-noise ratio (HNR) in high pitch condition (C5), HNR results for post vocal warm-up indicated that the non-high vowel /o/ had the highest values, intermediate for the non-high vowel /a/ and lowest for the high vowel /i/. The results of this study are inconsistent with the results of MacCallum et al. (2011). The low /a/ vowel had less harmonic activity in its signals, as indicated by its lowest SNR values. Conversely, the high vowels /i/ and /u/ had greater harmonic activity and higher vocal fold vibratory frequencies and demonstrated less complexity.

This suggests that per cent jitter, per cent shimmer and harmonics-to-noise ratio (HNR) are not useful parameters in reliably describing acoustic differences between vowels. Vowel effects on acoustic perturbation analysis in other voice types, including dysphonic voices, should be investigated to validate the acoustic effects of vowel selection found in this research.

5.5 Recommendations for future research

Singers from a wider range of geographical areas should be recruited in future research to control regional variations. A control group was not used in this study, and to ensure that results are related to the effect of the vocal warm-up, the use of a control group in future studies could be beneficial. The impact of vocal warm-up on different genders and ages in both men and women should be further explored for future research. More vowel types should be explored to assess the effects on voice quality. Use of a larger group of participants could also be conducted in future studies to enhance validity and data significance. Besides, the present study used a single before and after measurements. Future research using multiple before and after warm-up interventions could be useful. For future studies, the effects of vowels on acoustic analysis could also be discussed.

In conclusion, through an acoustic analysis paradigm, the findings presented here confirmed that vocal warm-up has significant evidence to increase the overall vocal quality of untrained female singers. Further emphasis on the above studies would be of great relevance and interest for singing teachers and their students.

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