PRE-PERFORMANCE PRACTICES:
BREATHING IMAGERY AND WARM-UP FOR SINGERS

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of requirements for the degree of
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Volume 1
Declaration

I, Lynda Moorcroft, hereby declare that this submission is my own work and that it contains no material previously published or written by another person except where acknowledged in the text. This thesis contains no material that has been accepted for the award of a higher degree.

Ethical approval has been granted for the study presented in this thesis from The University Human Ethics Committee. Participating subjects and perceptual judges were required to read and to sign an information document. Informed consent was obtained individually prior to the collection of data and to the collection of the judges’ results.

Signed: Date: 1st March 2011

Supervisor’s signature: Date: 1st March 2011

Supervisor’s certification

I hereby certify the thesis of Lynda Moorcroft Pre-performance practices: Breathing imagery and warm-up for singers to be suitable for examination.

Signed: Date: 1st March 2011
Acknowledgments

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Abstract

Research clarifying whether silent warm-up is possible and what constitutes a warmed-up voice is lacking. The acoustic correlates of a warmed-up voice are not clear, and perceptual correlates have centred on singers’ rather than both singers’ and listeners’ perceptions. This thesis therefore investigates the acoustic and perceptual changes following vocal warm-up and breathing imagery, and whether breathing imagery may serve as a silent warm-up for singers.

The literature review covers the acoustic and perceptual factors critical to optimal tone quality in singing, and the challenges of vocal assessment. It presents an historical survey of imagery and discusses the role of imagery in singing. It also investigates the relationship between optimal performance and vocal warm-up. As both imagery and warm-up for the voice are lacking thorough investigation, the review is supplemented with findings from sports psychology and sports medicine.

In study 1, singers were recorded before and after three non-vocal 25 minute tasks. One task involved imagery of the breath directed upwards and downwards as far from the larynx as possible. Such imagery is found in the teaching of Giovanni Battista Lamperti (Brown, 1957) as well as more recent pedagogical literature (Brünner, 1993; Holmes, 2003; Lehmann, 1922; Patenaude-Yarnell, 2003; Robison, 2001; Vennard, 1968; Yurisich, 2000). Another 25 minute task used Braille script as employed in the reading of music by the visually impaired. This provided the opportunity for the singer to engage in tactile, kinaesthetic and visual imagery related to music yet unrelated to breath function. A third task was a non-imagery breath-related activity that required the completion of a cloze passage about breath function for singers. In study 2, singers were recorded before and after a 25 minute vocal warm-up.

The singers’ vocal signals were acoustically analysed for pre- to post-test changes in vibrato rate, vibrato extent and sound pressure level. Singer-subjects self-assessed their performances, and listener-judges perceptually rated the vocal samples presented in a fully randomised block design.

Acoustic results for both breathing imagery and vocal warm-up produced three notable changes in vibrato rate: (i) more regularity in the cyclic undulations comprising the vibrato rate of a note, (ii) more stability in mean vibrato rates from one sustained note.
to the next, and (iii) a moderating of excessively fast and excessively slow mean vibrato rates for solos. The alternate imagery task based on Braille music code produced slower, less regular vibrato rates. This may have been due to the singers becoming too relaxed, as links are sometimes noted between imagery and relaxation (Hall, 1995; Hall, Mack, Paivio and Hausenblas, 1998; Ley, 1983; Wollman, 1986). The non-imagery cloze passage task produced no significant change in vibrato from pre-test to post-test. Singers indicated that they sang better and felt warmed up after both the breathing imagery and vocal warm-up. The majority of listener-judges, however, concurred only in cases where the singer’s pre-test vibrato rate was either the fastest for the group, the slowest for the group or the most unstable for the group. Unlike vibrato rate, vibrato extent showed no consistent patterns of change acoustically as a result of any intervention.

This thesis attempts to broaden our understanding of the relationships between imagery, warm-up and vibrato change. The findings support the use of vibrato analysis in the investigation of pedagogical practices. Furthermore, they indicate that change in the quality of vibrato, which impacts on tone quality, is central to both vocal warm-up and the long-standing use of directional imagery by singers. The findings of these studies may have direct bearing on teaching practice, physical and mental preparation, and the quality of vocal performance.

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INTRODUCTION

This thesis investigates the acoustic and perceptual changes following vocal warm-up and singers’ use of pre-performance imagery. It is generally held that singers warm up prior to performance for optimal vocal function the moment performance commences. Optimal vocal function for the classically trained singer equates to a healthily produced voice, capable of aesthetically pleasing tone colour, carrying power and artistic expression. That tone colour may undergo improvement as a result of warming up suggests that the singer’s vibrato characteristics may undergo change in the course of warm-up. Studies by the Seashore research team reported that vibrato has a subtle yet profound impact on our perception of tone colour (Seashore, 1932). Bartholomew (1937) believed vibrato to be the single most important determinant of vocal colour and that stability of vibrato rate was of particular importance (Bartholomew, 1934). Miller (1977) maintains that vibrato rate is related to *chiaroscuro*, or the balance of tone colour optimising brilliance and mellowness, which determines vocal beauty. However, to date, no studies have investigated vibrato change following vocal warm-up.

While vocal warm-up is universally accepted as aiding vocal performance, both performance and performance preparation may involve imagery, the value of which is disputed in modern day pedagogical texts. Miller (1998) maintains that fanciful images suggesting, for example, that the energy from the voice projects from a hole at the top of the head or descends down the spine, are “useless” (p. 42). Kagen (1960) refers to such images as absurdly surreal yet inexplicably helpful to some talented singers. This thesis is based on the premise that it is not the content of the image that is important. What matters is that the singer’s attention must be directed both up and down simultaneously as far from the larynx as possible (Vennard, 1968). This concept, in fact, concurs with traditional Italian pedagogy in which sensations in opposing directions are often required simultaneously (Miller, 1977).

Some authorities suggest that directional imagery may impinge on spinal alignment (Alcantara, 1997; Brünner, 1993; Sweigard, 1975), low diaphragmatic breathing (Baeumner, 2004; Brünner, 1993), stress and relaxation (Baeumner, 2004), performance anxiety (Bartley and Clifton-Smith, 2006; Langeheine, 2004; Stoyva, 2000), tone quality (Dunbar-Wells, 1999; Miller, 1977; Vennard, 1968), freeing laryngeal constriction and obtaining an “open throat” (Patenaude-Yarnell, 2003b; Yurisich, 2000a, 2000b), raising
the soft palate and lowering the larynx (Yurisich, 2000a, 2000b; Vennard, 1968), balancing upward and downward forces in the stylo-pharyngeal muscle complex (Doscher, 1994), larynx stability (Patenaude-Yarnell, 2003b) and warm-up (Linklater, 1976; Rodenberg, 1992). Indeed, Nordin and Cumming (2005) note that one image may often serve several functions depending on the needs of the performer.

As singers' vibrato appears to be influenced by individual stress levels, relaxation, diaphragmatic breathing, larynx height and tone quality (Bartholomew, 1934, 1937; Doscher, 1994; Miller, 1977, 1996, 2004; Seashore, 1932; Sundberg, 1987; Titze, 1994; Titze, Story, Smith and Long, 2002) there is reason to suggest that not only vocal warm-up but also non-vocal imagery may impinge on the vibrato signal. Accordingly, study 1 addressed the following questions:

1. Does breathing imagery alter the acoustic signal of the singing voice?
2. Does breathing imagery enhance vocal quality according to the singer and the listener?
3. Does imagery not based on traditional vocal concepts have any effect on the voice?
4. Does breathing imagery serve to allay performance anxiety and function as a silent warm-up?

It was not possible to compare the post-test vibrato signals from study 1 with those expected of the warmed-up voice, as no studies had been conducted in this area. Consequently study 2 clarified the characteristics of a warmed-up singing voice and posed the following questions:

1. How may vocal warm-up alter the acoustic signal of the singing voice?
2. Does vocal warm-up enhance vocal quality according to both listener and singer?
3. Can listener-judges consistently distinguish the warmed-up from the unwarmed-up sample of the same singer presented back-to-back?

These two studies explore the link between vocal practice and change in singers' vibrato. More broadly, they inform traditional singing techniques with objective acoustic measurement and perceptual assessment using a fully randomised block design, thus linking voice science with performance practice in the studio and on the stage.
2 LITERATURE REVIEW

The literature review commences with an exploration of tone quality, which is reportedly enhanced through vocal warm-up. It discusses different methods of obtaining optimal tone quality, including the role of imagery. In an historical overview of imagery, the place of imagery study in scientific research from the 19th century to the present day is surveyed. While vocal imagery lacks research, imagery in sport has been researched as a warm-up component and an aid to optimal performance. Hence, the findings of sports studies are presented in order to provide insight into imagery use. Following this, what is known about sports warm-up and speculated about vocal warm-up is explored. Finally, the challenges of rating vocal performance under research conditions are discussed.

2.1 TONE QUALITY IN MUSIC

Successful musical performance requires aesthetically appropriate tone quality. The following section discusses tone quality and what constitutes optimal tone quality according to the Western classical tradition.

2.1.1 Overview of tone quality

Tone quality in music is often referred to as timbre, tone colour or simply “colour” (Vennard, 1950; 1968). Musical sounds with the same pitch, duration or dynamic level may often be distinguished by their different tone qualities, and in an attempt to make such distinctions, many descriptive terms are used by musicians. However, tone qualities are difficult to describe, and the fact that terms used by musicians are numerous and seldom identical to those of the voice scientist adds to the problem of reaching agreement on classifying and accounting for tone quality (Fex, 1992; Vennard, 1962; 1968). The literature on tone quality in music offers a number of insights into the relationship between tone colour and visual colour as well as shedding light on the acoustic components of tone quality and the role of partials in producing tone. In an attempt to clarify the nature of tone quality in music and in particular vocal music, it is these areas which will first be broadly addressed before progressing to the finer details of specific vocal qualities.
The metaphorical term “tone colour” implies a relationship between music and the visual sense. Vennard (1968) explains that a relationship exists between colour and musical tones as both are the results of the body’s response to vibrations. Both evoke similar psychological responses too in that tones with high partials are metaphorically compared with bright colours of high intensity and tones with predominantly low partials are likewise compared with dull colours of low intensity.

The perception of a relationship between colour and music dates back in writing as far as Aristotle’s *De sensu* in the 4th century BCE (MacDonald, 1995). Both Greek philosophy and Greek music theory were subjects still studied in 17th century England, and in fact Newton was so inspired by the Pythagorean belief that the best in art and nature conformed to simple musical proportions, that in his *Opticks*, a collection of papers dating from 1672 to 1675, he sought to highlight a relationship between music and colour by dividing the colour spectrum into seven parts (Fara, 2002; Jeans, 1995; MacDonald, 1995). The breadth of his seven chosen colour bands in the spectrum (red, orange, yellow, green, blue, indigo, violet) each related to the seven string lengths required to produce a diatonic scale (Scholes, 1975b). Goethe, Helmholtz and later scientists found fault with Newton’s colour classification. He classified indigo, for example, as an important colour between blue and violet. Nevertheless Newton’s belief that pitch and colour were related through some overriding cosmic principle received much popular acclaim (Fara, 2002).

Certainly colour and pitch are related in that they are both sensory responses to vibrations. The human ear responds to an approximate range of 16 to 20,000 vibrations per second and the eye to much faster vibrations of about $451 \times 10^{12}$ to $780 \times 10^{12}$ per second (Scholes, 1975b). This latter range of vibrations which covers every colour in the rainbow would lie about thirty-seven octaves higher than the highest note on the piano, if only the vibrations could be perceived by the ear. Such observations have prompted the expression that “sound is colour, made audible, and colour is sound, made visible” (Scholes, 1975b, p. 206).

Yet although many colour terms used in music, such as “golden”, are colours in the visual sense, a musical colour term need not originate from the visual sense alone. For example, the visual term “dark” is often used interchangeably with terms not principally related to vision such as “sombre”, “rich” or “warm”. Vennard (1950, 1953, 1968) uses
these colour terms and many others to describe tones in which low partials are strong. Sonninen (1970) lists 59 terms used to describe the singing voice, though Vennard (1968) suggests many of these same terms may be repetitious as they describe similar vocal qualities. Most terms, however, were not originally intended to describe human sound at all. Terms such as “muddy”, “gravelly”, “woolly” (Fex, 1992, p. 155), “sweet”, “abrasive” (Doscher, 1994, p. 128) and “woofy” (Miller, 1996, p. 156) vividly remind us of this. Indeed, to describe a singer as having “a dumpling in the throat” (Miller, 1977, p. 75) suggests that many expressions relating to musical colour are limited only by the user’s imaginative twist of vocabulary.

What is perceived as tone quality in music is acoustically determined by the presence, absence, or relative strength of partials. The word “partial”, from the Latin pars meaning “part”, refers acoustically to each of the component frequencies of a musical tone, i.e. the fundamental frequency plus any other frequencies in the spectrum of tones which together may be perceived as a single sound (Brown, 1993; Sundberg, 1987; Titze, 1994). Partials in music were already mentioned in 1636 in the first treatise on sound and music, Harmonie Universelle by Marin Mersenne (Cohen, 1995a; Wood, 1962). In 1722 Jean-Philippe Rameau noted in Traité de l’harmonie that tones generate partials an octave, a 5th and a major 3rd above the fundamental tone (Cohen, 1995b). Significantly for the development of acoustic theory, the mathematician Fourier set forth a formula in 1822 for analysing timbre in terms of harmonics in his Théorie analytique de la chaleur (Vennard, 1968) and in 1862 Garcia’s contemporary, Helmholtz, explained in Die Lehre von den Tonempfindungen that “harmonic upper partial tones … determine the qualities of tone of almost all instruments and are of the greatest importance for those qualities of tone which are best adapted for musical purposes” (Helmholtz, [1877] 1954, pp. 4-5). This explanation certainly holds true for notes produced by wind instruments, including the organ, bowed string instruments and some harpsichords, the acoustic structure of which consists almost entirely of harmonic partials (Lindley, 1995).

Acoustically, harmonics are represented by a periodic waveform, i.e. one which repeats itself in a very regular fashion (Titze, 1994). However, partials created by some instruments are not solely harmonic. That is, they contain inharmonic partials that do not match the mathematical ideal of a harmonic series, according to which the frequencies of the upper partials are multiples of the fundamental frequency. The piano
has inharmonic partials to a small extent. Xylophones, bells and gongs have a great many inharmonic partials (Lindley, 1995). Hence the waveform of gongs, for instance, would be very irregular and classified acoustically as aperiodic.

With regard to the voice, partials are important in determining tone quality, though originally the role of inharmonic partials was disputed. Analysing vocal tone into harmonic partials, Helmholtz established much of the framework for our present day acoustic knowledge of the voice. In particular, he pioneered the study of exceptionally strong regions of resonance in the spectrum of frequencies which, as he noted, respond to the shape and size of the vocal tract (Helmholtz, [1877] 1954; Martienssen-Lohmann, 2001; Stark, 1999; Vennard, 1968). It was Herrmann who in 1890 named these resonant peaks “formants”. However, Herrmann believed formants could be analysed still further to show the presence of inharmonic partials vital to the distinctive tone colour of a voice (Martienssen-Lohmann, 2001; Winckel, 1960).

It is believed today that a combination of harmonic and inharmonic partials have a role in establishing the acoustic components of vocal quality (Titze, 1994; Vennard, 1968; Winckel, 1960). That is, the quality of the vocal tone is a product of the original glottal sound plus acoustic events dictated by the size and shape of the resonance cavities. Some harmonic partials become stronger, others become weaker, and some additional frequencies may be generated solely because air in resonance cavities is set in motion. This latter class of frequencies is known as inharmonic partials (Vennard, 1968). They do not exist in the glottal sound but can be heard, for example, in whispered vowels. Inharmonic partials are created in much the same way as the tone which occurs when air is blown across the top of a bottle.

Inharmonic partials have been noted to a small extent in the singing voice (Paget, 1930 cited in Vennard, 1968) but are more prevalent in a breathy singing voice where there is much turbulent noise (aspiration) filling the spectrum with inharmonic components, otherwise known as noise, between the harmonic partials (Titze, 1994). There are often more inharmonic partials than harmonic in the spoken voice and also in a voice which simply produces “noise” and loses a sense of musicality. The well-trained singer, creating a more musically acceptable quality, generally comes to intuitively shape the resonators to respond harmonically with the range of fundamental frequencies (Stark, 1999; Vennard, 1968).
Sundberg (1994) points out that in the singing voice, it is difficult to hear any partial as an autonomous tone, harmonic or inharmonic, other than the first partial i.e. the fundamental frequency or first harmonic. This applies even in cases where a particular partial is much stronger than all other partials. Yet curiously although the first partial is easily perceived as the sung tone it is not usually the loudest partial in the spectrum of the vocal sound. It is only the loudest partial in two cases. One is at high pitches such as in soprano singing, in which the fundamental is close to the first formant. The other case is in very soft phonation, in which the overtones of the glottal voice source are so weak that the partial exciting the first formant is weaker than the fundamental.

Despite this awareness of the acoustic basis of tone quality, Cleveland (1977) notes that as yet no cataloguing of specific acoustic characteristics of the many timbre types exists. Although inroads have been made by a number of voice scientists since Cleveland’s statement, scientific investigation into vocal tone quality is still far from conclusive.

### 2.1.2 Chiaroscuro and the tonal ideal

Singers trained in Western classical voice production generally aim for a form of tonal beauty that allows for projection over an orchestra without causing vocal harm to the singer. Although Miller notes that numerous technical approaches claim to achieve this, some influenced by cultural preferences regarding tone quality, he concedes that broadly speaking there is a quality that universally delights, particularly heard in singers of international stature. Such vocal quality displays an ideal Western classical tone colour sometimes referred to as *chiaroscuro* (Miller, 1977).

The term *chiaroscuro* stems from the Italian *chiaro* meaning clear or bright, and *oscruo* meaning obscure or dark. This Italian term first appeared in English usage in the mid-1600s. *Chiaroscuro* originally referred to the treatment of light and shade in the visual arts (Brown, 1993). In a vocal context, the concept that two contrasting tone colours, one bright and the other dark, can be produced simultaneously and blended to produce the ideal vocal colour was proposed in Italy from at least 1774 when Giambattista Mancini published an influential vocal tutor, *Pensieri e riflessioni pratiche sopra il canto figurato* (Practical thoughts and reflections on the art of singing) (Mancini, [1774] 1907). Giovanni Battista Lamperti, one of the leading teachers of the late 1800s, also stressed...
that *chiaroscuro* should always be present in the voice (Brown, 1957). The concept of *chiaroscuro*, if not always the term itself, has today become adopted internationally into Western classical singing technique, as a tonal ideal.

Miller, who champions considerable use of Italian terms in singing pedagogy, explains *chiaroscuro* as a “light-dark”, “bright-dark” or “clear-dark” tone and a tone with both “brilliance” and “depth” (Miller, 1977, 1996, 2001a, 2004). Miller sees a direct relationship between *chiaroscuro* and vibrato speed. He explains that whereas an overly bright timbre is characteristic of voices with particularly fast vibrato rates, and dark timbre is associated with very slow vibrato rates, a voice possessing *chiaroscuro* timbre displays an appropriately moderate vibrato rate, i.e. neither too fast nor too slow (Miller, 1977). Miller believes the singer associates *chiaroscuro* above all with the sensation of vocal “freedom” (Miller, 2004, p. 68) and refers to *chiaroscuro* as an ideal tone quality (Miller, 1977) containing an optimal distribution of lower and upper partials inherent in “well-balanced resonance” (Miller, 1996, p. 311). This echoes the belief of Giovanni Battista Lamperti that *chiaroscuro* is related to resonance (Brown, 1957).

Titze notes that vocal resonance is a poorly understood term acoustically. However, from the perspective of the singer, a resonant voice is associated with the efficient and ample reinforcement of vocal fold vibrations such that with seemingly minimal effort, maximal carrying power is produced in the voice. Titze points out that the singer’s perception of ease as opposed to vocal strain and the sensation of vibrations in the body are critical for the singer acquiring a resonant voice (Titze, 2001a). He explains that an efficiently produced resonant voice propagates sound along the entire airway system. Hence as far as the singer is concerned, only the vibratory sensations of an inefficient, poor quality voice are localised at vocal fold level. An efficiently produced resonant voice is sensed by the singer as vibrations extending from the sinuses above the eyes, down into the chest (Titze, 2001a).

Manuel Garcia Jnr. did not use the term *chiaroscuro* to describe ideal vocal quality, though he maintained that both *éclat* (a brilliant lustre) and *rondeur* (fullness and roundness) were necessary (Garcia, 1847 cited in Stark, 1999). Like many singers and singing teachers since, Vennard also refrains from the term *chiaroscuro*. However, he does explain that ideal vocal tone must contain both as much “brilliance” and as much “mellowness” or “depth” as possible. Vennard judged “brilliance” and “mellowness” to
be opposites, free from a sense of vocal strain and distinguished by the abundant presence of upper and lower partials respectively. Vennard insisted the contrasting qualities of “brilliance” and “mellowness” must coexist in the one tone and believed the joint presence of these colours provided the ideal distribution of partials for the voice to resonate well (Vennard, 1968). German pedagogical literature also stresses the necessity for tone quality to be free from force and, while urging the avoidance of bias towards excessively bright or exaggeratedly dark qualities, describes the tonal ideal as Helldunkel, literally a blend of bright-dark or chiasoscuro (Martienssen-Lohmann, 2001).

Stark (1999) believes the use of the term chiasoscuro, and similar terms such as éclat and rondeur, reduces a complex physiological and acoustic process to a simple aural image that falls easily within the mental grasp of the singer. Vennard advises that the visual-proprioceptive image of focusing the voice above and below the larynx, in both directions simultaneously, assists the singer in achieving the ideal vocal timbre:

“A good tone will seem to be anywhere except in the larynx. The more mellow it is, the more there will be the feeling that it goes ‘down’ and ‘back.’ The more brilliant it is, the more it will seem to go ‘up’ and ‘forward.’ The important point to remember is that it must go in both directions at once … [because] … it should be the objective of every singer to get as much brilliance as possible and as much depth as possible in the tone at the same time” (Vennard’s italics, Vennard, 1968, pp. 119–120).

Robison reports that the singer’s concentration on anatomical imagery and an “interactive web” of sensations throughout the entire body produces an ideal vocal tone colour (Robison, 2001, p. 11). He suggests that singers need to conceive of the sound as being associated with resonances not only above the vocal folds in the pharynx but also below the vocal folds in the tracheal tube. Furthermore, the singer must be constantly aware of the sensation that the “structures of the body (chest, ribs, spine, clavicles, shoulders, neck, skull, hard palate, trachea, etc.) are all being drawn flexibly away from the larynx” (Robison, 2001, p. 18). He maintains that this feeling is particularly helpful when the singer approaches extremes of pitch and dynamics, to produce the best possible tone quality.

Titze also observes that singers attaining an optimal, resonant tone quality free of vocal strain often describe the sensation as though “almost everything widens, lengthens or
expands somehow” (Titze, 2005, p. 499) and notes that the expansion of the airways appears to be a universal necessity for all creatures who wish to harness optimal vocal powers. For example, frogs expand air sacs in the region of the throat. Lions and tigers lengthen their vocal tract by lowering their larynx up to 30cm before a roar. For the classical singer the velum is often raised to expand the back of the oral cavity, the pharynx is widened, and the larynx is lowered to lengthen the airway (Titze, 2005). Without supporting research, it can only be speculated whether aural imagery of chiaroscuro timbre, Robison’s “interactive web” of sensations, or thoughts of directing vocal energy away from the neck (both up and down simultaneously as Vennard advocates) are actually all ways of encouraging appropriate expansion of the airways necessary for optimal vocalisation.

In conclusion, the concept of a tonal ideal appears to be supported and passed on from teacher to student as part of the practice of Western classical singing. Ideal tone quality, regardless of the different names under which it appears in the literature or the various ways it may be achieved, has as a common goal the perception of a voice free from vocal strain. Ideal tone quality contains an appropriate mix of high and low partials to create a well balanced, resonant tone colour combining brilliance and mellowness. Furthermore, ideal tone quality appears to be related to optimal vibrato characteristics. It is the aim of all singers trained in the Western classical tradition to obtain a tone quality that displays these qualities and it is these qualities that will now be discussed in more detail.

2.1.3 Vocal strain

2.1.3.1 What is vocal strain?
Vocal strain is a term used by singers, voice scientists (Sonninen, 1970; Vennard and Hirano, 1971; Vennard, Hirano and Fritzell, 1971; Wapnick and Ekholm, 1997) and speech pathologists (Hammarberg, 1998; Oates, 2009). Despite the lack of a universally accepted definition of vocal strain and its physiological correlates, the term is most often equated with excessive vocal effort, in particular, excess laryngeal muscle tension and constriction, and it is generally agreed that the perception of strain in the classical singing voice, whether aural or kinaesthetic, is undesirable.
2.1.3.2 Strain and similar terms

Although strain is related to the tense voice (Hamarberg, 1998), it should be noted that the terms strain and tension are not always used synonymously. Strain is always perceived as having negative connotations, whereas tension may be either beneficial or detrimental, depending on the amount of tension and where it occurs. For example, the strings of a lute, spanning the instrument from tuning peg to bridge are said to require a certain tension. Similarly, although singing teachers discourage strain in and around the neck, they often encourage the kinaesthetic awareness of a balance of tensions elsewhere in the body away from the area of the neck. Some muscles exert a healthy tension in a well-produced singing voice (Doscher, 1994; Vennard, 1950), and perhaps for this reason Vennard tends not to use “tension” when describing the perception of excessive vocal effort, preferring instead to use the term “tight” (Vennard, 1950) or “strained” (Vennard and Hirano, 1971; Vennard, Hirano and Fritzell, 1971).

In an attempt to describe the sensation of vocal strain, many alternate words are used within the vocal fraternity. Sundberg describes the sound of a loud, untrained singer as “tense”, resembling a “scream” and displaying “pressed” phonation (Sundberg, 1987, p. 86). Miller describes the “pressed” voice as being “pushed” (Miller, 1996, p. 177) and “forced” (Miller, 2004, p. 146). These terms are all descriptive of vocal strain.

2.1.3.3 Strain versus freedom

The concept of strain can be clarified somewhat by considering its opposing quality, which Vennard suggests is “freedom” (Vennard, 1950, p. 3). Miller (1996) refers to freedom as a desirable vocal quality occurring once inappropriate tension or strain has been overcome. He states that the need to “stay free” is the main goal of singers, but adds that this requires “flow phonation” (Miller, 2004, p. 59).

The term “flow phonation” was coined by Gauffin and Sundberg (1989) to describe a mode of phonation requiring particularly generous airflow where glottal adduction was reduced to an efficient minimum necessary for complete glottal closure. This mode of phonation lies between two extremes of phonation, that of the “hypofunctional / breathy” voice and the “hyperfunctional / pressed” voice (Sundberg, 2003). Both extreme modes of phonation, “pressed” as well as “breathy”, destroy the singer’s ability to “stay free” (Miller, 2004).
Sundberg notes that flow phonation is these days linked in the USA to the term “resonant voice” (Sundberg, 2003, p. 17). Indeed, Miller maintains that once vocal freedom is attained, acoustic energy in the region of 3,000 Hz is enhanced and a chiaroscuro vocal quality results (Miller, 1996, 2004). Vennard, too, explains that freedom is characterised by a sense of focus, the presence of a ringing overtone in the region of 3,000 Hz, clarity of vowel colour, a comfortably low larynx and no unnecessary muscular tension in the throat (Vennard and Hirano, 1971). Additionally, Doscher (1994) links freedom with the traditionally taught concept of the “open throat”. She describes an “open throat” as one in which there is freedom from constrictive pharyngeal tension which, she proposes, causes bunched up, flabby walls and increases the danger of damping the sound.

Interestingly, Vennard (1968) suggests there may be links between freedom from constrictive tension in the throat, pharyngeal resonance and images such as “open throat”, “head resonance” and “chest resonance”. He notes that there is more agreement amongst singing teachers upon the need for the throat to be free from constrictive tension than upon any other principle in singing.

2.1.3.4 The physiological basis of vocal strain

Research is still needed in order to clarify the physiological basis of a voice which is perceived as strained or tense (Doscher, 1994). Pedagogical literature warns of many forms of strain which may negatively affect the singing voice, including strain from tongue tension, jaw tightening, neck stiffness, pharyngeal constriction and laryngeal muscle tension. However, research on the physiology of the auditory perception of strain has largely focused on laryngeal muscle tension.

Research-based pedagogical texts hold that straining is related to a larynx that is too high, and an under-worked (hypofunctional) extrinsic network of elevator and depressor muscles, which in a freely functioning voice should work as an efficient unit providing antagonistic muscular equilibrium. In the strained voice it is further suggested that the intrinsic laryngeal muscles compensate for the disuse of the extrinsic muscular network and are over-worked (hyperfunctional) (Doscher, 1994). These findings owe much to the collaborative research initially of Vennard and later of Sundberg.
After considering the possible physiological correlates of vocal strain (Vennard, 1950, 1959, 1968), Vennard and colleagues conducted tests ((Vennard and Hirano, 1971; Vennard, Hirano and Fritzell, 1971; Vennard, Hirano and Ohala, 1970) on a select number of internal and external laryngeal muscles using electromyographic (EMG) feedback. It must be noted that when the activities of a restricted number of laryngeal muscles are studied, it is difficult to produce definitive conclusions, considering the complexity involved in the interplay of muscle groups and laryngeal biomechanics which should be taken into account (Kenyon, 1927 cited in Vilkman, Sonninen, Hurme and Körkkö, 1996). Additionally, Vennard acknowledges that placing electrodes for EMG studies is difficult and prone to unsatisfactory results. For his own studies, however, Vennard expresses confidence that the EMG specialists used were of exceptional international calibre and had perfected the skill of placing electrodes in the human larynx and the soft palate musculature (Vennard, Hirano and Fritzell, 1971; Vennard et al., 1970).

From these tests it was concluded that straining is very stressful and hyperfunctional in the intrinsic laryngeal muscles, specifically in both the lateral crico-arytenoid and thyro-arytenoid muscles (Vennard and Hirano, 1971). By contrast, the extrinsic laryngeal muscles are under-used and hypofunctional, specifically in the digastric, the levator veli palatini and palato-pharyngeus, and to some extent the thyro-hyoid as well (Vennard, Hirano and Fritzell, 1971). Vennard, however, refers to his 1971 studies as pilot studies only. The singer sample used was generally four. Vennard himself was the only singer used in the protocol in which EMG of the levator veli palatini showed that a strained [a] was sung with a relaxed nasal port causing greater nasality in the sound. Although vocal behaviour was uniform for all four subjects, Vennard recommends care be exercised in assuming that all other individuals function identically.

Nevertheless, these study results caused Vennard to reject his original theories on vocal strain (Vennard, 1968) that hyperfunctional tensing or overuse of the larger neck muscles may create an audibly strained voice. Vennard and Hirano (1971) conclude that in straining “tenseness seems to be in the glottis, as in holding the breath” (p. 28). Furthermore, Vennard and Hirano describe straining as related to “pinching”, except that in straining there is less neck and jaw tension. They suggest that with straining the singer has a very oppressive feeling in the upper chest, and often a feeling of pressure in the head, giving a pseudo-nasal quality.
Although Vennard and Hirano (1971) reason that straining results when some untrained singers try for greater power, their research shows that the strained voice actually produces less volume than a “free” or “focused” voice. Martienssen-Lohmann (2001) notes the same occurrence but adds that a singer may also strain to sing high notes softly. Sundberg (1987) observes that our aural environment can impact on our manner of voice production, stating that straining can also result from having silently listened to strained phonation.

Later investigations of the pressed voice by Gauffin and Sundberg (1989) further clarified and supported Vennard’s observation that tenseness was associated with the glottis as though the breath was being held. That is, it was found that a pressed voice was associated with excessively held glottal closure from adducting vocal folds. Sundberg (1987) describes a pressed voice as the result of insufficient air flow and the effort to counteract this. With this effort, subglottal pressure rises and the vocal folds are too tightly approximated and consequently hindered from free vibration. Sundberg and Askenfeldt (1983) noted that such phonation is associated with a raised larynx.

Nevertheless, it is possible that not all singers produce vocal strain in the same manner. Sundberg (1990) states that methods of voice production vary amongst singers trained in the Western classical style. Vilkman et al. (1996) stress that there are distinct differences between singers and non-singers in their balance of internal and external laryngeal muscle activity, and Titze (1994) notes that different singers have different target sounds in mind. Rock singers, for example, often display effort as part of the expected performance, whereas singers trained in the conventions of Western classical style place restrictions on the amount and kind of effort, both visual and aural, acceptable for display (American Academy of Teachers of Singing, 2010; Titze, 1994). Hence whether, how and to what extent singers strain may reflect many factors, including amount of training, style of training and where the singer’s weakest area of vocal technique possibly lies.

2.1.3.5 How is vocal strain avoided?

Pedagogical literature recommends many techniques to counter vocal strain. Hemsley (1998) observes that the more one is exposed to unstrained production by others, the more one is likely to sing in an unstrained manner as a result. Hence, the singer’s aural
imagery of unstrained production may play a role in remedying vocal strain. Certainly, aural imagery of the desired tone is considered vital for optimal singing (Burgin, 1973; Dunbar-Wells, 1999; Kagen, 1960; Miller, 2004; Rose, 1978).

Because a high larynx position is often associated with pharynx constriction (Doscher, 1994; Sundberg, 1987; Vennard, 1968) and pressed phonation (Sundberg, 1987; Sundberg and Askenfelt, 1983), other strategies rely specifically on encouraging a somewhat low larynx position. Such strategies may take a mechanistic approach to encourage proprioceptive awareness and sometimes incorporate the use of imagery as well.

Vennard (1968) recommends three techniques to lower the larynx and reduce strain. Firstly, he recommends diaphragmatic breathing, sometimes suggesting that having breathed diaphragmatically, just before vocal onset the singer should “take ‘an added sip’ of air to relax the valve” (Vennard, 1968, p. 109). Secondly, the singer may note the sensation of the beginning of a yawn. Vennard explains that the pharynx is habitually constricted, holding the larynx up against gravity all day. When yawning, this tension is relaxed as the opposing muscles contract. He suggests that at the beginning of a yawn, before the opposing muscles become tense and the larynx too low, there is an ideal balance in which no muscles are straining. Finally, he recommends the singer swallow and prolong the act of releasing the swallow, slowly feeling the larynx drop, the tongue flatten and the epiglottis rise, thus “opening the throat” (Vennard, 1968, p. 110).

Sundberg (1987) agrees that the beginning of a yawn lowers the larynx. He adds that this is one of a number of images used in vocal pedagogy which appear to be directed at vertical larynx position. Other images include “take your breath as if you were smelling a rose” and “sing as if you were crying” (Sundberg, 1987, p. 132).

Many methods to counteract strain are based on the belief that the swallowing muscles must relax, to avoid the upward and backward pull of the larynx which would otherwise cause constriction of the throat (Vennard, 1968). Vennard proposes that when the singing teacher urges a relaxed jaw, the “swallowing muscles” are perhaps the only muscles that need to be relaxed (Vennard 1959, p. 11). Vennard, Hirano and Fritzell (1971) state that instructing singers to generally relax the throat to overcome strain may actually exacerbate strain from even further extrinsic hypofunction. They maintain
that the singer really needs to make greater, well-balanced use of the extrinsic muscular network and release excessive tension in the internal laryngeal muscles (the thyro-arytenoid and the lateral crico-arytenoid) which are not under direct conscious control.

Vennard, Hirano and Fritzell (1971) recommend the use of falsetto as an indirect means of controlling the necessary muscles associated with strain. This approach is based on the idea that falsetto releases the thyro-arytenoid, and sometimes also the lateral crico-arytenoid. Thus, falsetto production offers a means of consciously directing activation towards a less strained, non-hyperfunctional use of the internal laryngeal muscles. “If a singer can transfer some of the feeling of falsetto into his ‘legitimate’ voice, he will achieve freedom and focus” (Vennard, Hirano and Fritzel, 1971, p. 28) - freedom and focus being Vennard’s preferred antonyms for strain (Vennard, 1950; Vennard and Hirano, 1971).

Miller (2004) also recommends using falsetto to relieve a “pressed” voice. He explains that falsetto adds a judicious amount of breath to sung tone as the vocal folds do not fully occlude in falsetto production and hence resistance to air flow is slackened. Sighing, which increases the rate of exiting breath, or slightly aspirated vocal onsets may also help correct “pressed” phonation often heard on high notes (Miller, 2004). However, he cautions “if you jut your jaw and raise your larynx for high pitch, you will never have freedom in the upper range” (Miller, 1996, p. 166).

Doscher (1994) notes that singers frequently associate the accessing of higher notes, including notes in the falsetto range, with a “lift feeling” (p. 51), and adds that this sensation appears to be necessary for the avoidance of strain and sensation of vocal freedom. She speculates that as the contraction of the stylo-pharyngeus results in the elevation and dilation of the pharynx (Zemlin, 1998), and as some fibres of this important long muscle complex blend with the palato-pharyngeus which in the strained voice is hypoactive, then perhaps this contraction could be related to the feeling of “lift” and overcoming high note strain.

Other techniques for reducing strain, however, focus on the tongue. Miller maintains that tension in the larynx may originate from tension in the tongue (Miller, 1996, 2004), and recommends the tongue tip rolled [r] as a means of inducing freedom in both
tongue and larynx (Miller, 1996). He explains that the tongue is attached to the hyoid bone from which the larynx is suspended by the thyro-hyoid membrane. In order for the flapping motion of the tongue blade to take place, no tension may exist within the muscle blades forming the body of the tongue, nor at the points of tongue contact, nor in the hyoidal musculature. Miller (2004) further suggests that tongue tension arises if the jaw and mouth are fixed in one position, not allowing the tongue to move freely. “Allowing the lips, jaw and tongue to follow patterns of spoken enunciation will cure most problems of tongue tension” (Miller, 2004, p. 102). Apparently assuming the singer already speaks without strain, he suggests the singer speak the words of a song while retaining the composer’s rhythmic values, then sing the words on a single pitch in low-middle range.

Yet although the articulators must never be rigidly fixed (Doscher, 1994), many singers recommend minimising lip movement when articulating vowels (Hines, 1982). Perhaps the need to stabilise the vertical position of the larynx (Sundberg, 1987) accounts for this. Sundberg (1987) notes that retracting the corners of the mouth raises the larynx. Hence it follows that keeping the corners of the mouth in a relaxed position may suppress the raising of the larynx and the possibility of associated pharyngeal constriction and pressed phonation.

Still other authorities (Bartley and Clifton-Smith, 2006) take a broader, holistic stance to remedying problems of tension linked to neck and jaw rigidity. From the perspective of the ENT specialist, Bartley observes that patients who present with neck and jaw tension habitually extend the jaw too far forward. Moreover, such posture is symptomatic of those who suffer from anxiety and depression, adopt imbalanced spinal alignment, subsequently hinder diaphragmatic breathing and assume clavicular breathing habits. Attention to well balanced spinal alignment in order to induce diaphragmatic breathing are suggested remedies from the medical fraternity not only for neck and jaw tension but also for anxiety attacks (Bartley and Clifton-Smith, 2006).

Vennard (1950) concedes that although proper use of the network of muscles associated with the larynx is crucial for optimal unstrained singing, undesirable tension in and around the throat cannot be considered a cause in itself, but rather the result of inefficient function elsewhere in the vocal apparatus. This he attributes to the complexity of the larynx and particularly its functional unity with the breathing
mechanism and the resonance cavities. Vennard suggests that the feeling of “effort in the voice box” and the perception of “tightness”, “strain” and “reaching for the tone” is replaced with the perception of freedom and the so-called “open throat” only when the breath is correctly used.

Doscher (1994) concurs, suggesting that all exercises, whether for efficient breathing or supra-glottal resonance, ultimately assist in reducing undesirable tension. If an open throat and optimal resonance are to be achieved, then breathing must not be clavicular, as this places such tension in the collarbone and neck areas as to make muscular equilibrium of the extrinsic network difficult or impossible. The deactivation of the extrinsic muscular network then results in the larynx rising too high and pharyngeal constriction (Doscher, 1994). Vennard, however, reverts to images when explaining what the correct method of breathing entails, saying that the tone must be allowed to “float on the breath” and the breath must have a sense of “support”. Chapman (1991) relates such sensations to posture, and reports from pedagogical experience that undesirable tensions throughout the entire body may affect breath flow, support and ultimately produce unwanted laryngeal tension.

Titze (1994) reminds us that in contrast to comfort words such as “freedom”, “flotation” and “support” mentioned above, the words “strain”, “pressure”, “stress” and “tension” are all effort words which in some singing teaching studios are discouraged. He speculates that this may be to discourage the inefficient effort of a pressed voice. Like Sundberg (1987), Titze associates stress with excessive mechanical effort expended when the natural vibratory modes of the vocal folds are constrained through hyperadduction. Titze sometimes likens this to “a ‘strangulation’ effect” (Titze, 1994, p. 272). He maintains that glottal flow resistance must be adjusted. More specifically, that maximum aerodynamic power must be converted to acoustic power with minimum disturbance of the free, natural vibratory pattern of the vocal folds. When this is achieved the singer becomes aware of vibratory sensations in the trachea, near the sternum, and in the facial regions, and also of the sensation of ease (Titze, 1994).
2.1.4 Mellowness

2.1.4.1 What is mellowness?

In pedagogical publications (Miller, 1977; Vennard, 1968) numerous colour terms may be used to describe a single vocal colour, and “mellowness” is often discussed in ways that acknowledge a close association with other colours. This reflects the practice in the singing studio where expressions such as “mellow richness” or “glowing warmth” combine words which overlap in meaning, one word reinforcing or enhancing the other.

In the few perceptual studies published, terms investigated have sometimes been combined, acknowledging such inter-relationships (Ekholm, Papagiannis and Chagnon, 1998; Wapnick and Ekholm, 1997). Ekholm et al. (1998) investigated the combination term “colour/warmth” and noted that amongst musicians “warmth” is equated with “richness”, “fullness”, “roundness” and “darkness”. This is in accord with Vennard (1950, 1968) who also acknowledges a close relationship between “mellowness”, “warmth”, “depth”, “darkness”, “richness” and “fullness”.

Tone colour terms are commonly used by voice teachers and singers with the presumption that, as with the acquisition of one’s native language, meaning becomes evident with time, context and experience. Yet where universal agreement is needed, this informal approach to descriptive terminology may be inadequate. Interestingly, the Royal Horticultural Society (U.K.) has created a flower colour chart, which is used internationally in botanical classification to precisely determine all colours. There is no equivalent audible tone colour register for the vocal fraternity and any calls such as that of Van den Berg and Vennard (1959) to reach agreement on expressions for specific vocal qualities have had limited response to date.

Although some element of informal consensus on vocal colour can be found, uncertainty exists over many details. Terms such as mellowness, warmth, richness, depth and darkness which, in the pedagogical writings of Miller (1977) and Vennard (1968), appear to be similar are particularly difficult to distinguish, especially as they are borrowed from differing areas of sensory perception. “Darkness” is borrowed from vision and “mellowness” from taste, “depth” is a spatial perception and “warmth” is a caloric term.
2.1.4.2 Distinctions between “mellow”, “warm” and “dark”

Only Vennard (1968) has attempted to define the differences between these terms. According to Vennard (1968) “mellow” is associated with depth and added strength in low partials. A mellow tone quality is rich, sweet, full and pure. Furthermore, certain high partials necessary for brilliance are present in mellowness, but undesirable high partials are muffled (Vennard, 1968). Vennard describes “warm” somewhat similarly, as rich in partials, especially the low ones. “Dark”, on the other hand, is defined as grey, muddy and depressing because of the preponderance of low partials and lack of high partials (Vennard, 1968).

Miller (1996) also questions the appeal of “dark” voices. He associates the word “dark” with “sombre”, which is “gloomy, dismal and oppressively solemn” (Fowler, Fowler and Allen, 1990). Yet Miller stresses that there is a positive side to vocal darkness on the proviso that it is used in sufficient moderation to allow for the coexistence of desirable high partials (Miller, 1977). This viewpoint is supported by Vennard (1968), but once these conditions have been met, “dark”, appropriately modified, seems possibly distinguishable from “mellow”.

In the singing studio, in pedagogical texts and in everyday language use, it is interesting to note that unlike “dark”, “mellow” only has positive connotations. When mellow is used to describe the taste of ripe autumn fruit of sensuous sweetness, mature wines, a person’s character when agreeable and free of stress, and the depth of rich warm autumnal tones, all are perceived positively. Vennard believes mellowness of vocal tone has similar characteristics and is likewise a consistently positive feature. He likens the quality of a mellow sound to that of a cor anglais which he describes as a “more mellow”, “deeper” sound than an oboe (Vennard, 1968). Forsyth (1966) uses the adjectives “smooth”, “warm” and “rich” to describe this sound and concludes that this quality is not unlike a contralto voice.

Despite the negative associations which may be attributed to a dark voice, many researchers use the term “dark” quite freely and not in any context that reflects a technical deficiency within the singer. Generalisations that baritones or basses sound “darker” than tenors (Ekholm et al., 1998; Sundberg, 1994) are not uncommon. Ekholm et al. (1998) concluded that all expert listener-judges prefer “darker” voices. Perhaps the simplicity of the word “dark” has found favour and researchers presume darkness
to be just as positive a term as warmth, depth or mellowness. From a pedagogical perspective Vennard reported on the “mellow” voice, but there are more explanations in the literature as to what acoustically constitutes a “full dark”, “round, full dark” or simply a “dark” voice.

2.1.4.3 Acoustic strengthening of low partials

Acoustically, Sundberg (1973) investigated “darkness” and found that the darker of two bass voices displayed a stronger relative amplitude of the lowest partials and that formant frequencies tended to be lower in the darker voice. Vennard (1968) cites studies that suggest a “mellow”, “full” voice may display strengthened low partials within the region of 330 to 750 Hz (E₄ to approximately F♯₅ in the treble stave). Oncely (1973) points out that singers enhance “sonority”, a term suggesting deep, rich, fullness of sound (Brown, 1993), by subtly shifting a formant’s frequency to occur on or near a harmonic of the notes being sung in a process referred to as formant tuning. This process can also involve approximating both the low first and second formants i.e. the vowel formants, which increases the amplitude of any harmonics in the vicinity, markedly affecting vocal colour (Sundberg, 1988; Stark, 1999).

In formant tuning, shifts in vowel formant frequencies may involve either a raising or lowering of frequency (Oncely, 1973). When the first harmonic (fundamental frequency) rises from lowest to highest notes of a singer’s range so too do the other associated harmonics, yet the vowel formants, F₁ and F₂, although being somewhat flexible, are more restricted in the amount of movement possible. Consequently as a note rises, vowel formant energy is gradually transferred to lower harmonics in order to stay within the same limited frequency range. However, once the note is sufficiently high, and depending on the vowel, the first vowel formant may coincide with the first harmonic. When this occurs, both the first vowel formant and the first harmonic may rise in unison. In a tenor voice, when the first vowel formant is enhanced or tuned to the first harmonic, vocal colour becomes “round, full and dark” (Stark, 1999). A female singing in the middle register may approximate both the first and second formants and tune them to the first or second harmonic to produce a “full, dark” sound, though Stark suggests this same strategy used at about D₅ (597 Hz) or higher would result only in a yell or a belt quality (Stark, 1999).
Regardless of whether formant tuning strategies are used, the proportion or strength of low and high partials may also vary depending on the dynamic level (i.e. loudness) of a voice (Sundberg, 1987). Sundberg verified that in soft singing the low spectrum partials below 1,000 Hz are much more dominant than when the voice is loud and that the fundamental has the greatest amplitude of any partial in the voice spectrum. At moderate loudness the partial closest to the first formant has the strongest amplitude. As loudness increases, the higher spectrum overtones gain more in amplitude than the lower spectrum overtones, possibly because singers tend to increase subglottal pressure on high notes (Sundberg, 1987).

2.1.4.4 How is mellowness produced physiologically?

Physiologically, longer vocal tracts produce lower centre frequencies of the singer’s formant and a darker or more mellow sound. Consequently basses, having longer vocal tracts than tenors, sound darker than tenors (Sundberg, 1994). Within all voice range categories, however, whether a tone becomes even darker or brighter depends on the shape of the highly complex and variable buccopharyngeal resonator, in particular the relationship between the soft palate and the larynx (Vennard, 1968). Manuel Garcia Jnr. reported that the soft palate and larynx always move in opposite directions and tone quality is greatly influenced by the resultant pharyngeal configuration (Garcia, 1894). Generally, a low larynx and consequent high arch of the palate darken voice quality by lowering all formant frequencies, especially the first formant (Stark, 1999). Conversely the higher the larynx and lower the arch of the palate, the brighter the tone (Doscher, 1994).

Larynx position is particularly dependent on the breath, for when a deep breath is taken the larynx automatically falls and the soft palate rises (Doscher, 1994). In high ranges assistance is given by raising the cheeks as, according to Doscher this allows maximum lifting of the soft palate without putting undue stress on the palatine arches. Singing techniques which appear to trigger low breath and a comfortably low larynx thereby producing an increase in vocal tract length and hence more mellow tone, include imagining the sensation associated with the beginning of a yawn, a sob or smelling the perfume of a rose (Sundberg, 1987). These techniques, however, are less effective if performance anxiety is present. Performance anxiety is associated with shallow breathing (Gevirtz, 2000), so the more nervous the performer, the less mellow
the tone quality. Interestingly, it has been suggested that singing techniques which encourage the singer to imagine head resonance space, actually provide a method of indirectly achieving buccopharyngeal resonating space large enough to strengthen the lower partials of the voice, creating mellowness (Vennard, 1968).

Laryngeal position is also influenced by the extrinsic muscles which must be balanced, favouring neither under-use nor over-use. The sterno-thyroid in particular is responsible for lowering the larynx (Sundberg, 1987) and, working in combination with its antagonist the thyro-hyoid, has a major effect on laryngeal position which helps determine the shape of the pharynx, the texture of its walls (Doscher, 1994) and the tone colour. Extrinsic muscles allied with tongue movement also impact on laryngeal position, for if the tongue is retracted it may force the hyoid bone and larynx into an excessively low position. This causes the walls of the vocal tract to become flaccid and the sound becomes too dark and muddy, with poor amplitude of sound and vocal projection (Doscher, 1994; Vennard, 1968). The softer or more relaxed the vocal tract walls, the more the high overtones become acoustically damped and low overtones are emphasized, giving a darker vocal sound that may lack “ring” in the region of 3,000 Hz (Vennard, 1968). Conversely when the soft walls of the vocal tract become taut, which occurs when the larynx is overly raised with excessive tension, the sound becomes bright, shrill and edgy (Miller, 1977; Sundberg, 1987). Additionally, as a lowered larynx is often associated with glottal abduction (Sundberg 1987), so an overly lowered larynx encourages a breathy, dull tone (Miller, 1977; Stark, 1999).

Although functioning largely beyond the level of direct conscious control (Van den Berg and Vennard, 1959), larynx movement needs subtle regulation for a mellow tone to result. If larynx movement is taken to extremes an imbalance of tone colour occurs. Since the larynx is suspended via a complex muscular scaffolding of extrinsic laryngeal muscles, sometimes referred to as the strap muscles, it is important that elevator and depressor muscles act as a unit, via balanced muscular antagonism, and never independently (Doscher, 1994). Doscher remarks that much research is still needed but suggests from pedagogical experience that few singers develop the extrinsic laryngeal muscles sufficiently for optimal singing before twenty-one or twenty-two years of age (Doscher, 1994). If a comfortably low but not depressed larynx is achieved, then optimal texture of the vocal tract, neither flaccid nor taut, can occur. This ensures that only undesirable high partials are dampened, leaving the high partials necessary for
“brilliance” and encouraging the low partials necessary for “mellowness” (Vennard, 1968).

2.1.5 Brilliance

2.1.5.1 What is brilliance?

The term “brilliance”, when used in an aural or visual context, is often allied with “bright” and “light” (Miller, 1996; Vennard, 1968). Musically, all three terms “brilliance”, “bright” and “light” appear to be attempts to describe a tone quality rich in high partials and which also serves as an antonym for a mellow or dark tone quality rich in low partials.

2.1.5.2 Distinctions between “brilliant”, “bright” and “light”

Nevertheless, distinctions should be noted between “brilliance”, “bright” and “light”. Brightness is not always perceived to be pleasant. A visually bright object may be blindingly intense, and similarly a “bright” sound may become excessively intense, piercing and shrill. Both visually and aurally, the adjective “light” is easily confused with soft, pale and insubstantial – words which should not generally describe a voice well trained in the Western classical tradition. Miller (1977, 1996), Stark (1999) and Vennard (1968) agree that vocal “brilliance” and some amount of “brightness” are imperative to excellent vocal colour. Vennard (1968) defines “brilliance” and “bright” as having high partials. He distinguishes the two, however, suggesting “bright” is the choice of words when looking for an antonym for “dark”, whereas “brilliance” which he often pairs with “mellowness” is the preferred option when the high partials add a seeming “glow” or “sparkle” to the voice.

Vennard suggests that “bright” and “dark” qualities may be so extreme as to be mutually exclusive and objectionable. “Bright” indicates high partials combined with a detrimental lack of low partials; “dark” indicates low partials combined with a detrimental lack of high partials. “Brilliance”, on the other hand, indicates a sound particularly rich in high partials which nevertheless permits a balance of low partials; and similarly “mellowness” indicates a sound particularly rich in low partials which nevertheless permits a balance of high partials.
Vennard believes that “brilliance” is always allied with pleasing vocal intensity and can only occur if the voice is neither too “tight” i.e. produced with too much laryngeal muscle tension, nor too breathy i.e. produced with too little laryngeal muscle tension. According to Vennard “brilliance” describes the vital glistening quality and sheen of a beautiful voice (Vennard, 1968). This agrees with the way we use “brilliance” in everyday language to describe an admirable quality, a glow of pleasing intensity, radiance, sheen, the sparkle of diamonds and jewel-like qualities. One meaning of “brilliant” in English, as well as Brilliante in German and brillante in Italian, is a diamond which has been skilfully cut to enhance the refraction of light and is very valuable (Brown, 1993; Götz, Haensch and Wellmann, 1993; Reynolds, 1988). Relating this to singing, Vennard believes that the ability to enhance desirable high partials in a vocal tone is one of the most valuable skills a singer can posses.

Within the literature, much more has been written about “bright” vocal quality than “brilliance” or “light” vocal quality, and despite Vennard’s standpoint, “brightness” is often presented by pedagogues and researchers as a desirable tone colour akin to and seemingly used interchangeably with “brilliance” and “light”. Miller translates the vocal term chiaro in some texts as “bright” (Miller, 1977) and in others as “light” explaining that it means “brilliance” (Miller, 1996, 2001a). In fact, when reference is made to brilliance and a carefully gauged degree of brightness, it is questionable where the distinction between the two lies.

2.1.5.3 The link with ring and singer’s formant
Both “brilliance” and “bright” appear to have some association with “ring” in the voice, another high partial quality that Vennard (1968) describes as possibly containing inharmonic high partials related to the singer’s formant. Close relationships are often acknowledged between the singer’s formant, “brilliance” and “ring” (Bartholomew, 1934; Miller, 1996; Van den Berg and Vennard, 1959; Vennard, 1968) or the singer’s formant and “brilliance” (Stark, 1999), the singer’s formant and “ring” (Omori, Kacker, Carroll, Riley and Blaugrund, 1996) and the singer’s formant and “brightness” (Ekholm et al., 1998; Helmholtz, 1877; Honda, Hirai, Estill and Tohkura, 1995; Miller and Schutte, 1990, 1994; Vennard, 1968). Consequently an investigation of brilliance and related terms requires some consideration of the singer’s formant.
Acoustically, formants are regions in the spectral sound wave where partials appear to have been strengthened (Sundberg, 2003; Wood, 1962). The partials within a formant may be both harmonically related to the fundamental pitch as well as inharmonic and dependent on the frequency of the resonator (Vennard, 1968). Sometimes two or three formants cluster together and when this happens their combined energy becomes particularly prominent on the spectral sound wave. It is generally thought that a well trained singing voice displays two such areas of very strong energy concentration.

The lowest area of concentrated energy normally consists of the first and second formants. These formants are mainly responsible for the perception of vowel quality (Sundberg, 1994) and so are referred to as vowel formants. Vowel formant regions used in speaking are substantially wider than those used in singing (Ekholm et al., 1998; Rzhevkin, [1956] 1980). Nevertheless this does not necessarily result in unacceptable singing diction. Often a singer’s intelligibility is aided because speech articulation may be used briefly in the vocal onset before being quickly modified to achieve the necessary balance of partials for optimal singing tone colour (Rzhevkin, [1956] 1980).

The third, fourth and fifth formants often tend to cluster producing a high frequency concentration of energy at approximately 3,000 Hz (Sundberg, 1974, 1987, 2003). Stark (1999) adds that sometimes it is only the third and fourth formants or the fourth and fifth formants which cluster together in this area creating a high frequency band of concentrated energy. Nevertheless this high frequency energy corresponds to a frequency region where the average sound pressure level of orchestral sound has dropped more than 20 dB below its maximum value and these phenomena enable the singer’s voice to be perceived above an orchestral accompaniment (Sundberg, 1974). Consequently it is this spectral region that is referred to as the singing formant, or more commonly these days, the singer’s formant (Sundberg, 2003). Because the human ear, by its own resonance favours similar frequencies, high frequency energy in the region of the singer’s formant may even be related to a feeling of pain in sensitive ears (Helmholtz, 1877). Sometimes the phenomenon of the singer’s formant is strongly associated in the studio with imagery such as “head voice” (Miller and Schutte, 1990, 1994), “head resonance” or “placement in the mask” (Gibian, 1972). This occurs seemingly despite the fact that the sensations of vibration in the head to which these terms refer are not dependent on producing a singer’s formant, but rather reflect back
to the singer a sense of the efficiency of effort and the carrying power of the voice (Titze, 2001a).

2.1.5.4 Acoustic strengthening of high partials

For any one voice displaying a singer’s formant, the position of that formant is not greatly influenced by changes in that singer’s fundamental frequency (Ekholm et al., 1998; Rzhevkin, [1956] 1980; Sundberg 1987). At least this appears to be the case with male voices. Any alteration in a male singer’s formant seemingly caused by pitch variations, can be ascribed to the fact that higher notes are normally sung louder than lower notes and louder tones display stronger overtones and hence a more pronounced formant peak (Sundberg, 1987). Vocal intensity, however, has a more enigmatic relationship with formant strength in the female voice. The low voiced female for example, singing the note A₃ (220 Hz) may have a singer’s formant even more pronounced than basses singing A₃ (220 Hz). Yet irrespective of vocal intensity, the female singer’s formant becomes weaker and more difficult to locate with increasing fundamental frequency (Bloothooft and Plomp, 1986; Schultz-Coulon, Battmer and Riechers, 1979).

The vocal classifications, soprano, alto, tenor and bass, influence the position of the singer’s formant (Dmitriev and Kiselev, 1979). In basses the centre frequency of the singer’s formant occurs generally between 2,300 Hz and 3,000 Hz, as opposed to 3,000 Hz to 3,800 Hz for tenors (Seidner, Schutte, Wendler and Rauhut, 1983). Ågren and Sundberg (1978) found that apart from the fourth formant, tenors and altos have basically similar formant frequencies when singing identical pitches. The fourth formant, however, appears to be consistently higher in altos, as the fourth formant responds to larynx tube dimensions which are smaller in women than men.

Formant issues are more complex the higher the voice. The level of concentrated energy begins to decrease in the spectral sound wave once the fundamental frequency rises into the male falsetto and corresponding female range (Bloothooft and Plomp, 1986). By the note C₅ (523 Hz) one octave above middle C, the presence of the singer’s formant is infrequent (Doscher, 1994). This is the same pitch at which Sundberg (1994) reports difficulties appearing in identification of the lower vowel formant as well. By the note F₅ (700 Hz) vowel identification is basically guess work,
the only vowel capable of successful identification being [a] (Sundberg, 1994), plus the existence at all of the singer’s formant from this point on is disputed (Bloothooft and Plomp, 1986; Sundberg, 1994).

For sopranos, a number of reasons have been suggested for the singer’s formant to appear on the vocal spectrum either very weakly or not at all. It may be that only the third and fourth formants form a less concentrated and somewhat lower area of high partial energy (Sundberg, 1988). Alternately, the soprano formant could be higher and/or broader in frequency than for other singers (Sundberg, 1994). This latter suggestion echoes that of Pelsky in the late 1930s (cited in Miller, 1996) and Peterson and Barney (1952) who concluded that the formant frequency range for women is somewhat higher than that of men. If this is the case, then a soprano formant may not necessarily appear in the fixed and rather narrow band-pass filters used. In fact more recently Titze and Jin (2003) reported that in initial studies with tenor voices, the higher the fundamental frequency sung, the more an additional formant appears to occur at approximately 9,000 to 10,000 Hz. They speculate that a similar acoustic phenomenon may occur with other voice categories, including sopranos. Titze and Jin concede, however, that the perceptual relevance of this “second singer’s formant” may be limited because the energy level produced by the singer at this frequency is lower than at 3,000 Hz, plus the sensitivity of the human auditory system is less at 10,000 Hz than at 3,000 Hz.

Complicating the issue of the “soprano formant” still further, it must be remembered that classically trained low female voices of professional calibre sing fundamental frequencies well above 700 Hz and often have a very similar range to sopranos with classification based more on vocal colour and tessitura or the stamina to stay at high or low extremities (Husler and Rodd-Marling, 1965; Rushmore, 1984). Consequently the disputed “soprano formant” may apply equally to altos and mezzos and it would be logical to speculate that once higher notes are sung, even a pronounced alto or mezzo singer’s formant may similarly disappear or become difficult to locate.

While issues regarding the female singer’s formant remain speculative, it is interesting to note that the violin possesses approximately the same fundamental frequency range as the female voice, and formant frequency research has been conducted on violins. Meinel (1939, 1940) found that not all, but the majority of famous old violins of
exceptional quality, possess an area of concentrated energy at approximately 3,000 Hz. Like Bartholomew (1934) and Bloothooft and Plomp (1986), who observed the singing voice, Meinel in his violin research notes that this 3,000 Hz energy peak is by no means the sole criteria of a quality sound. But such a finding regarding violins, invites the question whether female singers adopt a range of vocal techniques according to level of expertise, physiological strengths and weaknesses to achieve brilliance, brightness and the ability to ring out above an orchestra. Indeed, Barnes (2007) found that professional female opera singers of international standing produced a pronounced peak of high frequency energy in the vicinity of 3,000 Hz.

Bloothooft and Plomp (1986), nevertheless, maintain that for many female voices, the existence of a 3,000 Hz singer’s formant is not required for good vocal quality. Mitchell (2005) also found that whether a voice is produced poorly or well, current LTAS (long term average spectrum) technology analysing the region of the singer’s formant could not be used to differentiate between the two or support perceptual ratings of vocal quality. It would follow that as “brilliance” or “brightness” is essential in all good voices (Miller, 1977, 1996; Vennard, 1968), these qualities may indeed be created independently of an obvious singer’s formant.

There appear to be a number of alternate acoustic explanations for attaining “brightness”. Yet, those acoustic explanations which do not rely on a singer’s formant still maintain that some form of high frequency concentration of energy is necessary. It is questionable, however, whether for all strategies, aesthetically similar qualities of “brightness” result. Bloothooft and Plomp (1986) caution that “pressed” singing though not perceived as representing good tone quality nevertheless creates a high frequency spectral peak. Wang (1985) found that concentrations of high energy roughly between 1,800 Hz and 3,800 Hz, an area he refers to as the Bright Timbre Frequency Range, can produce “bright” timbre irrespective of any specific singer’s formant peak. Other researchers suggest that a much lower frequency range may be responsible for the perception of brightness. Stark (1999) reports that changes in vowel formants are responsible for “bright” and “dark” variation. He suggests that as females ascend from middle to head voice, tuning the first formant to the first harmonic gives the higher notes a less heavy, “brighter” sound. Similar acoustic phenomenon may also occur in males going from chest to head register (Lawrence and Weinberg, 1980; Stark, 1999), and it is proposed (Lawrence and Weinberg, 1980; Oncley, 1973; Stark, 1999) that this
acoustic occurrence is accompanied by a “lift feeling”. Additionally, Stark’s analysis of his own tenor voice suggests that males may align a strengthened second formant with the third or fourth harmonics. This concurs with the findings of Miller and Schutte (1990, 1994) and Schutte, Miller and Duijnstee (2005) in their acoustic analysis of “bright”, “head voice”. Stark (1999) maintains that this strategy, either in combination with a singer’s formant or alone, produces a form of brightness which gives “edge” to the tone. Vocal pedagogue Richard Miller (1977), however, associates “edgy” with “shrill”, an undesirable overly elevated larynx, a less than optimal tone quality and what he terms pseudo-brilliance.

Genuine brilliance or what constitutes an aesthetically pleasing degree of brightness depends to some extent on how “free” a voice sounds verses how “strained”, “pressed” or “tight” (Vennard, 1968). This often reflects a singer’s individual vocal ability, personal taste and the traditions of a particular vocal genre (Titze, 1994). Accordingly, a number of physiological strategies may be used to attain “brilliance” or “brightness”. Most studies have been carried out on classical soloists or choir singers influenced by classical vocal technique. Vennard (1968) believes that within this tradition, genuine brilliance only occurs if the voice is free of perceived tension. A smaller amount of research concerns popular contemporary singing which sometimes openly encourages displays of effort and greater degrees of visible and audible strain (Titze, 1994). It is notable that particularly within this genre researchers tend not to use the term “brilliance”, preferring instead the related but more aesthetically ambiguous adjective “bright”.

2.1.5.5 How is brilliance produced physiologically?

Physiologically it has been noted since the time of Helmholtz and Garcia (Garcia, 1894; Stark, 1999) that a more brilliant, stronger upper partial ring corresponds with longer, firmer glottal closure. This creates greater subglottal breath pressure, lowers the rate of airflow through the glottis, and results in a wider amplitude of the sound wave. Shorter or less firm glottal closure, creates lower subglottal pressure, increases the airflow rate, and gives a narrower sound wave amplitude producing duller vocal tone, with fewer and weaker harmonics (Doscher, 1994; Stark, 1999). Although firm glottal closure is related to a strained, pressed or tense voice (Sundberg, 1987; Titze, 1994) this is only if firm adduction is accompanied by a raised larynx (Doscher, 1994; Shipp, 1987;
Sundberg and Askenfelt, 1983; Vennard and Hirano, 1971). Stark (1999) argues that firm adduction can be regarded positively and is most probably counterbalanced against a low larynx in order to produce brilliance and upper partial ring without “pressed” or “tight” phonation. In support of this he cites Shipp (1987) who states that if larynx raising facilitates vocal fold adduction as in swallowing, then it may follow that larynx lowering inhibits the amount of vocal fold hyperadduction possible.

Although excessively bright shrillness is often associated with larynx raising (Sundberg, 1987; Miller, 1977), Sundberg notes some exceptions and has observed a number of classically oriented sopranos singing beautifully with an elevated larynx (Sundberg, 1987). Extreme raising of the larynx though ends ultimately in a swallow and no sound at all, and so is just as undesirable as extreme larynx lowering. Whether a somewhat raised larynx and the form of brightness it accesses is characteristic of a large percentage of female classical singers is unclear. Doscher (1994) relates that “brightness” may be increased when the larynx is high and the soft palate low. This concurs with the findings of Lovetri (2002) whose study was conducted on female singers of contemporary commercial music. The study found that “brighter” is a description given to vowel sounds made in a smaller vocal tract space which may entail any of the following configurations: (i) “a narrowed soft palate and constricted pharynx”, (ii) “a raised larynx and constricted pharynx”, (iii) “a raised tongue and a soft palate which has both lowered and come in”, (iv) “a constricted or compressed larynx with unchanged oral/pharyngeal space” (Lovetri, 2002, p. 249). It must be noted that because of electronic amplification used in contemporary commercial music, although brightness is a necessary vocal colour, a singer’s formant and the ability to project over the accompaniment are not (Lovetri, 2002). Lovetri’s study supports the opinion that “brightness” can be created independently of projection and a singer’s formant. In fact empirical observation tells us that when a small child sings, “brightness” of tone quality can obviously occur independently of projection and a singer’s formant. But brightness in a small child’s voice is a further example of the distinction Vennard sought to make between brightness and brilliance, as “brilliance” seems totally inappropriate to describe the tone quality of a small child.

Within the classical genre Sundberg (1974) supports the idea that most commonly a low larynx helps create a singer’s formant. Others authorities (Bartholomew, 1934; Ekholm et al., 1998; Helmholtz, 1877; Honda et al., 1995; Miller, 1996; Miller and
Schutte, 1990, 1994; Stark, 1999; Van den Berg and Vennard, 1959; Vennard, 1968) maintain that a low larynx may produce brightness or brilliance. Interestingly, Sundberg does not offer such timbre adjectives himself, preferring only acoustic and physiological descriptions of the singer’s formant. Sundberg acknowledges that lowering the larynx may not be the only way a singer’s formant is produced. The closing rate and efficiency of the glottis during each vibratory cycle is critical in influencing the amplitude of high harmonic partials necessary for the singer’s formant, and the individual shape of the pharynx and larynx may be such that there is no need for additional laryngeal lowering for optimal inharmonic partials (Sundberg, 1987). The necessity of a low larynx, however, is supported by Honda et al. (1995), who report that lowering the larynx not only lowers the mean “vowel formant” frequency, assisting the perception of “darkness”, but also increases spectral energy in the singer’s upper formant range and so assists the perception of “bright” vocal colours as well. Excessive lowering of the larynx though is counterproductive and removes high partial “ring” or “brilliance” (Van den Berg and Vennard, 1959).

Any change in larynx position will alter the formant frequencies (Sundberg, 1987; Doscher, 1994). Although this is also true of any change in the position of the lips, jaw opening, tongue and soft palate, it is the higher formant frequencies, particularly relevant to the singer’s formant, which are most affected by larynx position. Longer tubes have lower resonance frequencies (Sundberg, 1987) and when the larynx lowers there is an increase in the total length of the vocal tract (Sundberg, 1974). With a lowered larynx, the pharynx both widens and lengthens and this is important in lowering the fifth formant frequency. It has been suggested that pharyngeal widening may be linked to the expansion of the valleculae (Titze, 2005), and laryngeal lowering to the expansion of the pyriform sinuses (Sundberg, 1974). Meanwhile within the larynx the sinus of Morgagni or laryngeal ventricle expands, and this influences the fourth formant. Sundberg (1974) concludes that these adjustments enable the production of a singer’s formant, and this perhaps makes the observation all the more significant that good voices tend to possess a larger sinus of Morgagni than poor voices (Flach, 1964).

With a lowered larynx and resultant widened pharynx housing the small larynx tube, the ratio between the cross sectional area of the surrounding larger pharynx and the opening area of the smaller larynx may be greater than 6:1. This is particularly the case when notes within the male vocal range are sung. Referring to calculations of Ingard
and Fant (1960), Sundberg reminds us that when this 6:1 ratio occurs the larynx tube may act as a separate resonator (Sundberg, 1974, 2003) with the air space between the vocal folds and the aryepiglottic folds influencing vocal “ring” or the singer’s formant (Titze, 2005; Titze and Jin, 2003). Sundberg (1987) notes that lowering of the larynx and dilation of the pharyngeal sidewalls may occur during quiet inhalation through the nose, and suggests that the vocal technique of maintaining a sense of inhalation during singing may be a way of encouraging the sense of a lowered larynx. Sundberg proposes that expressions such as taking a breath as though smelling a rose, as though beginning to yawn, or as though crying may similarly lead to inhalation associated with a comfortable lowering of the larynx.

Apart from possibly encouraging a singer’s formant, there are other reasons related to the acquisition of vocal “brilliance”, as to why a comfortably low larynx is often encouraged in the classical singing studio. Doscher (1994) clarifies that a low larynx which influences the shape of the pharynx, consequently influences the texture of the vocal tract walls. The vocal tract walls may vary from taut through to flaccid, and this impacts on the acoustic properties of the fleshy vocal tract. Because hard walls encourage higher partials, when soft vocal tract walls become taut the voice becomes brighter. Conversely the more flaccid the walls of the vocal tract, the less responsive the vocal cavity is to the higher partials and the more a “darker” sound lacking high partials results. This is the effect of damping. Damping is the time rate at which energy is dissipated in a vibrating body. A dampened sound wave may lack crucial partials or certain partials in the wave will not have sufficient amplitude to be adequately reinforced (Doscher, 1994). All of our sound waves are dampened to a greater or lesser degree. In optimal singing, the singer has appropriately minimised the damping factor with the result that more sound is produced with less effort and a richer spectrum of overtones produces brilliance of tone (Doscher, 1994; Vennard, 1968). Sundberg explains that with a lowered larynx, the expanded sinus of Morgagni appears to counteract the dampening effect of the pyriform sinuses (Sundberg, 1974). Additionally, a lowered larynx facilitates the relaxation of all muscles leading upward from the hyoid bone and therefore tends to be associated with the perception of a voice free of general muscle tension (Sundberg, 1987), which is a vital feature of brilliance.

The lowering of the larynx is performed by the sterno-thyroid muscle, which is an infralaryngeal extrinsic muscle (Sundberg, 1987). However, Vennard regards
appropriate lowering of the larynx (whereby excessive lowering is avoided and maximal brilliance is produced) as a passive motion resulting from the relaxation of the supralaryngeal extrinsic muscles (Vennard, 1968). Doscher (1994) reminds us that laryngeal position is strongly influenced by the balanced action of all of the extrinsic muscles, both infra- and supralaryngeal. She adds, however, that the laryngeal musculature is so complex that no one strategy for seeking a particular tone quality is employed by all singers. Consequently, vast variation exists even amongst somewhat similar tone qualities. Some qualities are more appealing or more appropriate to given circumstances than others, but as Meinel (1940) noted last century, it is when dealing with tones displaying strong high partials that perceptual judgements become particularly dependent on personal taste.

2.1.6 Vibrato

2.1.6.1 How is vibrato perceived?

Vibrato is a regular undulation of pitch which, when favourably incorporated in performance is generally perceived, not as pitch undulation, but as either a subtle periodic change in the strength of the sound (Winckel, 1957) or simply an integral part of the timbre (Doscher, 1994). Music historians are uncertain whether vibrato has always been perceived as desirable in singers and, if so, to what extent. Over the centuries vibrato use by string players has been subject to fashion trends (Hauck, 1975) and this seems to apply to singers’ vibrato as well. The 12th century Bishop Aeldred wrote disapprovingly of “the voyce” which reminded him of “a horse’s neighings ... writhed, and retorted with a certain artificiall circumvolution” (Donington, 1995, p. 698). Opinions differed regarding the 17th century castrato Baldassare Ferri who was both praised as possessing a vocally “brillian shake” by some, yet derided for “a ludicrous and incessant wobble” by others (Westerman, 1938). In the 18th century Mozart wrote to his father of his dislike for singers who intentionally vibrate the voice as “the human voice already vibrates of itself, but in such a degree that it is beautiful” (Rushmore, 1984, p. 190). Instrumental vibrato was largely conceived as an imitation of such natural oscillation in the human voice, and descriptions of string playing that refer to what today is called vibrato have existed as early as 1528 (Hauck, 1975). However, the term “vibrato” has not been long in use either for singers or instrumentalists. Only in the late 18th century when larger orchestras and bigger concert halls demanded greater power from singers, did a continuous, clearly audible vibrato unquestionably
establish itself in the Western singing tradition (Moens-Haenen, 1992) and the term “vibrato”, from the Italian *vibrare*, to shake, come into common use to describe this phenomenon (Westerman, 1938). By the mid-19th century the term “vibrato” had also been adopted by instrumental players. Still, individual differences amongst performers and fashion trends in the use of vibrato continued, with one music critic in 1908 writing a particularly aggressive article against “everlasting vibrato … [that] trembles like jelly on a plate in the hand of a nervous waiter” (Hauck, 1975, p. 20).

Providing it stays within the bounds of moderation, vibrato is today recognised as an important part of a singer’s tone quality (Doscher, 1994). Seashore (1932) credited vibrato with the ability to give a tone “pleasing flexibility”, “tenderness” and “richness”. Seashore judged straight tone as “thin”, “rigid” and “cold” (Seashore, 1932; 1947). Subsequent investigations (Damsté, Reinders and Tempelaars, 1983; Ekholm et al., 1998) have supported Seashore’s findings and attributed the perception of richness and warmth to a well-controlled vibrato. These judgements lend credence to Schoen’s assertion that because trembling is often associated with emotional experiences, vibrato is a means of artistically conveying emotion (Schoen, 1922).

2.1.6.2 Acoustic characteristics of vibrato

The periodic, rather sinusoidal modulations of phonation frequency recognised as vibrato (Schultz-Coulon and Battmer, 1981) are characterised by two parameters: the extent (how far the phonation frequency rises and falls in each undulation), and the rate (how often per second these undulations occur) (Sundberg, 1987). Because vibrato involves rhythmic fluctuations in the fundamental frequency and associated partials, vibrato may increase the chance of partials, at some point or points within each vibrato cycle, approximating a vocal tract resonance, thereby boosting the amplitude and the overall carrying power of the voice (Dromey, Carter and Hopkin, 2003; Seashore, 1938; Sundberg, 1987). The perceptual significance of the amplitude fluctuations that characterise individual vibrato cycles is, however, uncertain. Sundberg reasons that the perceptual significance of the interplay of phase relationships between vibrato amplitude and vibrato frequency is often overestimated. He stresses that the main perceptual effect of vibrato undulations depends on the frequency modulation (Sundberg, 1987).
2.1.6.2.1 Vibrato extent

The extent of departure within a vibrato cycle from the perceived fundamental frequency is often expressed in fractions of a semitone both up and down from the perceived pitch. Alternately, some researchers express vibrato extent in cents with 100 cents corresponding to a semitone, or as a percentage of frequency difference, in which case 6% corresponds approximately to a semitone (Sundberg, 1987). The listener, discerning a mere fraction of the actual extent fluctuations, perceives the average fundamental frequency as the pitch sung (Sundberg, 1994), and only clearly notices frequency fluctuations if the vibrato is problematic (Seashore, 1938; Winckel, 1957).

Vibrato extent may vary widely. Miller (1996) suggests that the voice may fluctuate by a third of a tone both up and down (approximately ±0.66 semitones), however, Howes (2001) measured vibrato extents as large as ±2.62 semitones in powerfully dramatic opera. Shipp, Leanderson and Sundberg (1980) measured mean vibrato extents amongst student and professional singers ranging from ±0.8 to ±2.0 semitones; the average for all singers was approximately ±1.2 semitones, and ±1.4 semitones for professional female opera singers. Using professional recordings Prame (1997) found individual notes in dramatic passages from Verdi arias and dramatic sections of Schubert's *Erlkönig* displayed mean vibrato extents of ±0.5 to ±1.5 semitones. For the more restrained Schubert Lied *Ave Maria*, he measured mean vibrato extents for individual tones from ±0.34 to ±1.23 semitones and an average vibrato extent of ±0.71 semitones. Interestingly, singers' vibrato extents for *Ave Maria* were twice or more than those measured in violinists performing the same piece. Similarly, Sundberg (1987) reports that singers are more likely to produce vibrato extents exceeding ±0.5 semitones than wind instruments.

To some degree a well trained singer may vary vibrato extent according to the vocal task required. Beginner singers generally lack this ability, often singing vibrato-free or with minimal and irregular vibrato extent (Titze et al., 2002). Choir singers tend to perform with decreased vibrato extent, which possibly assists vocal blending and pitch definition (Sublett, 2009). Vibrato extent also decreases whenever there are fast notes enabling the melody to be more clearly defined (Titze, 1994) although Prame (1997) observed that of all long held notes in Franz Schubert's *Ave Maria*, the longer the note, the smaller the vibrato extent. However, Prame (1997) found so much variation from
note to note amongst professional singers, that he concluded it is difficult to attribute a
typical vibrato extent value to an individual singer.

Vibrato extent is greatly affected by factors such as training, personal taste and
conventions regarding tone quality or colouration which contribute to a sense of
musical style. Singers of early music, jazz and musical theatre often adopt styles where
extent is sometimes altered to give the perception of a straight tone which may blend
into vibrato (Sublett, 2009; Titze, 1994). Classical singers too may start a tone very
softly with no vibrato and then go into vibrato as the intensity increases (Large and
Iwata, 1971; Michel and Myers, 1991). Interestingly, the study of Michel and Myers
(1991) found that the reverse phenomenon never occurred when intensity diminishes.
That is, once a note is established vibrato extent remains wide even if that note
becomes soft.

Titze (1994) explains that when vocalists blend straight tone into vibrato by altering
their vibrato extent, the so called “straight” part of the tone is not completely steady in
frequency. It is difficult for a trained classical singer to completely eliminate vibrato for
more than a fraction of a second (Schoen, 1922). Stark (1999) explains that for a tone
to be perceived as straight, the muscles in a trained singer’s voice that normally
function in a work-rest cycle generating vibrato must be rigidly held, hindering flexibility
of movement or free function. Shipp regards straight tone as the “maximum inhibition”
and maintains that once such constrictions are removed vibrato emerges (Coleman,
Sundberg, Keidar, Rothman, Baer, Miller, Izdebski and Shipp, 1984, p. 122). In fact
listeners perceive tones with vibrato as being freer from tension (Titze et al., 2002).

Trained singers can control the extent of their vibrato, according to Shipp, Sundberg
and Haglund (1984). However, the aging classically trained professional singer
commonly experiences increased vibrato extent beyond the singer’s personal control
(Sundberg, Thörnvik and Sönderström, 1998) and this may be ruinous to the
perception of clearly defined intonation and aesthetically pleasing tone. Sundberg
(1995) suggests that vibrato extents exceeding ±2 semitones tend to sound bad.
Howes (2001) noted that although a mean vibrato extent of ±1.22 semitones (even with
a standard deviation of 0.27 semitones) could be rated as superb by listener-judges,
the more vibrato extent exceeds ±1.5 semitones, the less the singer was preferred.
Adding to the complex nature of vibrato, although some studies report that vibrato extent may increase considerably depending on intensity or sound pressure level, as in a crescendo (Bretos and Sundberg, 2002; Winckel, 1953), this is not always the case. Michel and Myers (1991) found that in crescendo and other gradations of vocal intensity, change in vibrato extent often displayed little consistency. Other studies (Michel and Grashel, 1980; Shipp et al., 1980) found no significant change in vibrato extent with notes sung softly and then loudly. In these studies, however, loud and soft notes were sung in the same neutral emotional context, not as part of a song but as an isolated note on a single vowel. The Bretos and Sundberg (2002) study which linked increased loudness with increased vibrato extent, used Verdi Aida recordings of two extracted crescendo notes. In contrast to such dramatic operatic arias, some less dramatic Lieder that were not composed to project over an orchestra show a smaller vibrato extent (Prame, 1997).

From these diverse studies it would seem that as emotional intensity and dynamic intensity very often combine in musical interpretation, vibrato extent displays a response to the emotional connection and interpretive artistic requirements of the song. Indeed although loud notes often join with strong emotions and large vibrato extents, notes sung softly need not necessarily forgo large vibrato extent if they portray equally strong emotions. Howes (2001) analysed a Donizetti vocal passage which theatrically represented strong emotions, and although it had the dynamic marking pianissimo (very soft), the singer most preferred by listener-judges had a robust average vibrato extent of ±1.22 semitones with a standard deviation of 0.27 semitones. This supports Schoen’s initial assertion that vibrato is a means by which an artist conveys emotion in a performance situation (Schoen, 1922). In fact the baritone Dietrich Fischer-Dieskau has reported varying his vibrato extent precisely for the purpose of artistic expression (Large and Iwata, 1971).

2.1.6.2.2 Vibrato rate

Vibrato rate, which is normally expressed in Hertz or cycles per second, varies greatly amongst singers; so too does the wave shape from which rate is measured (Shipp et al., 1980). Rates have been reported to range from as low as 2 cycles/sec (Titze, 1994) to as fast as 12 cycles/sec (Miller, 1996). Titze (1994) points out that Luciano Pavarotti, with a mean rate of 5.5 cycles/sec falls between the 4.5 and 6.5 undulations per
second, which he believes is generally perceived as desirable today. According to Miller (1996), classical singers tend to have vibrato rates ranging from 5 to 7 cycles/sec, although Doscher (1994) suggests that male singers today rarely reach the fast rate of 7 cycles/sec.

Excessively fast vibrato rates are sometimes linked to highly-strung nervous singers (Miller, 1996; Sundberg, 1987). This resounds with the findings of Howes (2001) that singers with a vibrato rate of 7.04 cycles/sec or higher were perceived as sounding in “fear of death”. Titze suggests an excessively fast machine-gun like vibrato or “bleat” may occur even with a vibrato rate of 6 cycles/sec or more. He notes that a vibrato bleat occurs in situations of nervousness or where there is excessive physical tension in musically hyperactive vocalists (Titze, 1994). Dromey et al. (2003) adds that for a vibrato to be perceived as a bleat, a fast vibrato rate is accompanied by a narrow vibrato extent. It is not uncommon, however, for young singers to have excessively fast vibrato (Titze et al., 2002), and Miller (1996) notes that generally the faster the vibrato rate, the narrower the vibrato extent.

If vibrato rate is too slow it may be perceived as a “wobble”. While slow vibrato rates are linked to relaxation (Westerman, 1938), overly slow vibrato rates are usually attributed to poor muscle tone in younger singers, poor technique, lack of excitement, fatigue or aging (Miller, 1977; Sundberg et al., 1998; Titze, 1994). Reasoning that psychological states may be reflected in physiological responses, both Vennard (1968) and Miller (1996) observe that there is a link between the low-key phlegmatic personality and slow vibrato rate. Sundberg (1995) proposes that vibrato rates below 5 cycles/sec sound unacceptably slow. Prame (1994) suggests the point at which a steady, aesthetically acceptable vibrato rate degenerates into a noticeable wobble appears to lie somewhere between 4.5 and 5 cycles/sec. Yet Doscher (1994) claims that a rate of 3 to 4 cycles/sec is common amongst singers of popular music. Titze et al. (2002) and Dromey et al. (2003) suggest that in addition to a slow vibrato rate, a large vibrato extent generally accompanies a wobble.

Some variation in vibrato rate appears necessary to prevent monotony and impart individual artistic expression (Seashore, 1947). However, untrained singers tend to either sing vibrato-free or have exceptionally variable vibrato rates. Singers may need considerable training for vibrato to improve (Sundberg, 1987; Titze et al., 2002),
although training generally avoids dealing directly with how to create vibrato (Reid, 1978; Vennard, 1968) and any vibrato rate variation is not under conscious control (Bretos and Sundberg, 2002; Prame, 1994; Robison, Bounous and Bailey, 1994). Yet it is generally agreed that the more highly trained and the better the voice, the more moderate and regular the vibrato rate (Bartholomew, 1934; Robison et al., 1994; Sundberg, 1987, 1995; Titze et al., 2002). Despite conscious control of vibrato rate not normally occurring (Shipp et al., 1984; Sundberg, 1994), Dromey et al. (2003) reported that given a target sound, singers can often imitate another singer’s vibrato rate for a few seconds. Whether singers could comfortably maintain large overall rate adjustments remains unclear. Vibrato rate certainly appears less controllable by the singer than is vibrato extent (Prame, 1997; Shipp et al., 1984; Titze et al., 2002), and is referred to by Sundberg as “mostly … a personal constant” (Sundberg, 1994, p. 117).

Vibrato rate is neither a function of pitch nor of vocal intensity according to Shipp et al. (1980) and Michel and Grashel (1980). These investigators studied professional singers and high level tertiary students singing individual tones not connected to an emotional context. Earlier reports have also disassociated vibrato rate from pitch (Mason and Zemlin, 1966; Seashore, 1938) and from dynamics (Sjöström, 1948). However, other authorities maintain vibrato rate may increase with pitch and level of excitement (Titze, 1994), or increase with loud singing and decrease in soft singing (Dromey et al., 2003; Winckel, 1953) and in art songs (Seashore, 1932), which are not as passionately loud as opera.

To what degree these variable findings may be linked to either varying ability levels of singer-subjects or influences from emotionally charged repertoire is unclear. Dromey et al. (2003) measured vibrato rates from singers with as little as two and a half years’ training, yet stability of vibrato rate which is one measure of the singer’s level of accomplishment, generally occurs as part of a gradual process often reflecting the number of years studied (Mürbe, Zahnert, Kuhlisch and Sundberg, 2007; Sundberg, 1987; Titze et al., 2002). If vibrato rate is influenced in part by effort expended as Vennard (1968) suggests, then it is also feasible that simultaneous variation in both rate and dynamics may be more pronounced in beginner than advanced singers, because muscular imbalance and poor technique in beginner singers may lead to greater physical exertion to produce a slightly louder note. The sensation of ease and greater control of dynamics generally comes with training and mastery of one’s
instrument. Vennard does caution, however, that Enrico Caruso who had a very high average vibrato rate, sometimes measured at 6.8 and up to 7.25 cycles/sec, was a high energy, excitable personality, prone to forcing the voice so much he had to cancel a season at La Scala and another at the New York Met (Vennard, 1968).

Stress and different emotional states appear to act as a trigger to some forms of tremulous vocal quality (Titze, 1994). Hence, the stresses associated with different performance situations and the interpretive demands of emotion-charged repertoire should not be overlooked as influences on vibrato rate. Vibrato rate tends to be faster in highly passionate operatic singing than in concert singing where, as Vennard expressed it, the singer “does not have to compete in volume with a sixty-piece orchestra” (Vennard, 1968, p. 196). It also appears to be substantially slower in the relatively subdued environment of the recording laboratory (Shipp et al., 1980). Even in the recording studio, however, emotions stemming from the singer’s response to the score may subconsciously exert a major influence on vibrato rate. Sundberg (1995) assessed vibrato rates of a professional singer in two different emotional contexts. In one, the singer recorded sustained vowels, in the other the same singer gave a real performance of a song. Though the standard deviation remained the same, the mean vibrato rate was 15% faster for the song.

Bretos and Sundberg (2002) observed that the vibrato rate of two long held notes in a Verdi aria generally increased during a crescendo. However, as the score at that point demanded an emotionally intense response from the singer, perhaps the emotional intensity triggered the increasing vibrato rate irrespective of dynamic markings. Howes (2001) measured the vibrato of Maria Callas singing pianissimo in an emotionally highly charged operatic excerpt. The mean vibrato rate was 7.14 cycles/sec. Titze describes vibrato rates of 7 cycles per second as being excessively fast (Titze, 1994). So although Bretos and Sundberg (2002) tend to link an increase in loudness with an increase in vibrato rate, it would appear that the views of Titze et al. (2002) and Vennard (1968) are most apt. That is, vibrato rate is generally a result of the singers’ energy, excitement or emotional response to the performance situation or to the score.

Exceptionally fast and exceptionally slow vibrato rates appear to be important when particularly intense emotions or extreme psychological states are portrayed (Titze, 1994; Westerman, 1938). For example, the very fast vibrato rate mentioned above, of
7.14 cycles/sec by Maria Callas, occurred during the famous mad scene from Donizetti’s opera *Lucia di Lammermoor* (Howes, 2001). By contrast, vibrato rates as slow as 4.1 cycles/sec have been recorded from Maria Callas in the renowned sleep-walking scene from Verdi’s opera *Macbeth* (Prame, 1995) where the singer is portraying overwhelming emotional “disintegration” (Kobbé, 1954, p. 438). Interestingly, Prame states that Callas’ exceptionally slow rate of 4.1 cycles/sec “does not sound as an acceptable vibrato” (Prame, 1995, p. 137). Considering the extreme emotional and mental states vocally enacted in these examples, it seems likely that if more moderate feelings were to be portrayed, then more moderate vibrato rates would be favoured.

Within a singer’s usual range of vibrato rates, it has been noted that the rate generally becomes faster for florid singing (Vennard et al., 1970; Prame, 1994) and tends to slow when the same singer produces more sustained notes (Howes, Callaghan, Davis, Kenny and Thorpe, 2004; Prame, 1994). Prame (1994) reasons that this difference occurs because extended notes, subdivided into beginning, middle and end, usually have a faster average end vibrato rate, when the end is calculated from the last one to seven vibrato undulations. He found that short notes with few undulations generally do not display the slower initial rates of extended notes. Yet even this could reflect a subtle link between musical notation and emotional expression whereby slow notes often demand the portrayal of calmness, and therefore display slower vibrato rates not found in faster passages. In fact, Prame (1994) maintains that the individual singer’s interpretation of a piece may also affect vibrato rate.

Some authorities associate vibrato rate with tone quality. Bartholomew believes vibrato is “… the most important single determinant of tone quality” (Bartholomew, 1937, p. 125). Miller states vibrato can be the distinguishing feature between good and bad vocal tone, giving the perception of warmth, resonance and a *chiaroscuro* quality of mellowness and brilliance in the voice (Miller, 1996). He proposes that females and those possessing brighter voices have a faster overall rate of vibrato than males and those possessing darker voices, and that there is a direct relationship between *chiaroscuro* and vibrato rate (Miller, 1977). To some extent this is supported by Shipp et al. (1980). Although they found no relationship between the vibrato rate of soprano and alto or between tenor and bass voice types within their small singer-subject pool, they nevertheless found a significant difference between the faster average vibrato rate of females and the slower average rate in males. This, however, was not the case for
all voices on all occasions and it should also be noted that Seashore (1936) did not observe any gender-based difference in vibrato rates.

The relationship between vibrato rate, tone colour and pitch may be particularly complex. Winckel (1960) reminds us that tone colour changes with pitch, becoming brighter with ascending pitch and darker with descending pitch. With vocal training, however, singers generally attempt to even out their tone colour throughout the range. Vocal pedagogues (Miller, 1977, 1996; Robison et al., 1994; Vennard, 1968) suggest that naturally high, bright voices often need to find a balance of mellow, dark quality, whereas for naturally dark, low voices the challenge is often to add brightness for optimal beauty. This implies that singers and instrumentalists may vary vibrato rate in response to the amount of brightness or mellowness required in the music. Interestingly string players, taught to dismiss a “one size fits all” view of vibrato in favour of exploring the various tone colours possible through vibrato tend to support this (Hauck, 1975).

Miller (1977), referring to bright-dark (chiaroscuro) vocal colour, states that vibrato is faster when the more brilliant chiaro aspects predominate, whereas vibrato is relatively slow and wide when the deeper oscuro elements of the sound are emphasised. He suggests that with aural training, singers may subtly adjust their vibrato rates by balancing bright and dark aspects of their voice (Miller, 1977). Some singers report that their ability to successfully alter their own vibrato rate for research is dependent on their perception of “placement”. That is, imagery which places the voice more forward speeds up the rate, whereas imagery which places the voice further back in the head slows their rate down (Carter, Hopkin and Dromey, 2010; Dromey et al., 2003). This supports observations by some singers and teachers that the more a tone is felt to be projected up and forward, the more it acquires a brilliance and chiaro tone quality, whereas the more a tone is felt to be projected back and down, the more it becomes mellow and the oscuro character is strengthened (Vennard, 1968; Westerman Gregg, 2001b). It seems feasible that some singers monitor the sound they produce by these sensations (Sundberg, 1974) and so, depending on the expressive demands of a piece, vary the tone colour of particular notes. According to Miller (1977), the well-trained singer keeps both depth and brightness factors in balance, which results in a favourable vibrato rate, neither too fast nor too slow.
Winckel’s observation that tone colour becomes brighter with ascending pitch (Winckel, 1960), Miller’s proposal that brighter voices have higher vibrato rates (Miller, 1977), and findings that suggest fast rate is central to florid singing (Vennard et al., 1970; Prame, 1994) also reflect the common observation that high, bright voices generally find florid coloratura passages far easier to negotiate than dark, low voices (Steane and Jander, 1998). How much a singer’s vibrato characteristics would vary if a different voice were needed, for instance for comic effect in a character role, if a singer changed Fach (vocal category) mid-career or successfully alternated between popular and classical styles, can only be speculated. It would certainly seem that an appropriate tone colour adjustment would demand significant vibrato rate adjustment by the singer, whether by conscious use of a different technique, or indirectly and possibly subconsciously with the help of aural imagery.

Archive sound recordings of opera singers indicate that vibrato rates may have slowed somewhat since the early 20th century (Stark, 1999; Titze, 1994; Vennard et al., 1970; Winckel, 1953). This may be due to “a shift in our aesthetic value system” (Rothman and Timberlake, 1984, p. 114) and a preference today for a more “settled” sound (Titze, 1994, p. 291). The desire for a more settled sound may stem from opera audiences in the mid-20th century becoming familiar with the popular, more “laid back”, “crooning” vocal style of the era that was only possible with the advent of electronic amplification of the voice over the accompaniment. Perhaps this new sound played a role in reshaping audience expectations even from classical singers. Prame (1994), however, does not rule out that our perception of fast vibrato rate in old recordings may be due to the shortcomings of early recording equipment.

To date, singing research has concentrated more on note-to-note vibrato rates and mean vibrato rates for entire segments of vocal music rather than cycle-to-cycle vibrato characteristics (Sundberg, 1995). Bartholomew (1934) and Sjöström (1948) both stressed that the cycle-to-cycle regularity of undulations within a given note is important in optimal vibrato production and improves with singer ability level. Referring specifically to cycle-to-cycle vibrato regularity, Prame (1994) observed that vibrato undulations accelerate towards the end of most, though not all, long held notes. However, while accepting that some variation occurs, Sundberg maintains that variation in vibrato undulation must have its bounds, as regularity of the undulations is considered “a sign of the singer’s vocal skill: the more skilled the singer, the more
regular the undulations" (Sundberg, 1995, p. 39). Mürbe et al. (2007), Sundberg (1987) and Titze et al. (2002) note that student singers often need considerable training and time for vibrato to become appropriately even.

Certainly for note-to-note vibrato rates, a sense of consistency appears to be important in optimal vibrato (Diaz and Rothman, 2003; Robison et al., 1994; Sundberg, 1987; Titze et al., 2002). The Howes (2001) study lends support to this; it lists vibrato rates from eleven recordings of a cadenza from Verdi's opera *Un Ballo in Maschera* and ranks singers according to listener preference. For notes judged to be particularly significant and sustained, the most preferred singer had the least standard deviation (0.08 cycles/sec). By comparison, the largest standard deviation (0.95 cycles/sec) belonged to one of the least preferred singers.

In fact, the four least preferred singers in the study of Howes (2001) each had one of the following distinctive qualities: (i) the widest mean vibrato extent; (ii) the fastest mean vibrato rate; (iii) the largest standard deviation from the singer's mean rate for the cadenza; (iv) the largest standard deviation of vibrato rates for notes judged to be particularly significant and sustained. This indicates a complex interplay of vibrato extent, vibrato rate and standard deviation of rate influencing singer preference. Furthermore, the differences in acoustic measurement separating most from least preferred singer were often quite small. For example, although one of the least preferred singers had the fastest mean vibrato rate, there was only a difference of 0.52 cycles/sec separating that singer from the most preferred singer in the group (Howes, 2001). In other words, seemingly small differences in vibrato may be very important for a singer.

### 2.1.6.3 Primary causes of vibrato

The underlying physiological origin of vibrato has not yet been established (Doscher, 1994; Titze, 1994). There are, however, two points generally agreed upon, namely that pitch and intensity fluctuations of vibrato are not related to the number of times the vocal folds adduct and abduct per second (Mason and Zemlin, 1966), and that vibrato appears to be the result of the intricate functional interdependence of the total singing instrument (Doscher, 1994). It has been suggested that the abdominal, diaphragmatic, and thoracic muscles of the respiratory system, the extrinsic and intrinsic muscles of
the larynx, and possibly the articulatory muscles may be involved in producing vibrato (Rothenberg, Miller and Molitor, 1988). However, Titze (1994) points to some confusion regarding whether vocal vibrato may be created outside the larynx. He suggests this stems from movements often observed in the abdomen, jaw and tongue, which appear to be associated with vibrato but which may merely be reactionary and not causal.

Of the internal laryngeal muscles, the crico-thyroid and thyro-arytenoid muscles are regarded by many as conceivably the primary producers of vibrato, as both muscles work together to determine fundamental frequency (Hirano, 1988; Hsiao, Solomon, Luschei and Titze, 1994; Mason and Zemlin, 1966; Niimi, Horiguchi, Kobayashi and Yamada, 1988; Shipp, Doherty and Haglund, 1990; Titze et al., 2002; Vennard et al., 1970). Moreover, in some investigations (Hsiao et al., 1994; Niimi et al., 1988; Shipp et al., 1990) increased activity in the intrinsic laryngeal muscles appear to precede the rise in the pitch of vibrato sufficiently to suggest that crico-thyroid and thyro-arytenoid influence may be causal rather than reactionary. Hirano, Hibi and Hagino (1995) also suggest it is possible that the crico-thyroid muscle may even interact with an extrinsic laryngeal muscle such as the sterno-thyroid or the sterno-hyoid, which are known to lower the larynx, and thereby perhaps shorten the vocal folds. Miller (2004) suggests that an excessively lowered larynx may produce “wobbly” vibrato rates (p. 83), while an excessively raised larynx is linked to fast vibrato rates.

Whether conscious changes in the use of the respiratory musculature can affect vibrato rate is contentious (Stark, 1999). Although deliberate, abdominally produced breath impulses by singers performing a series of rapid marcato tones have been found to immediately alter vibrato rate for those tones (Vennard et al., 1970), Titze (1994) points out that such fabricated effects do not constitute what experienced singers or listeners would call natural vibrato. Appleman (1967) reasons that as dramatic intensity and musical phrasing influence respiratory response and breath pressure, so changes in the respiratory muscles and subglottal air pressure play a dominant role in varying vibrato rate when working in conjunction with infra- and supra-hyoid muscle groups affecting laryngeal stability. Pedagogical texts certainly suggest that the respiratory muscles are part of the complex interplay of muscles which can, over time, be trained to offer a measure of control over amplitude, intensity and expressive quality and the attendant development of vibrato (Fischer, 1993). Nevertheless, many researchers maintain that just as changes in respiratory musculature vital for control of pitch and
loudness are not under conscious command (Sundberg, 1993), so too vibrato rate is not significantly influenced by respiratory, auditory or any other form of conscious control (Shipp, et al., 1984).

Other factors influencing vibrato have yet to be explored. Doscher points out that no one has studied the effect of resonance tract adjustments on vibrato (Doscher, 1994). This is a notable omission as each variation of *chiaroscuro* in the vocal tone and corresponding changes in vibrato mentioned earlier would require different resonance tract adjustments. Vennard certainly maintained that variations in the use of the breath can affect not only the vibrato rate (Vennard et al., 1970) but also the “open throat” (Vennard, 1950), implying an inter-relationship between breath, resonance tract adjustments and vibrato. In addition, Wapnick and Ekholm (1997) and Ekholm et al. (1998) found that all terms relating to vocal tone showed some relationship with the other terms and it was concluded that no qualities investigated, including “appropriate vibrato”, were actually independent elements.

Vibrato also appears to have a neurological component, as string, brass and woodwind vibrato can be of similar rate (Titze et al., 2002). It has been proposed that vibrato may be related to tremor frequencies (Schoen, 1922; Shipp et al., 1984; Stark, 1999; Titze, 1994; Titze et al., 2002; Westerman, 1938; Winckel, 1957). Tremors occur when the body’s natural neuro-muscular rhythmic pulse sends action currents from the central nervous system to motor units of active muscles throughout the body (Robison et al., 1994; Westerman, 1938; Winckel, 1957). Tremor activity is capable of protecting all paired muscles under conditions of tension from fatigue by alternately contracting and relaxing, in a work-rest cycle (Stark, 1999). Titze (1994) notes that there may be some mechanical system in the larynx that can physically stabilise tremor activity, maintaining it at a more constant rate and extent. He proposes that tremor activity in combination with auditory memory of the desired sound and kinaesthetic memory of the required muscle effort and co-ordination, combine to create a cortical response (Titze et al., 2002). The response appears to trigger an interaction between the central nervous system and that part of the peripheral nervous system known as the autonomic nervous system (Shipp et al., 1980) which regulates the automatic functions of the body (Anthony and Thibodeau, 1979). This in turn affects the transmission of nerve impulses to the crico-thyroid and thyro-arytenoid muscles or other agonist-antagonist muscle pairs which facilitate vocal fold tension (such as a strap muscle...
working with either the thyro-arytenoid or the crico-thyroid, or the lateral crico-arytenoid working with the crico-thyroid) thus creating vibrato (Titze et al., 2002).

It has not been established just what type or types of tremor generally appear to contribute to vibrato. There are many types of tremor, some occurring naturally in all people and others linked to psychological causes, drug use, alcohol withdrawal or neurological disease. Often different types of tremors are associated with specific ranges of frequency but sometimes there is an overlap with a number of tremor types sharing similar features, hence identifying specific tremor types is sometimes problematic (Hou and Jankovic, 2002). A normal physiologic tremor that we all experience, for example after exercise, typically ranges from 8 to 12 cycles/sec (Coleman, Hakes, Hicks, Michel, Ramig and Rothman, 1987; Hou and Jancovic, 2002). Ramig and Shipp (1987) found a relatively consistent rate of 5 to 6 cycles/sec in the vibrato of professional opera singers and also in patients with pathologic tremor such as Parkinson’s disease. However, Damsté stresses the need for the singing community to realise that tremor may also stem from emotional tension and so have a psychological basis (Coleman et al., 1987). Anger, frustration and anxiety, for example, are all expressed by tremor and, like Schoen (1922), Damsté maintains that the singer who wants to express emotion must appeal to the audience by the tremorous quality of vibrato (Coleman et al., 1987).

Shipp et al. (1980) propose that because of the perceived link between the singer’s emotional state and vibrato, the role of the sympathetic part of the autonomic nervous system may be particularly significant in vibrato production. The sympathetic nervous system signals states such as fear, relaxation and performance anxiety which are known to impact on tremor activity. Command of the sympathetic nervous system, however, is not a simple procedure, as the sympathetic nervous system is generally not willed into action voluntarily (Anthony and Thibodeau, 1979). In order to allow the emotional content of the music to prevail, musicians of high ability must find a means of managing sympathetic nervous system responses so they can signal the desired emotion to the audience while at the same time being sufficiently distanced from the emotions to maintain technical control (Parnutt, 2007). Importantly, this process needs to be kept free of interference from the stress of performance anxiety.
2.1.6.4 How may vibrato be modified?

When vibrato rate is problematic, Miller (1996, 2004) suggests that evening out the vocal timbre, learning abdominal breath management and applying appoggio technique leads to improvement. Miller offers the following definition of appoggio:

“The term appoggio includes concepts of breath management, [and] it unquestionably also relates to resonance sensations as well, which are in petto [in the chest], or in testa [in the head], or in both simultaneously” (Miller, 1977, p. 79).

Miller (1977) explains that in traditional Italian pedagogy, the singer may often be reminded to sense the breath, or resonance sensations, in two opposing directions, i.e. the head and chest, simultaneously. Stark (1999) sums up appoggio very broadly as “a complex coordination of all the muscles of singing” (p. 120). Thus appropriate vibrato involves the functional unity of the entire singing instrument (Doscher, 1994).

Miller notes the inter-relationship between breath management, muscular equilibrium and psychological state, i.e. emotional equilibrium, which is expressed in the singer’s vibrato rate, and explains that suboptimal vibrato requires “psychological-physiological discipline” (Miller, 1996, p. 192) in order to find the proper “dynamic balance (muscle equilibrium)” (Miller, 1996, p. 193). He maintains that one of the clearest indicators of the state of proper dynamic balance or muscle equilibrium is the vibrato rate, and proposes that if the vibrato rate is too slow there is a muscular imbalance in the singer’s technique (Miller, 1996), and the larynx is often too low (Miller, 2004). If the vibrato rate is excessively fast, then the larynx is generally too high (Miller, 2004), and the singer’s techniques of breath management need to be addressed (Miller, 1996).

Miller (1977) maintains that the breath can be taken so as to induce varying degrees of laryngeal descent, and once singing commences the larynx should not rise or fall with pitch changes. He reasons that breath management is necessary for singers with a fast vibrato rate, because release of inappropriate tension and acquisition of muscular equilibrium does not occur merely by being commanded to relax. On the contrary, this demand encourages hypofunction in some part of the complex musculature, causing even greater instability and ultimately more tension at other points (Miller, 1996; Vennard, Hirano and Fritzell, 1971). Titze et al. (2002) propose that vocal relaxation exercises with the mental image of letting the tone flow easily rather than pushing it could possibly reduce excessively fast vibrato, which is particularly common in young singers.
It is interesting to speculate whether activities which may promote muscular equilibrium such as the Alexander technique, the Feldenkrais method and Tai Chi (Plummer, 1982), or perhaps simply warming up (Coleman et al., 1984) have the potential to influence vibrato rate for the better. Perhaps breathing techniques taught to sufferers of anxiety conditions may also have a role in the singing studio, as they address the close association between breath management, emotion and bodily function (Stoyva, 2000). According to Cheng (1991) Eastern meditational practice may also influence vocal quality. Certainly, the sympathetic nervous system can be influenced indirectly by imagery (Cumming, Olphin and Law, 2007; Kunzendorf, 1990; Lang, Levin, Miller and Kozak, 1983; Lindauer, Van Meijel, Jalink, Olff, Carlier and Gersons, 2006; Neumann, Kugler, Pfand-Neumann, Schmitz, Seelbach and Krüskemper, 1997; Rockliff, Gilbert, McEwan, Lightman and Glover, 2008; Sheikh and Jordan, 1983; Sheikh, Richardson and Moleski, 1979) and by meditation (Wallace and Benson, 1972; Young and Taylor, 1998) which often incorporates abdominal breath management and imagery components (Baueomer, 2004; Bartley and Clifton-Smith, 2006; Stoyva, 2000). To date, however, there is a lack of scientific studies to validate whether any of these activities impact on vibrato and vocal quality.

A complex inter-relationship exists between vibrato and other elements, many of which elude direct control. Doscher (1994) suggests that vibrato is so complex and produced in so many different ways that correcting it is just as much an emotional and psychological issue as it is physical. This echoes Bartholomew’s (1934) holistic stance, when he warns that although in musico-scientific studies, the acoustical, physiological, psychological and aesthetic aspects must not be divorced, this is doubly true of studies on the voice as the voice is never entirely under conscious control.

2.2 THE ROLE OF IMAGERY IN VOCAL PERFORMANCE

As conscious control of the voice is never entirely possible, how singers develop technical skill is a challenging and sometimes contentious issue. The following section explores different methods of obtaining optimal tone quality and the role of imagery.
2.2.1 Overview of methods of teaching singing

There are many approaches to training the singing voice with the aim of producing a vocal quality belonging to the Western classical style of singing. Some vocal authorities have simplified teaching methods into two prominent groups, the mechanists and the empiricists (Christy, 1961; Helding, 2008). Mechanists emphasise anatomy, physiology and the findings of voice research, as opposed to empiricists who may have little or no knowledge of the functional characteristics of the voice and employ strategies because experience suggests they work. Jorgenson (1980) reminds us that all opinions about the voice were based on empirical findings before the advent of the voice scientist, and for centuries perhaps the most important area of agreement amongst the empiricists was that in singing there should be no apparent vocal strain, but rather a sense of vocal freedom and ease. Additionally, Campbell (1980) suggests that empiricists tend to approach the voice from the perspective of artistic creation, often using imagery to achieve a psychological response in the singer.

Some authorities suggest divisions to cover many other approaches to training the Western classical singing voice including bel canto based methods (Ross, 1959). However, although bel canto is renowned for its emphasis on principles of ease (Jorgenson, 1980) it is often loosely used as a vocal term and open to a variety of interpretations (Jander, 1998). Kagen (1960) notes the prevalence of sensation-based methods of vocal teaching which often emphasise “placement” imagery and the importance of feeling the breath or sympathetic vibrations of the voice throughout the body. Yet other methods of teaching may be referred to as holistic, eclectic or the “trial and error” approach. Miller reminds singers that no matter what methods are employed “new techniques of singing are never new” (Miller, 2004, p. 205).

Vennard (1958) divides methods of vocal teaching into six approaches: demonstration, speech based, learning by singing, inspirational, mechanistic and imagery. The literature offers the following insights into the philosophies behind each of these approaches.

*Teaching by demonstration* stems from the belief that words alone may be inadequate to describe sound and its method of production (Vennard, 1958). Furthermore, Hemsley (1998) notes that we can be influenced very positively by listening to a healthy, well-produced voice, whereas when we listen to a singer straining for notes
our own throats become strained. Learning by imitation has been recommended since at least the time of the Italian master Tosi ([1723] 1986). Whether singers are conscious of it or not, it is believed that singers only sing as beautiful a tone as they can imagine, as aural thought of the tone subconsciously activates the muscular activity necessary to produce such a tone (Fields, 1984; Günter, 1992a; Martienssen-Lohmann, 2001; Patenaude-Yarnell, 2003a). Consequently singers must develop an aural memory of the desired tone and must be able to make fine aural distinctions between optimal and non-optimal tone, just as they must also be familiar with any demonstrable cues related to both successful and unsuccessful performance (Vennard, 1958).

The speech based approach assumes that the singer’s speech habits are a good basis for effective singing production. Si canta come si parla (one sings as one speaks) is a maxim attributed to Tosi (Patenaude-Yarnell, 2003b). This approach recognises that healthy vocal habits are vital both for successful speaking and singing, and poor vocal habits will impact from one area to the other (Mielewska, 1991). Sometimes the teacher may concentrate on pronunciation and draw the student’s awareness to the way vowels and consonants are produced, encouraging those vowels and methods of articulation that best suit the demands of singing (Vennard, 1958). At other times, using the speaking voice as a starting point it may be possible to develop a singer’s lower notes which are often said to be in “chest” or “speech quality”. Care must be taken, however, as overuse of chest or speech quality by female singers is generally considered hazardous (Allen, 2004). In fact pedagogues suggest that although marginal improvement can be brought about by incorporating speech mechanics into the singing tone, because vocal musculature is used more vigorously and requires greater precision in singing than in speech, it is more usual that learning to sing produces substantial improvement in the speaking voice (Reid, 2005).

Learning by singing acknowledges that certain aspects of singing may be improved simply with repeated vocal exercise. This approach acknowledges that mastering the complexities of muscle coordination, the most important elements of which are beyond the singer’s conscious awareness, requires extensive practice as the singer’s voice is a product of habit formation (Fields, 1984; Titze, 1994; Vennard, 1958). This approach provides goals such as mastering repertoire and learning from performance experience. It also allows for the possibility that some singers, generally the more
advanced singers (Bunch, 1993; Ekstrom, 1960) may with practice recognise some of the finer physical sensations associated with tone production. However, although repertoire in this approach is often selected to facilitate specific aspects of vocal development such as legato line or the acquisition of agility, learning by singing is based on the premise that the voice is already free of major impediments, or else faults may simply be reinforced.

The *inspirational* or psychological approach encourages the singer to respond emotionally to the music and to the climate of encouragement fostered in the studio. This method of instruction stresses the importance of the teacher-pupil relationship and the role enjoyment, relaxation, confidence and “losing oneself in the music” plays in overcoming inhibitions restricting the free functioning of vocal technique (Fields, 1984; Günter, 1992b; Vennard, 1958). According to Vennard it accepts that positive suggestion and indeed some form of hypnosis, preferably autohypnosis, may benefit the singer. This approach recognises that most of the muscles involved in singing lie below the level of consciousness and must be stimulated indirectly (Vennard, 1958). It encourages the singer to use elements such as the lyrics, the imagined setting, the phrasing or other musical features in a piece to achieve an emotional response that influences vocal production. Stressing the importance of a psychological approach to singing, Nehlich maintained in 1853 that *Tonmalerei* (“painting” with sound) was a direct outpouring of the soul which produced the most sublime tonal beauty (Günter, 1992a). Sundberg (1987) notes that emotions affect a person’s breathing patterns and subsequent subglottal pressure, and states that it is reasonable to assume that emotions and attitudes also have articulatory effects on the singing voice. Fónagy (1962) observed glottal behaviour during emotional speech and concluded that the emotional state or attitude of the speaker has considerable effects on laryngeal adjustments. According to Trojan’s study of the speaking voice, emotions such as pleasure and disgust are reflected in changes in pharyngeal width (Trojan, 1952 cited in Sundberg, 1987), which subsequently affect articulation and strength of the formant frequencies (Sundberg, 1987). Studies with singers show that some emotions elicit faster or slower tone onsets, cause changes in the dynamics of the singing voice (Kotlyar and Morozov, 1976) and influence vibrato characteristics (Shipp et al., 1980; Titze et al., 2002; Vennard, 1968) which in turn affect the perception of tone quality.
The *mechanistic* approach, otherwise known as the scientific school, teaches the singer the physical details of the act of singing. The singer then attempts to replicate and coordinate them (Vennard, 1958). The science based approach to the teaching of singing largely began in 1855 when Manuel Garcia Jnr. gained fame from using a long-handled dentists’ mirror in combination with a hand mirror to observe his own vocal folds (Radomski, 2005; Rushmore, 1984; Woo, 1996). Garcia wrote the first scientifically validated publications on singing. Curiously however, English baritone and pupil of Garcia, Sir Charles Santley, wrote in *The Art of Singing and Vocal Declamation*:

> “Manuel Garcia is held up as the pioneer of scientific teachers of singing. He was – but he taught singing, not surgery! I was a pupil of his in 1858, and a friend of his while he lived [to 1906], and in all the conversations I had with him I never heard him say a word about larynx or pharynx, glottis, or other organ used in the production and emission of the voice” (Santley cited in Scholes, 1975c, p. 956).

Nevertheless, Freed (2000) traces the controversy between the scientific and empirical approaches to the perceived conflicting pedagogies of Manuel Garcia Jnr. and his contemporary Francesco Lamperti whose writings emphasise imagery rather than the adjustment of anything physical. Many voice studios today place increasing emphasis on science based mechanistic approaches over traditional empirical approaches which have not been scientifically validated (Burgin, 1973; Freed, 2000; Günter, 1992a, 1992b). Yet some singers and pedagogues reject the scientific approach (Helding, 2007, 2008) claiming:

> “Having anatomical and physiological knowledge does not necessarily give the singer the information that solicits those coordinations, since the coordinations in question often involve muscles that lie beneath the threshold of conscious control” (Ihasz and Parmer, 2006, p. 65).

Vennard notes that the mechanistic approach is useful where conscious control of physiological function is possible. However, he reasons that the crucial question is where to draw the line between those habits which we believe can be learned and those patterns of behaviour which we think are beyond conscious control and better achieved by indirect methods (Vennard, 1958).
Teaching singing through imagery is based on the philosophy that while some physical details may be highly complex, not precisely known or directly controllable, the student can be assisted with the use of analogy involving similes, metaphors, or an image which may or may not reflect physical reality (Vennard, 1958). Günter (1992a) defines an image as a recollection of a sensory experience. However imagery does not necessarily occur in the absence of corresponding sensory input. Reybrouck (2001) reasons that it is possible to have imaginative projections in the presence of perceptual input as well. Furthermore, Tyre (1991) notes that images may be compilations, variations or exaggerations of remembered events, which then create seemingly new sensory experiences, and do not have to be limited to sensory recollections of an exact past experience. For example, we can all form the mental image of a frog jumping over a rhinoceros. The concept that certain mental images may facilitate vocal change stems from the premise that adjustment of musculature which functions beyond the level of consciousness is only possible when one works indirectly, through the use of the imagination (Linklater, 1976). For example, when one thinks of impending disaster the heart races. Imagery has occupied such an established role in traditional singing technique that remarkably Burgin (1973) finds it necessary to remind singers that the commonly used terms “head” and “chest” voice are only images and not physiological reality. However, although considerable imagery use has been documented (Hines, 1982; Patenaude-Yarnell, 2003b), the effectiveness of imagery is often disputed due to a lack of research evidence.

No one method of teaching voice need have the monopoly on right answers in voice instruction, and generally some aspect of each method becomes vital in a balanced approach to teaching singing (Burgin, 1973; Vennard, 1958). Consequently, effective vocal teaching rarely employs only one of the above mentioned methods in their pure form. Most frequently a voice teacher makes use of procedures based on a combination of approaches (Kagen, 1960). The choice of approaches and emphasis that individual teachers may place on one basic philosophy over another may depend not only on the students’ abilities and needs, and the particular demands of the repertoire but also reflect the teacher’s own background of study and performance experience.

Although singing teachers produce some excellent results with their students, much remains unknown about the singing voice. According to Jorgenson (1980) it is
unfortunate that neither empirical opinion nor research findings provide any conclusive means by which a singer can be assured of success. He stresses that despite a body of knowledge which could explain the acoustic and physiological reasons why professional singers sound the way they do, there was still no help concerning how this was achieved. Most teachers are singers themselves who have initially learnt their craft through the oral tradition as it has been passed down for centuries. Depending on the level of professionalism achieved as a performer, they may have come to rely heavily on bodily sensations. Empirical reports suggest that the more professional the singer, the greater the reliance on physical sensations (Bunch, 1993; Ekstrom, 1960; Herbert-Caesari, 1971; Puritz, 1956). There still remain, however, many sensations for which specific associated physiological adjustments have yet to be clarified. Hirano (1988, p. 69) stated:

“Finally, we admit that the science is far behind the art…our knowledge of the vocal mechanism in singing is quite limited.”

The bulk of research has been directed at the larynx, vowels and consonants, perhaps because these areas are the easiest to study given the limitations of technology (Bunch, 1993). As Günter points out, vocal research has largely disregarded the vital relationship between physiological-acoustical activities in our bodies and psychological phenomena in our brains during singing, and in the absence of objective verification, pedagogues are voicing increasing scepticism about the validity of enhancing vocal function through non-mechanistic, psychological methods (Günter, 1992a, 1992b). Cleveland (1989) proposes that in particular we now need to extend voice research into the science of mental imagery.

### 2.2.2 The imagery debate

There is much confusion to date regarding imagery and its role in voice production. There is disagreement in the literature not only as to what kind of imagery may be helpful to singers and at what stage of development it should be introduced into lessons, but even whether imagery is helpful and should be introduced at all.

Miller supports his stance against imagery by citing historical precedence:

“Vague imagery is insufficient for adequate communication… But what about teachers of the past? Didn’t they use imagery? It may come as a surprise to
learn that most actually did not. Almost all of the material dealing with vocal technique that is found in historic treatises offers precise information as to what happens with breath management, resonator tract adjustment, and with laryngeal freedom” (Miller, 1998, pp. 41-42).

However, Miller’s perspective of traditional practices stands in direct contrast to that of other authorities. Cleveland notes that “the discipline of singing and vocal pedagogy … has consistently and historically used mental imaging techniques to achieve its objectives” (Cleveland, 1989, p. 41).

Stark maintains that imagery, including that in which sensations are directed far from the larynx and to some point outside the body, has played “an important role in voice teaching since at least the 16th century” (Stark, 1999, p. 52). By 2004, Miller modified his view somewhat, stating:

“But what of great teachers of the past? Didn’t they use pure imagery? It may come as a surprise to learn that most famous teachers of the past did not rely chiefly on imaging to build a reliable technique” (Miller, 2004, pp. 196-197).

Responses to imagery differ strongly. Some vocal authorities assess the well-known image from Lilli Lehmann’s book *Meine Gesangskunst*, also published in translation as *How to Sing*, where pitches are related to sensations directed far away from the larynx, as a great help (Günter, 1992b). Others claim such images achieve nothing other than to “put to shame the most fantastically-minded surrealist poet” (Kagen, 1960, p. 82), prompting Anna Russell to make the mischievous observation that singers must have resonance space where one’s brains ought to be (Vennard, 1962).

Miller (1997, 1998, 2001b, 2004) advises voice teachers not to suggest any imagery to students as an aid to technical control. Patenaude-Yarnell (2003a) believes images can assist vocal technique and teachers should select and suggest specific images to their students on the proviso that an image is quickly abandoned if it does not produce the anticipated result. Heirich (1992) maintains that the proficient use of imagery can assist vocal technique but the act of sensing an image strongly enough to activate a psycho-physical response is a skill in itself which needs perseverance as it is acquired slowly by some singing students.
Miller (1997), like Hixon (1991), strongly advocates that imagery of the body, if used at all, should not distort physiological reality. Miller stresses that many fine singers free the imagination for artistic expression, never using imagery for reasons of vocal technique but only for the purpose of musical interpretation. However, the singers Joan Sutherland (Hines, 1982; Patenaude-Yarnell, 2003a), Elisabeth Schumann (Puritz, 1956) and Lilli Lehmann (1922) associated imagery with vocal technique and all used images in which they imagined their highest notes coming out of the very top of their heads, slightly back from the crown. This is hardly physiological reality. Likewise, commenting on empirical observations from both speech and song, Spencer (1989) notes that the voice tends to be more artistically acceptable if it feels to the user as if it were being produced in practically any other region of the body than the throat. She supports specifically selected imagery often consisting of “creative physiology” not necessarily representing reality as an aid to learning new vocal techniques. Doscher (1994) maintains that imagery of some physiological realities, such as the strong driving forces involved in exhalation during a song, would even be counterproductive to eliciting good vocal technique.

Vennard (1968) acknowledges a degree of concern when discussing imagery because he can offer no complete scientific explanation for its effectiveness as observed in his own teaching practice. Nevertheless, he maintains that imagery is an aid supplied by the teacher and is a vital tool to improve vocal technique (Vennard, 1968). On occasion he suggests that imagery should only be introduced as a means of retaining the memory of a vocal experience rather than as a means of achieving a particular experience for the first time (Vennard, 1958). However, it is sometimes difficult to define a “first time” vocal experience, as the process of learning singing often involves the balancing of pre-existing experiences which the singer had previously misjudged, dismissed as unimportant or otherwise left unheeded. For example, it is posited that the experience of sympathetic vibrations located around the lips, the nose and cheek bones, the forehead and, for the highest notes, the top of the head, is a phenomenon which simply occurs when gently humming [m] on an ascending scale (Westerman Gregg, 2001a). The teacher, however, helps the singer locate, recognise, strengthen and ultimately become aware of similar sensations over a range of sung vowels, using methods which often involve imagery. This raises deeper philosophical questions of when a thought or sensation indeed becomes a “first time” concept or mental image. Certainly when explaining the image of “focusing” the voice, Vennard (1968) does not
decry approaches he has encountered in other studios which suggest that imagery has been openly discussed and encouraged before the desired tone quality has been achieved.

Bodily sensations and vocal adjustments empirically reported to be the result of imagery are nevertheless often regarded with particular distrust by some pedagogues who maintain that the image of a sensation cannot play a causal role in cause-and-effect behaviour. Taylor (1908, pp. 114-115) states that “an effect cannot produce its cause. .... Nothing else can bring about the sensations of correct singing, but correct singing itself”. Freed (2000) notes that this view is still heard within the pedagogical community.

Yet is a constant expectation of cause-and-effect behaviour simplistic? For instance, good behaviour may be rewarded, but the desire for a reward may also produce good behaviour. Wolfe makes the observation:

“Symptoms of anxiety may in turn become causes: the flutist’s dry mouth may lead to failure to produce tone, resulting in increased anxiety in an endless vicious cycle” (Wolfe, 1989, p. 50).

Bugelski (1983) maintains that a reversal of cause-and-effect behaviour may be possible if the chain of events occurs with some frequency; furthermore, other associated events can enter the chain and act as a new cause for the old effect. For example, Pavlov’s dog taught us that although the presence of food (cause) commonly produces salivation (effect), this order of events is not unalterable. Given the right circumstances even a bell can cause salivation (Ridley, 1987).

Certainly teachers who favour the use of imagery do so in the belief that imagery causes changes in bodily response including muscle function. Dunbar-Wells (1999) hypothesises that imagery triggers the neural responses which in turn trigger physical adjustments which dictate the tone outcome. This is in accord with the Carpenter ideo-motor principle which states that any idea that dominates the mind finds its expression in the muscles (Carpenter, 1894).

Freed (2000) notes an increasing effort to avoid empirical imagery where possible amongst teachers who prefer to instruct with an emphasis on sound scientific principles, but poses the question of whether the traditional image of placing the tone
“in the mask” versus a request to “raise the zygomatic arch”, is any more than a matter of using scientific terminology to describe the same process. He then asserts that if teachers help students identify sensations and help the sensations recur, it is difficult to fault the method, whether scientific or empirical.

2.2.3 How do voice scientists regard vocal imagery?

It is notable that opposition to imagery as a technique in today’s voice studio, though regularly expressed by pedagogues favouring a science based approach (Miller, 1998, 2004; Sjoerdsma, 2001), rarely stems from voice scientists themselves. Voice scientists such as Sundberg and Titze have in fact offered speculative explanations as to why imagery may be beneficial to singers.

Sundberg (1987) states that our emotions, often aided by imagery, influence the way we breathe, our subglottal pressure and our ability to facilitate laryngeal adjustment. For example, the frequently encountered image of taking a breath as if beginning to yawn or as if smelling the perfume of a rose is likely to lead to inhalation associated with the activation of the diaphragm, a lowering of the larynx and attendant widening of the pharynx which subsequently affects the strength of formant frequencies. Additionally, if the larynx is lowered all muscles leading upward from the hyoid bone relax, increasing the articulatory variability available to the singer. Sundberg notes that the imagery of “sing as if you were crying” often similarly invokes a condition that seems to involve a lowering of the larynx and a widening of the pharynx.

Sundberg (1987) makes the observation that a predominant role in vocal imagery is given to the vibratory sensations singers aim for, particularly those associated with “chest resonance”, “head resonance” and “singing in the mask”. He notes that the vibratory sensations singers are encouraged to imagine are sensations that genuinely occur once a tone is produced well. For example, so long as the pitch is below D₄ (294 Hz) then strong vibrations felt in the chest appear to indicate that the fundamental tone is strong and phonation is not extremely “pressed”. Sensations in the frontal part of the face may result from the strength (amplitude) of higher partials but Sundberg speculates that sensations “in the mask” may also stem from changes in the blood supply caused by the vigorous vibrations generated by phonation. He observes that vibrations perceived in the head, which are very vowel dependent, appear to be
particularly useful to singers as they report the quality of phonation in a rather involved way, enabling singers to monitor tone production through some means other than directly listening to themselves (Sundberg, 1987). Accordingly, Sundberg (1974) suggests that recognising the vibrations accompanying good tones may possibly be an efficient way to control vocal production.

Furthermore, on the basis that maintaining an image of a particular technical goal may be a necessary part of attaining that goal, Sundberg (2001) speculates that although the vibrations singers often refer to as resonance sensations result from well produced singing, imagery of the desired vibrations may indeed elicit the complex subconscious muscular coordination required and hence the desired vocal production. While speculating that vocal coordination skills may be similar to other skills involving complex physical coordination for which imagery assists outcome, Sundberg provides the following analogy. We learn to jump a puddle or throw a ball through a hoop, not by observing the angle or pressure in the muscles of our legs or arms, but by looking as if into the future at the intended objective, i.e. the place we intend to land or where we want the ball to go. Perhaps singers have a similarly valid need to focus on what they perceive to be their goal (Sundberg, 2001).

Titze (1994) acknowledges that vibratory sensations and imagery of such sensations often play a considerable role in voice production because a tactile or proprioceptive means of sensing sound gives singers the advantage of having more than just an auditory reference to the sound they produce. Relating vibratory sensations of vocalisation to acoustic phenomena, Titze explains that sensations in the trachea, near the sternum, and in the face are evidence that aerodynamic power has been converted to acoustic power. Regarding vocal imagery of vibratory sensations, he suggests that the acoustic basis of the illusion of “voice placement” or where a vowel is “focused” may be the alternating patterns of high and low acoustic pressure in the sound wave. These pressure patterns are formed in the vocal tract during phonation and are likely to be sensed internally at fixed locations by the vocalist. He explains that there are several locations where vibratory sensation should be maximised. For example, with the [i] vowel, pressures are high in the hard palate. For the [u] vowel, pressures are high in the velar region, and for [a] pressures are high in the pharynx. Titze finds it conceivable that some vocalists rely on these pressure sensations to modify their vowels as needed, and other sensations such as “aiming” the tone into the mask or
“resonating in the cheekbones” may also be related to achieving acoustic pressure maxima at specific locations in the vocal tract.

Titze proposes that the terminology used in much imagery contributes to successful vocal outcome, and for effective teaching or therapy one should experiment with vocal imagery. For example, rather than effort words, comfort words such as support, freedom and flotation relax and calm the hyperfunctional singer. He suggests that images such as “cushion the tone with air” or “let the voice float on the breath” elicit an adjustment of average glottal flow resistance in “pressed” voices giving improved aerodynamic to acoustic energy conversion, reduced disturbance of the natural vibratory patterns of the vocal folds, and less strangled or pressed production. He notes that images of energy, vitality, strength, power and efficiency appear to assist maximum sound output. Still other images paint pictures using colour words, such as brilliance, shimmer and darkness, and underline the beauty of the tone to the student. Titze suggests sensory words such as placement, chest or head register and focus have a legitimate place in the voice studio, as these terms used in imagery direct singers towards a tactile or proprioceptive awareness of their sound (Titze, 1994).

Furthermore, Titze proposes that some mental images may be necessary to allow the brain to override automatic motor responses which a singer may otherwise instinctively produce. For example, the early portion of a very long, sustained phrase needs particularly well managed breath in order to cope with the powerful elastic recoil forces designed for rapid expulsion of large lung volumes. Titze therefore suggests the mental images of “breathing in” while breathing out, or the feeling of “drinking in” the tone while vocalising may enable the brain to counter the recoil reflexes normally fundamental to breathing and survival (Titze, 1994).

2.2.4 The senses employed in vocal imagery

Imagery has many forms. It may be visual, but can also include the auditory sense, the gustatory and olfactory senses and those senses belonging to the haptic system, namely the tactile sense and the sense of proprioception. According to Cleveland (1989), imagery has consistently and historically been used by singers to achieve performance objectives and often involves the use of several sense modalities simultaneously.
In the interests of musical interpretation of a text, all of the senses may be employed by singers and the images are often emotionally charged. Baritone Dietrich Fischer-Dieskau referring to his use of imagery says:

“A singer nourishes the fantasy of the poet by keeping pictures vividly in the imagination. One must follow the images which are evoked by the verse” (Peterson, 2000, p. 10).

In a similar manner, Lotte Lehmann advises singers of Schumann’s Frauenliebe und Leben (Woman’s Life and Love):

“Feel the music streaming through your body...Sing as if you were standing in the warm summer sunshine, with the warm wind blowing through your hair... In your imagination you are walking to the altar in your bridal gown... Look into the face of God... Visualise the finality of the word ‘fällt’” (Lehmann, 1971, pp. 91-101).

When text based imagery using any of the senses at all produces an audible change in performance, it can be said that not only has the musical interpretation of a piece changed but indirectly, vocal technique has also changed (Hemsley, 1998). Non-text based imagery aimed specifically at optimum technical function, however, usually centres on the auditory, visual and proprioceptive senses (Callaghan, 1997; Dunbar-Wells, 1997). One notable exception believed to enhance breathing technique is the acclaimed traditional image of “smelling the perfume of a rose”. On the surface this image which is still widely used today is one of olfaction. However, it can also impinge strongly on the sense of proprioception (Miller, 1977, 1996; Patenaude-Yarnell, 2003b).

Proprioception is not a single sensation but a group of sensations (Blakemore and Jennett, 2001) concerned with the awareness of movement and relative position of body and limbs, orientation in space, the gauging of effort and tension, static and dynamic balance, and the perception of fatigue (Alcantara, 1997). Occasionally called “muscle sense” or the “sixth sense” (Brown, 2002; Garlick, 1990; Günter, 1992b; Kay, 1963), proprioception often functions automatically (Alcantara, 1997) and goes unnoticed unless it is impaired in some way. Damage to the sense of proprioception typically occurs through a stroke, excessive alcohol consumption, syphilis or other disorder causing deterioration of the nervous system, in which case there is marked
impairment of tasks requiring manipulative skill and the co-ordination of multiple muscle
groups, such as walking (Blakemore and Jennett, 2001; Kandel and Schwartz, 1985).

Although the term proprioception is often used interchangeably with kinaesthesia
(Garlick, 1990) these terms have emerged from different historical backgrounds and
belong to somewhat different but overlapping approaches that divide the functions and
organisation of the nervous system into subcategories (Anthony and Thibodeau, 1979).
Proprioception stems from the Latin for “receiving stimuli from within oneself”, and
kinaesthesia from the Greek “to move” and “perceive” (Brown, 1993). Like
proprioception, kinaesthesia may also be associated with the sense of body position
and movement through nerve receptors located in muscles, tendons and joints
(Anthony and Thibodeau, 1979; Jonassen and Grabowski, 1993), and in fact according
to some authorities proprioception and kinaesthesia evolved to be synonyms
(Blakemore and Jennett, 2001).

The nervous system, however, is so complex that it is not fully understood (Azar, 1998;
Kandel and Schwartz, 1985). There appears to be consensus that kinaesthesia,
proprioception and also the tactile sense are all dimensions of a broader category of
sense modalities referred to as haptic perception (Azar, 1998; Jonassen and
Grabowski, 1993). However, there is disagreement as to whether the tactile sense and
kinaesthesia should be grouped together as one modality (Aiello and Williamon, 2002)
or regarded as two separate modalities (Jonassen and Grabowski, 1993). Additionally
the view that proprioception and kinaesthesia are synonymous is at odds with
authorities who note that only proprioception deals with sensory receptors in the
internal ear (Anthony and Thibodeau, 1979; Garlick, 1990). Consequently Garlick
(1990) maintains that proprioception covers the sense of body position and balance
whereas kinaesthesia covers the sense of movement. Kandel and Schwartz (1985)
partly support this and explain that proprioception may be static or dynamic. Static
proprioception or position sense is the sense of stationary position of the limbs.
Dynamic proprioception is the sense of limb movement, and Kandel and Schwartz note
that this submodality of proprioception may also be referred to as kinaesthesia. Still
other authorities (Zemlin, 1998) state that both proprioception and kinaesthesia refer to
a sense of bodily awareness, however, it is proprioception that is responsible for fine
control of muscle movement, balance and posture at a subconscious level. Zemlin
refers to this as unconscious proprioception. An example of unconscious
Proprioception that is linked to the fine control of muscle movement is the skill that makes phonation frequency control possible, sometimes called “muscle memory for pitch” (Sundberg, 1987, p. 62). The fine control of muscles responsible for singing a precise pitch, although capable of responding to training, do not function at a conscious level.

Definitive comparisons of proprioception and kinaesthesia are lacking in the literature perhaps because these terms tend to be used in separate occupational contexts. Proprioception, whether static, dynamic, conscious or unconscious, is generally the terminology of the neurophysiologist and the broader medical fraternity (Mendelssohn, 2006). Kinaesthesia on the other hand is a term mainly adopted, and it seems adapted, by those in the sports community involved in peak performance to encompass all aspects of “muscle sense” including movement, stationary position, balance and gradations of effort which, for instance, a gymnast or high tower diver may train. As competition sport demands a high degree of trained muscular coordination reproduced in public performance under conditions which may be psychologically stressful, it is perhaps not surprising that literature devoted to sports psychology makes occasional reference to music performance, which places similar demands on the performer (Rushall and Lippman, 1998). When this occurs kinaesthesia then becomes associated with music performance. It should be noted that the term kinaesthesia is also found in music literature where instrumental performance usually requires well-coordinated finger movement. On such occasions kinaesthesia is seen by some authorities to encompass the tactile sense as well (Aiello and Williamon, 2002).

Because voice research bridges vocal health, the domain of the speech pathologist and ENT specialist (Harvey and Baldock, 1996) as well as music which sometimes lends comparison to athletic performance (Loucks, Duff, Wong and Finley-Detweiler, 1998), it reflects the combined input from these areas. Hence both terms, kinaesthesia and proprioception, are encountered in vocal literature (Hudson, 2002b). Generally however, when either term is used in relation to voice production it is with reference to the sensuous perception of tension in the muscles and of movement in muscles and joints (Brown, 2002; Günter, 1992b) which vocalists use as a form of learnt inner “tactile steering” (Winckel, 1956, p. 42).
This inner tactile steering, whether called proprioception, kinaesthesia, muscle sense or the sixth sense, is reputed to be the primary means of vocal control (Kay, 1963). It enables the singer to monitor and guide the physical sensation of breathing and producing a tone and underlies much of the imagery practiced by singers. A singer must be familiar with the sensations occurring in the body and must know what “feels perfect” (Hagenau, 1992a; Nisbet, 1998). Vennard reminds us that in the “Golden Age of Song” the bel canto taught was based on the experienced sensations of singers (Vennard, 1968). However, such sensations generally need to be focused on in lessons so that singers develop a stronger awareness of proprioception (Brown, 2002; Günter, 1992b). Dunbar-Wells (1997) maintains that musicians develop proprioceptive imagery to such a degree that when they merely think of playing or singing, their unconscious physical responses correspond to the actual act.

Imagery involving the sense of proprioception is frequently used in conjunction with visual imagery. Unlike proprioception which often needs training before it is even noticed, we are well aware of our visual sense. According to Ryan and Simons, visual imagery is used frequently by approximately 40% of a normal group of people. Only about 20% are seldom or never aware of using visual imagery in their thinking. The remaining 40% fall between these two extremes (Ryan and Simons, 1982). Some authorities argue that because language is a vehicle for identification purposes, the names of all objects are linked with a visual image (Dunbar-Wells, 1999). However, whatever a singing student’s natural capacity for visualisation, teachers who consciously employ visual imagery do so in the belief that a student’s capacity for creating mental images can be enhanced with practice (Heirich, 1992).

Visual imagery used by vocalists sometimes attempts to reflect physiological reality. Puritz (1956) notes that a piece of anatomical information may become a visual concept in the student’s mind, and so help the student to acquire “the right feeling” for a certain note or notes. Leyerle (1998) advocates a form of visual-proprioceptive imagery which he calls organic imagery where he uses very simple sketches to explain complicated physiology. For example, a triangle is drawn over the picture of a torso with the base of the triangle representing the base of the diaphragm and the apex of the triangle representing the direction of the breath flow. From his own experience F. M. Alexander warns, however, that if a person whose sensory awareness is untrustworthy places reliance upon a picture he visualises or a feeling he senses, he is
depending on an illusory basis of rightness which is of no benefit. Yet, in response it is argued that a well co-ordinated person with better developed sensory awareness risks nothing from visualising and may gain from it (Alcantara, 1997).

Visual imagery, however, sometimes seems totally fanciful and removed from physiological reality. For example, it may involve images of the sound shooting out of the top of the head or projecting down like tree roots under the stage floor. Kagen (1960) describes this type of imagery as surrealist nonsense on the one hand yet concedes that particularly gifted singers appear to respond to such images. Such surreal images are used and recommended by many professional singers (Brünner, 1993; Lehmann, 1922; Puritz, 1956; Taylor, 1996; Yurisich, 2000b). Yet a lack of research into the effectiveness of this kind of imagery has left many vocal pedagogues in doubt as to its validity as a technique suitable for teaching.

Another skill singers train is auditory imagery or the ability to silently “hear”. Coming under the category of aural skills in the music studio, it involves the ability to reproduce in memory or imagination the likeness of an actual auditory sensory experience such as pitch, rhythm, harmony and tonal variation. Throughout the literature the importance of this skill is not contested. Aural imagery is one basis from which musical ability is judged and is widely acknowledged as being a vital tool in musical development. Although science still has much to discover about how auditory imagery is accomplished, it is undisputed that auditory imagery can have profound results. Both Mozart’s auditory memory which allowed him to transcribe from one hearing the *Miserere for double choir* by Allegri, considered the exclusive preserve of the Sistine Chapel choir (Sadie and Hicks, 1995), and Beethoven’s auditory imagination whereby he could compose even though deaf (Kerman and Tyson, 1995), serve as evidence.

Many voice teachers believe the aural image of sound, even though it may be subconscious, affects the vocal apparatus. Kagen (1960) emphasises that appropriate muscular contractions are not the cause of a desired vocal sound, rather the effect of having conceived of the sound image. Likewise Rose (1978) points out that it is the mental concept of pitch whilst singing which effectively alters the mass, length and tension of the vocal folds according to the breath pressure employed at the time. Burgin (1973) reports that it is generally accepted that the better a student can conceive of a perfect tone, the better the muscular coordination and sound will be.
While Rose and Kagen both stress the importance of the singer conceiving of the tone first, according to Manen (1987) it is equally the role of the teacher to use tonal imagery to judge and correct the sound being made. Manen maintains that the lack of refinement of the teacher’s tonal imagery and too strong a reliance on a Garcia inspired mechanistic approach has contributed to the decline of bel canto in today’s singers (Manen, 1987), though it seems the loss of an elusive Golden Age of singing technique is a theme of music criticism throughout the ages (Rose, 1978; Rushmore, 1984).

Of all the senses that may be employed for imagery in the singing studio, a combination of auditory, visual and proprioceptive senses is recommended by Dunbar-Wells (1999) because this provides information from three perspectives that cover the major preferred sensory approaches of most people. This concurs with Bandler and Grinder (1979) who maintain that in order to assimilate information most people favour either visual, auditory or proprioceptive strategies, with the combination of all three making learning more indelible. Dunbar-Wells (1999) concluded that imagery using these three senses was a vital element in the metamorphosis that occurs between the teacher’s instruction and the student’s resultant vocal quality.

2.2.5 When is imagery used?

Some authorities contend that imagery is so pervasive a tool that it cannot be avoided and often creeps into oral teaching strategies unnoticed (Dunbar-Wells, 1999). It is human nature to simplify complex concepts by relating them to concepts we can more readily grasp. For instance, to say that the sun “rises” and “sets” is to use images, as does the most basic musical concept that pitch can “rise” or “fall”.

In an attempt to simplify or elucidate complex vocal concepts imagery is often used as an adjunct to what may be conceived as a lesson based on some other approach. For example, a mechanistic explanation of vocal registers may mention “chest voice”, or if wishing to avoid this traditional image the term “speech quality” is sometimes substituted (Estill, 1996a, 2002). This latter term is more mechanistically correct, yet still encourages imagery, for however similar, the image that when we sing we are speaking, is nevertheless an image. Likewise in a mechanistic based approach, reference to muscular synergism or cooperative action may entail reference to the
A traditional concept of "support", or alternately "leaning" (Brünner, 1993) or "anchoring" (Doscher, 1994; Estill, 1996b), but all are terms of imagery.

Many professional musicians and music authorities recommend using aural, visual or proprioceptive imagery well in advance of a performance, to provide a means of mentally rehearsing the music or some aspect of the presentation (Aiello and Williamson, 2002; Barry and Hallam, 2002; Roland, 1997). In fact, on some exceptional occasions silent mental rehearsal has been used as the sole means of learning an entire work (Günter, 1992a). Günter (1992a) notes that during mental rehearsal involving “inner singing” the muscles of the larynx have been found to be active and that muscular reflexes also occur in the breathing apparatus. Thus “thought is action in rehearsal” (Freud cited in Foulds-Elliott, 2006, p. 5), and it is suggested that mental rehearsal provides a form of neuromuscular programming so the performer is more likely to behave as imagined during the performance (Roland, 1997). Wilson and Roland (2002) and Langeheine (2004) liken this process to a form of self-hypnosis and suggest that imagery of a successful performance may assist cognitive restructuring for the purpose of confidence building.

Directly prior to performance, imagery is often used to focus the mind on one element of the present moment. It may consist of simply focusing on some sensation that the performer associates with inner confidence. There are many diverse ways of achieving this. For example, anecdotally some performers may imagine they are radiant like the sun. Students are sometimes encouraged to think of a famous performer whom they admire and imagine they have become that person (Green and Gallwey, 1986). On other occasions imagery may resemble Eastern meditation or aspects of traditional Chinese healing techniques (Baeumer, 2004) where the ability to focus the mind, for example on the breath, serves to calm anxiety and assist with the body's stress related responses. Pre-performance imagery is frequently used to allay the fight-or-flight response, usually perceived by the performer as nervousness, and is also used in the belief that it may enhance performance potential. Authorities on optimising performance maintain that pre-performance imagery may distract the performer from anxiety cues such as negative “self-talk” i.e. an internal monologue of self-criticism generally thought to hinder successful performance (Green and Gallwey, 1986; Langeheine, 2004; Roland, 1997). A better performance than would otherwise be expected under conditions of nervousness may then result. This supports the concept
of a defensive role for imagery, protecting performers from nervousness so they may retain their usual level of proficiency. Anecdotally many performers nevertheless prefer to believe that something more positive, surpassing one’s base-line skill level, may also be gained from pre-performance imagery.

During performance singers often recall images. The images used may be innumerable. They may be similar to images used directly prior to performance, though this is not necessarily the case and each singer seems to have their own preferred way of dealing with a performance (Hines, 1982). Singers use imagery during a performance for many reasons, including the belief that imagery may enhance musical interpretation (Miller, 1997), that imagery may enhance technical control (Hines, 1982), or that imagery may assist with both interpretation and technique indirectly (Hemsley, 1998) by at least focusing the thoughts away from pessimistic self-talk (Green and Gallwey, 1986). According to Roland (1997) even thinking negatively produces physiological changes in the body, and it is notable that focusing the thoughts away from negativity and onto almost anything else is a technique recommended by the Stanislavski school of acting to be used during performance for control of performance anxiety (Stanislavski and Rumyantsev, 1975).

Post-performance, imagery may be used to revise and analyse both the most and least successful moments (Barry and Hallam, 2002). In this way areas which need improvement are reviewed for future correction, while particularly successful moments may indicate the direction for future progress plus provide a means of building performance confidence (Green and Gallwey, 1986; Roland, 1997).

2.2.6 Imagery as mental diversion and mental focus

Pedagogical literature acknowledges that imagery may serve as a diversionary tactic (Linklater, 1976), distracting the vocalist from anxiety cues or the impulse to strain or otherwise misplace vocal effort. However, lack of anxiety or lessened exertion does not necessarily improve vocal quality. For example, a sense of laziness and with it a weaker, perhaps feeble vocal quality could conceivably result from calming imagery that distracts from anxiety. Authorities appear to support the view that although imagery may serve as a necessary mental diversion, selected imagery may in addition re-focus the mind in such a way that vocal function and tone quality are enhanced.
Alcantara (1997) recommends selected imagery based on postural alignment. He maintains that as improved postural alignment of the spine promotes enhanced vocal function, well co-ordinated people with a reliable sense of body awareness may enhance vocal function by using imagery which focuses attention on the head rising up and forward and the back lengthening and widening. He believes such imagery reflects best postural practice as taught by F. M. Alexander even though imagery was discouraged by Alexander himself.

Imagery based on sensing sympathetic vibrations in the sinuses, while different from Alcantara’s posture-based imagery, similarly directs the vocalist’s attention away from the neck. Dunbar-Wells claims sinus tone imagery which directs attention away from the intrinsic muscles of the larynx, vocal folds and vocal tract, and focuses attention on stronger extrinsic muscles and bone structures not in the vicinity of the larynx is successful. This is because it leaves the larynx, vocal folds and vocal tract free to respond in an uninhibited and flexible manner which supports enhanced vocal function (Dunbar-Wells, 1999).

From the arena of spoken voice production, Linklater (1976) suggests that directly prior to vocalisation, imagery of one’s breathing creates a “blueprint for sound” (p. 27) which should be directed to a spot on the ceiling or in the sky. At other times before vocalisation she suggests performers imagine their ankle joints filled with air or, perhaps alluding to postural alignment, that the performer should picture the skull floating like a balloon off the top of the spine. The images of Linklater differ from those of Alcantara and Dunbar-Wells, yet all the images share a common theme - that of focusing the vocalist’s attention away from the vicinity of the throat.

Although any imagery at all, for instance imagining a holiday destination, could be used as a distraction from a source of anxiety, these authors are selective with the imagery they promote, believing that not all imagery produces the same result. They maintain that specific imagery can focus the performer’s attention in some way which improves vocal quality. Furthermore, Linklater’s theory of a mental “blueprint for sound” implies that imagery may also act as a silent warm-up prior to vocalisation.

Of course it cannot be discounted that the belief that specific imagery enhances performance may build self-confidence, leading to less mental distraction from
performance anxiety, therefore enhancing performance outcome. Currently the interaction between imagery, mental diversion, mental focus and vocal quality is unclear due to lack of research. However pedagogical literature often upholds that some relationship between these elements exists. Furthermore, within this relationship images which focus the vocalist’s attention away from the throat often play an important role.

2.2.7 Breathing imagery

Traditionally, the majority of images used by singers focus the vocalist’s attention away from the neck and the source of sound production. Baritone Johannes Messchaert (1857-1922), whose teachers included Julius Stockhausen, pupil of Manuel Garcia Jnr., warned singers not to concentrate on sensations in the larynx, saying: Beim Singen soll man im Kehlkopf nicht mehr spüren als im Auge beim Sehen. (One should be no more conscious of the larynx when singing as one is of the eyes when seeing) (Brünner, 1993, p. 29). This echoes a fundamental view held by many vocal authorities. “Sensation in the larynx means lack of freedom in the larynx” (Miller, 1996, p. 154) and in keeping with this belief, imagery related to breathing also focuses attention away from the larynx.

However, breathing imagery is not taught by all teachers. That is, while some teachers attempt to avoid the use of imagery (Freed, 2000; Miller, 2004), some teachers do not teach breathing, with or without imagery, believing breathing to be a natural process that the singer should not manipulate (Mason, 2000; Miller, 1977, 2004). Even the term “breathing imagery” is not generally referenced in vocal texts. Nevertheless, images concerning the singer’s breath are sometimes passed on in the oral tradition, they may evolve through trial-and-error as a singer attempts to master the challenges of performance, and they are scattered throughout pedagogical literature when other areas, such as the enhancement of tone quality, are discussed.

2.2.7.1 Main types of breathing imagery

Breathing imagery most often uses both the proprioceptive and visual senses. The images aim to offer insight into sensations or concepts which are complex and, due to the subconscious nature of much singing, difficult to directly define and often not thoroughly understood. The three most common forms of breathing imagery that occur
in vocal literature are rose perfume imagery, imagery in which the breath is directed upwards, and imagery in which the breath is directed downwards. These three types of breathing imagery may be distinguished as follows.

*To inhale as though smelling the perfume of a rose* is the one breathing related image that is often mentioned in pedagogical texts and appears to have universal support from singing teachers. It is frequently used throughout the broader singing community (Patenaude-Yarnell, 2003b; Sundberg, 1987). Miller (1977) equates rose perfume imagery with traditional Italian pedagogy. “Imagine breathing in steam when you have a cold” (Patenaude-Yarnell, 2003a, p. 426) is a variation of the rose perfume image, and similarly directs the singer’s attention away from the throat to the nasal cavities. Sundberg (1987) notes that breathing in as if beginning to yawn is also related to the rose perfume image, and it would seem that breathing in quickly as though experiencing a pleasant happy surprise is a faster variation of this imagery.

Rose perfume imagery is mostly linked with the breath taken directly before the singer commences a vocal exercise or song. During vocalisation, although the image may still be used, time available for breathing may be so short as to make the image impractical. Breathing perfume is rarely done quickly. For fast breaths, the image of taking a breath in sudden pleasant surprise is presumably more apt. However, imagining beautiful rose perfume, sudden pleasant surprises, yawning or having a cold and inhaling steam may not always be appropriate if emotional associations attached to these images conflict with a song’s message. Hence it appears that the role of this imagery is to introduce proprioceptive sensations that the singer may recognise and learn to reproduce. Once this is achieved the image itself may be discarded.

*Upwardly directed images of the breath* often mirror “focus” or “placement” imagery, which is commonly linked with sensations “directed” towards the sinus cavities, the top of the cranium or even above the head. Such imagery is sometimes also called “resonance imagery” (Stark, 1999, p. 51), despite the fact that the accomplished singer’s perception of a resonant voice involves sensations not merely in these areas but throughout the entire body (Brünner, 1993; Holmes, 2003; Robison, 2001). In reality, the voice cannot be directed to some focal point of sensation as the images suggest. Nevertheless, resonant voice sensations felt by the singer throughout the body are real (Sundberg, 1974, 1987; Titze, 1994, 2001a) and images which focus the
singer’s attention towards the targeted point or points of sensation have played a significant role in traditional singing technique (Miller, 1977; Stark, 1999; Vennard, 1968).

Images of directing the sound may equally be used to direct the breath. In the traditional Italian school of singing, the “focus” or “placement” of tone and control of the breath are considered to be one action with no change of sensation felt when going from breathing in to singing out (Miller, 1977). Giovanni Battista Lamperti taught:

“The desire to feel the ‘touch’ of the ‘point’ of tone, becomes the objective guide to the breath” (Brown, 1973, p. 70).

Thus, the maxim “Breathe where you sing. Sing where you breathe” has come to be associated with the Italian master Lamperti (Anderson, Munro and Hawkins, 2008). Often, sensing the breath or the tone may be expressed as sensing a column of air, a fountain of notes, or a pathway for vibrations. These are just some of the numerous related images singers employ to “direct” vocal energy.

In the studio, upwardly directed images are frequently accompanied by an upward arcing hand gesture. The gesture appears to trace a line from the soft palate to the top of the head and then above the head rising over towards the audience. It is normally paired with the instruction that the voice must go “up and over” (Miller, 1977; Vennard, 1959).

Upwardly directed imagery may be used during performance. However, experienced vocalists, like all performers, often silently rehearse the sensations they associate with optimal performance in their imagination (Dayme, 2005; Dunbar-Wells, 1997; Habermann, 1978; Roland, 1997; Yurisich, 2000a). Consequently, if the singer has come to associate the sensation of directing their attention upwards with optimal performance outcome, as many singers do (Herbert-Caesari, 1951; Husler and Rodd-Marling, 1965; Lehmann, 1922; Leyerle, 1998; Patenaude-Yarnell, 2003a; Puritz, 1956; Yurisich, 2000a, 2000b), it follows that this sensation may also be rehearsed prior to performance without vocalisation. In fact Linklater recommends upward directional imagery of the breath as a form of silent pre-performance exercise to place or focus the speaking voice, maintaining that imagery of one’s breathing creates a blueprint for sound (Linklater, 1976).
Unlike rose perfume imagery, the validity of presenting a student with images of the breath or the tone directed up towards the skull or above the head, that is, in a manner that does not correspond with physiological reality, is often disputed. This imagery does not receive universal support amongst pedagogues. Miller states:

“Do not ask any student to place tone forward, back, down, under, up, over or up and over because such actions are not possible” (Miller, 2004, p. 82).

Nevertheless Stark (1999) suggests it may be more effective to suggest a pupil imagine focusing the voice in a particular direction, than to ask, for instance, for more second-formant resonance in the tone. Thus, directional imagery is still taught to many singers (Brünner, 1993; Günter, 1992b; Hagenau, 1992a, 1992b; Löfqvist, 1984; Puritz, 1956; Yurisich, 2000b) and has a long and successful history of use in voice studios worldwide (Löfqvist, 1984). Furthermore, established singers may still use this form of directional imagery throughout their professional careers in the belief that it promotes optimal voice production (Bunger, 2000; Hines, 1982; Lehmann, 1922; Patenaude-Yarnell, 2003a; Puritz, 1956; Taylor, 1996).

Although debate regarding the validity of directional imagery continues, pedagogical literature for the voice has not acknowledged that the imagery of upward directed sensations which singers use is, in fact, not unique to vocalists. Langeheine (2004) recommends upward directed imagery of the breath to pianists, cellists or anyone needing to control performance anxiety. Similar upward directional imagery is also employed in the dance studio to enhance posture (Hanrahan, Tétreau and Sarrazin, 1995; Sweigard, 1975), used in Eastern meditation, in Qigong breathing exercises, and practiced in Chinese traditional healing (Baeumer, 2004) as well as in Western physiotherapy (Baeumer, 2004; Middendorf, 1995).

**Downward directed images of the breath** are generally presented as counterbalancing upward images (Brünner, 1993; Herbert-Caesari, 1971; Robison, 2001; Vennard, 1968). Downward images sometimes refer to the tone, the vibrations, or some form of abstract vocal energy felt deep inside the body or at least to some point at chest level. Most often, the downward images are related specifically to breathing and the perception of breath at diaphragm level or lower. Images of a downward flow of breath below diaphragm level, involving sensations as though breathing into the pelvic floor, the knees, the soles of the feet or into broad, deep roots below the stage floor, have avoided significant attention in pedagogical debate. However, Miller (2004)
disapproves of “down and out” techniques of breath management which he associates with imposed muscular force and maintains:

“It is unnecessary to invent functions for the breath. It is far easier, simpler, and faster to explain recognizable physical and acoustic facts regarding the singing voice, and it is far more honest” (Miller, 2004, p. 190, Miller’s italics).

Michael (2010) offers an alternate view, explaining that “the lungs fill down and out” (p. 548), but as singers have no kinaesthetic sensation of air movement in the lungs or of the diaphragm contracting, and

“…because we cannot directly sense the ‘working parts’ of the vocal mechanism, the use of imagery is necessary. It might be best to rely on images that have nothing to do with the singing mechanism itself” (Michael, 2010, p. 550).

Although not mentioned in pedagogical literature on singing, downward directional imagery of the breath, similar to that which singers use, is also found in acting (Linklater, 1976; Rodenberg, 1992), in Eastern meditation, in Qigong breathing exercises, and practiced in both Chinese traditional healing (Baeumer, 2004) and Western physiotherapy (Baeumer, 2004; Middendorf, 1995). Related images are also employed in the dance studio (Hanrahan, Tétreau and Sarrazin, 1995; Sweigard, 1975).

2.2.7.2 Directional imagery and optimal tone

Every singer or vocal pedagogue may have a different way of describing the sensation of directing breath or tone, yet the literature reveals a notable similarity in the concepts underlying the images used. Many singers and pedagogues also appear to have similar views as to where optimal sensations occur.

Vennard (1968) stresses that the production of good tone involves proprioceptive sensations which are never in the throat but instead appear to be directed, both “up” and “forward”, as well as “down” and “back”. He stresses that for the best chiaroscuro tone quality, one which combines brilliance and mellowness, both of these directionally opposing sensations must occur simultaneously, as sensations that appear to be directed up and forward are related to brilliance and those directed down and back are related to mellowness. Vennard acknowledged that the voice cannot in reality be
focused or directed, yet he took an eclectic approach to singing teaching and believed that all schools of thought including those that teach “focus” or “placement” held something of value. Hence he maintained that although the breath or the tone is sometimes imagined to be in physiologically impossible places, such as where the brain is, nevertheless, “it is better to admit the validity of imagery as a teaching aid” (Vennard, 1968, p. 121). As an advocate of focus imagery, he declared:

“A sensation, illusory perhaps … of ‘point’ or ‘focus’ is the prime essential of good tone” (Vennard, 1968, p. 150).

Herbert-Caesari (1971) endorses similar imagery of directionally opposing sensations. He teaches that the voice student must first concentrate attention on sensations while thinking upwards, then concentrate attention on sensations while thinking downwards, and finally divide attention between the sensations and think upwards and downwards simultaneously. This is understood to mean that the singer must first learn to mentally focus on proprioceptive sensations above the larynx, for example in the vicinity of the soft palate, the sinuses and up to the top of the head. Then the singer must learn to mentally focus on proprioceptive sensations below the larynx, for example in the vicinity of the chest wall, deep within the torso and perhaps even lower in the body. Like Vennard, Herbert-Caesari emphasises that it is the sensations felt simultaneously up and down in the body that are vital for vocal mastery (Herbert-Caesari, 1971).

The soprano Elisabeth Schumann’s reliance on mental pictures is extensively documented by her daughter-in-law and pupil Elizabeth Puritz (1956). Amongst her repertoire of images, Elisabeth Schumann taught her students to concentrate on putting the notes on an imaginary ladder behind the nose and up to the forehead. The concept of a ladder or upward pathway is a recurrent theme in the teaching of voice. It often involves internal visualisation of the head as though it were hollow or at least free of obstructions. The notes, as they ascend in pitch, are then imagined to be “placed” in the head as though finding an ascending pathway or ladder. Precisely where the ladder is positioned is believed to affect the resultant tone quality and ease with which a note can be produced. A similar image of a tilted ascending “road” from the soft palate to the top of the head is recommended by Herbert-Caesari (1951).

These images find their parallel in the literature on voice as taught to actors. Linklater teaches that each note in the voice has its own “resonating rung” (Linklater, 1976, p.
on a ladder which extends from the chest to the top of the skull. She teaches students to imagine an unbroken stream of sound flowing all the way up through the body, through the air to a chosen arrival point. Rodenberg (1992) suggests performers “think” the voice right up through the skull, or bore the sound into a spot at the furthest point in space. Both Rodenberg and Linklater believe proprioceptive sensations should also be employed in the opposite direction. Performers are instructed to feel the breath open the back area and travel right down to the buttocks (Rodenberg, 1992), or think the breath into the soles of the feet (Linklater, 1976).

Images directing the performer’s attention deeper than the torso and higher than the head are also used by singers. The mezzo-soprano Margretha Elkins recommends:

“When you get that big fortissimo high F or A or C, pick it up off the floor and shoot it to the stars” (Taylor, 1996, p. 5).

Lilli Lehmann (1922) writes of the necessity of always having an inner picture of the stream of breath which directs the head tones progressively higher until they project high above the head as though shooting into the air. Brünner (1993) teaches that the sensation of directing the tone becomes progressively higher and tapered as the note ascends, while at the same time a good singer strikes broad, deep roots “into the earth” (p. 24) “like a powerful tree” (p. 91). He writes that this is achieved by visualisation of the instrument’s shape, clarifying this by using pictures of broad based triangles where the base represents the diaphragm, and in the downward muscle sensation that accompanies the preparation for diaphragm support. Bunger (2000), former principal baritone with the Vienna State Opera, echoes this concept when he maintains that singers should breathe to their imaginary roots deep below the stage floor. The baritone Thomas Quasthoff, noting strong similarities between the sensations of both breathing and sound maintains:

“It is very important to feel the breathing inside your entire body, and not only in a separated part of your body. The whole human being is the instrument, not only the larynx. The larynx is the producer of tone, but the sound you create uses all parts of your body, and of your head resonance” (Holmes, 2003, p. 264).

These images find their historic counterpart in the imagery of Giovanni Battista Lamperti:
“From the trunk descend the roots of the rose tree into the ground, while from the same stem the branches are lifted into the air, and bloom. From the waist descend the roots of the breath into the abdomen while from the same place the branches of the breath rise upward, and sing” (Brown, 1957, p. 77).

2.2.7.3 Explanations of directional imagery

Explanations as to what directional imagery hopes to achieve are rarely presented. Indeed physiological explanations from previous centuries have often been found at later stages to be incorrect. More recently it has been variously suggested that imagery which directs attention away from the area of the neck will “relieve pressure on the throat” (Rodenberg, 1992, p. 286), “translate physical effort into mental energy” (Linklater, 1976, pp. 137-138) or provide a mental diversion “in such a way that the muscles governing the vocal folds are strengthened and the folds themselves function more and more efficiently” (Linklater, 1976, p. 84). Although such explanations are obscure, they are based on a common hypothesis that directional imagery triggers neural responses which in turn trigger physical adjustments. These adjustments, often subtle and beyond conscious control, dictate tonal outcome (Dunbar-Wells, 1999).

A more detailed physiological explanation for imagery in which the air or sound is directed to the crown of the head, is offered by Yurisich (2000a, 2000b). He reasons by deduction that as this imagery assists in making beautiful tone colour and enhancing resonance, it therefore must free pharyngeal constriction and “open up” the pharynx by simultaneously lowering the larynx and raising the soft palate as high as possible. This resonates with the earlier view of Bartholomew (1935, 1937) that all upward directional imagery relaxes interfering tension in the swallowing muscles, thereby encouraging an “open throat”. Bartholomew maintained that only once such an action is achieved can problems of strain on high notes and of objectionable vibrato be resolved. Similarly, Patenaude-Yarnell (2003b) explains upward directional imagery as a means of balancing the buccopharyngeal resonators and obtaining open throated emission of the voice, as well as improving breath management and obtaining more efficient vocal control. More specifically, Doscher proposes that the action of the stylo-pharyngeal muscle complex, which elevates and widens the pharyngeal cavity and facilitates the
forward tilt of the thyroid cartilage on high notes, is linked to the sensation of an upward "lift feeling so necessary for top voice singing" (Doscher, 1994, p. 51).

Upward sensations as imagined by the singer are not, however, always absolutely vertical; they may be sensed more forward or slightly back in the head. Elisabeth Schumann used both forward and backward directions, but for the very highest notes the sensation was always slightly to the back of the crown of the head (Puritz, 1956). Joan Sutherland (Hines, 1982; Patenaude-Yarnell, 2003a), Herbert-Caesari (1951) and Lilli Lehmann (1922) also maintain that imagining the sensations of breath or tone slightly tilted to the back of the crown of the head assists the highest notes.

There are possible reasons for this common perception on the highest notes. Vennard believes imagery that focuses the singer’s attention on backwards sensations produces increased mellowness (Vennard, 1968). Tone colour becomes brighter the more the fundamental frequency increases (Winckel, 1960). So this imagery appears to be related to keeping mellowness in high notes which may otherwise become excessively bright and strident. Upward imagery with a slight tilt to just behind the crown of the head is prevalent in German singing technique where dark vocal tone is often preferred (Miller, 1977). Vennard describes the Germanic vocal sound as being full bodied and powerful such as Wagnerian opera demands. By comparison, he notes that the Italian tradition of emphasising “forward placement” makes for greater brilliance (Vennard, 1968). Similarly, Westeman Gregg (2001b) notes that for Broadway singing a brilliant, bright sound can be obtained with a forward tilt to the directional imagery associated with sensations in the head, whereas backward tilted directional imagery produces a darker sound not generally used for Broadway singing.

Interestingly, the concept of bright tones being forward and of dark or more mellow tones being back is upheld in phonetics where a bright sound such as [i] in “see” is described as a front vowel produced with the arch of the tongue towards the front of the mouth. By contrast, a darker sound such as [ɒ] in “saw” is described as a back vowel produced with the arch of the tongue further back in the mouth (Miller, 1996; Vurma and Ross, 2002). Whether singers’ imagery of a pathway tilted slightly forwards or backwards is related to forward or backward change in the arch of the tongue and subsequent phonetic change lacks research. The Vurma and Ross (2002) study, however, suggests this may be so. Sundberg (1987) and Titze (1994) note that what is
perceived by the singer as the point of focus high in the head varies according to phonetic change in the vowel sung. Many vocal pedagogues agree that vowel formation helps determine the kind of “focus” or “resonance” the vocalised tone will have (Miller, 1977). Sung vowels often deviate from what one hears in ordinary speech (Sundberg, 1977), and pedagogues note that front vowels need to be modified as pitch ascends in order to reduce the incidence of high harmonic partials (Miller, 1996). Successful vowel modification prevents excessive brightness on high notes and encourages an even balance of bright-dark tone throughout the vocal range. However, Miller (1996) warns that optimal singing requires vowel modification so subtle as to be beyond the level of conscious throat adjustment.

Acoustically, for an overly bright tone to obtain a better bright-dark balance and become more mellow requires the strengthening of low partials (Vennard, 1968). As low partials need large resonators, Vennard reasons that imagery equated with mellowness is linked to pharyngeal enlargement. Miller (1977) also notes that imagery of posterior sensations is said to enlarge the pharynx and that pharyngeal enlargement increases the influence of the low partials. This corresponds with his observation that technique concentrating on imagery of backward sensations appears to produce notably dark vocal tone (Miller, 1977).

With regard to the arcing up-and-over hand gesture which frequently accompanies upward directional imagery, Vennard (1959) suggests that this gesture pantomimes a very slight forward movement of the jaw. Vennard notes that forward jaw movement is part of the complex counterbalancing movements related to achieving high notes and supports this view with research conducted by Sonninne (1956). In fact, as indicated in Sonnine’s schematic diagrams from X-rays of physical adjustments occurring on high notes (Sonninen, 1956, p. 81), the up-and-over hand gesture also pantomimes the upward and slight forward movement of the thyroid cartilage which occurs on high notes. This action was also documented in the early research of Merkel (1863) and Kenyon (1927). The forward motion of the thyroid cartilage lengthens the vocal folds, provided that the cricoid cartilage is simultaneously fixed by the contraction of the cricopharyngeal muscle. This then increases vocal fold tension on high notes and is one of many theories as to how high notes are produced (Vilkman et al., 1996).
Further research by Sonninen, Hurme and Vilkman (1992), however, indicates that after increasing vocal fold tension, trained singers on very high notes then prefer to reduce the vibrating mass of the vocal folds. That vertical changes in the pharyngeal-laryngeal tissues cause a thinning in the mucosa of the vocal folds thereby reducing the vibrating mass of the vocal folds is only a theory (Vilkman et al., 1996). It is unknown whether vertical stretch from, for example, a raised soft palate, activated stylo-pharyngeal muscle complex, plus lowered larynx and tracheal pull from the descent of the diaphragm may cause sufficient thinning of the mucosa of the vocal folds to enhance singers' high notes. Nevertheless, such a theory may fit well with Yurisich's view, previously mentioned, that vertically directed imagery is related to the soft palate rising, the larynx lowering and high note tone improvement.

Regarding images which encourage a sense of directing the sound or breath simultaneously up and down away from the larynx, Patenaude-Yarnell (2003b) states that as we sing higher and sensations rise in the head, breath pressure needs to be sensed lower in the torso and indeed the entire vocal mechanism does seem to become longer. Patenaude-Yarnell maintains that vertically directed images help the singer feel the length of the entire vocal mechanism, from the sensation of head resonance down to the lower torso. She believes that to conceptualise the voice as being directed equally as high as it is low helps counter the tendency for singers to “reach up” for high tones and “dig deep” for low tones. This helps the singer stabilise the larynx and balance the resonating factors efficiently (Patenaude-Yarnell, 2003b). For larynx stability to occur implies that directionally opposing images relate to the action of the network of muscles suspending the larynx, i.e. the extrinsic laryngeal or strap muscles which work in pairs to pull the larynx up and down. Miller (2004) notes that larynx stability is important as it influences vibrato. He maintains that too high a larynx produces fast vibrato, and too low a larynx often results in a slow “wobble” (p. 83).

It could be reasoned that images of the sound or breath creating broad powerful tree roots, as well as images of broad based triangles where the base of the triangle appears to represent the diaphragm from which the sound arises, are also designed to stop the singer from “reaching up” for high notes. These images may also serve to maintain the sense of breath pressure as low as possible in the torso and stabilise the larynx so it resists the tendency to rise and create high notes lacking in mellowness.
Brünner (1993) states that spine position, proprioceptive sensation and the ability to produce a resonant tone quality have an interdependent relationship that may be assisted by such imagery. Above all he maintains that the small of the back (sacral region including the lumbar lordosis), the middle of the back (thoracic region) and the nape of the neck (cervical lordosis) should not feel any sense of collapsing, though he cautions at the same time that the posture must remain supple and never stiff. His belief, that one should have the feeling from breath and tone as though the spine is both lengthening upward like a tree and being drawn downwards as though by broad powerful tree roots, resounds with statements from authorities influenced by Alexander technique who recommend musicians focus attention on the head rising and the back lengthening and widening (Alcantara, 1997).

Interestingly, dancers too are advised to use similar physically surreal imagery of the body lengthening in opposing directions. This imagery is used to both mentally prepare dancers for performance and assist posture while performing. Dance authorities maintain such imagery is best able to facilitate optimal muscular alignment, as voluntary contributions to a movement must be reduced to a minimum in order to lessen interference from established neuromuscular habits that may be inefficient or inappropriate (Hanrahan and Salmela, 1990; Sweigard, 1975). This goal resonates in the singing studio as well.

Vocal literature seldom relates directional imagery to regulating the fight-or-flight response that impacts on the singer’s experience of performance anxiety. In fact, vocal literature seldom mentions performance anxiety in any context. Perhaps this is because, as Mornell notes, performance anxiety is generally not spoken about in the music studio and in most cases performers are expected to find their own solutions to the problem of nervousness, stage fright or performance anxiety - terms which musicians appear to use interchangeably (Mornell, 2002). Performance anxiety management is usually relegated to literature specialising in the field. Bearing this in mind, it is interesting to note the different views expressed by vocal pedagogues versus health authorities regarding low breathing and imagery of low breathing.

Vocal pedagogues Vennard (1968) and Miller (1977) link low breathing and imagery of directing the sensations of the breath very low into the body with mellow or dark tone colour. Miller (1996, 2004) associates an overly dark tone colour with a phlegmatic
personality, a particularly slow vibrato rate and an excessively low larynx. Brünner (1993) associates images of low breathing with the descent of the diaphragm and links diaphragmatic breathing with optimal breath technique essential if vocal tone is to sound “supported”. Doscher (1994) relates low diaphragmatic breathing in singers with the larynx falling and the soft palate rising. However, literature dealing with stress and health associates low diaphragmatic breathing with moderating the fight-or-flight response and relieving stress including performance anxiety (Bartley and Clifton-Smith, 2006; Stoyva, 2000). High, shallow breathing is associated with stress (Bartley and Clifton-Smith, 2006; Gevirtz, 2000) and, as Bartley notes, is commonly accompanied by tension in the shoulders. In a strategy to reduce such tension he suggests “if you are focusing on your feet you cannot tense your shoulders” (Bartley and Clifton-Smith, 2006, p. 126). Chinese traditional healing uses imagery of breathing to the soles of the feet and to roots below the floor to encourage unforced diaphragmatic breathing and reduce stress (Baeumer, 2004). Interestingly, it is left to singers Elisabeth Schumann (Puritz, 1956) and Marilyn Horne (Hines, 1982) to state that low breathing and working with the diaphragm deals with stage fright. Marilyn Horne clarifies this observation by saying “… that won’t take the fright away, but that will take the shake away” (Hines, 1982, p. 136). This warrants the further observation that while vocal literature acknowledges that emotional stress and relaxation impact on singer vibrato (Miller, 1996; Sundberg, 1987; Titze, 1994), the possibility that vibrato may be influenced by imagery of low breathing has not been directly expressed.

2.2.7.4 Do all singers feel the same sensations?

One objection to the teaching of directional imagery, as voiced by Miller, is that not all singers feel the same sensations. Some singers don’t think about the sensations associated with directional imagery, while reports from singers that do concentrate on directional imagery often vary markedly from one another (Miller, 2004).

Lilli Lehmann believed the sensations of head voice are perceived chiefly by those newly introduced to singing high notes well and the more a singer’s head voice is natural, the less the singer is aware of sensations in the head associated with resonance (Lehmann, 1922). This resonates with observations made by both Jung and Alexander that often, once an action has become a habit we no longer notice that we do it (Murrow, 1994). It is tempting to speculate that some who see no place in the
studio for directional imagery such as Lehmann’s belong to this category of natural singer. Indeed Miller notes that he has strong sensations in the front of his face when singing but pays no attention to them as they are simply always there. He believes this is the case with most skilful singers (Miller, 2004).

Nevertheless, Vennard (1968) believes directional imagery to be of paramount importance to good tone, and singing teachers generally agree that singers need to be trained to become aware of the sensations of good singing (Brown, 2002; Hagenau, 1992a; Heirich, 1992; Nisbet, 1998). Moreover, within the variety of up, down, forward and back directional sensations as noted by Miller, there appear to be principles which may be generally observed. Traditionally, low notes are “placed” in the chest (voce di petto) and high notes in the head (voce di testa) (Stark, 1999). As the pitch rises, so sensations rise towards the top of the head (Hagenau, 1992a, 1992b; Westerman Gregg, 2001a, 2001b). Further differences in the perception of breath or tone then indicate the quality of mellowness or brilliance present in the voice and how these tone colours are blended (Vennard, 1968) i.e. the chiaroscuro mix. For instance, it is advisable to maintain some sense of “focus” to the top of the head irrespective of pitch, as no note should be devoid of the brilliance which upward projection facilitates (Yurisich, 2000a). Singers with dominant sensations directed very low in the body produce particularly dark tone quality (Miller, 1977; Vennard, 1968). Different sensations also may relate to whether the singer favours more forward and bright or more back and dark pronunciation of the vowels being sung (Sundberg, 1987; Titze, 1994; Miller, 1977). Hence, as singer ability, tone colour and range vary, so singers may note different sensations. The soprano Anna Moffo states that for her very highest notes, “I feel as though a column of air is coming right out of the top of my head, but it starts at my feet” (Hines, 1982, p. 185); while contralto Kathleen Ferrier renowned for her limited but very deep, dark vocal quality simply states, “I am singing in my boots” (Brünner, 1993, p. 23). Birgit Nilsson notes that her placement varies depending on the repertoire and whether a slender or a dark, full bodied sound is required (Hines, 1982). Accordingly, Sundberg (1987) and Titze (1994) note that professional singers may use directional imagery and its associated sensations to monitor the voice for efficiency and tone control.

Does it matter that directional imagery may be so varied and personal? Vennard thinks not. He maintains that for the singer to focus attention “anywhere except the larynx”
(Vennard, 1968, p. 120) is a good start. He believes the degree to which the singer perceives the breath, the tone or some abstract sense of vocal energy above the larynx and below the larynx will simply represent the balance of high and low partials in the tone and no two voices are exactly alike. He does consider it best, however, if the singer perceives upward and downward directions of focus to be as far away as possible from the larynx and is adamant that if the tone is to maintain an optimal blend of light and dark colour “it must go in both directions at once” (Vennard, 1968, p. 120, Vennard’s italics). Miller too notes that in traditional Italian pedagogy, sensations in opposing directions are often required simultaneously (Miller, 1977).

In conclusion, although sensations of directing breath or tone into tree roots, internal pathways and above the head may be described as surreal (Kagen, 1960), there may be more to these sensations that mere “illogical verbiage” as Miller states (1998, p. 42). It needs to be considered that such imagery is not unique to a select few singers. Similar directional imagery may be found in areas such as Eastern meditation, traditional Chinese healing, dance and physiotherapy. It is also recommended to pianists, orchestral players and those who may suffer from performance anxiety. The use of directional imagery by singers, in its many variations of breath, tone, or some abstract form of energy directed away from the larynx, enables the singer to focus attention away from the throat, shoulders and neck where muscles often become tight and overworked at times of stress. Imagery of opposing directions recognises that for singers the sensation of lengthening or expansion is an important proprioceptive goal which must be obtained without force. While it is claimed that improved spinal alignment and management of performance anxiety may be obtained in other fields where directional imagery is used, it would seem advisable that singers use similar imagery, as these goals are fundamental to good voice production as well. To date, however, there has been scant formal investigation into any reputed effects of vocal imagery.

### 2.2.8 Review of imagery studies in singing

In one of the few studies into images of directing or “placing” the voice into the head and the chest, Löfqvist (1984), using four female singers, investigated Lilli Lehmann’s imagery (Lehmann, 1922) as later developed by Husler (Husler and Rodd-Marling, 1965). The imagery required the singers to “place” the voice in five different locations,
four in the head and one in the chest. As the voice cannot in reality be placed in the head or chest, though it may feel to the singer as though it can, placement concepts constitute imagery. Löfqvist reports that such imagery has often proved useful in practice and is perceived as “very successful” in studios throughout the world (Löfqvist, 1984, p. 62). However, the acoustic results from the Löfqvist study were equivocal. The most consistent finding was that the two most “forward” placements (near the nose and the front teeth) produced the highest 2nd and 3rd formants. The failure of Löfqvist to more clearly demonstrate the acoustic basis for the different modes of projection may have been due to limiting acoustic analysis to a comparison of only the 2nd and 3rd formant frequencies from only four singers, as well as to a misinterpretation of the basic philosophy behind this method. Lehmann stressed that her imagery differed according to the pitch of a note. Likewise, the “placements” of Husler are an extension of this idea. According to Husler the success of this approach depends on matching the various placements to both the pitch and the volume of sound required. Löfqvist recorded each singer producing the whole material at a similar sound level and fundamental frequency. It would seem that high notes with and without imagery directed to the very top of the head, as well as low notes with and without imagery directed to the chest, were needed for distinctions in upward and downward placement to be more readily apparent. In addition, further research which looks at a broader range of acoustic factors appears to be necessary.

Vurma and Ross (2002) limited their investigation to two placement directions for the voice, namely “forward” and “backward”. (See Section 2.6 regarding the reliability of perceptual rating of the singing voice.) Twenty singers, consisting of both male and female, were asked to demonstrate such placement on a series of vowels while singing descending major triads. Vurma and Ross did not stipulate to the singers where exactly “forward” and “backward” should be sensed, nor did the researchers enquire as to whether the singer-subjects had a common understanding of these terms. When all vocal samples were assessed by listener-judges, the majority of samples were considered indistinguishable. However, when only select samples which achieved listener-judge agreement regarding placement were acoustically assessed, there was a tendency for forward placement to show higher frequencies for the 2nd and 3rd formants. This concurs with the Löfqvist (1984) study. In addition, Vurma and Ross found that forward placement tended to produce increased strength in the singer’s formant. Vurma and Ross subsequently posited that the terms forward and back may
correspond to light and dark tone colour, and that these vocal colours are somewhat
dependent upon whether phonetically a front vowel (for forward singer’s placement) or
a back vowel (for backward singer’s placement) is used.

The Mitchell (2005) studies investigated “open throat” technique in six female singers
(see Section 2.6 regarding the reliability of perceptual rating of the singing voice). Open
throat is a term of imagery, as except for swallowing or in strangulation the throat
always remains open. With a closed throat both breathing and vocalisation are
impossible. As Miller (2004) states, spatial arrangements of the pharynx and the mouth
are influenced by tongue position when forming vowels and “persons who attempt to
make space locally in the throat do not achieve more space, but simply rearrange the
components of the vocal tract” (Miller, 2004, p. 109). Even the worst singers have an
opening along the length of the throat. Nevertheless the term open throat is used
frequently in vocal pedagogy to denote a throat well shaped for the purposes of
classical singing.

Of particular interest in the Mitchell (2005) studies is the conclusion that Long Term
Average Spectrum (LTAS) analysis up to 6,000 Hz, while indicating energy peaks, fails
to distinguish between good and bad vocal quality. Instead, Mitchell found that
analysing vibrato appeared to produce a more reliable indication of vocal quality. The
Mitchell (2005) studies show statistically significant changes in vibrato extent and
vibrato onset as a result of singing with and without open throat. Without open throat
technique, vibrato onset time was delayed and vibrato extent reduced by an average of
more than 40%.

Mitchell (2005) notes that vibrato undulations on singers’ spectrographs appeared
more stable in the open throat task and that this is an indication of better vocal quality.
By comparison, the non-open throat task had more irregularity in the undulations on the
spectrograph, which is considered a sign of poor vocal quality. Although the standard
deviation of note-to-note mean vibrato rates showed no significant change, it may profit
future studies of open throat or other imagery techniques to look into the finer details of
cycle-to-cycle stability in singer vibrato rate.

It should also be mentioned that a connection may exist between open throat imagery
and imagery of opposing directions where the singer imagines the sound, the breath or
some form of vocal energy projecting upwards above the head and downwards towards the stage floor. Yurisich (2000a, 2000b) and Patenaude-Yarnell (2003b) link such directional imagery to a lowered larynx, pharyngeal width and raised soft palate, while these same complex physiological actions appear to be related to open throat imagery (Mitchell, 2005). Bartholomew (1935) proposes that most or even all of the images singers use may actually be strategies to enlarge the throat.

As with the Löfquist (1984) study, Callinan-Robertson, Mitchell and Kenny (2006) also used four female singers to investigate imagery of directing the sound towards the crown of the head. Callinan-Robertson, Mitchell and Kenny undertook LTAS analysis of each singer’s spectral energy up to 6,000 Hz with particular attention paid to two areas, one from 0 Hz to 2,000 Hz and the other from 2,000 Hz to 4,000 Hz. Though changes in tone colour were perceptually reported (see Section 2.6 regarding the reliability of perceptual rating of the singing voice), no consistent acoustic change in LTAS measurements was produced following the singers’ use of this directional imagery. This may be due to the use of female singers in the project and the fact that a significant peak of vocal energy between 2,000 and 4,000 Hz, possibly consisting of a clustering of the 3rd, 4th and 5th formants, and representing a singer’s formant is not as readily found in the female voice as in the male voice. As with the Mitchell (2005) studies, it was concluded that conventional LTAS data, while indicating energy peaks, could not distinguish other changes in vocal quality which may be important to good singing technique. Again as with the Mitchell (2005) studies, singers’ vibrato cycles represented on spectrographs were reported as appearing more even following the imagery task. Formal investigation of vibrato, however, did not proceed.

2.3 AN HISTORICAL SURVEY OF IMAGERY

Imagery use is not restricted to the performing arts. To understand the place of imagery in scientific research today and why imagery has at times received both endorsement and denigration requires some knowledge of historical events that have influenced man’s view of imagery, as will be discussed in the following historical overview.
2.3.1 Imagery before the scientific era

Before primitive man verbalised his thoughts, he first related to the world through his senses. Aristotle held that sensory imagination, such as visual thought, helped man to become a goal oriented creature (McMahon, 1973). It has been speculated that primitive man believed that by drawing his image of hunted animals on cave walls and scarring these representations with spear marks, he could exert his power over the soul of the animal to be hunted and so achieve the goal of a successful hunt (Jung, 1968). This is possibly the earliest evidence of man’s involvement with imagery.

With the development of language, writing and civilisation, rational thought became dominant and imagery was relegated to the mystic, the medicine man, religious practice and the teller of legends. The ancient north European epics Edda and Beowulf abound with images created by word-pictures such as “swan-way” for river, “breast-hoard” for thoughts, and “whale-road” for sea (Harwood, 1958). It has been suggested that the Egyptian followers of Thoth thought that disease could be cured by visualising perfect health (Samuels and Samuels, 1987).

The Renaissance physician Paracelsus, considered to be the father of modern drug therapy and scientific medicine, embodied the link between occult mysticism and science:

“The spirit is the master, imagination the tool, and the body the plastic material...The power of the imagination is a great factor in medicine”

Physicians today still recognise the efficacy of placebos. Since Paracelsus’ time however, religious and scientific methods of healing have split into two distinct systems.

The physiological basis of the role of imagery in the relationship of mind and body is still not understood. This is perhaps the most controversial area of imagery, often attracting severe criticism. For instance, Franz Anton Mesmer, an 18th century physician specialising in mind-body cures, was a popular but controversial figure within the Viennese imperial court and the salons of pre-revolutionary Paris. Influenced by an apparent misunderstanding of Newtonian physics, his views were not in accord with those of the medical establishment. Mozart, a close friend of Mesmer, based a character in his opera Cosi fan tutte on Mesmer and humorously draws our attention to
the controversy surrounding Mesmer's unique approach. In 1784 a royal commission appointed by the King of France, reported that Mesmer's cures of nervous illness, although not denied, were due solely to the excitement of the imagination of the patient. Although officially discredited, mesmerism later became linked with hypnotism and imagery, and as such had a distinct effect on what is nowadays known as psychological medicine (Zangwill, 1987).

2.3.2 The emergence of imagery study

The rigorous, experimental approach of scientific study is a modern concept and indeed the first recorded use of the word “scientist” only occurred in 1833. Newton, for example, was not known as a scientist but rather a writer and philosopher, and up until much of the 19th century those who inquired into the workings of the world were known at best as natural philosophers (Fara, 2003). In the 19th century, however, science gradually began to emerge as a separate discipline from philosophy. Yet by its unquantifiable nature, the study and practice of imagery has often maintained an uneasy relationship between mainstream science and philosophical theory.

Despite difficulty in finding a scale to measure personal experience, attempts were made to do so. Between 1829 and 1834 Weber tried to measure tactile and kinaesthetic sensations in studies that are regarded as marking the beginning of experimental psychology (Jacobson, 1930a, 1932). Fechner, in 1860, continued the study of the “relation or relations of dependency between the body and mind” and called this science “psychophysics” (Jacobson, 1930a, 1932). In England in the 1880s, interest in mind-body phenomena saw Galton study imagery by gathering statistical data from questionnaires. His questionnaires, for example, asked people to describe the colours and patterns on their breakfast tablecloth from memory. Considering the dynamics of gender issues in 19th century British society, such questions could hardly be described as unbiased. He concluded that the more intellectually gifted, the less vivid was the imagery; a finding which appears to have been greeted with firm support from his male colleagues (Forrest, 1974; Galton, 1883).

During the 19th century, the study of brain function was strongly influenced by the concept of cerebral dominance. Broca discovered in 1861 that some forms of aphasia were related to specific lesions of the left hemisphere (Lindell, 2006), confirming earlier
clinical observations of Head (1926). In 1874 Jackson made the clinical observation that imagery was associated with the right hemisphere (Jackson, [1874] 1958). However, because of the importance of language function, the left hemisphere of the brain was generally considered to be more important or dominant than the right hemisphere and received more scientific attention (Ley, 1983). Today, although the literature acknowledges that the verbal/nonverbal notion of left and right cerebral hemisphere function is unrealistically simplistic (Dogil, Ackermann, Grodd, Haider, Kamp, Mayer, Riecker and Wildgruber, 2002; Lindell, 2006), the concept of cerebral dominance is still upheld. That is, neural activity in one cerebral hemisphere, either left or right, generally dominates according to the task required (Cengage, 2005; Lindell, 2006). However, no one hemisphere is considered more important than the other to the human condition, and “the fact that one hemisphere has superior capability for a given task need not imply that the other hemisphere is completely bereft” (Lindell, 2006, pp. 143-144).

Although there was a comparative neglect of the study of right brain functions, towards the end of the 19th century imagery attracted interest in clinical practice. Carpenter (1894) proposed the “ideo-motor principle” that any idea that dominated the mind finds its expression in the muscles, and in fin-de-siècle Vienna, Breuer was one of the first modern doctors to use hypnosis and the elicitation of images for treating a patient (Anna O). Freud credited Breuer with creating psychoanalysis and adopted Breuer’s techniques in his own work (Decker, 1991).

2.3.3 Imagery-based therapies in the early 20th century

In early 20th century European clinical practice, theories on the role and application of imagery were developed by psychologists such as Freud, who drew our attention to the idea that thinking doesn’t have to be conscious (Bugelski, 1983). Freud wrote:

“Thinking in pictures … approximates more closely to unconscious processes than does thinking in words” (Freud, 1960, p. 19).

In order to more easily facilitate “thinking in pictures”, Freud devised the psychiatrist’s couch, thus establishing one of the most basic premises for all further imagery-based therapies in the 20th century: that imagery ability is most keen while a subject is relaxed. At this time, many European clinical psychologists developed therapies based on combinations of muscle relaxation and imagery. Kretschmer, Happich and Jung all
made extensive use of meditation and imagery in their therapies. Schultz encouraged relaxation and imagery, and in so doing developed a technique later known as “autogenic training” (Sheikh and Jordan, 1983).

2.3.4 Imagery and muscular response

In 1920s America, Jacobson, tracing the roots of his investigations back to Weber a hundred years earlier, developed a sensory awareness technique called progressive relaxation (Jacobson, 1929). In this technique he used both real and imagined muscular movements to train people to sense progressively smaller increments of muscle tension. Jacobson believed that when the skeletal musculature was completely relaxed anxiety was impossible (Jacobson, 1938), and his research on relaxation and muscle physiology provided the groundwork for treating tension related diseases such as high blood pressure. With the development of the electromyogram (EMG), Jacobson (1930a, b, c, d, 1931a, b, c, 1932) measured muscular change that resulted from mental activity, and found support for Washburn’s earlier hypothesis that vividly imagined events produce similar neuromuscular responses to those produced by actual experience, although with less intensity (Washburn, 1916). Jacobson confirmed that “imagined” movement of bending the arm was associated with small but measurable contractions in the flexor muscles of the arm. Likewise, when people think in words (inner speech) there is measurable tension in the muscles of speech, especially in the tongue and the muscles of the jaw, whereas when visual imagery is employed tension is transferred to the eye muscles.

2.3.5 The behaviourists’ rejection and post-war acceptance of imagery

It was at this time, that the behaviourist school of psychology appeared in Northern America. The American behaviourists, in contrast to European clinical psychologists, sought to assert psychology’s independence from philosophy by avoiding all reference to introspection, “focus of attention” and “imaging”. Radical behaviourists either relegated imagery as an epiphenomenon or denied the existence of mentally imagined sensations altogether (Kunzendorf, 1990). The study of imagery in America was largely dismissed until the latter half of the 20th century when post-war developments brought a change of research focus.
In the 1950s, with the end of the Korean War, concern spread over mental phenomena such as “brainwashing” and the psychological effects of sensory deprivation, which the behaviourists had sought to avoid, and research funding was given to these areas. Numerous developments outside mainstream psychology, including the treatment of World War II veterans with lesions to either the left or right hemispheres from missile injuries, the treatment of severe epilepsy with split-brain surgery and developments within psycho-cybernetics had also opened the way for a new scientific focus (Richardson, 1983). Engineering psychologists too expressed interest in imagery. They were faced with serious practical problems from radar operators, high-flying solo fighter pilots and snow cat drivers in Antarctica, all of whom endangered their lives and equipment by “seeing” things that were not physically present. Social changes such as greater American awareness of Eastern beliefs and the increasing problem of hallucinogenic drug use also contributed to renewed North American scientific interest in inner experience. Psychologists began to realise that they could apply research techniques developed by the behaviourists to topics such as imagery. Imagery: The Return of the Ostracized by the American psychologist Holt (1964), welcomed back imagery as an important area of scientific pursuit.

2.3.6 Imagery and neural activation

In this climate of renewed interest in psychophysiological occurrences, a number of contributions were made to imagery research. Electroencephalographic (EEG) recordings of brain wave patterns were used to monitor brain activity during various tasks including imagery. In a waking state, the interrelationship of two types of electrical activity of the brain can be observed: alpha and beta waves. Alpha waves, exhibit a regular pattern of 8 to 13 cycles per second, and are associated with relaxed, resting states and the complete absence of stress. Virtually any stimulus, even one as slight as opening one’s eyes will disrupt the alpha wave form, which is replaced by beta waves that have faster rhythms. However, Short (1953) found that visual imagery was associated with alpha activity.

The neurophysiologist Eccles (1958) confirmed and added to Jacobson’s earlier findings on imagery of motor response. He recorded slight firings of neural pathways which occurred during imagery of motor responses, establishing what he termed a “mental blueprint”. He proposed that this mental blueprint helps the individual execute
that movement at a later time. Penfield (1963) demonstrated that the locus of image excitation corresponded to the localisation of sensory functions in the brain. In fact, imagery and perception appear to be two processes represented by the same neuronal networks in the brain and therefore may be both experientially and neurophysiologically comparable processes, indistinguishable from each other at certain levels of the nervous system (Sheikh and Jordan, 1983).

This theory received support from studies demonstrating that while it may be easy to engage in visual imagery while listening to music or to imagine a melody while looking at a picture, it was difficult to either use visual imagery while closely observing something else or to use aural imagery while listening to irrelevant auditory input (Segal and Fusella, 1970). Segal and Fusella (1971) demonstrated similar modality-specific interference in six sensory modalities (vision, audition, touch, smell, taste and kinaesthesia). The fact that images interfere with perception suggests channel space is taken up by images in competition with perceptual signals, hence at some level of the sensory pathway, imagery and perception activate the same neuronal structures.

Our incomplete knowledge of neural function (Kandel and Schwartz, 1985; Mellet, Petit, Mazoyer, Denis and Tzourio, 1998; Mendelsohn, 2006) severely limits the ability to understand the process of imagery. However, aided by the development of brain imaging techniques, Mellet et al. (1998) concluded that

“...mental imagery shares common brain areas with other major cognitive functions, such as language, memory, and movement, depending on the nature of the imagery task....There is no unique mental imagery cortical network; rather, it reflects the high degree of interaction between mental imagery and other cognitive functions” (Mellet et al., 1998, p. 129).

Lending support to this view are more recent studies that highlight similarities between imagery and perception where neural pathways or cortical areas are concerned (Dogil et al., 2002; Halpern, 2001; Lafleur, Jackson, Malouin, Richards, Evans and Doyon, 2002; Lotze, Montoya, Erb, Hulsmann, Flor, Klose, Birbaumer and Grodd, 1999; Riecker, Ackermann, Wildgruber, Dogil and Grodd, 2000). For example, Dogil et al. (2002) mapped neural activation using functional magnetic resonance imaging (fMRI) during inner speech and overt speech. The study found that the network of activation observed during inner speech remained intact during overt speech, but was enriched by the activation of further cortical areas responsible for articulation. The research of
Dogil et al. (2002) was part of a larger study also investigating inner singing and overt singing (Riecker et al., 2000). As Dogil et al. (2002) observe, the singing task fMRI results closely resembled an inverse image of the speaking task fMRI results. That is, areas of the brain active during inner singing remained active during overt singing, with further cortical areas registering activation once articulation was added, however, left and right brain areas of activation were reversed when the results for speech and song were compared.

Related to these findings, and a subject attracting considerable attention in the neuroscience community in the past decade, is the so-called human mirror system. Neurological studies currently provide strong evidence for the existence of a neural network of “mirror” neurons that fire in the brain not only when an action is executed but also when it is observed, anticipated or imagined (Aziz-Zadeh and Ivry, 2009; Filamon, Nelson, Hagler and Sereno, 2007). Mirror neurons show greater activation the more the individual has a strong sense of the goal to be achieved (Gazzola, Rizzolatti, Wicker and Keysers, 2007; Johnson-Frey, Maloof, Newman-Norlund, Farrer, Inati and Grafton, 2003). For example, mirror neurons may show greater activation when an individual observes someone jumping a puddle, as opposed to when similar muscle movements are observed devoid of a context. Mirror neurons also tend to fire more strongly the more the individual is skilled in the action involved (Calvo-Merino, Glaser, Grezes, Passingham and Haggard, 2005). The existence of mirror neurons that fire both during the performance of a task and during kinaesthetic imagery of that task, may account for the use amongst performers of mental rehearsal. That is, muscular response to kinaesthetic imagery, as recorded by electromyography, is too slight to facilitate improved muscle strength (Feltz and Landers, 1983; Rushall and Lippman, 1998; Smith, 1991). However, the strengthening of appropriate neural pathways rather than the strengthening of muscles per se, appear to be at the crux of imagery use by performers. Thus, recent findings on the mirror neuron system not only support Eccles’ earlier theory of kinaesthetic imagery providing a “mental blueprint”, but also provide a neuroanatomical basis for imagery function.

Furthermore, evidence from mirror neuron studies that the observation or imagery of a goal leads to corresponding neuromuscular activation (Aziz-Zadeh and Ivry, 2009; Filamon et al., 2007; Gazzola et al., 2007; Hurley, 2008; Johnson-Frey et al., 2003), represents an important departure from the concept of cause-to-effect, or at least
where cause is considered to be the initiation of neuromuscular activation (e.g. to bend the knees and push) and the effect is the goal (e.g. to jump the puddle). Where “the mere observation of the goal of the action is enough to trigger mirror motor activation” (Urgesi, Moro, Candidi, and Aglioti, 2006, p. 7947), the traditional concept of the cause and the effect become reversed. Illustrating this, Hurley (2008, p. 6) states:

“Merely imagining a skilled performance, in sport or music, improves performance – [and] is a way of practicing – as many athletes and musicians know.”

In fact the presence of mirror neurons enable the functioning of means/ends associations from either direction (Hurley, 2008).

2.3.7 Imagery in anxiety control

Studies in the latter half of the 20th century continue to frequently associate imagery with relaxation and control of the “fight-or-flight” response. This term, first coined in the 1920s by physiologist W. B. Cannon, refers to the fear response which readies the body for action by stimulating the sympathetic part of the autonomic nervous system and by stimulating the adrenal glands to release epinephrine. Such stimulation causes a shift in blood flow from the digestive organs to the muscles, lungs and brain. Blood pressure rises, oxygen consumption increases, and stored glucose is released into the blood stream (Anthony and Thibodeau, 1979). In extreme cases death may be caused by prolonged over-stimulation of the adrenal glands as a result of fear-induced over-activity of the vagus nerve which innervates the heart. In fact, Frank (1961) hypothesised that the fight-or-flight response, induced by imagining terrifying consequences, may provide a possible explanation of death by bone-pointing amongst some Australian aboriginal tribes. This provides a reminder that although imagery is frequently associated with relaxation in clinical psychology, some imagery may be emotionally charged and may be associated with many responses including fear.

Using imagery and mental associations with fear and relaxation, Wolpe (1958, 1969) legitimised the investigation of covert processes within a behaviouristic framework to treat phobic anxiety. He termed his technique “systematic desensitisation”. Systematic desensitisation involves two types of imagery, the first being relaxation imagery, after which the subject then images the feared stimuli in closer and closer approximations.
In the 1960s, Benson measured the body’s physiological response to the sensation of relaxation and named these changes “the relaxation response”. He hypothesised that the fight-or-flight response is the opposite of the relaxation response. This concurred with the conclusion previously reached by Hess (1881-1973), who was the first physiologist to investigate the central nervous system in relation to these areas of behaviour, with his research on animals (Nathan, 1987). Wallace and Benson (1972) also noted that as opposed to the fight-or-flight response, a highly relaxed meditative state of mind displays an intensification of slow (8 to 9 cycles per second) alpha waves in electroencephalographic (EEG) recordings of brain wave patterns in the frontal and central brain region.

Benson regarded the relaxation response as uniting a number of practices from both Eastern and Western cultures. He wrote:

“There are many religious and secular techniques which elicit the physiological changes characteristic of the relaxation response. Some of these are autogenic training, [Jacobson] progressive relaxation, sentic cycles, yoga and zen, and transcendental meditation” (Beary, Benson and Klemchuk, 1974, p.119).

Imagery is often a component in the above relaxation inducing techniques. Several studies have since reported changes following meditation with an imagery component, or imagery alone, consistent with countering the fight-or-flight response. Changes include reductions in heart rate, oxygen consumption and blood pressure, as well as changes in gastrointestinal activity and body temperature, which are also functions of the autonomic nervous system (Neumann et al., 1997; Sheikh and Jordan, 1983; Young and Taylor, 1998). However, heightened physiological responses, including increases in heart rate and respiratory rate, have been shown to result from imagery of a feared event (Lang, Levin, Miller and Kozak, 1983; Lindauer, Van Meijel, Jalink, Olff, Carlier and Gersons, 2006). The strength of physiological change may sometimes depend on training in imagery or meditation (Cumming et al., 2007; Lang et al., 1983; Young and Taylor, 1998).

Although current literature still links relaxing imagery with decreases in levels of physiological arousal and stressful imagery with increases in mental and physical anxiety (Cumming et al., 2007; Gersons, Carlier, Lamberts and Van der Kolk, 2000; Lindauer et al., 2006), not all people agree as to what is relaxing and what is stressful. The study of Rockliff et al. (2008) showed that imagery may produce divergent heart
rate results if individuals have different emotional responses to particular images. That is, when asked to imagine experiencing love, kindness and warmth from another person, Rockliff et al. (2008) found that changes in heart rate were consistent with decreases in anxiety for some participants and increases in anxiety for others. The study concluded that while some participants responded with positive emotions to the image, others became sad or felt vulnerable and even threatened, as the image required participants to draw on emotional memories of attachment.

Psychologists have shown increasing interest over the last decade in finding ways to modify the emotional responses that athletes commonly have to signals of anxiety, that is, in replacing negative associations with positive associations. Cumming et al. (2007) used scripted imagery to both encourage strong physiological arousal and assure the athlete that such responses may be beneficial to performance. The excerpt below is part of a script recommended only for use with those athletes who may benefit from particularly high levels of arousal.

“You have …. a slight feeling of nausea … telling you that adrenaline is pumping round your body … confirming that you are prepared … your body is in its optimal state …. Your heart is racing faster … and faster … and your breathing is rapid…. You recognise these as feelings that you always experience prior to your best performance” (Cumming et al., 2007, p. 644).

Faster heart rates, signalling heightened arousal, were measured following the imagery. Cumming et al. (2007) concluded, in agreement with earlier imagery studies of Lang et al. (1983), that “images containing response propositions will produce a physiological response (i.e. increased heart rate)” (p. 629). Yet the same athletes registered the perception that emotionally they could cope better with anxiety after the imagery. The study suggests that the combination of increased heart rates and lower perceptual ratings of anxiety was dependent on two factors. Firstly, the participants were openly encouraged to allow the imagery to affect them emotionally; and secondly, as athletes, the participants believed that the imagery employed represented a worthwhile physiological goal.

The fact that it is possible to change how a person perceives the emotional content of an event, whether real or imagined, is fundamental to psychotherapy. Psychotherapists use this principle extensively in the treatment of posttraumatic stress disorder. That is, treatment employs a combination of techniques including repeated, detailed,
personalised, trauma-related imagery to provoke posttraumatic stress disorder and promote habituation to stressful images, and therapy to modify the sufferer’s beliefs about and emotional connections with the events experienced during the trauma-related imagery. This process is designed to mitigate the emotional impact of the imagery and results in measurable decreases in heart rate and anxiety ratings (Gersons et al., 2000; Lindauer et al., 2006).

Thus, in relation to anxiety, the effect of an image may vary depending on multiple factors. Not only may training in imagery be necessary to strengthen an effect, but effects vary depending on an individual’s belief system, emotional history and interpretation of the imagery’s relevance to personal goals.

2.3.8 Imagery and biofeedback

While increasing interest has been shown in the use of biofeedback to measure neural and muscular processes that occur during imagery (Guillot and Collet, 2005), there have also been attempts to use biofeedback as a means of bringing autonomic functions under voluntary control. In the late 1960s, biofeedback was adopted by the behaviourists for this purpose.

Miller, a pioneer in biofeedback research, carried out a series of experiments on animals and reported success, for example, with training rats to alter their heart-rate using biofeedback (Miller and DiCara, 1967). Although many of Miller's experiments were found impossible to replicate, such reports helped pave the way for an acceptance of the concept that autonomic functions could be brought under voluntary control, and related biofeedback studies were conducted using human subjects. However, Schwartz (1975) reported that biofeedback subjects who could raise and lower their heart rate in alternating feedback sessions were subjects who spontaneously imaged emotional agitation in one session and emotional tranquillity in the other. Subsequently, Hirschman and Favaro (1977, 1980) reported that biofeedback subjects who could raise their heart rate were subjects who were able to more vividly imagine, and Kunzendorf (1991) cites over thirty studies reporting that mental imagery alone with no biofeedback could be used to control heart rate. Miller (1972) eventually conceded that “fear can innately produce psychosomatic effects, such as changes in heart rate …” (Miller, 1972, p. 470), and that fear-related imagery
may indeed have produced the underlying drive responsible for changes in autonomic processes observed in his research.

Nevertheless, many practices other than imagery are currently recognised as capable of producing changes in autonomic processes. Mornell (2002), for example, lists numerous alternate approaches that musicians use to manage the fight-or-flight response, and notes that imagery is not the sole means of management. Imagery is, however, one of the most practical methods of all those listed. That is, imagery may be applied at any time or place. It does not involve appointments with psychotherapists, masseurs or teachers of yoga, there is no financial outlay, no special equipment is needed, and unlike the use of alcohol, or pharmacological drugs that claim to reduce symptoms of anxiety (Sataloff et al., 2000), there are no potential health risks.

2.3.9 Imagery and performance skills

With the development of sports psychology in the late 1960s and 1970s, research into imagery and performance skills began. Not only academic researchers and sporting professionals, however, were interested in sports psychology. The general public wanted to improve their own performance skills, whether in a sporting or even a public speaking capacity which, although not sport, still demanded related skills such as mental focus, mental preparation, a confident attitude and anxiety control. Furthermore, general music literature began to reflect an awareness of the broader application of sports psychology, and popular books such as The Inner Game of Tennis (Gallwey, 1974) and The Inner Game of Golf (Gallwey, 1981) were adapted to become The Inner Game of Music (Green and Gallwey, 1986). By focusing on common performance needs and particularly on the use of imagery and how it may be applied in performance preparation to optimise performance skill, techniques researched in the sports field may well be useful to other performance-related disciplines. Consequently, the findings from sports psychology warrant detailed discussion. This aspect of imagery and performance skills is reviewed in the next section.
2.4 IMAGERY AND PERFORMANCE IN SPORT

The latter part of the 20th century has seen a “golden age” in imagery research directed at athletes (Denis, 1989). Within world-class sport, imagery is receiving considerable attention as a tool that cannot afford to be overlooked.

2.4.1 Definition of sports imagery

Imagery as used in sport psychology may be defined as:

“the mental invention or recreation of an experience that in at least some respects resembles the experience of actually perceiving an object or an event, either in conjunction with, or in the absence of, direct sensory stimulation” (Finke, 1989, p. 2).

Other terms have been used interchangeably with imagery, including visualisation, visual motor behaviour rehearsal (VMBR), symbolic rehearsal, imagery rehearsal, mental rehearsal, mental imagery, mental practice and ideomotor training. VMBR was developed specifically for musicians and athletes wishing to improve their skills (Suinn, 1976) and refers to an “imagery package” technique where imagery is preceded by a relaxation exercise.

The term visualisation, commonly used in books directed at the amateur athletics market, unfortunately fosters the misapprehension that imagery is totally or largely visual in nature. A number of sport psychologists and researchers point out that imagery need not be confined to the visual sense (Calmels, d’Aripple-Longueville, Fournier and Soulard, 2003; Hall, 1995; Hall, Mack, Paivio and Hausenblas, 1998; Hanrahan and Salmela, 1990; Kossert and Munroe-Chandler, 2007; Lane, 1980; Moran, 1993; Moritz, Hall, Martin and Vadocz, 1996; Munroe, Giacobbi, Hall and Weinberg, 2000; Suinn, 1980b; Vealey, 1986; Vealey and Greenleaf, 1998; Wenz and Strong, 1980; Weinberg, 2008). It may be charged with emotional overtones such as the exhilaration of achievement and mastery. It may incorporate any of the other senses, for example “smelling” the chlorine of a swimming pool, “hearing” the sound of the ski edge carve a turn, and in particular it incorporates “feeling” body movements with respect to the body itself or through space, with no ostensible movement taking place. Sports psychologists refer to this latter form of mental experience as kinaesthetic imagery, and it is the prominent use of kinaesthetic sensation in imagery which most strongly links the imagery of the athlete with the imagery of the singer.
2.4.2 The vocal athlete

From the audience’s perspective singing is an art rather than a sport. Nevertheless, vocal artistry demands such a high degree of physical coordination, requiring years of exercise that within the profession singers generally regard what they do as a combination of art and specifically directed physical training. The literature, in fact, often refers to singers as vocal athletes.

Miller calls singing “vocal gymnastics” (Miller, 1996, p. xxi), and believes the singer must have a keen awareness of dynamic muscular balance and translate technical ideas into specific physical coordinations “like any athlete” (Miller, 1990a, p. 20). Loucks et al. (1998) define singers as vocal athletes:

“Vocal athletes are individuals who train their voices for optimal and consistent function and incremental control over a wide pitch and loudness range. This group is predominantly composed of classically trained singers and actors, but includes others who have trained their voices to maintain consistent phonatory function” (Loucks et al., 1998, pp. 349 - 350).

Laryngologists have been known to regard professional singers as the most highly skilled of all vocal athletes and refer to classical singers as “the Olympians of the vocal folds” (Liversey, 2000).

The Macquarie Dictionary (Delbridge, 1985) defines sport as “an activity pursued for exercise or pleasure, usually requiring some degree of physical prowess”. Certainly this describes one aspect at least of singing. However, Titze (1994), while likening singers to athletes, notes some distinctions:

“Vocalization is not primarily a strength-related motor task... Efficiency, coordination and precision are words that come to mind when one describes the motor function of the larynx, the respiratory system, and the articulators” (Titze, 1994, p. 183).

Titze draws a parallel between singers and highly trained older horses. Young horses, two to three years old, have the strength to win an all-out speed race, but older horses, aged ten to twelve years are often preferred for riding in obstacle courses because of their highly developed sense of coordination, discipline and precision. He supports this analogy with the observation that whereas most young athletes tend to achieve the peak of their performance ability in their 20s, vocal performers often peak in their 30s or 40s.
Despite singing being a performance discipline that has consistently and historically used imagery to achieve its objectives, little imagery research has been directed at singing (Cleveland, 1989). However, if singing is viewed as a form of physical exertion akin to athletic performance, then there is a body of imagery research that can be drawn on.

2.4.3 The origin of imagery as used by athletes

Imagery is increasingly perceived as a necessary part of an elite athlete’s mental strategies for optimal performance, yet imagery strategies were not originally developed by teachers, coaches or sports psychologists (Smith, 1991; Taylor, 1993). With the exception of the dance studio where there is a long tradition of teacher-initiated imagery (Overby, 1990), imagery strategies have generally been developed by the more accomplished athletes as a result of trial and error (Barr and Hall, 1992; Orlick and Partington, 1986; Schmid and Peper, 1998). According to Hall, Pongrac and Buckolz (1985), “the nature of the task and the individual’s personality interact and determine when and how imagery strategies will be utilised” (p.110).

This self-initiation of imagery by athletes was particularly apparent in a questionnaire administered to Olympic gymnasts and their coaches by Smith, Martens, Burton, Vealey and Bump (1982 cited in Smith, 1991). It found that most coaches did not emphasise imagery because they felt they did not know enough about it to effectively train their athletes. Yet while 42% of the coaches did not encourage imagery and may have stood in the way of athletes utilising a systematic approach for the development of imagery skills, 92% of gymnasts declared that they used imagery in varying degrees to practise skills, recall and control emotions, improve concentration and set goals.

More recently, with mounting scientific and experiential evidence supporting the use of imagery practices, and the publication of handbooks for assistance (Rushall, 1991), coaches are increasingly implementing imagery in their programmes (Gould, Tammen, Murphy and May, 1989; Vealey and Greenleaf, 1998). Indeed, imagery based interventions are now viewed as “a central pillar of applied sport psychology” (Morris, Spittle and Perry, 2004, p. 344).
2.4.4 Imagery and muscle memory in sport

Since Jacobson’s electromyographic (EMG) studies first verified a physiological relationship between imagery and muscular response (Jacobson, 1930, 1931, 1932), many other studies have confirmed the ability of imagery to produce EMG tracings indicating muscular change (Bakker, Boschker and Chung, 1996; Bird, 1984; Gandevia, Wilson, Inglis and Burke, 1997; Guillot, Lebon, Rouffet, Champely, Doyon and Collet, 2007; Hale, 1982; McGuigan, 1971; Suinn, 1980a). Pioneering imagery research in sport, Suinn (1980a), for example, measured activity in the thigh muscles of an alpine skier while the skier imagined skiing a downhill run, describing the run as he did so in order that turns and jumps could be plotted on the EMG readout. Bursts of EMG activity coincided with imagery of turns, jumps and braking when substantial movement of the leg would have been needed if the skier had been skiing in reality. Suinn’s studies of imagery used in mental rehearsal by elite athletes indicate that “without fail, athletes feel their muscles in action as they [mentally] rehearse their sport” (Suinn, 1980b, p. 308).

A major difference, however, between physical and mental (image-based) instigation of a neuromuscular pattern seems to be intensity (Guillot and Collet, 2005). Accordingly, Feltz and Landers (1983) question whether the minimal muscle innervation registered during imagery is sufficient to account for the effects of imagined practice on actual skilled performance. Smith (1991) and Rushall and Lippman (1998) suggest that slight tracings of innervation at muscular level give an indication of central nervous system activation, and the benefit of imagined practice may lie in the rehearsal and refinement of the correct sequencing of muscular contractions facilitated by the central nervous system. Vealey and Walter (1993) refer to this process of muscles firing in correct sequence as “muscle memory”. Additionally, Rushall and Lippman (1998) reason that if, during performance preparation, imagery of a learnt task facilitates the appropriate neuromuscular patterning, then overt physical warm-up time is minimised.

The acquisition of muscle memory is one of numerous theories attempting to clarify the underlying mechanisms that account for how imagery affects motor function. Another theory concerning muscle memory states that a performer may become so conditioned to the feel of a particular muscular response that if the response is practised often enough, the feel of the response may even very slightly antedate the action (Greenwald, 1970). In time, the kinaesthetic image of the response associated with the
action may, therefore, directly elicit the action. This theory is in accord with more recent concepts of neural function (see Section 2.3.6) as propounded by Hurley (2008).

Yet not all studies show kinaesthetic imagery to be linked to EMG activity for every subject (Dickstein, Gazit-Grunwald, Plax, Dunsky and Marcovitz, 2005; Li, Kamper, Stevens and Rymer, 2004). Neuroimaging studies seeking to locate areas in the brain responsible for imagery often cite no evidence of consistent or significant EMG activity, in order to establish that brain activation resulted only from imagery and not from retroactions from muscle spindles (Gentili, Papaxanthis and Pozzo, 2006; Gerardin, Sirigu, Lehericy, Poline, Gaymard, Marsault, Agid and Le Bihan, 2000; Mulder, de Vries and Zijlstra, 2005; Mulder, Zijlstra, Zijlstra and Hochstenbach, 2004). In fact, neuroscientists have found that subjects with visual feedback of their own EMG activity can be trained to register no activity while imagining kinaesthetic movement (Hashimoto and Rothwell, 1999; Lotze et al., 1999; Naito, Kochiyama, Kidata, Nakamura, Matsumura, Yonekura and Sadato, 2002). In the study of Lotze et al. (1999), for example, subjects imagined making a fist while observing their EMG readout. They then underwent training that lasted from 60 to 90 minutes and only terminated once subjects showed no increase in EMG activity above the baseline level, while at the same time verbally registering a rating of 4 out of 6 for their self-assessment of imagery vividness.

Many reasons for inconsistent EMG findings in the literature have been suggested. Reasons include methodological problems, such as whether surface electrodes register deep muscle activity, the difficulty in judging the correct placement of electrodes in relation to active muscle fibers, the different measurement techniques used, and individual variation amongst subjects in motor command inhibition (Farina, Merletti and Enoka, 2004; Guillot and Collet, 2005; Guillot et al., 2007; Lebon, Rouffet, Collet and Guillot, 2008).

As yet, neurophysiological explanations of imagery are incomplete. What is clear in the sports literature, however, is the persistence of reports and mounting empirical data that imagery is related to enhanced performance. The literature also reveals a pattern of variables, such as supporting techniques and circumstances that appear to affect mental practice in sport. It is these issues, having direct practical application to performers, which are discussed in the following section.
2.4.5 Case reports

A number of world class athletes are advocates of mental imagery (Suinn, 1983; Weinberg, 2008). Ballet dancers too, including Rudolf Nureyev, make extensive use of mental imagery (Nordin and Cumming, 2005; Percival, 1975). However, public awareness of imagery use became more widespread since professional sportsmen such as Tim Gallwey in *The Inner Game of Tennis* (Gallwey, 1974) and Jack Nicklaus in *Golf My Way* (Nicklaus, 1974) attributed much of their success to mental practice. Tennis stars Arthur Ashe (Ashe, 1986), Pat Cash, Andre Agassi, Jim Courier (Perry and Morris, 1995) and Chris Evert (Vealey and Greenleaf, 1998) have also extolled the benefits of imagery in maximising performance.

Many athletes perform all or parts of their event in their mind before actually executing the skill (Barr and Hall, 1992). Olympic high jumpers Tim Forsyth and Dwight Stones shut their eyes and make an imaginary jump just prior to approaching the bar (Perry and Morris, 1995; Vealey, 1986). Triple gold medallist alpine skier Jean Claude Killy reports that one of his best performances ever occurred when, as a result of injury, the only preparation he could do was to mentally ski the course (Suinn, 1983). Gold medal Olympic diver Greg Louganis uses imagery to practice each dive (Vealey, 1986), and Olympic medallist and world record holders Kieren Perkins and Nicole Stevenson both use imagery to "see" themselves at the pool, swimming at their best (Perry and Morris, 1995).

2.4.6 Sports imagery research issues

Sports imagery researchers generally deal with athletes in actual performance situations rather than non-athletes in laboratory situations. Consequently, a number of challenges to systematic investigation are raised in sports research literature.

Suinn (1976, 1983) points out that talented athletes and musicians have sufficient skill to practise correct responses in imagery rehearsal, rather than inadvertently rehearsing incorrect responses. However, when baseline performance levels are already high, they are statistically less subject to change. Consider the improvement possible for someone high jumping 180cm prior to training versus the improvement realistically probable for someone already jumping 218cm. The higher the standard the smaller will be each measurable step to further improvement.
Smith (1991) questions whether the effects of imagery on performance can be accurately judged in a controlled experimental setting where a true reflection of performance anxiety is unlikely to be achieved. Smith sees imagery for motor skill development intimately related to imagery for psychological skill development, and maintains that psychological skills are particularly relevant to elite athletes who have already mastered the necessary motor skills. He proposes that imagery is part of a cycle whereby if athletes believe imagery will help, they gain confidence in their ability. Confidence reduces anxiety and may alleviate other psychological barriers to successful performance. Appropriate arousal levels may be better maintained and mental focus may be enhanced. However, because stress and anxiety vary according to the performance situation, Smith proposes that imagery effectiveness may differ even when research involves inter-squad competitions as opposed to national tournaments in front of thousands of screaming fans.

The difficulty of obtaining a control group is particularly challenging for studies dealing with performance enhancement techniques (Suinn, 1983). For example, Suinn placed alpine ski racers into pairs according to ability. From each pair, one was assigned to a VMBR programme and the other to a no-treatment control group. Although the coach had agreed to race all skiers during the season, he ultimately raced only those who displayed improvement - an understandable action considering a coach’s first priority is not to provide research data but to provide the best athletes to win the immediate competition. Nevertheless, this amounted to all of the treatment subjects and only one of the control subjects racing. One could consider the coach’s decision as data itself; but as the coach was not blind to the study, his decision may have been subject to bias (Suinn, 1983).

However, not even improvement by an imagery group necessarily reflects improvement because of imagery. In what is often referred to as the Hawthorne effect (Grouios, 1992b), study results may simply reflect that as opposed to a no-treatment control group, the special treatment an experimental imagery group receives increases performance motivation. Giving non-imagery groups similar attention within some other activity may remedy this. Alternately, the length of the study may help control this element because over time, according to Drew (1976), the “specialness” and immediate influence on motivation dissipates and any Hawthorne effect declines as subjects become used to the new routine.
Another challenge for imagery studies is that of the “self-fulfilling prophecy”. That is, the belief that imagery may improve performance can be sufficiently strong in itself to create a performance difference (Ryan and Simons, 1982). Some researchers stress that a prerequisite for successful imagery results is that subjects chosen for imagery training must be interested in receiving it (Weinberg and Williams, 1998), cannot be overly sceptical and are encouraged to believe in the efficacy of imagery (Vealey, 1986). These prerequisites appear to be ideal conditions for a self-fulfilling prophecy. However, the effectiveness of imagery cannot be dismissed if a belief in imagery combined with its use consistently produces the desired performance results (Smith, 1991).

Interestingly, although a belief in imagery may be desirable, in one study where the subject had a negative, doubting attitude towards imagery (Suinn, 1972) results were still positive. In this early study, before Suinn suggested visuo-motor behavior rehearsal (VMBR) was applicable for musicians and athletes, he used it with a PhD student suffering such extreme performance anxiety that he could not be given a pass in a viva voce. After VMBR intervention he was unanimously judged as successful by the examiners. However, the sceptical subject before being told of his success, remained unaware of his improvement and dubious about the effectiveness of imagery strategies.

Yet another issue in sport psychology field research is that when imagery is presented to players, it is often part of a package of techniques combining, for example, relaxation, imagery and positive self-talk (Calmels et al., 2003; Hall and Rodgers, 1989; Perry and Morris, 1995; Weinberg, 2008). Suinn (1977) maintains that imagery is not a technique to be used in isolation. One difficulty with the package approach is that it is unclear which element or elements of the package are responsible for the effect (Driskell, Copper and Moran, 1994). Barr and Hall (1992) suggest it “may be that the use of kinaesthetic imagery is facilitated by other internally oriented techniques such as relaxation and focusing” (p. 255). Certainly numerous studies attest to the efficiency of imagery as a facilitator of successful performance when combined with other elements (Bakker and Kayser, 1994; Kendall, Hrycaiko, Martin and Kendall, 1990; Marnassis and Doganis, 2004).
Imagery combined with relaxation is the preferred choice for many elite athletes in genuine performance situations (Barr and Hall, 1992; De Francesco and Burke, 1997). This combination has been found to be more effective than either imagery or relaxation alone (Weinberg, Seaborne and Jackson, 1981), and is used so often in applied work that Perry and Morris (1995) suggest it could be seen as a single technique. Nevertheless, sport is not played in a hyper-relaxed state. Hence, relaxation strategies incorporated into imagery practices must be carefully considered, with the aim being to create the “calm mind – aroused body” observed in elite performance (Holmes and Collins, 2001, p. 71).

Not only do imagery “packages” contribute to experimental complexity but different control combinations mean inter-experimental design is often diverse making consistently comparable results difficult to find (Driskell et al., 1994). Subjects employing imagery may be instructed to integrate physical practice with imagery before recording a result (Savoy and Beitel, 1996), to restrict physical practice (Grouios, 1992b), or to incorporate relaxation (Bakker and Kayser, 1994), possibly in combination with positive self-talk (Kendall et al., 1990). The subsequent results may be compared with a physical practice only group (Savoy and Beitel, 1996), a no practice control (Grouios, 1992b), a negative imagery group (Woolfolk, Parrish and Murphy, 1985), a relaxation placebo group (Hanrahan et al., 1995) or a relaxation and positive self-talk control group (Taylor, 1993).

In field studies where elite athletes and their coaches are not willing to act as or supply control subjects, where there are often small numbers of elite athletes, and where not every athlete needs the same treatment, single case designs are often adopted. This way each subject acts as his or her own control during a pre-treatment baseline assessment prior to imagery intervention and reassessment. According to Perry and Morris (1995) most studies on imagery use this multiple baseline, across-subject design, and if each subject is moved from the baseline to the treatment condition at a different time, chances that an extraneous variable might account for changes are somewhat minimised.
2.4.7 Trends across research results

Despite research challenges and methodological variations, a number of trends across studies have been noted (Grouios, 1992a, 1992b; Suinn, 1983). Results generally show that the imagery group’s performance varies noticeably from the no-treatment control (Perry and Morris, 1995). It is also clear that, with the exception of physical incapacity (Suinn, 1983), mental imagery should not be considered a substitute for regular physical practice, and it is unrealistic to expect great levels of achievement through imagery without a sufficient and continued volume of physical practice (Grouios, 1992b; Rushall, 1991).

Adding support to the landmark review of Richardson (1967), Weinberg (1982) assessed 27 imagery studies and reported the following apparent consistencies:

• physical practice is better than mental practice;
• a minimum skill proficiency is needed in order for mental practice to be effective;
• mental practice combined and alternated with physical practice is more effective than either physical or mental practice alone.

The meta-analysis of 60 studies conducted by Feltz and Landers (1983) looked at the effect of mental rehearsal on performance and also concluded that mental practice influences motor skill performance and is better than no practice at all. Furthermore, it indicated that the largest mental practice effects occurred when imagery of tasks with a strong motor skill content were practised frequently or for a long period of time, generally between 15 and 25 minutes per session. This is consistent with Driskell et al. (1994) who concluded that mental practice sessions of approximately 21 minutes may be optimal. The average effect for the studies measured by Feltz and Landers (1983), translated into the equivalent of changing a competitor's ranking out of 100 competitors, from 50th to 30th rank. Statistically this is considered a “medium effect” but in athletic terms this is a very considerable one (Taylor, 1993).

In a subsequent review which was broadened to include studies of both physical and mental practice combined, Feltz, Landers and Becker (1988) concluded:

“For some tasks for which actual physical practice may either be expensive, time-consuming, or physically or mentally fatiguing, the combined [physical and mental] practice may be advantageous, since the effects are nearly as good as
physical practice with only half the number of physical practice trials” (Feltz, Landers and Becker, 1988, p. 65).

More recent meta-analyses (Driskell et al., 1994; Hinshaw, 1991-1992) have also confirmed the general results of earlier reviews (Feltz and Landers, 1983; Richardson, 1967; Weinberg, 1982). That is, mental practice effects are real, mental practice is superior to no practice at all, and mental imagery associated with physical practice can produce better performance than physical or mental practice alone.

Researchers agree that imagery results may be affected by many variables (Bird, 1984; Grouios, 1992b; McKenzie and Howe, 1997; Weinberg, 2008). Greater recognition of these variables and refinement of investigation may lead to less disparity of outcomes (Bird, 1984; Driskell et al., 1994; Hall et al., 1985) which is often considerable (Grouios, 1992b; Suinn, 1983; Taylor, 1993; Wollman, 1986). However, under an emerging pattern of variables, which shall be discussed below, imagery appears to play an important role in motor performance at its most successful.

2.4.8 Imagery, confidence and success

In any successful performance many factors play a role. It is sometimes suggested that the most consistent, major factor distinguishing elite from sub-elit performers is self-confidence (Gould, Weiss and Weinberg, 1981; Heyman, 1982; Highlen and Bennett, 1983; Mahoney, Gabriel and Perkins, 1987; Meyers, Cooke, Cullen and Liles, 1979; Moritz et al., 1996).

Doyle and Landers (1980 cited in Suinn, 1983) compared 184 rifle and pistol shooters, all of them champions, for variables which distinguish elite from sub-elite. They observed that self-confidence is by far the main distinguishing factor, however, after self-confidence, imagery use then becomes highly relevant in defining how successfully the athlete performs. Other researchers (Barr and Hall, 1992; Hall et al., 1998; Hall, Rodgers and Barr, 1990; Salmon, Hall and Haslam, 1994; Vealey, 1986) also maintain there is a relationship between imagery use and successful performance. Feltz reasons that imagery and self-confidence are related:
“Perhaps just mentally seeing oneself successfully performing the desired task is enough to convince the athlete that he or she has the ability to successfully execute the task” (Feltz, 1984, p. 193).

Hall (1995) argues that this then affects confidence levels. Mumford and Hall (1985) found that positive, controlled imagery plays a causal role in the confidence of figure skaters. Calmels et al. (2003), Hall (1995), Mamassis and Doganis (2004), Moritz et al. (1996), Munroe et al. (2000), Nordin and Cumming (2005) and Woolfolk et al. (1985) also maintain that an important source of task related confidence, or self-efficacy, is mental imagery.

However, Mahoney and Avener (1977) suggest the reverse, that is, that confidence may play a causal role in positive, controlled imagery. They found that less successful gymnasts experienced images of failure. The gymnasts in the study were already so proficient they had been selected to try out for the American Olympic team. It would seem improbable that gymnasts within such a high ability group would intentionally choose to focus on negative imagery. A more likely explanation may be that lack of confidence affects the success content of imagery. Hence, confidence and imagery may each affect the other.

Others have suggested that success itself may be a variable which affects imagery (Heyman, 1982). That is, success may be so enjoyable that it leads to greater imagery use with the athlete reliving the experience of their successful performance. This may then bolster further confidence (Mumford and Hall, 1985), further success (Suinn, 1983) and further imagery use (Heyman, 1982), in a mutually beneficial interaction between all three elements. If this were so, then regardless of the initial role of imagery, it would appear to have the potential to become a tool to facilitate further successful performance.

2.4.9 Frequency of imagery use

Many researchers have investigated the relationship between frequency of imagery use and ability level. Overby (1990) found that in dancing, teacher-initiated imagery was used frequently irrespective of the level of dance ability. However, other athletes use more imagery the higher their ability level (Calmels et al., 2003; De Francesco and Burke, 1997; McCaffrey and Orlick, 1989; Orlick and Partington, 1988).
The elite athletes’ frequent use of imagery is not necessarily related to the amount of time available to devote to sport. McCaffrey and Orlick (1989) compared two groups who spent similar amounts of time involved in their sport. One group consisted of top touring professional golfers who had won tournaments and the other was a lesser skilled group of professional golf teachers. One of the elements common to all top touring pros was the extensive use of mental imagery for every facet of their game from pre-tournament preparation and practice to tournament play and post-tournament analysis. By comparison, professional club teachers not only used imagery less, but when used, it was only for specific aspects of their game such as putting. The researchers compared these results with those of Orlick and Partington (1988), and they were found to agree, in that extensive use of imagery was also a distinguishing feature of Canadian Olympic medallists and world champions. It could be argued that the teachers were in a situation where there was less performance anxiety and less stress to win. This may have influenced their tendency to use less imagery. Gravel, Gaston and Ladouceur (1980) suggest that imagery could merely be a means of replacing negative ruminations with body awareness or confidence boosting thought. But regardless of the underlying reasons, it would still appear that imagery is either a contributing trigger for elite performance or at least makes elite performance possible in stressful conditions.

Even amongst professionals playing the same international tournament, where opportunity to use imagery, stress to win and performance anxiety are potentially more evenly dispersed, De Francesco and Burke (1997) found that imagery use was related to player ranking. Of 115 international tennis players, the higher ranked professionals rated their dependence on “imagery” and “mental preparation” noticeably higher than lower ranked players. De Francesco and Burke do not mention how they distinguished mental preparation from imagery. Researchers generally maintain that imagery is a major factor in mental preparation (Munroe et al., 2000; Orlick and Partington, 1988; Suinn, 1983).

**2.4.10 Internal and external imagery**

Of particular interest to sports researchers is the effectiveness of imagery rehearsal. This is the ability of athletes to perform all or parts of their event in their mind before executing the skill (Barr and Hall, 1992; Driskell et al., 1994). Whether an athlete uses
imagery which is external and visual, or internal and kinaesthetic, or some combination is an issue that appears to impact on performance outcome.

The classic study of Mahoney and Avener (1977) spurred considerable interest in imagery perspective. It reported that all finalists for the American Olympic gymnastics team trials not only used imagery extensively, but the qualifiers were inside their bodies “experiencing those sensations which might be expected in actual situations” (p. 137) instead of viewing themselves from outside as in “home movies”. This study showed that it was not simply frequency of imagery use but also the choice of imagery perspective which related to greater success in athletic performance. This was confirmed by Doyle and Landers (1980 cited in Suinn, 1983) who found elite rifle shooters used predominantly internal imagery, whereas sub-elite rifle shooters used more of a mixture of internal and external imagery. Rotella, Gasneder, Ojala and Billing (1980) also confirmed a similar trend amongst skiers of international calibre. World Cup winners used more internal, kinaesthetic imagery compared to other skiers at this international level. Subsequently, Orlick and Partington (1986, 1988) studied 235 Canadian Olympians and concluded that superior athletes adopt an internal perspective in imagery that utilises kinaesthetic sensation. They stated:

“The extent to which the athletes could … feel performance images from the inside as if doing it, was directly related to performance outcomes at the Olympic Games” (Orlick and Partington, 1986, p. 5).

The idea of internal and external imagery being physiologically distinct is supported by research findings (Hale, 1982; Harris and Robinson, 1986; Jacobson, 1930, 1931; Lang, 1977; Shaw, 1938, 1940) that greater muscular activity occurs during internal kinaesthetic imagery than during external visual imagery.

A more diverse sample, consisting of 713 athletes ranging from novice recreational level to elite, was surveyed by Mahoney et al. (1987). Yet again, a primary difference found was that elite athletes reported relying more on internally focused and kinaesthetic imagery than on externally focused visual forms of mental preparation. This finding is supported by Barr and Hall (1992) who assessed 348 rowers from high school, university and national team level. One of the most striking differences in this study between novice and elite rowers was their use, or lack of use, of kinaesthetic imagery. The younger, less experienced rowers consistently adopted a more external visual perspective than the older, more experienced rowers. Generally there were no
substantial gender differences in the responses, although women did report greater use of imagery. This could be because women, who as a group may be more susceptible to anxiety (American Psychiatric Association, 1994), adopted imagery as a means of controlling performance anxiety. But it may also be relevant that the women in the study on average had rowed longer and so had greater opportunity to experience and develop imagery skills. Hall et al. (1990), also investigating trends common to a variety of skill levels, reported that recreational athletes were more likely to use pre-performance imagery not from an internal, kinaesthetic perspective, but to externally "see" the atmosphere of the competition day.

One explanation for this trend could be that kinaesthetic imagery rehearsal is possibly a skill in itself that needs to be gained before subjects can benefit from its use (Driskell et al., 1994; Suinn, 1983). A novice is less aware of the precise muscular sensations which accompany physical manoeuvres. Taylor (1908), writing on singing imagery, maintains that "the sensations of correct singing cannot be felt until the voice is correctly used. An effect cannot produce its cause" (p. 114). In like vein, Suinn (1983) asks: "Can a beginner visualize the sensations of coming smoothly out of a tuck, if he or she has not yet physically experienced the movement?" (p. 531). Because that option may only come with experience to the more accomplished, Suinn too draws our attention to the difficulty of distinguishing the causal factor from the consequence. However, there is the possibility that whatever the role of imagery and performance level, it may not be fixed. Each may have the ability to affect the other (Hurley, 2008).

It is important to note that although an elite athlete may use a predominantly internal imagery perspective, this does not discount an external perspective being adopted occasionally in partnership. Conversely, while novices may be less aware than professionals of the precise muscular sensations needed for optimal performance, novices may nevertheless experience internal kinaesthetic imagery to some extent (Gordon, Weinberg and Jackson, 1994). Indeed, imagery may spontaneously alternate between one perspective and another for both students (Gordon et al., 1994) and elite performers (Calmels et al., 2003; Nordin and Cumming, 2005). Gymnasts (Calmels et al., 2003), figure skaters (Mumford and Hall, 1985) and dancers (Nordin and Cumming, 2005) appear to find both perspectives important. Perhaps this is because these disciplines, while requiring highly complex athletic co-ordination of muscles, are nevertheless judged largely according to visual appeal – hence the need for the
performer to sometimes “view” the end result as though a member of the audience. Nordin and Cumming (2005) quote one professional dancer as “feeling it from an internal perspective but seeing it from an external [perspective]” (p. 406). Experienced performers often tend to report their imagery in a way which suggests that both internal and external perspectives operate simultaneously. Holmes and Collins (2001) maintain that this is actually because elite performers tend to switch between perspectives at great speed.

Not all sports disciplines, however, benefit from a predominantly internal perspective. The literature suggests that internal kinaesthetic based imagery is much more important to “closed” skills than to “open” skills (Barr and Hall, 1992; Hall et al., 1990; Highlen and Bennett, 1983; McLean and Richardson, 1994). Closed skill sports are those where the environment is relatively constant and predictable; so gymnastics is a closed skill sport, and singing, if classified as a sport, would be considered a closed skill. Open skill sports are those where the athletic environment is not totally within the control of the athlete; so white river rafting and wrestling are open skill sports. Some sports combine, to a greater or lesser degree, both closed and open elements. In slalom skiing, for example, the position of the poles, undulations of the course and snow conditions necessitate a degree of external, open skill awareness, yet the skier has attempted to memorise and anticipate the demands of the run and performs a highly structured sequence of rehearsed muscular patterns with a strong degree of closed skill repetition. In basketball, the player must be aware of the changing team tactics, and this is an open skill. Yet shooting from the foul line is a closed skill.

Hall et al. (1990) found that gymnasts and figure skaters more often incorporate the internal “feel” of performing in their imagery than do squash and football players. Highlen and Bennett (1983) found that frequency of internal kinaesthetic imagery rehearsal correlated with the selection of divers for nation teams, yet there was no similar distinction for the selection of wrestlers for national teams. Diving and wrestling were specifically chosen as representatives of open and closed skill sports, and the results could imply that differing open and closed skill requirements may influence the effectiveness of different types of imagery rehearsal. The results could also reflect the findings of the Feltz and Landers (1983) meta-analysis that imagery of motor performance appears to be of least benefit in predominantly strength tasks, as opposed to tasks with a stronger cognitive component.
When elite professional athletes do use a large amount of internal imagery, it is conceivable that the reason for this may simply be that, in their desire for performance excellence, they try as many strategies as possible, as frequently as possible. However, it is noteworthy that this body of athletes has generally not persisted with maintaining an equally powerful dependence on external imagery use as well (Morris and Summers, 1995). If athletes alter the ratio of internal / external perspective by the time they reach top elite level, it suggests that they have found something through experience which is more reliable. This view accords with studies (Hardy and Callow, 1999; White and Hardy, 1995) that investigated the early stages of training and found an external visual perspective to be beneficial in memorising new sequences of gross motor movements. Hardy and colleagues concluded that an internal kinaesthetic perspective was best applied when the main consideration in a performance was accuracy in the finer detail of specific skill components.

Hardy maintains, however, that visual imagery need not only be linked to an external perspective; it can also be internal. He proposes that internal visual imagery presents a view to the athlete from a first person perspective as though a camera were positioned at the athlete’s own eye level looking out onto the sporting event. For example, using internal visual imagery, a canoe-slalom athlete may visualise the tip of his own canoe pointing towards a slalom gate, and a gymnast performing a cartwheel would see the world upside-down. In external visual imagery, these sports would be visualised as though filmed from the riverbank or grandstand, thus offering a third person perspective (White and Hardy, 1995; Hardy and Callow, 1999). Singers may also use visual imagery that has either an external or an internal perspective. However, the diagrams drawn, for example, by Brünner (1993) indicate that internal visual imagery for a singer involves visualising the inside of one’s own body and perceiving it to be a hollow space to be filled with air or vibrations, or imagining the view of one’s own soft palate rising or one’s own diaphragm descending deep inside the body. A singer’s external visual imagery, on the other hand, may involve viewing the action on the stage not only as though filmed from the auditorium but also as though filmed from a camera at the singer’s own eye level pointing out towards the audience. Despite the differing ways in which visual imagery may be classified, it is Interesting to note that Hardy and Callow (1999) conclude that

“regardless of the visual imagery perspective, kinesthetic imagery contributes an additional beneficial effect to performance” (p. 108).
In summary, it would appear that the sports literature acknowledges that different imagery perspectives have advantages and disadvantages depending on the task requirements. It is recognised that performers may switch quickly from one perspective to the other. For closed skill sports such as gymnastics, dance and figure skating, that require a precise, detailed “feel” for specific components of a movement as well as visual appeal for the audience, both internal kinaesthetic imagery and external visual imagery are necessary. However, in these disciplines once a skill is learnt, a predominantly kinaesthetic approach is favoured at elite level.

2.4.11 Imagery use prior to competition

Although research shows that the more proficient athletes practice imagery often in day-to-day training, numerous studies show that imagery use plays a particularly significant role directly before execution of a skill in a competition situation. Hall et al. (1990) discovered that amongst general trends common to a variety of sports and skill levels, athletes report using imagery more in competition than in training. A subsequent study involving 348 rowers (Barr and Hall, 1992) supported these findings, adding that in competition elite rowers use imagery more before the race than in or after the race, but in training they use imagery more during physical practice than before or after this practice. Most rowers also reported using more imagery than they normally would just prior to their all time best performance. This supports the findings of Hall (1995) that the more athletes use imagery, the more beneficial it seems to be. Some Olympic athletes devote two to three hours to imagery techniques at the Olympic site in the last few hours prior to competition (Orlick and Partington, 1988).

Possible reasons for greater imagery use directly prior to competition may be not only to warm up without actual physical exertion (Rushall and Lippman, 1998), but to clear the mind of distractions, focus, increase confidence and reduce anxiety (Calmels et al., 2003; Munroe et al., 2000; Nordin and Cumming, 2005), thus gaining a psychological advantage (Smith, 1991). According to Kozar and Lord (1983) success in high level sport competition is 10-20% physiological and 80-90% psychological. Similarly, Orlick and Partington (1988) found that out of physical, technical and mental readiness, “the highest and only significant predictor of Olympic percentile rank was the mental readiness variable” (p. 124). Top athletes excel because they are better prepared psychologically for competition.
The psychological preparation of athletes has been the subject of many studies. De Francesco and Burke (1997) found that of 115 professional tennis players, the higher ranked professionals attributed significantly more of their performance to psychological variables than lower ranked players. McCaffrey and Orlick (1989) found that during a competition, top touring professional golfers use imagery to experience “the doing before the actual doing” (p. 261). They maintain that this sort of imagery keeps the players focused and deeply concentrated on the task and halts irrelevant thoughts or outside distraction. Other studies (Barr and Hall, 1992; Calmels et al., 2003; Hall, 1995; Munroe et al., 2000; Nordin and Cumming, 2005) have found support for elite athletes using imagery to maintain focus, increase self-confidence and control arousal and anxiety levels just before they perform. Rushall (1991) and Hall et al. (1998) cite numerous studies where imagery reportedly decreased anxiety, stress and uncertainty. Moritz et al. (1996) also suggest there may be a link between imagery use and anxiety management.

Anxiety has been shown to have a negative linear effect on performance (Cox, 2007). That is, as anxiety increases, performance quality decreases. In a study conducted on young people involved in activities including sport and music, it was found that without intervention, pre-event anxiety levels (measured physiologically) vary depending on the activity. There was an increasing hierarchy of pre-event anxiety levels from team sports to band participation to solo sports performance to a peak at solo music performance (Simon and Martens, 1979). In an effort to find techniques that can assist athletes in coping with anxiety, many techniques have come under consideration including progressive relaxation, meditation, hypnotism and biofeedback (Cox, 2007; Nideffer, 1981; Pressman, 1980; Wallace, 1991; Weinberg, 1982).

Imagery is also receiving attention from sports researchers as a tool to cope with anxiety (Weinberg, 2008). Yet imagery has not received similar attention from music researchers. This is unfortunate since, according to Simon and Martens (1979), in comparison to other athletic disciplines the solo musician has even greater need of pre-performance strategies to cope with anxiety.
2.4.12 Imagery use during competition

Because of issues such as anxiety, optimal imagery during competition may vary from that used in day-to-day practice situations. On the day of competition, imagery used directly prior to or in competition may place great emphasis on general mental focus and somatic arousal. Away from competition, when the goal is day-to-day training of movement coordination and sequencing reinforcement, the imagery employed may emphasise different elements (Rushall and Lippman, 1998).

Time devoted to imagery use during competition possibly varies from sport to sport depending on factors including the type of imagery in use and the amount of time involved in skill execution. For example, although marathon athletes may use imagery during the event (Couture, Singh, Lee, Chahal, Wankel, Oseen and Wheeler, 1994; Morgan, 1980), high tower divers delegate imagery to a pre- and post-performance strategy only (Taylor, 2000). De Francesco and Burke (1997) found that of 115 professional tennis players, 95% used imagery strategies “during competition”. But details of whether “during” simply involved short breaks between play, whether imagery was used directly prior to selected tasks such as serving, or continuously throughout all phases of skill execution were not indicated.

Rushall and Lippman (1998) stress that during competitive skill execution, it is ill-advised to allow attention to focus on individual performance components such as portions of a golf swing or elbow position. Norman and Shallice (1986) maintain that if pre-performance and performance attention is on specific features of cognitive control, physical performance will be disrupted. They advise that highly developed skills, once achieved, leave attentional resources available for other uses. Rushall and Lippman (1998) suggest the athlete use imagery to focus on some overall interpretation of performance or to attend to effort expended. This is perhaps where global (whole-body) imagery, and imagery of projecting energy to some focal point outside the body seem particularly relevant. These types of images do not necessarily relate to reality, and in fact often resemble a surrealistic fantasy.
2.4.13 Surreal imagery

“My image is really that the space is turning completely red. And what you associate sometimes with red is either blood or heat, and it’s about heat” (Nordin and Cumming, 2005, p. 403).

This is not the image of an hallucinogenic drug user; it is the image of a professional Kathak male dancer. Dance literature makes frequent mention of images that defy reality:

“Imagine your arms are touching either side of the room” (Nordin and Cumming, 2005, p. 403).

Although dance imagery may be visual and kinaesthetic and contain direct images referring to specific body parts and indirect images or metaphors, Hanrahan and Salmela (1986, 1990) identified further sub-categories. These included global whole-body imagery and directional lines of movement imagery, both of which generally contain elements of fantasy. Global or whole-body imagery does not refer to a specific body part but is more general, such as imagining the feeling of air swirling around the body or imagining the whole body is radiant. Global imagery may influence the quality of energy and emotional arousal felt in a performance, and often generates specific dynamics in movement (Hanrahan et al., 1995). For the Kathak dancer mentioned above, the global image of the space turning completely red triggered a sense of energy and emotional arousal.

Directional lines of movement imagery, as in the image above of the dancer’s arms touching either side of the room, involves the sensation of projecting energy to a focal point often outside the body. It is associated with ideokinesis, which teaches people to visualise lines of movement travelling through their bodies while at rest in the absence of movement, and while they move about at their normal activities (Dowd, 1981). According to Hanrahan et al. (1995), ideokinesis was first proposed by Sweigard (1975) as a metastrategy for improving posture and used as a form of physical and/or mental preparation for dance. For example, an image that can be used to elongate the neck muscles while standing is to visualise the neck growing like an “Alice in Wonderland” neck (Sweigard, 1975). The rationale behind this imagery can be traced largely to efficient communication. That is, a picture given by the teacher may be worth a thousand words, and it is easier for the student or performer to remember an image than to remember several instructions for moving the various body parts (Hanrahan
and Salmela, 1990). Additionally, Sweigard maintains that selected imagery facilitates subtle but optimal muscular alignment because on many occasions

“all voluntary contributions to a movement must be reduced to a minimum to lessen interference by established neuromuscular habits which may not be efficient or appropriate” (Sweigard, 1975, p. 6).

Nordin and Cumming (2005) investigated what imagery dancers use and why they use it. They noted a frequent use of mastery-related imagery, suggesting that such imagery helps the dancer feel prepared and in control, enhances self-confidence and reduces anxiety. However, in accord with earlier dance studies, they also found it was not unusual for the images used to suggest physiologically impossible actions:

“Sometimes when you’re learning a new skill, you become bogged down by the physics of the movement. And sometimes it takes someone to say to you ‘try and just let the air come out of the top of your head’. And suddenly you’re not so much worried about your foot but you’re focusing on some other part of your body, and that will just allow the leg to do what it needs to do” (Nordin and Cumming, 2005, p. 407).

As distinct from most other sports, in dance, imagery has a long tradition of being initiated by the teacher and used across all ability levels as an integral rather than additional part of training (Hanrahan and Salmela, 1990; Overby, 1990). Although the images used often centre on fantasy and actions that cannot actually be performed (Nordin and Cumming, 2005), these images are intended for use directly during execution of the skill and may even be used throughout a sustained performance lasting many hours (Hanrahan and Salmela, 1990; Nordin and Cumming, 2005; Overby, 1990). Imagery initiation and application in dance is, in fact, remarkably similar to that used in singing. Global and directional imagery and a strong element of fantasy also feature in vocal training. For example, it is often suggested that singers summon the global image of feeling the music streaming through the entire body (Lehmann, 1971), with the aim of eliciting the desired emotion-related physiological responses in the performer. Some singers use images of singing in a specific colour such as mauve or glowing orange (Edwin, 1999; Freed, 2000; Miller, 1998). Miller even notes the image of singing “out the chimney at the top of the head” (Miller, 1998, p. 42), which is quite similar to that of the dancer mentioned above, who let the air come out of the top of the head. Singers may recognise directional lines of movement imagery as forming
the basis for many voice placement and breathing images (see Section 2.2.7) – images that often resemble a surrealist fantasy (Kagen, 1960). Furthermore, the images proposed by Sweigard (1975), in which the head is rising and the back is lengthening, are echoed in the postural images often used by musicians (Alcantara, 1997).

2.4.14 Imagery studies in dance

A number of dance studies have found global, whole-body imagery and directional lines of movement imagery to have a positive effect on motor skills. Minton-Cerney (1981 cited in Hanrahan et al., 1995) tested the effect of posture-improvement imagery on the performance of beginning modern dancers, and found that selected imagery improved the alignment of specific parts of the body as measured in pre- and post-test photos. Studd (1983 cited in Hanrahan et al., 1995) also found the use of ideokinesis as a preparation for dance to positively affect simple dance skills.

The study of Hanrahan et al. (1995) involved 65 intermediate level dancers and combined elements of both directional and global images. The dancers in the study were instructed to direct the flow of imagined energy throughout the body and beyond according to the technical goals of the specific skill, and this they did during performance. The skills chosen were the battement, développé and arabesque, where one leg is raised either to the front, side or back. An example of the imagery used with the arabesque follows:

“Imagine you are a tree. Your supporting leg is a tree trunk with roots growing down from your foot into the ground. Sap is flowing up to feed energy to your head, arms and arabesque leg that are branches growing out from your trunk towards the sky. Grow towards the sky for 5 seconds” (Hanrahan et al., 1995, p. 420).

The results showed a facilitatory effect of imagery on the battement and arabesque, as compared to the no-treatment and relaxation placebo control groups, and suggested that directional and global imagery can provide a psychological tool for performance enhancement that is effective when used during the execution of certain dance skills. Curiously, the imagery chosen for the développé did not produce a significant performance enhancement effect, although a previous study (Hanrahan and Salmela, 1986) comparing the effect of global imagery on the développé found imagery to have
a significant effect. Hanrahan et al. (1995) suggest the reason for the differing response may have been that the members of the imagery group in the study obtained far better pre-test results than did the members of the control groups. Consequently there was less room for improvement from the imagery group. Controlling for different base line ability before any intervention is an inherent challenge of performance related research.

Also of interest in the Hanrahan et al. (1995) study is the finding that the improvement of the relaxation placebo group was not significantly different from that of the no-treatment control group. These findings seem to indicate that, contrary to imagery, relaxation instructions alone are not sufficient to significantly increase performance. The researchers, however, did not totally rule out a possible relaxing (Wollman, 1986) and/or placebo effect from imagery use and suggest that a non-relaxing image and/or a technique which is known to be neutral and consistently ineffective could be used to counter any placebo effect in further research on imagery (Hanrahan et al., 1995).

Overall, the 1995 study supported the suggestion of Sweigard (1975) that any imagined flow of energy should be directed according to the desired bio-mechanical goal. This is similar to Freed’s suggestion that in singing, “more often, the imagery should help to reinforce a physiological principle” (Freed, 2000, p. 10). Freed may be referring to occasions when directional images suggest a flow of energy. A global image, for example, of singing in a mauve or orange colour, does not serve to reinforce a physiological principle. Yet indirectly, as in dance, the global imagery used by singers perhaps provides a psychological means of influencing the level of physiological arousal. Clearly, there are many aspects of imagery that are complex due to the link between imagery and subconscious functioning.

2.5 VOCAL WARM-UP

Though many sub conscious processes are involved in expert performance, the conscious striving for optimal function, whether in an Olympic discipline, in dance or in music, demands deliberate practice for the development of technical skill. According to Ericsson, Krampe and Tesch-Römer (1993) approximately 10,000 hours of efficient, attentive practice is necessary to excel in almost any competitive discipline such as
ballet or music performance. Warming up is a fundamental part of every disciplined performer’s practice routine (Karvonen, 1992; Miller, 2004).

2.5.1 What is vocal warm-up?

Vocal warm-up refers to the practice of vocalising using exercises or repertoire to prepare the voice for optimal performance. Vocal warm-up commonly commences with mid-range tasks perceived to be minimally strenuous. Scale and arpeggio patterns are often used, as are pitch glides (glissando or portamento) from one note to another. Incremental progressions of increased vigorous vocal use then follow during which the accomplished singer will cover an extensive vocal range (Miller, 1990b; Thurman, Theimer, Klitzke, Grefsheim and Feit, 1997a; Thurman, Theimer, Welch, Grefsheim and Feit, 1997b; Titze, 1993, 2001b; Vennard, 1968).

Because exercises used to develop a singer’s technical skill commonly employ these same techniques, there may essentially be no difference between exercises used for warm-up and exercises for technical development. Miller (2004) recommends singers make a selection from his exercises for vocal development and use them to establish a consistent, daily warm-up regimen. However, he puts limits on what he believes should constitute a vocal warm-up. Miller (1990b) maintains that warm-ups should mainly favour agility rather than long sustained phonations, that they should never employ any “heavy” (p. 22) vocalisation, and that work on technical problems should be avoided during the warm-up phase.

Vocal warm-ups may also include studies by vocal authorities such as Vaccai, Concone or Marchesi. Often, most commonly towards the end of a warm-up, exercises related more specifically to the music about to be performed may be incorporated. For example, a few bars of the piece to be performed may be sung on selected vowels, or selected for repetition while concentrating on appropriate kinaesthetic sensations. There is an endless number of possibilities for vocal warm-up exercises.

In order for a warm-up to be effective it is suggested that between 15 and 30 minutes may be necessary (Mantel, 2003; Thurman et al., 1997a; Vennard, 1968). During this time, the gifted singer will refine and groom vocal quality over a wide pitch range. By
contrast, the less talented singer may simply attempt to establish a usable range of
notes (Titze, 1993).

The premise underlying warm-up is that muscle activity and coordination improve
(Amir, Amir and Michaeli, 2005). Titze (1993) notes that by vocalising on scales,
arpeggios or a glissando over a wide range of pitches and intensities, singers
incorporate a considerable amount of laryngeal and respiratory stretching. The
stretching and releasing of joints, tendons, ligaments and muscles promotes important
cell and fibre growth and strengthens all tissue, both muscular and connective. Titze
suggests that vocal warm-ups may provide somewhat similar benefits to the stretching
exercises and warm-ups used by gymnasts, figure skaters and dancers who, like
singers, rely heavily on flexibility and control rather than brute force. Thurman et al.
(1997b) add that as with athletes, singers too need to “tune up” their neuromuscular
programming for vigorous, high-speed, but precise and smooth movement.

Sundberg also compares singers’ warm-ups to those of dancers and athletes. The
vocal folds contain muscle tissues as a major component, and singers, like dancers
and athletes, rely on optimal muscle function. All muscles depend on efficient blood
circulation in order to retain good function and viscosity. Hence, as with dancers and
athletes, singers’ warm-up exercises most probably stimulate good circulation
(Sundberg, 1987).

2.5.2 Warm-up exercises and articulation

Warm-up exercises sometimes serve not only to warm up the voice but also to improve
enunciation. Such exercises may be based on practices commonly used in the
development of the spoken voice and found in books on speech (Vennard, 1968).
Singers from elementary level onwards, including singers in choirs or at acting courses
may often have their attention directed towards enunciation. However, for the
classically trained singer either at or working towards professional level, warm-up
exercises more frequently serve to direct the singer’s attention to beneficial
kinaesthetic sensations throughout the entire body (Miller, 1996; Thurman et al.,
1997a; Vennard, 1968). In particular, in imagery terms, exercises are given to “place”
or “focus” the voice, and to heighten the awareness of “support” (Miller, 1996; Vennard,
1968).
Vocal warm-up exercises often use vowels or consonants as pilot sounds to alter the articulatory shape of adjoining vowels or consonants. This may be referred to as the principle of co-articulation (Thurman et al., 1997a). For example, a tongue-front vowel such as [iː] as in “see”, used directly before [aː] as in “ah” may lead the singer towards an optimal, more tongue forward production of [aː]. Thurman et al. (1997a) point out that the principle of co-articulation is also used when the singer employs aural imagery to “think” a more tongue-back vowel such as [ɛː] as in “air” while singing [iː] on a high pitched note which may otherwise sound “narrow” or “pinched” in tone quality with the tongue too forward.

Singers frequently use humming in warm-ups to become aware of vibratory sensations in the sinuses and areas where sympathetic vibrations are experienced (Miller, 1996; Westerman Gregg, 2001a). Additionally, humming may be used to heighten “support” sensations experienced in the torso that result from total or partial closure of the mouth (Miller, 1996). The tongue-point rolled [r] may also be used to draw the singer’s attention towards awareness of the sensations of good breath management in the torso. Furthermore, it may allow the singer to sense a feeling of ease in the throat. That is, a tongue-point rolled [r] requires an absence of tension in the muscle blades that make up the body of the tongue, as well as at the points of tongue contact at the front of the mouth and in the hyoid musculature to which the tongue is attached (Miller, 1996).

Vennard suggests there is probably no consonant that has not been used in warm-ups and exercises, each having its own value (Vennard, 1968). For example, the consonants [t], [d], [n], [l] and [y] are useful in isolating jaw muscle action from tongue muscle action. The voiced fricative consonants [z] and [v] do not require the tongue to move from a neutral, at rest shape and so reduce the possibility of interfering muscular involvement being introduced in the vocal tract. The nasal consonant [ŋ] as in “singer” is commonly used directly before vowels that need more openness and so serves a co-articulatory role. It brings into play tongue and soft palate interaction, which helps singers sense the releasing open of the oropharyngeal area on the vowel.

But a word of caution is offered by Thurman et al. (1997a) that not all consonants help all singers all the time. For example, [g] and [k], when articulated well, with a sense of releasing completely into a succeeding vowel such as “ka”, can aid in developing a
releasing open sensation in the oropharyngeal area and in developing efficient soft palate coordination. When articulated poorly, with excessive effort, the same consonants can influence successive vowels to be constricted. Indeed, Sundberg states:

“Every vowel can be articulated in various ways, not only with respect to vertical larynx position but also with respect to jaw opening, tongue shape, and so on…” (Sundberg, 1987, p. 112).

The singer’s manner of articulation will impact on formant frequencies produced, but most specifically on the lower formant frequencies. Jaw opening influences first formant frequencies, and if the jaw is prevented from moving, another articulator such as the tongue will take over this function. The shape of the tongue body is also capable of changing the second formant frequency quite considerably. Rounding as opposed to spreading the lips is associated with a lowered larynx, lengthening of the vocal tract and a lowering of all formant frequencies. Sundberg notes, however, that

“the higher the formant frequency, the more its frequency depends on nonarticulatory factors…” (Sundberg, 1987, pp. 104-105).

Consequently, merely because vocal exercises are done with clear diction and well enunciated vowels does not mean the voice will produce a singer’s formant or otherwise project well. Most choral singing, for example, demands excellent diction but not the strong projection mandatory for classical soloists (Sundberg, 1987).

In fact, Martienssen-Lohmann (2001) maintains that it is not what vowels, consonants or scale patterns a singer uses in exercises, but rather the manner in which a singer exercises that matters in the development of the singing voice. It is vital, for example, that concentration is appropriately applied, that posture and breathing are optimal, and kinaesthetic sensations are appropriately located and securely linked through the use of muscle memory to the desired tone quality.

2.5.3 Speculated effects of warm-up

There is general acceptance amongst performers, vocal pedagogues and researchers that for optimal vocalisation it is best to first warm up the voice (Amir et al., 2005; Blaylock, 1999; Duncan, 1997; Elliot, Sundberg and Gramming, 1995; Heman-Ackah, Sataloff, Hawkshaw and Divi, 2008; Hines, 1982; Milbrath and Solomon, 2003; Miller,
1990b, 2004; Motel, Fisher and Leydon, 2003; Sataloff, 1991; Sundberg, 1987; Thurman et al., 1997a, 1997b; Titze, 1993, 1994, 2001b; Vennard, 1968). However, scant research has been conducted as to the difference between the warmed-up and the unwarmed-up voice. Specific acoustic and physiological factors that can be measured and can explain the effect of vocal warm-up have proven elusive (Amir et al., 2005; Sundberg, 1987; Vinttur, Alku, Lauri, Sala, Sihvo and Vilkman, 2001).

Tone quality is claimed to improve after vocal warm-up. From the perspective of the listener, Miller (2004) believes the voice loses its “thickness” (p. 244) after warm-up. Whether by “thickness”, Miller is referring to a lack of “focus” or to an excessive use of “heavy mechanism”, sometimes referred to as “thick mechanism” and associated with chest voice (Miller, 1977) is not explained in his discussion of warm-up (Miller, 2004).

It has been speculated that improved tone quality following vocal warm-up may be linked to improvement in vibrato characteristics (Coleman et al., 1984; Miller, 2004). Miller (2004) proposes that vocal warm-up increases a singer’s vibrato rate, and without a warm-up the voice exhibits “oscillation” (p. 244), a term Miller uses for “slow vibrato rate” (Miller, 1996, p. 186). It is suggested in the discussion of Coleman et al. (1984) that although performance anxiety may perhaps quicken vibrato rate, warming up may slow vibrato rate to a more acceptable level. Hence, the physical act of warm-up may moderate tremor frequencies produced by the nervous system that are thought to be at the basis of subconscious vibrato function (Schoen, 1922; Shipp et al., 1984; Stark, 1999; Titze, 1994; Titze et al., 2002; Westerman, 1938; Winckel, 1957). However, such speculation regarding the influence of warm-up on vocal characteristics lacks investigation.

If indeed a change in tremor characteristics, vibrato and tone quality occurs, it may also be linked to the psychological impact of warm-up. Elliot et al. (1995) point out that professional singers tend to sing so frequently that they are virtually in a constant state of physical warm-up. The fact that, on the whole, they nevertheless warm-up implies that warm-up has psychological benefits. Miller (1990b) suggests an established warm-up routine offers psychological security by assuring the singer that the voice is capable of functioning in the tasks ahead.
Sometimes singers warm up intermittently over the entire day leading to a performance (Hines, 1982). On such occasions warm-up generally becomes part of a performance day routine or ritual. Authorities on the management of performance anxiety recommend adopting a set routine on the day of a performance (Mantel, 2003; Roland, 1997), as such routines allow the performer to maintain a sense of mental focus, feel in control and tackle the challenge of performing with a familiar sense of security.

In summary, warm-up may be linked to both physical and psychological changes that impinge on vocal tone quality. Warm-up supplements a singer’s mental preparation, which may assist in the management of anxiety. The control of anxiety is important as it may influence subconscious muscle tension and tremor frequencies linked to vibrato.

2.5.4 Warm-up and sports medicine

With scant warm-up research conducted on singers, voice science tends to look to reports from sports medicine in order to shed light on the warm-up process. In sport, warm-up has become an accepted way of preparing an athlete’s mind and body for performance. Research in sports medicine shows that warm-up literally warms up muscles. This speeds metabolic processes to produce faster, smoother and more forceful contractions and increase intramuscular connective tissue elasticity.

Researchers sometimes distinguish between warm-up and warm-up programmes (Gilchrist, Mandelbaum, Melancon, Ryan, Silvers, Griffin, Watanabe, Dick and Dvorak, 2008; Mandelbaum, Silvers, Watanabe, Knarr, Thomas, Griffin, Kirkendall and Garrett, 2005). Warm-up may refer to the process of warming the body before execution of a particular sports discipline. Warm-up may be so passive as to consist of having a hot shower, a sauna or a massage. It may be active and involve physical exertion such as running or skipping with a rope until the body is heated. These rudimentary forms of warm-up are sometimes referred to as a “general” warm-up (Karvonen, 1992, p. 190). In sport, a general warm-up need have no direct relationship to the skills required of the athlete’s chosen disciple. The purpose of the general warm-up is to increase body temperature, increase blood flow to muscles, reduce muscle viscosity and increase transmission of nerve impulses (Karvonen, 1992).
A “warm-up programme” is described by Gilchrist et al. (2005) as an “alternative warm-up” (p. 1477). The Gilchrist et al. (2005) warm-up programme consists of warm-up, stretching, strengthening, plyometrics and sport-specific agility exercises. It places emphasis on learning correct biomechanical techniques necessary for the chosen sports discipline. Mandelbaum et al. (2005) refer to a similarly structured sequence of activities as both a “warm-up program” and as “neuromuscular and proprioceptive training” (p. 1004). Such programmes have much in common with warm-up routines recommended by Karvonen (1992). Karvonen suggests athletes initially carry out a “general” warm-up and then a “specific” warm-up (p. 190), and that the entire process should take between one and two hours. Specific warm-up involves exercises that repeat movements important for the sports discipline to follow, and this allows the athlete to focus on the “kinaesthetic sense of correct movement” (Karvonen, 1992, p. 203). This phase of the warm-up is used to improve neuromuscular co-ordination, to gain confidence in task mastery and to mentally focus. In addition, towards the end of the warm-up process athletes may include “mental training” (p. 207) involving imagery of necessary skills. For example, ice skaters may imagine skating the straights and the curves (Karvonen, 1992).

Sports warm-up is sometimes credited with reducing the incidence of sports injuries (Gosheger, Liem, Ludwig, Greshake and Winkelmann, 2003; Karvonen, 1992). Yet this is not always the case (McHardy, Pollard and Luo, 2007; Mechelen, Hlobil, Kemper, Voorn and Jongh, 1993). Many factors, including fatigue and improper technique (Safran, Seaber and Garrett, 1989), amount of training (Ekstrand, Gillquist, Möller, Oberg and Liljedahl, 1983), age and level of fitness (Pope, Herbert, Kirwan and Graham, 2000) affect the likelihood of injury. Ekstrand et al. (1983) also note that warm-up content must be addressed if sports related injuries are to be avoided.

Current research indicates that sports warm-up does play a major role in reducing the incidence of sports injuries if, while focusing on the specific demands of the particular sports discipline, the warm-up

- promotes balanced strength between antagonistic muscle groups
- includes exercises for balance, agility and co-ordination
- trains the athlete’s sense of correct joint position and optimal alignment
- offers visual examples of what constitutes correct and incorrect biomechanical technique (Croisier, Forthomme, Namurois, Vanderthommen and Crielaard, 2002;
That there is a role for warm-up in the prevention of injury resonates strongly with voice authorities who recommend warming up the voice prior to performance to avoid vocal injury, facilitate vocal repair and maintain optimal vocal health (Blaylock, 1999; Darby and Rulnick, 1991; Heman-Ackah et al., 2008). Furthermore, correct biomechanical technique, often learnt through demonstration, plus optimal physiological alignment, balanced strength between antagonistic muscle groups, agility, co-ordination and a keen sense of proprioception are fundamental goals for the singer during warm-up, lesson time and performance (Brown, 2002; Brünner, 1993; Doscher, 1994; Günter, 1992b; Miller, 1996; Vennard, 1968).

In sport, as with singing, experimental data is lacking to define the mechanism of the protective effect of warm-up. A number of suggestions have been put forward and a combination of factors may be involved in injury prevention. One suggestion is that warm-up increases muscle temperature which reduces muscle viscosity, making muscle contractions smoother, and smoother contractions may possibly reduce muscle injury (Safran et al., 1989). It is also held that warm-up exercises which promote balanced strength between antagonistic muscle groups are central to injury prevention (Croisier et al., 2002, 2008; Heiser et al., 1984; Noffal, 2003; Safran et al., 1989). In addition, it is believed that in a technically thorough warm-up, neuromuscular training occurs. When, for example, the athlete focuses on correct joint position, balance and optimal alignment, the athlete’s sense of proprioception is believed to eventually improve, resulting in injury reduction (Gilchrist et al., 2008; Mandelbaum et al., 2005; Pánics et al., 2008).

Whether stretching exercises have a role to play in warm-up and injury prevention is contentious. It is sometimes posited that muscle tightness which restricts the range of motion predisposes to muscle strain, and therefore to avoid muscle strain stretching exercises are an important part of warm-up. Yet adding stretching to warm-up programmes has not always had positive results (Safran et al., 1989). Pope et al. (2000) found that a series of 20 second static muscle stretching exercises incorporated every four minutes in a warm-up contributed at most a 5% benefit to the reduction of
muscle injury. Some authorities who consider that stretching exercises may contribute substantially more to injury prevention, however, stress that stretching should only be undertaken after the initial warm-up is complete. Stretching exercises undertaken too early in the warm-up process may in fact contribute to torn muscles (Safran et al., 1989).

Hence, whether stretching has a role in warm-up, seems dependent on how warm-up is defined. That is, whether the term “warm-up” covers a comprehensive programme of exercises undertaken prior to performance, or whether it is taken to indicate the more rudimentary process of warming the body prior to use.

Interestingly, although sports warm-up, when conducted in an optimal manner, is credited with injury prevention, it has long been debated whether sports warm-up is capable of enhancing performance standard (Safran et al., 1989). Karvonen (1992) maintains that warm-ups, appropriately tailored to each sports discipline, are vital for optimal performance. Yet Gray and Nimmo (2001) found no significant difference in cycling performance irrespective of whether the cycling was preceded by a combination of general and sports specific warm-ups. This is at odds with the vocal fraternity, which credits vocal warm-up not only with injury prevention but with consistently enhancing performance standard.

The lack of consistency in performance enhancement following sports warm-up has been attributed to many factors. One factor may be the intensity of the warm-up (Gray and Nimmo, 2001) which, if too intense, may cause fatigue. When fatigue occurs, biomechanical technique may falter (Gilchrist et al., 2008). Of course, cardiovascular issues which may bring about fatigue for the sports person, do not apply to the singer. Furthermore, vocal warm-ups are considered to protect the voice so admirably from fatigue as to be recommended to sufferers of vocal fatigue (Blaylock, 1999; Heman-Ackah et al., 2008).

It has been suggested that the mismatch between exercises involved in a general sports warm-up and the skills needed for a particular sports discipline may also be responsible for the lack of consistency in performance enhancement following warm-up (Massey, Johnson and Kramer, 1961). For example, a general warm-up for ice hockey may involve running on the spot in a warm gymnasium until the body is heated rather
than practicing the skills necessary for ice hockey. However, Karvonen (1992) explains that a general sports warm-up should usually be followed by a sports specific warm-up.

The concept of general and specific warm-ups has its counterpart in singing, though the distinction between the two does not appear to be as great for singers as it is for sports people. For singers it is usual to commence with a general warm-up and progress to a more specific warm-up aimed at the performance ahead. General exercises may be either non-vocal or vocal. Hines (1982) makes reference to a singer skipping with a rope at the commencement of a warm-up programme. However, this is a practice seldom documented in vocal literature. Sports literature which recommends that warm-up intensity be increased to alleviate excessive tension and anxiety (Karvonen, 1992), perhaps illuminates our understanding of the singer placing increased cardiovascular demands on her body in this way. Most usually, non-vocal warm-up activities for the singer reflect skills directly related to singing. For example, a singer may silently attend to diaphragmatic breathing or spinal alignment (Amir et al., 2005), replicating the type of breathing and posture employed during optimal singing. Frequently, general warm-ups for a singer are totally vocal (Elliot et al., 1995; Hines, 1982; Miller, 2004; Motel, Fisher and Leydon, 2003; Titze, 1993, 2001b; Vennard, 1968). Thus, as opposed to warm-ups for sport, the basic focus of both general and specific warm-ups for singing is the honing of skills and techniques vital to performance. This may explain why singing authorities, in contrast to sports authorities, are united in equating warm-up with enhanced performance.

Other explanations as to why sports warm-up does not consistently produce enhanced performance include the suggestion that improvement may to some extent depend on psycho-physiological variables. That is, warm-up is more effective the more the athlete believes it to be effective (Karvonen, 1992). Massey et al. (1961) tested 15 college athletes for performance on a bicycle ergometer following two conditions. One condition consisted of a ten minute general warm-up followed by rest, the other condition consisted solely of rest. During both conditions the subjects were under deep hypnosis. The researchers maintain that because of this, the subjects could not recall whether they had undergone warm-up or not. No differences were observed between subsequent performance results. Smith and Bozymowski (1965) observed that subjects with a favourable attitude towards warm-up improved their performance capacity markedly after warm-up. Subjects with a less favourable attitude towards warm-up did
not improve their performance. Furthermore, it is believed that psycho-physiological factors associated with warm-up may affect an athlete's arousal level. If the warm-up results in the athlete attaining an arousal level that is too high or too low for the tasks ahead, then performance will suffer: the choice of exercises is crucial. Warm-up exercises need to be tailored so as to achieve the arousal level required for the performance (Cox, 2007; Karvonen, 1992).

2.5.5 Arousal levels

Arousal may be defined as the intensity level of behaviour (Landers and Boutcher, 1998). It is synonymous with the concepts of activation and alertness and may be represented on a continuum from deep sleep to extreme excitement (Cox, 2007; Oxendine, 1980). Changes in arousal levels are reflected in changes controlled by the autonomic nervous system, namely in heart rate, blood pressure, respiration, sweating, muscle tension, digestion, urination, body temperature and many body functions that to some extent are considered to be involuntary. With training, some degree of conscious control of autonomic nervous system function is possible (Anthony and Thibodeau, 1979; Bartley and Clifton-Smith, 2006; Cox, 2007; Oxendine, 1980).

The arousal response is initiated by any sensory stimulation from the environment or from the cerebral cortex, which is that area of the brain responsible for conscious thought (Cox, 2007). The term “arousal” is often used interchangeably with terms such as “excitement”, “exhilaration”, “motivation”, “rage”, “fear” and “anxiety”. However, arousal is neither synonymous with positive nor with negative emotions (Cox, 2007; Landers and Boutcher, 1998; Oxendine, 1980). An increase in arousal may be associated either with negative conditions such as anxiety or with positive conditions such as exhilaration. In fact physiologically there may be a high degree of overlap between these conditions (Mornell, 2002; Oxendine, 1980).

There is an optimal level of arousal for whatever task is undertaken (Cox, 2007). Performance authorities (Oxendine, 1980; Wilson and Roland, 2002) note that the following generalisations can be made about arousal and performance:

- A high level of arousal is essential for optimal performance in gross motor activities requiring strength, speed and endurance.
- A high level of arousal impairs performances requiring a complex series of
movements, coordination, fine muscle movement and concentration.

- A slightly above average level of arousal is preferable to a normal or sub-normal arousal state for all motor tasks.

Cox (2007) illustrates the relationship between arousal level and task proficiency with the story of a man chased by a lion. The man ran faster than ever before. Seeing a tree branch about four meters from the ground, he jumped, hoping to reach it. He missed the branch going up but caught it coming down. That is, the man’s speed and energy were astounding when highly aroused, but his accuracy was impaired. Cox (2007) maintains that for the sports coach and athlete, it is important to adopt strategies which suppress cognitive anxiety and produce arousal levels appropriate for the task.

Performance literature sometimes likens arousal to anxiety (Crocker and Graham, 1995; Emmons and Thomas, 2008). However, Cox (2007) and Salmon (1990) stress that whereas anxiety calls for the perception of being in a threatening situation, this is not the case with arousal. Addressing musicians, Salmon (1990) argues that it is important to achieve an optimal level of arousal while nevertheless suppressing anxiety – particularly somatic anxiety which interferes directly with skilled performance.

2.5.6 What is anxiety?

Anxiety may manifest itself in a range of somatic, cognitive and emotional responses (Barlow, 2000; Sataloff, Rosen and Levy, 2000; Wallace and Alden, 1997), and is characterised by a sense of unease (Brown, 1993) and helplessness in personally salient situations (Barlow, 2000). The term “anxiety” stems from Greek and Latin words meaning “pressing tight”, “strangling” and “constriction”, and unlike our modern use of anxiety to mean fear, it originally denoted disquiet and sadness (Marks, 1987). For singers in particular, sensations of constriction, strangling and sadness court disaster. Strangling links anxiety directly to the throat and the source of vocal function. Sadness is associated with poor posture, consequent poor breathing habits (Bartley and Clifton-Smith, 2006) and impeded vocal function, to which the choking voice giving a funeral eulogy will attest.

Anxiety produces both an increase in arousal and a widespread somatic reaction referred to as an alarm, emergency, distress or stress response. If an alarm response
occurs prior to or during a performance it may be called performance anxiety, stage fright or nervousness, to name a few of the terms available.

Occasionally authorities attempt to distinguish between the many terms to describe performance anxiety, but not always. As a medical doctor to whom sufferers turn, Brandfonbrener (1999) believes semantic distinctions are unwarranted “... call it performance anxiety, stage fright, or musical performance anxiety, I think we all understand what we mean” (p. 101). Brodsky (1996) proposes that stage fright is a more severe level of stress than performance anxiety. However, Fehm and Schmidt (2006) point out that stage fright is sometimes interpreted as involving a less severe level of stress than performance anxiety. This semantic disagreement may stem from the fact that the term for stage fright in German is *Lampenfieber* (Mantel, 2003, p. 20), which literally suggests the performer becomes feverish under spot lights (Götz et al., 1993). Yet the shaking and perspiring of a fever differs from the mental anguish of a fright. Salmon (1990) suggests all terms for the nervousness associated with music performance be discarded and replaced with the single label – musical performance anxiety (MPA). Brodsky (1996) champions the use of music-performers' stress syndrome (M-PSS).

Anecdotally, performers tend to view “performance anxiety” as an academic term for stage fright or nervousness. Distinctions between other terms available for nervousness are rarely made. In fact, while in a theatre or concert venue “stage fright”, “having the jitters”, “being nervous”, “scared”, “freezing” or “choking” are not mentioned by performers at all. The reason may be the wish to avoid either auto-suggestion or the possibility of influencing fellow performers to focus on performance anxiety. For actors and singers this behaviour is often handed down as part of theatre lore, and acknowledges that some performers may hold to the superstition that to name something may summon its presence. Perhaps it is pertinent that not only is the theatre associated with many superstitious practices and rituals, but according to Barlow (2000) superstition and ritual are often the resort of the anxious.

The literature indicates that performance anxiety sometimes occurs in those who show a propensity for other anxiety disorders, in particular, social phobia. The body’s same automatic alarm response mechanisms that are linked to performance anxiety are also linked to panic attacks and phobic disorders (Mornell, 2002; Sataloff et al., 2000).
Nevertheless, for other performers, the experience of anxiety may focus solely on the performance situation (Kenny, 2008b).

When an alarm response is present the sympathetic and parasympathetic divisions of the autonomic nervous system do not work together to create a state of homeostatic balance. Instead, the sympathetic branch of the autonomic nervous system, acting in a massive and powerful way, may prepare the body for “fight-or-flight” activity. Alternately, the parasympathetic branch may initiate a “freeze-or-faint” response, sometimes referred to as a response from the “death nerve” (Mornell, 2002 p. 36). Thurman (1997) uses the comprehensive term, the “fight, flight or freeze response” when referring to the alarm response. In fact the sympathetic and parasympathetic alarm responses may to some extent become activated together, resulting in the anxious performer experiencing a mixture of symptoms, some stemming from sympathetic and some from parasympathetic activation (Mornell, 2002; Sataloff et al., 2000).

Somatic changes that occur as a result of the imbalance in function between the sympathetic and parasympathetic systems may include increased heart rate, muscle tension, a loss of fine motor control and acute awareness of surroundings. Often a widening of the airways produces a feeling of breathlessness. Under severe stress, hyperventilation and collapsing from lack of carbon dioxide may occur. Often breathing becomes fast, shallow and uneven. Additionally, changes in blood circulation and chemicals transported in the blood may cause confused thinking, concentration blackouts, a feeling of agitation and unpleasantness, frequent bladder emptying, diarrhoea, excessive sweating, cold hands, dry mouth, a constricted throat and difficulty in swallowing. Blood pressure may increase or become so low as to cause fainting. While some individuals may feel overheated and blush, others may turn ghostly pale. Some may experience a craving to eat, while others may feel nauseous. Headache, muscle spasms and insomnia may also result (Anthony and Thibodeau, 1979; Bartley and Clifton-Smith, 2006; Mornell, 2002; Salmon, 1990; Sataloff et al., 2000). The range of symptoms produced varies as individually as a fingerprint from person to person.

Likewise, an individual’s emotional reaction to anxiety and the alarm response may vary greatly from, for example, embarrassed giggling to anger. Depression may also possibly be an emotional reaction to anxiety (Sataloff et al., 2000), though Bartley
notes that whether depression is a consequence or a cause of anxiety lacks clarification. From the perspective of an ear, nose and throat medical specialist, Bartley suggests depression may impact on posture negatively, ultimately causing the same dysfunctional breathing symptoms as observed in patients suffering from anxiety and panic attacks. Certainly it is agreed that depression and anxiety are related (Bartley and Clifton-Smith, 2006; Grossman, 1983). In fact, the original use of the word “anxiety” to denote a sense of unease and sadness sounds very similar to a modern day description of depression.

Cognitive reactions may also occur in varying degrees as a result of anxiety. For example, sufferers of anxiety may both expect to fail and believe that failure may have dire consequences. They may experience a heightened responsiveness to the reactions of anyone deemed to be evaluating them, and expect to be negatively evaluated. Sometimes, even when positive feedback is given, anxious persons view their actions in retrospect as not achieving positive results (Wallace and Alden, 1997).

### 2.5.7 Factors that contribute to anxiety

Literature dealing with performance psychology suggests that specific anxiety conditioning experiences contribute towards the development of performance anxiety (Kenny, 2008b). For musicians, some anxiety conditioning experiences may be more directly linked to music performance than others. For example, if music performance demands are unachievable, then a connection between music performance and anxiety may be learnt. However, a person’s parenting and other interpersonal relationships also influence the role that anxiety plays in that person’s life (Kenny, 2008a). Lack of confidence arising from anxiety conditioning experiences is often expressed in negative self-talk and “catastrophising”, which in turn tends to contribute further to performance anxiety (Langeheine, 2004; Roland, 1997; Sataloff et al., 2000).

While not generally mentioning anxiety, pedagogical literature occasionally alludes to the adverse impact of negative thinking and depression on performance. Vocal pedagogues (Fields, 1984; Günther, 1992b) believe it is important the performer feels a sense of radiant contentment in singing, and stress the need for a joyful, relaxed atmosphere in the singing studio. It is even suggested that if a student is depressed then the lesson may need to be rescheduled (Günther, 1992b). Sataloff et al. (2000),
however, note that antidepressants are prescribed as a treatment for performance anxiety. In fact, the psychological literature on anxiety indicates that depression is closely related to anxiety (Barlow, 2000).

Performance literature suggests a relationship between poor posture, poor breathing and performance anxiety; though often links between all three factors are not presented in the one source. The influence of posture on breathing is emphasised in the singing literature (Brünner, 1993; Doscher, 1994; Miller, 2004; Vennard, 1968). The influence of breathing on anxiety levels, though seldom mentioned in singing texts, is widely acknowledged in literature dealing with stress management and performance anxiety (Langeheine, 2004; Roland, 1997; Stoyva, 2000). Additionally, musicians studying practices such as the Alexander technique learn to associate optimal posture with optimal performance outcome (Alcantara, 1997; De Graaff, 1994) and sometimes use Alexander technique as a means of coping with performance nerves (Brodsky, 1996; Mornell, 2002).

In literature dealing with ear, nose and throat problems, the physiological link between posture, breathing and anxiety is clarified. Bartley and Clifton-Smith (2006) explain how posture with the head extended too far forward and then tilted slightly up will tense both the jaw and the muscles at the back of the neck, compromise spinal stability, the tilt of the pelvis and the mobility of the lower back. Lower back mobility is important to optimal breathing because diaphragmatic crura, a muscular portion of the diaphragm, attach to the lower spine. If low back mobility is restricted, this leads to low back tension, the free functioning of the diaphragm is impeded and shallow upper chest breathing then takes over. Bartley maintains these symptoms serve to activate the alarm response and panic attacks. He notes, however, that slumped posture with the head held in an extended forward position and tilted up somewhat in order that the person may see ahead is typical of patients suffering from depression. Hence, Bartley presents the possibility that a psychological trigger such as depression may encourage the poor posture which leads to poor breathing, resulting in the alarm response.

To date, both sports and music performance literature tends to stress that the fundamental cause of anxiety is the perception of being in a threatening situation (Cox, 2007; Roland, 1997; Sataloff et al., 2000). It does not matter whether the threat is coming from an encounter with a wild animal, the sight of a critic in the audience or
even the thought or dream of being negatively evaluated by judges, a sense of threat produces anxiety. For the musician who equates failure in performance with failure as a person, performance anxiety may be particularly severe, as the threat is to the person’s identity and sense of self-worth (Kenny, 2008b).

Whether or not a musician sees a situation as threatening depends on a number of factors. One is the musician’s level of musical competence or level of task mastery. Yet optimal task mastery alone is not sufficient to avert performance anxiety. Some musicians suffer performance anxiety irrespective of years of training, practice and level of accomplishment (Kenny, 2008b). Another factor is the musician’s subjective evaluation of the level of threat present in any given situation and belief in his or her ability to meet the perceived demands of that situation. Anxiety which varies according to the situation is known as state anxiety (Mornell, 2002). State anxiety, in part at least, may involve conditioned responses depending on whether similar situations have occurred and been interpreted positively or negatively. A third factor is trait anxiety, which reflects the role anxiety generally plays in an individual’s personality irrespective of the situation. Trait anxiety may be linked to a number of factors including genetically inherited predisposition (Barlow, 2000). Kawamura, Hunt, Frost and DiBartolo (2001) suggest that the role played by perfectionism in a person’s life, which itself appears to be a response to specific conditioning, may impinge on trait anxiety.

Wilson (1997, 2002) maintains it is the interplay of task mastery, state anxiety and trait anxiety that largely determines the level of anxiety a person may experience and the severity of any subsequent alarm response. Teasing out the complexities of this statement, it would appear that a vast network of factors is involved. To summarise the factors presented here, they include the performer’s inherited biological vulnerability, plus conditioning relating to both performance experiences and to interaction with the world in general. They include the quality and quantity of instrumental practice that has taken place, plus the performer’s perfectionist tendencies and susceptibility to depression especially if perfection seems illusive. All these factors influence the degree to which a performer establishes a confident or negative mindset, in turn influencing postural and breathing habits.
2.5.8 Anxiety as performance enhancing

Some musicians attempt to see nervousness in a positive light and think of it as a form of excitement (Smith, 2004). Some maintain that anxiety heightens their performance (Fehm and Schmidt, 2006; Roland, 1994; Steptoe, 1989; Wolfe, 1989, 1990b). However, the studies of Wolfe (1989, 1990b) which reported anxiety as sometimes enhancing performance, relied on responses from members of recorder ensembles, handbell choirs and choral groups. To a large extent responses were from amateur and part-time musicians involved in group community performances. Group performance situations may produce less anxiety than solo performance situations as the musician is shielded from a degree of exposure (Roland, 1994; Simon and Martens, 1979). Wolfe (1990b) states that the age range of respondents was 10 to 86 years, and that the studies conducted were specifically not directed at tertiary music students. The critical evaluation of tertiary music students’ performances is sometimes associated with “intense” anxiety responses (Craske and Craig, 1984, p. 277). The Wolfe studies were also not directed at members of professional orchestras where performance anxiety is sometimes noted as a “severe health problem” (Wolfe, 1989, p. 49). Wolfe (1990b) points out, had responses come more from aspiring and professional soloists, then different coping strategies may have come to the fore. It could also be argued that ringing handbells does not involve the fine motor coordination skills required of pianists or most orchestral instrumentalists, who may consequently have very different needs regarding anxiety levels.

To what extent aspiring and professional musicians genuinely believe in the enhancing effect of anxiety is difficult to assess. Often professional musicians are not forthcoming about their anxieties, for fear of repercussions should management think them unfit for employment (Brodsky, 1996). It could be that some musicians simply attempt to gain a psychological advantage by making positive affirmations about anxiety. A positive response in a questionnaire or to an interviewer is akin to positive self-talk, a recommended and commonly used strategy for coping with anxiety (Langeheine, 2004; Roland, 1994, 1997; Wilson and Roland, 2002). Many people, however, do not even acknowledge their fears privately to themselves, as a means of coping with stress (Weinberger, Schwartz and Davidson, 1979). Certainly, those who claim that anxiety is a positive factor in performance are at odds with Salmon who states:

“
In reality, it is a heightened state of arousal – not anxiety – that performers attempt to optimize” (Salmon, 1990, p. 4).
Anxiety is such a complex construct that consensus amongst all performers regarding its value is not possible. On the one hand, heightened arousal is necessary for optimal music performance (Salmon, 1990; Wilson and Roland, 2002); and becoming anxious is one way of increasing the level of arousal. Yet the performer must promote sufficient relaxation to counteract the negative symptoms of imbalanced autonomic nervous system activity (Brontons, 1994; Roland, 1994). For a performer to maintain that performance improves because of anxiety displays a very positive attitude and generous approach to self-assessment not normally found in high anxious individuals. Wallace and Alden (1997) found that high anxious individuals exhibit a negative bias in self-evaluations of their performance. It would therefore seem that if performers genuinely believe anxiety produces enhanced performance, such performers are probably low anxious individuals in situations where the demands placed upon them are met with minimal difficulty. Perhaps Salmon’s statement that performers need to raise arousal levels, but not anxiety, may best be directed to high anxious individuals in demanding situations.

Nevertheless, how do listener-judges assess performances given under varying degrees of stress? Based on listener-judges’ assessments of recorded performances, Hamann (1982) concluded that anxiety combined with high task mastery produces enhanced performance. In the Hamann (1982) study, tertiary music students, whose training varied from 1 to 15 years, were identified as possessing either high or low levels of task mastery. Each student made two recordings of the same free-choice piece after which anxiety levels were self-rated. One recording was made before an audience and the other was made alone. However, the audience consisted of their fellow repertory class members and instructor, the venue was familiar, and the performance was not presented as competitive. Indeed, it is accepted practice that tertiary music students regularly perform in front of each other. Although the students registered more anxiety in front of their class, it is unclear from this study whether, in more taxing situations greater anxiety still would enhance performance.

Furthermore, no recordings were taken that represented the students’ usual performance standards and anxiety levels during lessons on the piece with their teacher. A more robust methodology could have included this third condition. It could then clarify whether performances before an audience were better, worse or merely similar in standard to those recorded during lesson time. With Hamann’s two
performance conditions, it cannot be ruled out that rather than improving in standard when in front of an audience, as Hamann concluded, perhaps the high task mastery students simply suffered from insufficient arousal and subsequent lowering of standard when playing alone.

The Craske and Craig (1984) study also used listener-judges to rate tertiary music students with and without an audience. In this study all music students, pianists, were considered to possess a sufficient level of task mastery. The audience situation, however, was designed to induce distress. A video camera was prominently displayed and a five member audience was introduced as a judging panel of accomplished pianists and experts in behavioural assessment. Craske and Craig (1984) found those students classified as low anxious were judged as improving their performance when more anxious, in front of the judging panel. However, as with the study of Hamann (1982), no recordings were made of students’ regular performance standards during lessons with their teacher. Therefore, the possibility remains that under conditions of increased anxiety, the performance judged as “significantly improving” (Craske and Craig, 1984, p. 274) may have been no better than the usual standard exhibited during a lesson where stress was perhaps minimal. The Hamann (1982) and Craske and Craig (1984) studies do indicate, however, that under conditions of increased anxiety, it is the low anxious musicians in possession of high task mastery who are more likely to cope best.

2.5.9 Anxiety as performance debilitating

The literature often notes that anxiety amongst music students hinders optimal music performance and is in need of subduing (Fehm and Schmidt, 2006; Langeheine, 2004; Mantel, 2003). Professional performers, for all of whom high task mastery is mandatory, frequently claim to suffer from unwanted performance anxiety. The study of Van Kemenade, Van Son and Van Heesch (1995) found 59% of musicians in symphony orchestras reported anxiety so severe as to impair performance. James (1998) found that from 56 orchestras, 70% of musicians reported anxiety so severe as to impair performance. Sometimes those who suffer from debilitating anxiety when confronted by public performance prematurely terminate their career (Clark and Agras, 1991; Steptoe and Fidler, 1987).
2.5.10 Strategies to manage anxiety

In a review of treatments for music performance anxiety, Kenny (2008d) notes that it is difficult to draw firm conclusions from the literature about the effectiveness of the various approaches taken, due largely to a lack of consistency and strength in research methodologies. There is also no assurance that high anxious performers may ever manage to subdue anxiety to the level of their low anxious colleagues, as complete cure from unwanted anxiety is not always possible (Kenny, 2008b). Nevertheless, musicians use many practices in an attempt to manage their anxiety levels.

Often musicians are advised:

“Take every opportunity to build up your performing experience, moving gradually on to the more demanding situations…” (Tarrant, 2008, p. 16).

Yet many professional musicians, having incrementally progressed from simple childhood performances in front of the family, to school age performances associated with carefully graded examination systems, small performances at secondary school, larger performances at tertiary level and eventually professional performances with major orchestras, still suffer performance anxiety. Several studies indicate that performance anxiety and years of experience are not related (Caine, 1991; Clark and Agras, 1991; Wesner, Noyles and Davis, 1990). Enrico Caruso said:

“Of course I’m nervous. The artist who boasts he is never nervous is not an artist – he is a liar or a fool” (Caruso, 1963, p. 76).

Beliefs that performance anxiety is best treated by not mentioning it and that the answer lies solely in “practice, practice and more practice” are also flawed (Mornell, 2002). Efficient and extensive practice is critical to high level success (Ericsson et al., 1993), yet a combination of strategies may be necessary to tackle anxiety. Questioned about how anxiety is managed, 162 respondents in the study of Wolfe (1990a) offered 478 strategies. This represents an average of three strategies per respondent.

Sports research lends support to the use of a package of strategies for anxiety management. Strategies often combine warm-ups and extensive practice with positive self-talk, relaxation and imagery of successful performance (Barr and Hall, 1992; Cox, 2007; Hall, 1995; Hall et al., 1998; Moritz et al., 1996; Orlick and Partington, 1988; Rushall, 1991; Smith, 1991; Vealey and Greenleaf, 1998; Williams and Harris, 1998; Zinsser, Bunker and Williams, 1998).
Activities reported in music performance literature include warm-up, breathing awareness, meditation, prayer, positive self-statements, imagery, mental rehearsal, self-hypnosis, muscle relaxation exercises and Alexander technique (Brodsky, 1996; Clark and Agras, 1991; Fehm and Schmidt, 2006; Hines, 1982; Kenny, 2008d; Langeheine, 2004; Mantel, 2003; Mornell, 2002; Roland, 1994, 1997; Wesner et al., 1990; Wilson and Roland, 2002; Wolfe, 1990a). Additionally, performers may come to believe in certain anxiety reducing rituals or objects (Hines, 1982; Mantel, 2003; Roland, 1994, 1997; Wilson and Roland, 2002). Performance day rituals often combine a number of the above-mentioned strategies.

Despite research efforts demonstrating the effectiveness of cognitive-behavioural therapies (Brodsky, 1996; Kenny 2008a), professional counselling or psychotherapy tend to be “seen as a last resort” by musicians (Brodsky, 1996, p. 94). Cognitive therapy involves changing the way the performer thinks, so that inappropriate muscle tension does not build up. Cognitive therapy generally tries to replace negative, catastrophic thinking with more realistic appraisals of performance and positive self-talk. Behavioural therapy generally addresses muscle tension with the use of relaxation exercises. Relaxation exercises may also be combined with imagery of the performance situation and mental rehearsal. Cognitive-behavioural therapy is a combination of both approaches, which is then applied to the performance situation and evaluated for effectiveness post-performance (Kenny, 2008a).

Musicians often avoid professional counselling or psychotherapy that would introduce them to cognitive-behavioural strategies for fear of being perceived as mentally ill (Brodsky, 1996). However, many performers amass a number of cognitive and behavioural based strategies for coping through other means (Esplen and Hodnett, 1999; Fehm and Schmidt, 2006; Roland, 1994). This may involve attending music seminars, picking up hints from master classes, reading the many popular books dealing with stress and performance anxiety, such as The Inner Game of Music (Green and Gallwey, 1986) or The Confident Performer (Roland, 1997), seeking out breathing workshops or meditation classes, seeking advice from people they know and trust, and using a trial and error approach until strategies are found that work for the individual.

A considerable number of performers, however, appear to forgo the use of cognitive-behavioural approaches in favour of less effective methods perceived to be quick and
easy (Brodsky, 1996). According to Brodsky (1996), the most frequently used methods to cope with performance anxiety are substance-related, that is, alcohol, recreational drugs and prescription medication.

Fishbein, Middlestadt, Ottati, Straus and Ellis (1988) conducted a national survey of professional orchestral musicians. Of those musicians who suffered from severe performance anxiety, the most frequently reported method of coping (used by 40%) was “prescribed medication”. In another study of professional musicians from two major London orchestras, Steptoe and Fidler (1987) reported that 32% used some form of meditation to alleviate anxiety, and 21% used sedatives. In the same study 51% of advanced undergraduate students stated they used alcohol to cope with performance.

Sataloff et al. (2000) and Wilson and Roland (2002) maintain that neither alcohol nor anxiolytics (i.e. pharmacological drugs claiming to reduce anxiety) should be used due to factors such as addiction, potentially dangerous side effects and the lacklustre performances that often result.

In the Roland (1994) study of professional musicians, 10% used sedatives regularly; a further 20% used sedatives occasionally. Alcohol or recreational drugs were used by 7%. However, it was noted that in addition, the performers regarded many other non substance-related strategies as important in managing anxiety. All saw musical practice over a very long term as essential in the management of performance anxiety, and a good warm-up prior to performance was often part of their pre-performance routine to facilitate physical and psychological preparation. Nearly all performers (97%) used mental rehearsal of the music, sometimes together with reading through the score or words of their performance; 80% used visual imagery of rehearsal; 71% used slow diaphragmatic breathing; and 69% used positive self-talk.

Use of sedatives and alcohol were lowest in the study of Wolfe (1990a), which relied to a large extent on responses from amateur and part-time musicians involved in group community performances. Only 2.3% of respondents used “drugs / alcohol before performance”. The most frequent strategies reported were “thorough preparation / practice / coaching”, used by 24.3% of respondents, and “deep breathing / relaxation / physical activity”, used by 15.5% of respondents (Wolfe, 1990a, p. 35). The study grouped meditation with “prayer / meditation / imagery / visualization” (used by 7.3% of respondents) rather than with deep breathing. However, deep breathing is fundamental
to meditation (Bartley and Clifton-Smith, 2006). It follows that Wolfe’s mediators were also deep breathers, just as the 32% of professional musicians in the Steptoe and Fidler (1987) study mentioned above must have employed deep breathing in the process of meditating.

Interestingly, in the Wolfe (1990a) study, strategies including “deep breathing / relaxation / physical activity” and “prayer / meditation / imagery / visualization” were predominantly linked with the reporting of greater confidence and competence, and less self-consciousness and distractibility. This suggests that by using these strategies, not only was anxiety held at bay, but existing symptoms of anxiety were attenuated.

This is in accord with Bartley and Clifton-Smith (2006) who maintain that slow, deep breathing as found in meditation may be employed not only to prevent anxiety from surfacing, but may, if necessary, be employed to reverse existent anxiety responses. Changing breathing patterns to a slower rate and the use of low, diaphragmatic breathing is linked not only to restoring the homeostatic balance of bodily function, but also to reductions in both the subjective and physiological indicators of anxiety (Bartley and Clifton-Smith, 2006; Grossman, 1983). Indeed, many professional performers in the Roland (1994) study stressed the importance of employing breathing exercises to deal with unexpected performance anxiety “on the spot” (Roland, 1994, p. 32).

With strategies such as deep breathing to reverse the anxiety response, it is possible for musicians to accept the concept that “Instead of running away from anxiety, it is wisest to ‘move through it’ …” (Reubart, 1985, p. 13). Performers are often advised to accept performance anxiety as inevitable but totally natural, as acceptance often attenuates the symptoms of anxiety (Salmon and Meyer, 1992). “Moving through it” could involve the performer becoming aware of excessive anxiety, changing to slow diaphragmatic breathing, and then trusting that further signs of anxiety will abate.

2.5.11 Optimal performance and warm-up

From the literature reviewed, it would appear that for the greatest chance of optimal performance, it is vital that the performer have a high level of task mastery, can generate arousal levels that meet the technical and artistic demands of the repertoire, but can also subdue anxiety to a manageably low level. Some musicians attain these
goals without necessarily being low anxious individuals. Enrico Caruso (Caruso, 1963; Vennard, 1968) and Pablo Casals (Mantel, 2003; Salmon, 1990) were both renowned for being high stress individuals. However, performers coping with high stress generally employ numerous compensatory strategies to subdue anxiety (Kenny, 2008c). For example, they may “over-learn” the repertoire and they may arrive at the venue particularly early in order to settle down and feel a sense of familiarity with the surroundings (Kenny, 2008c).

All successful performers appear to use strategies not only for attaining a high level of task mastery, but also for keeping anxiety in check while assuring optimal arousal levels for performance (Brontons, 1994; Hines, 1982; Roland, 1994). Strategies recommended in the literature are based largely on

• maximising efficient practice so that confidence is increased in the ability to respond to performance demands
• learning to modify the perception of threat
• learning to identify the sensory signs of appropriate arousal, and where necessary, to adjust excessively low or high arousal levels.

Vocal warm-up is capable of playing a role in all these areas. Vocal warm-up is considered to make healthy, efficient practice possible. The exercises involved assist in attaining the vocal facility necessary for high task mastery. Knowing that the voice is functioning well and using warm-up as part of a performance day ritual contributes towards a sense of control and relieves an element of anxiety. In addition, vocal warm-up may assist in activating the vocal musculature until an appropriate arousal level is reached.

The literature does not suggest that vocal warm-up is a fast solution to deal with unexpected performance anxiety “on the spot”. Performers tend to use other strategies such as slow, diaphragmatic breathing for this purpose. The literature fails to mention whether vocal warm-up may be linked to the release of mood enhancing endorphins which may serve a similar function to antidepressants currently used in the treatment of performance anxiety. Yet overall, the literature strongly recommends that warm-up be used in combination with other worthwhile techniques for optimal performance.
2.5.12 Review of vocal warm-up studies

2.5.12.1 Acoustic and physiological studies

Little formal investigation has taken place to clarify what happens during vocal warm-up and why it is that trained singers experience the impression of improved vocal quality. Acoustic and physiological studies investigating vocal warm-up have, to date, focused on the speaking voice (Milbrath and Solomon, 2003; Vintturi et al., 2001), on voices with vocal problems (Blaylock, 1999), on the untrained singing voice (Stemple, Lee, D'Amico and Pickup, 1994) and occasionally on the trained singing voice (Amir et al., 2005; Elliot et al., 1995; Motel et al., 2003). It is the studies dealing with the trained singing voice which will now be reviewed.

Elliot et al. (1995) investigated the effect of a 30 minute vocal warm-up on phonation threshold pressure. It was hypothesised that warm-up would cause increased blood flow in muscles and consequently decrease vocal fold viscosity, which in turn would produce systematic changes in phonation threshold pressure. However, phonation threshold pressure varied greatly between the ten singers in the study, increasing with pitch for some singers, decreasing with pitch for others, and remaining broadly unaffected by pitch in yet others. It was concluded that there must be other more important factors associated with warm-up than changing phonation threshold pressure. Also measuring phonation threshold pressure, Motel et al. (2003) gave singers aged 19 to 21 years, a 10 minute warm-up. Although all singers reported the warm-up to be insufficient for optimal performance, and results were found to vary greatly between singers, six out of nine singers nevertheless experienced elevated phonation threshold pressure at high pitch. Motel et al. (2003) concluded that vocal warm-up may cause an increase in the viscosity of the vocal fold’s mucosal cover from a loss of water while simultaneously water absorption may increase in the vocal fold’s muscular body, that is, the thyro-arytenoid or vocalis muscle. This, they argued, may serve to stabilise high notes.

Amir et al. (2005) studied warm-up effects in 20 female singers, most of whom were younger than those in the studies mentioned above (mean age = 18.6 years, SD = 3.2 years). Neither specific exercises nor a specific time frame were set for each singer’s warm-up. Some singers took 7 minutes, others 23 minutes, the average warm-up time being 11 minutes. Many singers did not warm-up solely with vocal exercises, as in the
studies of Elliot et al. (1995) and Motel et al. (2003), but incorporated exercises for body posture, relaxation and breathing as well. Thus, vocal warm-up time was generally less than 11 minutes. Mean results indicated significant improvement after warm-up in perturbation (i.e. small irregularities) of frequency and amplitude parameters, in the noise-to-harmonic ratio and in the singer’s formant amplitude as measured by the singing power ratio. The singing power ratio results, however, warrant further consideration.

The singing power ratio (SPR) expresses in decibels the difference between the greatest energy peak from 0 to 2,000 Hz and the greatest energy peak from 2,000 to 4,000 Hz. Omori et al. (1996) first presented the concept of measuring the SPR and using it to distinguish between singers and non-singers. They found the SPR is lower for non-singers than for singers. Of the females assessed by Omori et al. (1996), namely 10 non-singers, 8 amateur singers and 13 professional singers, the mean SPR was -24.2 for non-singers, -16.9 for amateurs and -14.0 for professionals. A similar though marginally higher series of incremental values was produced by males. Unfortunately, the mean SPR values noted by Amir et al. (2005) of -29.25 before warm-up to -27.82 after warm-up, show that despite warm-up the subjects produced lower SPR results than even non-singers, when compared to Omori et al. (1996). Although Omori et al. (1996) found no statistically significant relationship between SPR and the singer’s age, Omori’s subjects represented a more mature age group (mean age = 32.4 years, SD = 10.9 years) than those in the study of Amir. Clearly the acoustic results of Amir et al. (2005) using a subject pool predominantly of teenagers, should not be seen as representative of the adult voice.

**2.5.12.2 Singer-subject perceptual assessment**

Perceptual studies of the warmed-up voice have, to date, only involved singer self-assessments. In the study of Elliot et al. (1995) 10 amateur choral singers aged 22 to 57 years reported improvement following warm-up in vocal tone colour and ease of singing, particularly at high pitches. The voice after warm-up appeared to be “a more obedient instrument” (Elliot et al., 1995, p. 39). This description concurs with Sundberg who notes that if singers do not warm-up, their voices will “not function as readily as otherwise” (Sundberg, 1987, p. 192).
Duncan (1997) gave 10 student singers, aged 20 to 23 years, a list of 17 aspects of voice production. They were asked to self-rate their voices accordingly, both with and without an initial vocal warm-up. Results showed that the majority of singers perceived warm-up to be linked to improvement in vocal range, onset of sound, fine adjustments in volume, focus, placement, vocal quality and energy levels. Among those features for which only a minority of students perceived change following warm-up, one fifth of students perceived improvement in “even vibrato” (Duncan, 1997, p. 70). Other aspects of vibrato change, such as perceived increases or decreases in overall vibrato rate or extent were not included for rating.

Duncan (1997) does not indicate if definitions were supplied or agreement otherwise reached between researcher and student as to the meaning of the features rated. Consequently, it is not clear whether distinctions between terms of imagery on the list such as “focus” and “placement” were teased out prior to rating. Nor is it clear whether “energy levels” were understood as referring to the singer’s state of arousal or, as Duncan (1997) sometimes implies, referred to the sensation of effort required to sing. When voice production is rated perceptually, it is important to ensure that where terminology could prove ambiguous, definitions are provided (Oates, Bain, Davis, Chapman and Kenny, 2006). Nevertheless, Duncan (1997) does offer insight into warm-up from the singer’s perspective and lends support to anecdotal reports that the vocal range and quality of sound produced, as well as the kinaesthetic sensations that the singer associates with sound production are all influenced positively by vocal warm-up.

In both perceptual studies the majority of singers felt clear differences in vocal function after warming up (Duncan, 1997; Elliot et al., 1995). Whether clear distinctions are as apparent to listeners is not known. Listener-judge perceptual evaluation of the voice before and after warm-up is an area of vocal study that lacks research.

2.6 LISTENER-JUDGE PERCEPTUAL EVALUATION OF VOICE

Designing a protocol for reliable listener-judge perceptual evaluation of vocal tone quality has, to date, proved problematic. Vocal pedagogues pride themselves on being able to assess fine gradations of tone quality when listening to singers in the teaching
studio. Yet reliability is often elusive when vocal samples are perceptually assessed under research conditions. The review of Kreiman, Gerratt, Kempster, Erman and Berke (1993) reveals “a rather bleak picture of the current state of voice quality ratings” (p. 32). Effective methods of evaluation are still not assured. Ryan and Kenny (2008), for example, found that while singers could correctly distinguish between the vocal quality of two audio samples of their own voice, highly experienced vocal pedagogues could not perceive any difference. Effective methods of evaluation must ensure that listener-judges are consistent in their marking standards and that there is considerable agreement amongst listener-judges as to what vocal qualities are present and the extent to which that particular quality is present.

2.6.1 Review of rater reliability in perceptual studies

2.6.1.1 Tone colour terminology

Some perceptual qualities appear to be easier for listener-judges to reach agreement on than others. For example, deciding whether a voice is in tune or not seems to pose few problems and singing studies have found strong rater agreement with this fundamental musical skill (Oates et al., 2006; Wapnick and Ekholm, 1997). By contrast, both inter- and intra-judge agreement on the perception of vocal tone colour is problematic (Wapnick and Ekholm, 1997; Vurma and Ross, 2002). Van den Berg and Vennard (1959) express concern that with few terms for vocal tone colour possessing an established physiological or acoustic basis, even professional musicians display a degree of inconsistency when using tone colour terminology. Defining any given tone colour is also problematic because the adjectives musicians use to describe tone colours are relative. That is, tone colours are gradations of other tone colours, changing their name according to the colour intensity or sense of desirability that some cultures may attach to a particular colour. For example, a “bright” voice becomes “piercing” when the brightness is too intense; “dark” becomes “muddy” when it is overly dark and no longer desirable. As for fine distinctions where one colour becomes another, and where “acceptable” becomes “good”, the literature suggests that judges have their own personal standards.
2.6.1.2 Calibre of vocalists

Another factor influencing rater reliability and agreement appears to be the varying calibre of participating vocalists. Although there is a universally recognised beauty in the tone quality of singers of international standing (Miller, 1977, 2004), opinions differ widely regarding the acceptability of voices of lesser calibre (Miller, 1977). Hence, agreement may be more easily reached when rating excellent rather than gradations of lesser vocal quality. In the study of Oates et al. (2006) professional singers from a national opera company were assessed. There was a much higher degree of both intra-judge consistency and inter-judge agreement compared to other studies that assessed voices of more wide ranging or lesser calibre. The Wapnick and Ekholm (1997) study, for example, rated singers that varied widely in level of accomplishment, from novice to advanced, and found such high intra- and inter-judge variability that they concluded that “even experts have difficulty in evaluating vocal quality” (p. 435). Reliability in this study did not appear to be related to age, teaching experience or adjudication experience amongst the judges, but the authors did find that

“... judges appeared to be more reliable for very good performances than they were for average performances” (Wapnick and Ekholm, 1997, p. 432).

Similar findings regarding middling and outstanding vocal assessment appear in the literature covering the spoken voice. Kreiman et al. (1993), for example, found that listeners disagree most about the extent of mild-to-moderate vocal behaviour. Where vocal quality is less than ideal, Wapnick and Ekholm (1997) noted that one reason for low rater agreement could be that professional examiners of singing have learnt to adjust their personal marking standards according to the level of the singer. Consequently, it would appear that before reaching the highest level there is no standard by which all voices are judged.

2.6.1.3 Personal rater standards

Personal standards that judges rely on for rating vocal quality are, however, prone to drifting. Drift in personal standards may occur from situation to situation and even within a single rating period, irrespective of training or formal experience (Kreiman et al., 1993). This influences both intra- and inter-judge reliability. Kreiman et al. (1993), who studied the impaired speaking voice found, for example, that during extended rating sessions of voice qualities, if most voices are rated as being somewhat similar, then the judge’s personal standards may become altered such that an exceptional
voice may appear more so, causing a systematic drift in ratings. Ratings of sung quality may similarly drift. Wapnick and Ekholm (1997) noted a judge's rating may drift to become more lenient for timid amateur singers than for professional performers.

Kreiman and Gerratt (1998) and Kent (1996) maintain that reliable rating of vocal quality is greatly hindered because in traditional rating protocols judges rely only on an aural memory of their personal standard to assess voices. Both Kreiman and Gerratt (1998) and Kent (1996) suggest that “reference voices” are needed, providing fixed external standards which would negate drift and inconsistent internal representation of a quality. Setting up a data base of reference voices could prove an enormous and complex task as the singing voice has over 20 broad vocal classifications from soubrette to seriöser Bass alone (Wapnick and Ekholm, 1997). It should be acknowledged, however, that last century Van den Berg and Vennard (1959) recommended that such a data base of vocal qualities be made.

Yet even with reference voices, reliability is not assured. From studies of the impaired speaking voice, Kreiman and Gerratt (1998) note that agreement amongst raters quickly declines if the reference voice used as an “external anchor” for an assessment is less than identical to the voice being assessed. They also caution that “All tasks are subject to errors due to individual differences, perceptual biases, influences of perceptual context, mistakes, and changes over time in attention to … complex multidimensional stimuli” (Kreiman and Gerratt 1998, p. 1606).

2.6.1.4 Number of samples
Kent (1996) reports that it is human nature to commonly have lapses in perception and “mishear”. Some situations in which listener-judges are subjected to a large number of vocal samples may be innately flawed. In Kent’s study of speech voice quality he found that if a word or a segment of speech is played repeatedly for a long time, the listener often reports changes occurring which are not there.

“Auditory-perceptual processing is not perfectly reliable” (Kent, 1996, p. 10).

2.6.1.5 Sample duration
It is also interesting to note that the strongest degree of listener-judge reliability and agreement obtained in the Mitchell (2005) study was when two single note vocal
samples of the one singer were presented in a row for paired assessment. A lesser degree of reliability was obtained when longer vocal samples representing six different singers were randomly mixed for assessment one after the other. This lends support to the notion that short samples present fewer rating problems than long samples, and suggests that assessments of different samples of the same voice may be more reliable when made one after the other, rather than randomly presented with other voices.

However, presenting short vocal samples consisting of only three notes each and using a somewhat homogenous singer subject pool of tertiary singing students, Vurma and Ross (2002) still found considerable listener-judge ambivalence when “forward” and “backward” vocal tones were assessed. Vurma and Ross (2002) suggest that perhaps some singer-subjects were not clear themselves about what the differences between the two qualities should be.

Three note vocal samples used in the study of Erickson (2009) also failed to produce reliable listener-judge assessments. Of the three notes, each sung at different pitches, two notes were sung by the one singer and one note was sung by another singer. Once the intervals sung spanned an octave or more, both experienced and inexperienced listener-judges predominantly chose the note most dissimilar in pitch as sung by the different singer. When the most dissimilar pitch was not sung by the different singer, correct identification even by experienced judges was only at or below chance, averaging 27.5%.

2.6.1.6 Specific perceptual decisions

The literature often indicates that assessments involving detailed or subtle unidimensional aspects of vocal quality are associated with poor inter-judge and intra-judge reliability (Kent, 1996). Kreiman and Gerratt (1998) reviewed five studies on spoken vocal quality and found that listeners were unable to selectively attend to individual aspects of quality. They question the validity of attempting to aurally dissect a complex vocal sound into component aspects and rating each aspect individually, as is generally done in perceptual assessments of voice quality. Moreover, studies of the singing voice (Ekholm et al., 1998; Kent, 1996; Wapnick and Ekholm, 1997) suggest that individual vocal qualities are not generally independent. In the Ekholm et al. (1998)
study, for example, faulty intonation, although not even specifically rated by listeners, appeared to adversely influence all the ratings for one particular singer, no matter what specific quality was under investigation. Furthermore, it has been suggested that the more a detailed rating is requested of a multi-dimensional sound signal, the more some judges may have their own understanding of what component cues are relevant, thereby decreasing inter-judge agreement (Kreiman and Gerratt, 1998).

Perhaps the task of rating large sample numbers for an individual aspect of vocal quality, for which raters had their own understanding of relevant component cues, may account for the total lack of agreement amongst listeners in the study of Rothman and Timberlake (1984). The study presented twenty samples of a single sung vowel to listener-judges, all of whom were singing teachers. The task given was to assess whether the samples displayed straight tone, vibrato, tremolo or wobble. Definitions of these terms were provided, yet no consensus was reached for any sample and often responses differed radically. For example, in one sample 58% of responses agreed the sung vowel displayed straight tone, but 42% thought it was either vibrato, tremolo or wobble. For professional singing teachers to mistake straight tone for wobble, or vice versa, seems astounding as it could be thought that the perceptual difference between these two qualities is not slight. Yet Rothman and Timberlake suggest that those samples with “no ring” in the tone colour appeared to be frequently confused for samples displaying straight tone (Rothman and Timberlake, 1984, p. 113).

2.6.1.7 Broad perceptual decisions
Assessments requiring broad perceptual decisions about vocal quality, on the other hand, often receive higher rater reliability than those which involve detailed discrimination. Listener-judges tend to agree with one another if asked to decide which voices are moderately similar in overall quality (Kreiman and Gerratt, 1998), if asked to identify girl from boy choristers (Howard, Szymanski and Welch, 2002), or to broadly rate overall performance quality of individual singers (Wapnick and Ekholm, 1997).

However, not all studies follow this trend. Barnes (2007) used highly experienced listener-judges, eliminated listener-judge fatigue by limiting sample numbers to ten and limiting sample duration to ten seconds, and yet found little agreement amongst raters for a broad perceptual decision on the overall quality of individual professional operatic
soprano voices. Perhaps, unlike the varied quality of singers in the study of Wapnick and Ekholm (1997), the singers in the Barnes study were all so outstanding that rating merely reflected subtle variations in personal taste. Nevertheless, the raters in the Barnes’ study reached significant agreement on a task requiring considerable detailed discrimination, namely, deciding the likely carrying power of individual voices if orchestral accompaniment were to be involved.

2.6.1.8 Rating scales

Rating scales used by listener-judges have also encountered criticism. Traditional rating methods such as Visual Analogue (VA) scales or Equal Appearing Interval (EAI) scales are generally used to assess the perceived strength or amount of a particular vocal quality, but appear to be associated with poor intra- and inter-judge reliability (Bergan, Titze and Story, 2004; Kent, 1996). Although EAI scales may commonly extend from 0 to 3 (Bergan et al., 2004) or from 0 to 7 (Kreiman and Gerratt, 1998), Bergan et al. (2004) used a somewhat larger rating scale from 0 to 10 and found that even if a scale enables finer judgements of vocal qualities, increased freedom of judgement produces decreased inter-rater agreement and a tendency for raters to use only the middle values. How well rating scales can reflect subtle variation in vocal quality has not been established (Oates et al., 2006) and it appears this problem applies regardless of whether uni-dimensional or overall features are assessed.

Callinan-Robertson et al. (2006) incorporated both a 10 point scale to rate singers’ overall quality and a 5 point scale to rate head tone, vibrato and richness/warmth. However, the study concluded that when one singer in a group is at a better standard compared to the others, then the better singer may receive a consistently high rating regardless of change in experimental conditions while singers of lesser vocal ability are rated lower irrespective of experimental conditions.

2.6.1.9 Forced choice assessment

Mitchell (2005) avoided rating scales and instead gave listener-judges a forced choice yes/no option regarding whether they heard “open throat” in classical singers. Strong intra- and inter-rater reliability was achieved in most cases. Reliability seems to have been further assisted by using singer-subjects of fairly similar calibre and requesting a broad perceptual decision from the listener-judges. That is, open throat is described as
“fundamental” (p. 20), “essential” (p. 20 and p. 101) and “critical” (p. 95) to good classical singing (Mitchell, 2005). Mitchell also notes the following wide ranging descriptions of open throat that were supplied by experienced singing teachers. It produces a voice which is clean, pure, free, healthy and unconstricted. It is a well-coordinated sound giving a sense of evenness and ease. It produces a round, warm, rich and full sound; a bigger, more secure, stable, confident and effective sound. It facilitates a voice which is resonant, has better ring, concentrated energy and a range of beautifully balanced harmonics. Furthermore, it is a sound quality which makes technical dexterity possible and requires good breathing (Mitchell, 2005). The breadth of vocal qualities linked to open throat technique and the fact that all are associated with good singing appears to have assisted reliability. Even the singer-subjects described open throat singing as their “best” singing (Mitchell, 2005, p. 94). As Mitchell acknowledges, studies indicate that listeners tend to be reliable when making gross judgements, for example, when assessing good or poor performance. Thus it follows that listener-judges were particularly reliable in this perceptual study.

Reliability weakened in the Mitchell (2005) study, however, in the case of singer 5 who, compared with the other singers, performed relatively well irrespective of the experimental condition. She was most often assessed by listener-judges as singing with an open throat even in samples where she had been asked to close her throat somewhat. Reliability also deteriorated with singer 6 where vocal quality was neither definitely good nor definitely bad, but somewhere in between the two. Mitchell suggests this lack of reliability may have been due to judge confusion as to the exact standard of the singer being assessed. In other words, the varying judge presumptions of singer standard influenced whether assessments veered on the side of lenience or not. The lack of listener-judge agreement and poor reliability regarding singers 5 and 6 also highlight the inherent weakness of forced choice dichotomous assessment, that is, yes/no assessments tend not to allow for assessment involving fine gradations of tone quality.

Vurma and Ross also presented judges with a forced choice and found poor agreement as to whether singers used “forward” or “backward” placement. Perhaps the task set for listener-judges was too subtle for forced choice responses, as singers in this study had been requested to “stay in the limits of the classical Western style of singing” (Vurma and Ross, 2002, p. 385). The authors acknowledge that “to alter the
voice to a great extent would likely have resulted in exaggerated deviations from the ‘normally’ accepted opera singer’s timbre, which was not the aim of our study” (Vurma and Ross, 2002, p. 388). Only 43% of samples were correctly assessed according to the singer intention, 46% of samples were considered indistinguishable in forward/back tone quality, and 11% were marked as the opposite quality.

2.6.1.10 Listener-judge experience

Despite shortcomings in rating procedures, some researchers propose that perceptual evaluation of descriptive vocal terms is ultimately reliable and reproducible if listener-judges are well trained and experienced, having had long exposure to, and active listening for, various vocal qualities (Fex, 1992; Hammarberg, Fritzell, Gauffin and Sundberg, 1986). While agreeing that listeners may need many years to develop a stable set of criteria for rating, Kreiman et al. (1993) nevertheless concluded:

“Even highly experienced listeners frequently disagree completely about what they hear” (p. 33).

These authors also concluded that it is a mistake to presume that judges with even twenty years’ experience are necessarily more consistently reliable in their ratings than those with only two years’ experience. The Kreiman et al. (1993) review of rater variability in 57 clinical voice studies found that task-specific training, extensive experience, common formal background, undergraduate or professional status amongst raters did not assist intra-rater or inter-rater reliability or agreement.

Although the Kreiman et al. (1993) review investigated the perception of the speaking voice, it produced a similar finding to the study of Wapnick and Ekholm (1997), which investigated perception of the singing voice. Wapnick and Ekholm concluded that for judgements of singers from wide ranging ability levels, covering novice to advanced, neither the age nor the experience of the judge impinged on judge reliability. Referring to both inter- and intra-judge reliability which varied considerably, they concluded:

“It is unclear at present what it is related to, or even if it is a skill that is easily teachable” (Wapnick and Ekholm, 1997, p. 435).

In studies of the spoken voice, when listeners were asked to match voices of similar quality, Kreiman, Gerratt and Precoda (1990) even found that, contrary to the
assumption that training of judges increases the likelihood of consensus, the opposite may be the case:

“Training and experience causes listeners to differ more, not less, in how they perceive vocal quality” (p. 109).

Kent (1996), however, distinguishes between training and experience. He maintains that identical training which uses reference samples and is undertaken by all judges may aid inter-judge agreement for perceptual rating tasks, as opposed to vast experience gained differently by each judge, which may detract from inter-judge agreement.

2.6.1.11 Speech and singing voice findings

Whether all findings regarding the evaluation of the speaking voice apply to the singing voice remains unclear. However, with the exception of some landmark studies (Barnes, 2007; Callinan-Robertson et al., 2006; Ekholm et al., 1998; Erickson, 2009; Mitchell, 2005; Oates et al., 2006; Rothman and Timberlake, 1984; Vurma and Ross, 2002; Wapnick and Ekholm, 1997), there have been relatively few scientific studies involving the evaluation of vocal qualities in singing. Certainly differences between the two areas must be acknowledged. The evaluation of the speaking voice generally centres around assessment of below average vocal control, whereas evaluation of sung quality focuses on vocal control that by comparison is extraordinarily good. It is also interesting that in Kreiman’s extensive review of studies on the impaired speaking voice, rater training for recognition of perceptual terms was classified as extensive if it entailed more than 19 practice trials (Kreiman et al., 1993). In the singing world this amount of aural training would be regarded as negligible. Years of exposure to and refinement of auditory judgement are mandatory for all professional classical singers and singing teachers.

Until further studies on perceptual evaluation of sung vocal quality are forthcoming, it would appear that an understanding of the limitations and achievements in rating spoken vocal quality may illuminate the challenges common to both fields. The evaluation of vocal quality in both the spoken and the singing voice is complex and problematic, needing much more investigation before it is understood.
3 METHOD

Two studies were conducted. Each study explored pre- to post-test acoustic change in singers’ vibrato signals as well as listeners’ and singers’ perceptions of vocal change. The University of Sydney Human Ethics Committee approved these studies (Appendix 1).

3.1 STUDY 1: BREATHING IMAGERY

3.1.1 Tasks

3.1.1.1 Vocal excerpt

Average vibrato rates for different performers can only be compared if they are derived from the same piece of music (Prame, 1994). For this reason, a musical excerpt from the standard vocal repertoire was sought. The excerpt needed to be

- Sufficiently short for the voice not to warm up on the excerpt alone.
- Sufficiently long for analysis of a number of sustained vibrato tones.
- Within a pitch range appropriate for all singer-subjects.
- Easily learnt, as singer-subjects’ time is freely donated.
- Sung to a pre-recorded accompaniment played over earphones, thus providing a uniform measure of pitch, pulse and accompaniment volume, while not being recorded with the voice.

An eight bar excerpt from the Aria (Cantilena) from Bachianas Brasileiras No 5 by Villa-Lobos was selected. Within the vocal line were eleven sustained notes from 0.8 to over 3 seconds in duration. It was considered that singers would produce vibrato suitable for acoustic analysis on these notes. The excerpt covered a vocal range of a major 10th from the notes D₄ (294 Hz) to F♯₅ (740 Hz). This was an achievable range for female singers undergoing classical training regardless of voice type. The instrumental restatement of the singer’s theme, which is only in Villa-Lobos’ soprano-celli arrangement of this work, was used as the pre-recorded accompaniment. Figure 3.1 shows the vocal excerpt and Figure 3.2 the score of the accompaniment used.
Excerpt from *Bachianas Brasileiras No. 5*

I Aria (Cantilena)

Arranged by the Composer

HEITOR VILLA-LOBOS

Figure 3.1 Score given to singer-subjects for rehearsal purposes
Figure 3.2 Bars 23 to 34 of the soprano-celli arrangement used as the pre-recorded accompaniment
As indicated in Figure 3.1, singer-subjects commenced on the third phrase of the main theme (bar 5). The first two phrases were omitted to simplify subject demands. That is, bar 4 required a sustained B♭s (932 Hz) and it was thought that some student singers may find this difficult. Furthermore, producing classical high notes has been likened to yelling with vibrato (Estill, 1996a; Estill, 2002). High shouting may have a warm-up effect on the voice due to increased muscle activation (Ryker, Roy and Bless, 1998; Scherer, Titze, Raphael, Wood, Ramig and Blager, 1991). As breathing imagery was being tested for its potential to warm up the voice, it was thought best to avoid other possible warm-up stimuli.

The composer’s instruction to sing on “ah” (the vowel [a:]) created ease of learning for singer-subjects. A great deal of singer training is done on [a:] and singers frequently show a preference for this vowel. Pedagogues promote its use because it avoids tongue constriction of the vocal tract, and being midway between the forward and the back vowels, neither a bright nor dark vowel, [a:] assists with the equalisation of vowel timbre, a major goal in classical technique (Miller, 1996; Sundberg, 1987; Vennard, 1968). In fact, Ekholm et al. (1998) found that more than any other vowel, [a:] tends to be representative of a singer’s overall voice quality as perceived by listener-judges. Acoustically, the use of a single vowel gives a vibrato pattern that is generally more consistent and easier to measure, since no consonants interrupt the peaks and troughs of the vibrato wave form (Howes, 2001).

The excerpt was 35 seconds long. What the minimum time may be before a singer feels warmed up lacks research. Ten minutes is described as a “short term” warm-up by Motel et al. (2003) whose singer participants all reported feeling partly warmed up after ten minutes but not sufficiently warmed up for performance. Thirty minute warm-ups were used by Elliot et al. (1995) who then measured vocal change. At 35 seconds, the excerpt was considered sufficiently short for singer-subjects not to experience a warm-up effect, especially considering an extended period of silence immediately followed.

### 3.1.1.2 Intervention activities

In order to ascertain whether non-vocal breathing imagery could serve as a silent form of warm-up, all interventions needed to involve vocal rest. In an investigation of vocal
warm-up and vocal rest, Motel et al. (2003) compared the effect of ten minutes vocalisation with ten minutes vocal silence, but suggested that three minutes vocal rest may be sufficient for positive physiological changes from warm-up to begin to reverse. With limited research conducted on optimal duration for a vocal cool-down period, it was judged that all silent intervention tasks should be as protracted as time availability would permit. To strengthen the integrity of the project design, three interventions were employed: a breathing imagery intervention, an alternate imagery intervention and a non-imagery intervention.

In order to reduce the influence of independent variables, the following criteria were adopted as common to all interventions:

• The singer should remain silent for the duration of all interventions.
• The researcher should talk the singer through all interventions.
• All interventions should take approximately 25 minutes.
• All interventions should be presented such that singers can achieve them, independent of prior task related knowledge.
• Singers should not feel they have performed a useless task.

**Intervention A: Breathing imagery**

The breathing imagery intervention involved guided imagery of the breath and associated kinaesthetic sensations. In breathing imagery the breath is perceived to be directed above and below the larynx, as far away as possible, in opposite directions simultaneously (see Section 2.2.7). This is based on practices found in the Western classical singing tradition (Brown, 1957; Brünner, 1993; Bunger, 2000; Carter, 1993; Herbert-Caesari, 1951, 1971; Hines, 1982; Holmes, 2003; Husler and Rodd-Marling, 1965; Lehmann, 1922; Moorcroft, 2007; Patenaude-Yarnell, 2003b; Puritz, 1956; Robison, 2001; Taylor, 1996; Vennard, 1968; Yurisich, 2000b). Anecdotally, such imagery may be performed either over a long time frame or may be used to rapidly concentrate attention as far from the larynx as possible. However, with considerable variation in the way singing is taught, it was anticipated that singer-subjects may neither be aware of such imagery nor of the related concept of imagining vocal effort being directed as far away from the larynx as possible once singing commences. It was therefore decided to commence the breathing imagery intervention with less demanding awareness activities, combining kinaesthetic and visual imagery, which otherwise may be bypassed once breathing imagery is regularly employed. It was also
deemed important to maintain the same postural conditions for all three interventions. As the other interventions were most comfortably performed while seated, the directional breathing imagery was performed in a sitting position.

Prior to commencement, in order to avoid hyperventilation, singers were asked not to consciously change in the way they breathe, but rather to perceive the subtle sensations from the natural ebb and flow already present in their breath. Awareness was first drawn to the ribcage-diaphragm area and to the subtle sensations of expansion at the front, sides and back of the ribcage. Awareness of sensations was then directed lower, towards the area of the abdomen, to the small of the back, to the base of the spine and deep in the torso. Finally, it was suggested the singer imagine the sensations of the breath going progressively lower into the tops of the legs, the knees, the soles of feet and deep into the stage floor.

Following this, the singer was asked to concentrate on upward sensations. Again awareness commenced with the easier task of perceiving the breath above the roof of the mouth in the nasal cavities. From there the singer was asked to imagine the breath directed upwards as though behind the eyes, to just under the top of the skull, then above the head, towards the ceiling and higher as though above the roof and to a point as far away as possible yet directly above the head.

Lastly, the tasks already presented were combined, that is, singers imagined the breath going in both directions, far below and far above the larynx, simultaneously. First the singer was asked to concentrate on sensations in both the ribcage-diaphragm area and the nasal cavities above the soft palate. Attention then focused on sensations in the area of the abdomen and around to the small of the back, and at the same time behind the eyes. Next, attention progressed to subtle sensations at the base of the spine and deep in the torso as well as up to underneath the top of the skull. The breath was subsequently imagined flowing down to the top of the legs and above the head; to the knees and to the ceiling; to the soles of the feet and above the roof; and finally down into the floor and to a point as high in the sky as possible directly above the head.

Visual imagery was used in this intervention as a possible aid for those unfamiliar with sensing the breath beyond the diaphragm-ribcage area. For the farthest sensations downwards, it was suggested that the singer imagine breathing into broad, deep roots
going down under the stage floor and into the earth. For the farthest sensations upwards, it was suggested the singer imagine the breath directed towards a star directly above the head. However, it was emphasised throughout the activity, that once attention had been diverted so far away from the larynx that the sensation of subtle growth and elongation of the body was acquired, the retention of any form of visual imagery aid was purely optional. See Appendix 1.21 for the complete text of the breathing imagery passage.

**Intervention B: Braille music code imagery**

As imagery is reported to possibly have a relaxing effect on the participant (Hall, 1995; Hall et al., 1998; Ley, 1983; Moritz et al., 1996; Wollman, 1986) and relaxation may be associated with improved execution of physical tasks (Fansler, Poff and Shepard, 1985; Hanrahan et al., 1995; Weinberg, 1982), it may be that the relaxing element of imagery alone produces improved performance. Consequently, a control activity involving imagery was required, so that vocal change due to breathing imagery could be compared with vocal change from an alternate imagery activity. It was decided that the alternate imagery should not exploit the possibility of imagery-induced relaxation by suggesting singer-subjects imagine, for example, lying under a palm tree on a tropical island. As imagery unrelated to singing may be very distracting, it was thought that the alternate imagery task should relate in some way to singing. Nevertheless, it could not involve imagery traditionally associated with Western classical singing technique.

An imagery intervention based on sensing the feel of Braille music code was used. Braille music code uses the same raised dot patterns as literary Braille, with reassigned musical meanings. Braille script was prepared at the Royal Victorian Institute for the Blind, Melbourne, where guidance with reading and producing Braille as well as constructive advice and reference material on Braille music code (Williams, 1987, 1995) was given by Dr Barbara Williams, the music resource consultant. Successful “reading” of Braille requires a refined sensation of touch and as used in the intervention activity provided the singer with an opportunity to experience both visual and kinaesthetic imagery. Braille code was presented to the singer so that sometimes the singer saw the Braille pattern before feeling it. At other times the Braille was passed to the singer through a small open ended box, similar to a post box, which ensured the singer could only feel the Braille and not see it. On those occasions the singer had to visualise the pattern of dots from their touch. Singers were also asked to remember the
feel of particular dot configurations and the feel of their hand sweeping over the textured code.

During the intervention, the first few Braille patterns presented to the singers were chosen for their relative ease of identification by feel. Subsequent patterns chosen were those which in a musical context may be read as a sharp, flat or natural sign, double bar line, notes from a C major scale, quavers, crotchets and minimis. The strict rules of Braille spacing in which Braille cells are usually placed very close together, were not observed so that individual Braille cells could be perceived by the beginner more readily. See Appendix 1.22 for the complete text of the Braille passage.

**Intervention C: Non-imagery cloze passage**

An intervention with no direct imagery content was also needed as a further control activity. Singer-subjects could not be told to sit silently doing nothing for 25 minutes, as this may lead to them feeling neglected, bored, and day-dreaming or perceiving inactivity to be of no benefit and not trying to perform as well as they otherwise may. The intervention activity needed to involve a mental task so singers were not free to engage in unsolicited imagery, yet the task should not increase or decrease singer-subjects’ performance anxiety levels, nor alter their existing state of mental or muscular relaxation. Additionally, the task could not be so distracting as to be completely unrelated to singing.

Intervention C consisted of a cloze passage activity based on the writings of Sundberg (1987, 1993) about the physiological process of breathing. Cloze passages test the reader’s comprehension of a text by omitting key words which must then be filled in. In this particular cloze passage, so as not to increase the singer’s existing state of cognitive anxiety, the text was edited to avoid complex information, and the researcher slowly read the full text while the singer followed looking at her own cloze copy, which had a list of the omitted words in alphabetical order at the end of each paragraph. During a pause at the end of each paragraph, the singer wrote the omitted words into her copy of the text. The activity demanded thought but was easily achievable. No reference in the passage was made to what singers consciously should or should not do to breathe “correctly”. Instead, the passage dealt with aspects of breathing physiology which it stressed, occurred beyond the level of conscious control. This was done so as not to encourage the singer to alter their accustomed manner of breathing.
3.1.1.3 Questionnaires

Listener-judge questionnaire

Listener-judges rated mellowness, brilliance, absence of vocal strain and vibrato. These features were chosen on the basis that, according to vocal studies and pedagogical literature, they appeared to be of particular importance for beauty of tone often referred to as *chiaroscuro* quality (Bartholomew, 1937; Ekholm et al., 1998; Jorgenson, 1980; Miller, 1977, 2004; Oates et al., 2006; Robison et al., 1994; Van den Berg and Vennard, 1959; Vennard, 1968; Wapnick and Ekholm, 1997).

Vibrato has been assessed by listener-judges in a number of singing studies (Ekholm et al., 1998; Oates et al., 2006; Wapnick and Ekholm, 1997) as listener responses to vibrato may be directly compared with objective acoustic findings. Vibrato characteristics, though not warranting conscious attention in good performances (Doscher, 1994; Sundberg, 1994), determine the beauty of vocal tone more than any other single vocal feature (Bartholomew, 1937). Optimal vibrato reflects the strong presence of both mellowness and brilliance, which form the basis of the ideal *chiaroscuro* quality (Miller, 1977). Furthermore, *chiaroscuro* is associated with vocal freedom and ease of production otherwise indicated by an absence of vocal strain (Miller, 2004; Vennard, 1968). Hence there is a relationship between mellowness, brilliance, vocal strain, vibrato and beauty of tone.

However, Wapnick and Ekholm (1997) found individual vocal characteristics to be so inter-related that they proposed that singing may be rated most reliably on “overall” vocal quality. Kreiman and Gerratt (1998) made a similar suggestion and questioned whether listener-judges were able to selectively attend to individual elements or dimensions of vocal quality. For this reason, overall classical vocal quality was also rated.

A second overall rating of vocal quality i.e. “legit” vocal quality was also included. The term “legit”, an abbreviation for “legitimate” vocal quality, acknowledges the perception of sound classical singing technique which forms the basis of this popular style of
singing (Edwin, 2003, 2007, 2009; Gardner, Davis and Brennan, 1995; Light, 1992; Popeil, 2007). Legit has been described as sounding “decidedly classical” (Edwin, 2003, p. 431) and “unmistakably operatic” (Light, 1992, p. 13). Indeed, the soprano Kiri Te Kanawa, renowned for classical singing has sung the role of Maria in West Side Story, which Edwin (2009) describes as legit. Yet the difference in timbre between classical and legit may be as profound as the difference in vocal quality between Kiri Te Kanawa singing opera and Haley Westronra singing “popera” (Adams, 2009). That is, the classical singer sounds as though extensive training has occurred in order that the voice projects unaided above an orchestra; the “popera” legit singer communicates a less formally trained quality and lightness which may not necessarily project well but is generally enhanced by a microphone. Hence, legit singing in some respects may be considered not as technically demanding as formal classical singing. The possible consequence that some singers, when unwarmed up, may achieve a higher rating for legit than for a fully classical vocal quality, was considered sufficient reason for including a rating of legit vocal quality in the questionnaires.

Both equally appearing interval (EAI) and visual analogue (VA) scales have been used in previous research for rating voices. Though expert judges appear to express no clear preference for either scale type, Oates et al. (2006) tentatively suggest the use of the EAI scale, finding it had slight advantages in intra-rater reliability. Consequently, questionnaires were prepared that rated performances on an EAI scale. This consisted of a ten centimetre line subdivided every centimetre with each subdivision representing a mark from 1 to 10 (1 = poor; 10 = excellent). The following qualities were rated:

- Mellowness
- Brilliance
- Absence of vocal strain
- Vibrato
- Overall rating of classical vocal quality
- Overall rating of legit vocal quality.

Definitions accompanying these terms are shown in Appendix 1.20. Definitions were based on those found in the professional and scientific literature (Edwin, 2003; Ekholm et al., 1998; Gardner et al., 1995; Heartz, 1995; Light, 1992; Miller, 1977, 1996; Oates et al., 2006; Scholes, 1975a; Stark, 1999; Sundberg, 1973; Titze, 1994; Vennard, 1968; Wapnick and Ekholm, 1997). A new rating sheet was used for each vocal sample and
at the end of each sheet listener-judges were given the opportunity to add any further comments (Appendix 1.18).

**Singer-subject questionnaires**

Singer-subjects self-rated 18 qualities using an EAI scale of 1 to 10 (1 = poor, 10 = excellent), and were invited to add any further comments at the conclusion of the questionnaire (Appendix 1.16). Although the qualities rated were not presumed to be independent and may be inter-related, the qualities fell broadly into three categories. The first six qualities self-rated were the same as those rated by listener-judges, given above, and related to tone colour. The next six, listed below, could be considered to relate particularly to singer psychological disposition and psycho-physiological factors.

- Satisfaction with the way you sang
- Absence of performance anxiety
- Absence of audible nervousness
- Confidence
- Inner calmness
- Energised alertness

A further six qualities, listed below, related in particular to singer technical judgements and proprioceptive feedback from vocal technique.

- Concentration on appropriate vocal technique
- Sensation of being vocally warmed up
- Resonant voice sensations
- Vocal connection throughout the body
- Perception of ease
- Postural alignment for singing

The twelve qualities above are subjective aspects of performance which music research has to date largely ignored. Yet they warrant investigation as a singer’s psychological state affects the singer’s physiological response (Miller, 1996; Titze, 1994) and a singer’s physical sensations throughout the entire body are closely linked with vocal colour (Holmes, 2003; Robison, 2001; Vennard, 1968). Furthermore, self-scrutiny is an essential performance technique (Barry and Hallam, 2002; Brown, 2002; Green and Gallwey, 1987; Günter, 1992b; Hagenau, 1992a; Nisbet, 1998; Roland, 1997).
Three smaller singer-subject questionnaires were also prepared; one for each intervention (Appendix 1.17). These questionnaires monitored how capably each singer felt they could perform the intervention tasks and each singer’s prior experience with activities or content similar to the intervention. This was considered necessary, since the ability to control visual imagery and the strength of sensation from proprioceptive imagery may vary according to the individual, their amount of prior imagery practice and level of related performance skills (Murphy and Martin, 2002; Rodgers et al., 1991; Ryan and Simons, 1982; Suinn, 1983; Weinberg, 1982, 2008).

3.1.2 Participants

3.1.2.1 Singer-subjects

Only female singers were recruited. This prevented gender-related variables entering into the vibrato analysis, as male vibrato rates tend to be slower than female vibrato rates (Miller, 1977; Shipp et al., 1980). Singers studying Western classical technique at first year tertiary level or higher were sought in order to ensure that sufficient training had taken place for vibrato to be present in the voices (Sundberg, 1987; Titze et al., 2002). This minimum level of experience also increased the likelihood that singers would meet further criteria, namely that they were familiar with the sensations of a warmed-up voice and that they could work independently to learn the set piece.

Advertisements (Appendix 1.3) were placed in locations such as university campuses where classical music was taught. Once a singer expressed interest in the project a brief phone interview (Appendix 1.15) was arranged. The interview established the singer’s musical background, including years of singing study, highest qualifications and extent of performance experience. If criteria for participation were met and the singer decided to participate, an information package was posted out.

The information package did not to mention that the project centred around the efficacy, if any, of imagery. Instead it was stated that the project was investigating how pre-performance activities with varying levels of relaxation affect the singing voice. This ensured that singers viewed each intervention as an equally valid activity. The package contained a summary of the procedure (Appendix 1.5) and the soprano-guitar arrangement of the excerpt to be learnt, as the guitar reduction was easy to play on piano for rehearsal purposes (Figure 3.1). To further assist the singer in learning the
excerpt, the package also included a recording of the vocal line played on the piano, and a recording of the cello ensemble accompaniment (Figure 3.2) so the singer could rehearse with the same accompaniment to be heard on the day of recording. Instructions in the package asked the singer not to warm up on the day of the recording session. It was considered that if the singer had already vocally warmed up such that they were singing their best prior to the recording session, then perhaps only if an intervention had a detrimental effect on the voice could a change in vocal performance be noted. Additionally, as singers sometimes report that by listening to an exemplary vocalist their bodily response is such that they experience a form of silent warm-up themselves, singers were also asked not to listen to vocal recordings directly before their recording session.

Six singers, or some multiple of six, were needed because the three interventions could be performed in six different orders (ABC, ACB, BAC, BCA, CAB, CBA). With the interventions performed in all six orders, the effect of task order could be offset. Six singers fulfilled the criteria, chose a convenient time to take part and were successfully recorded. Singer profiles are presented in Table 3.1. The singers could largely be placed in two categories, those still studying at tertiary level with limited performance experience (singers 1, 2 and 3) and those who had completed tertiary studies and had professional experience at state level (singer 4, 5 and 6). Each singer came from a different studio, and none were taught by members of the research team.

Table 3.1 Study 1 singer profiles

<table>
<thead>
<tr>
<th>Singer-subject</th>
<th>Age</th>
<th>Years of vocal study</th>
<th>Vocal education</th>
<th>Performance background</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>19</td>
<td>7</td>
<td>B.Mus 1st year</td>
<td>student exams</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
<td>9</td>
<td>B.Mus 2nd year</td>
<td>student recitals</td>
</tr>
<tr>
<td>3</td>
<td>25</td>
<td>9</td>
<td>B.Mus 3rd year</td>
<td>student recitals</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>semi-professional engagements at a municipal level</td>
</tr>
<tr>
<td>4</td>
<td>27</td>
<td>12</td>
<td>B.Mus (Hons)</td>
<td>winner of state-wide vocal competitions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>state opera Young Artists training programme</td>
</tr>
<tr>
<td>5</td>
<td>49</td>
<td>26</td>
<td>Dip Operatic Art</td>
<td>state opera company chorus member</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>solo recitalist</td>
</tr>
<tr>
<td>6</td>
<td>29</td>
<td>16</td>
<td>B.Mus., Dip Opera</td>
<td>winner of nation-wide vocal competition</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>state opera company soloist</td>
</tr>
</tbody>
</table>
3.1.2.2 Listener-judges

No criteria exist in the literature that assures listener-judge reliability. Studies have found that reliability of listener-judges is highly problematic when subtle variation of vocal quality is rated in a research situation (Bergan et al., 2004; Kent, 1996; Kreiman et al., 1990; Kreiman et al., 1993; Kreiman and Gerratt, 1998; Wapnick and Ekholm, 1997). Rater reliability, according to Wapnick and Ekholm (1997) is unrelated to the rater age, teaching or adjudicating experience and expertise, and according to Kreiman et al. (1993) is unrelated to task-specific training, extensive experience, common formal background or professional status of the rater. However, criteria for participation as a listener-judge in this project placed emphasis on experienced listener-judges because experienced judges have shown better inter- and intra-judge reliability when assessing more fundamental perceptual qualities such as intonation accuracy (Oates et al., 2006; Wapnick and Ekholm, 1997), whether a singer is “belting” or not (Sundberg, Gramming and Lovetri, 1993), or whether well trained classical singers are trying to sing their best or intentionally demonstrating some degree of throat constriction (Mitchell and Kenny, 2004). Furthermore, as inexperienced listener-judges have not proven to be any more reliable than experienced judges, it was decided to seek specialists in the singing voice. Specialists were considered to be experienced singing teachers and examiners and experienced vocal researchers from recognised musical institutions.

Notices were placed in university music departments requesting experienced listener-judges to assist with the project (Appendix 1.4). Additionally, members of the singing and vocal research community were emailed, alerting them to the project and asking that they make contact if interested in taking part. Respondents were sent a project information sheet (Appendix 1.6) and if they decided to participate, individual appointments were made for the assessments to take place.

Six listener-judges took part in the project; five singing teachers and examiners, two of whom were also engaged in voice research, and one full time voice researcher. All were highly experienced in judging the singing voice, and worked at recognised tertiary institutions. None of the listener-judges were teachers of the singer-subjects.
3.1.3 Procedure

3.1.3.1 Recording and self-evaluation of singer-subjects

Before commencing to record, singers were shown the questionnaires they were to fill in after each performance. They were instructed that on the rating scale each of the ten subdivisions represented a mark from 1 to 10. A score of 1 indicated the worst possible self-evaluation. A score of 10 indicated the best possible self-evaluation. Definitions of perceptual terms used in the questionnaires were discussed with the singers. The singers reported no difficulty in understanding the terminology used.

Singers were then fitted with an AKG C-477 miniature condenser omnidirectional microphone (AKG Acoustics, Vienna, Austria) which was head-mounted so as to maintain a constant distance of 7cm from the corner of the mouth to the microphone. This placement is particularly effective in recording the direct energy from the voice as opposed to room reflections, thereby enabling the use of studio environments with low ambient noise rather than an anechoic chamber (Caberra, Davis, Barnes, Jacobs and Bell, 2002). The microphone was connected to a DAT Marantz compact disc recorder model CDR-640 (Marantz Japan Inc., Kanagawa, Japan) via a Behringer Ultragain Pro MIC-2200 preamplifier (Behringer International, Willich, Germany). Singers listened to the pre-recorded accompaniment which was played on a Sony compact disc player model CDP-291 and heard through Beyerdynamic DT331 free-field earphones (Beyerdynamic GmbH & Co. KG, Heilbronn, Germany). These earphones enabled the singer to hear both the pre-recorded accompaniment plus their own voice.

The recording level of the voice was checked while the singer sang once through the excerpt. As fluctuations in the level of performance stress may influence vibrato characteristics, this process served also to allay singer unfamiliarity with performance conditions. The singer then recorded the eight bar Villa-Lobos excerpt while listening to the pre-recorded accompaniment over earphones. This ensured that the voice was recorded for analysis without the accompaniment. The singer then self-rated her performance (Appendix 1.16). Following this, one of three intervention activities was randomly undertaken while the singer maintained vocal silence for 25 minutes. Post-intervention, the excerpt was re-sung, with the request that the singer sing as near as possible with the same volume level previously used. The singer then self-rated her post-intervention performance (Appendix 1.16) and filled in a further questionnaire.
regarding her ability to perform the intervention tasks as requested and her amount of prior familiarity with the intervention content (Appendix 1.17). After a break for organisational tasks, the entire process, minus the initial recording level check, was repeated using another intervention.

It took 45 minutes to achieve one pre- and post-intervention 35 second voice sample, with long spaces of time between vocal activities. Time taken to complete all three interventions and associated tasks was 2¼ hours. A total of only four minutes’ singing occurred within this time. Consequently, it was felt that effects from vocal use during the brief recording periods would be minimal. Nevertheless, singers were asked to indicate if they felt they had vocalised sufficiently to warm up during any part of the recording session. Also to avoid bias from either singer warm-up or fatigue, and bias from lessening performance anxiety due to increasing familiarity with the procedure of the recording session, as three interventions can be ordered six different ways, each of the six singers performed the interventions in a different order.

At the conclusion of the recording session, calibration tones were recorded onto the end of each singer’s voice samples to establish singer SPL in decibels. The calibration tones consisted of a pre-recorded 1,000 Hz pure sine wave tone which was played at two different decibel levels. A Rion Integrating Sound Level Meter model NL-06 (Rion Co. Ltd, Tokyo, Japan) and the same microphone used by the singers were positioned together at an identical distance from the sound source. The two sound signals were recorded using the same recording gain as for the singer’s performance. The two decibel readings from the SPL meter were noted for comparison with the corresponding voice samples at a later time.

### 3.1.3.2 Playback and listener-judge assessment

Before rating commenced, the six listener-judges were shown definitions of the perceptual terms about to be assessed (Appendix 1.20) and invited to discuss these definitions should clarification be needed. Listener-judges agreed to rate accordingly to the definitions provided.

Listener-judges were instructed that on the rating scale each of the ten subdivisions represented a mark from 1 to 10. A score of 1 was the most negative rating. A score of
10 was the most positive rating. Four preliminary samples broadly representing the range of voices to be rated were then heard. Preliminary samples ensured that right from the start of rating judges had some frame of reference against which to make comparisons (Bergan et al., 2004; Gelfer, 1988; Scherer, Gould, Titze, Meyers and Sataloff, 1988). After hearing the preliminary samples, rating using EAI scales commenced.

In an effort to avoid rater fatigue (Kent, 1996) not all 36 vocal samples were aurally assessed. In order to arrive at a representative selection of singers from each condition, and because most acoustic change involved vibrato rate change, the singers were grouped according to their pre-intervention vibrato rates. Singers 1 and 2 had relatively fast vibrato rates, singers 3 and 4 had somewhat slow vibrato rates, and singers 5 and 6 had more moderate vibrato rates. Three singers, one each representing fast, slow and moderate vibrato rate production, were randomly selected from intervention A, intervention B and intervention C. This gave 18 vocal samples, that is, three pre-intervention performances from each of intervention A, B and C, and their corresponding post-intervention performances. All were arranged in random order. From this selection, six performances (three pre- and three post-intervention) were repeated at intervals throughout the assessment to determine intra-rater reliability. Hence, a total of 24 vocal samples were rated by listener-judges.

To ensure the volume level of singers’ voices did not inadvertently influence tone quality rating, the SPL peaks of all samples were normalised. That is, loudness and softness are two different dynamic elements, but they are not two different forms of tone quality. The term “tone quality” is traditionally defined as “that attribute of auditory sensation in terms of which the listener can judge that two sounds similarly presented and having the same loudness and pitch are dissimilar” (American National Standards Institute, S1.1.12.9, p.45, 1960). Likewise, Habermann (1978) notes that tone colour is one of four factors that contribute to the singing voice, the other three being loudness, pitch and note duration. The practice of normalising to keep the volume levels on replay similar for all vocal samples was also adopted by Barnes (2007), Bloothooft and Plomp (1988), Howard et al. (2002) and Jacobs (2004) when assessing timbre in sung vowels.
All listener-judge perceptual tests were conducted in the same quiet environment. Voice samples were played on a Marantz PMD 330 CD player (Marantz Japan Inc., Kanagawa, Japan) and heard through Sennheiser HD-650 open-air circumaural stereo headphones (Sennheiser, Tullamore, Ireland). The playback level was set for listener comfort and maintained for each recording.

3.1.4 Data analysis

3.1.4.1 Acoustic analysis

As six singers recorded the excerpt six times each, 36 solos with their corresponding calibration tones were converted into graphic form. This was done using the computer software programmes Pho Interactive Phonetography System Version 2.0 (Hitech, Sweden) and Soundswell Core Analysis Version 4.0 (Hitech, Sweden). Spectrograms of the 11 sustained notes from each vocal solo, i.e. 396 sustained notes in total, were produced and each vibrato cycle assessed for rate and extent. The 11 notes assessed are indicated in Figure 3.3.

![Figure 3.3 The 11 notes acoustically assessed for vibrato rate and vibrato extent](image)

The screen resolution for each spectrogram was the result of settings providing the FFT size 1066/2048, frequency range to 5,476 Hz, window length 33ms and a Hanning Window with a bandwidth of 30 Hz. Each spectrogram displayed the undulations of the partials over the length of a selected note. These undulations which represented vibrato cycles were measured by selecting one of the clearly displayed high partials, manually placing a computer cursor over the peak and trough of each vibrato cycle in that partial and registering the corresponding time and frequency from the spectrogram.
onto a spreadsheet (Excel, Microsoft 2000). High partials were used, as resolution increases with the partial number (Prame, 1997). From the spreadsheet the registered frequencies were divided by the number of the partial to establish their related fundamental frequencies.

To ascertain vibrato extent, the maximum departure from the average fundamental frequency was measured by taking each vibrato cycle, calculating the distance from peak to trough in semitones and dividing the result by two. Hertz were converted into semitones using the formula:

$$F_0 \text{ in ST} = \frac{12 \left( \log_{10} F_0 - \log_{10} 16.35 \right)}{\log_{10} 2}$$

Vibrato rate was measured from the time difference between adjacent vibrato peaks and expressed in cycles per second. For both vibrato rate and vibrato extent, the mean values and corresponding standard deviations were calculated for the following:

- For the group of singers as a whole under each condition
- For each solo under each condition
- For each of the 11 sustained notes in each solo

In addition, from the 11 mean vibrato rates per solo, the fastest, slowest and median values were selected in order to observe the range of vibrato rates for each solo and the average range of vibrato rates per condition.

Changes in both vibrato rate and vibrato extent were also compared with SPL changes. SPL was measured in decibels and established from the graphic representation of an upper and a lower calibration tone recorded directly after each singer’s solos. Mean SPL was extracted from each solo using the Hitech Soundswell Core Analysis histogram function with a resolution setting of 512 bins. Acoustic findings were also compared with perceptual evaluations from both singer-subjects and listener-judges.

Acoustic data were subject to statistical analysis using SPSS (Statistical Package for the Social Sciences). The design of the study was a fully randomised cross-over block design, in which each singer received each intervention in random order. Repeated measures multivariate analyses of variance were used to analyse the results. The study comprised a 6 x 2 design: (six dependent measures: mean vibrato rate; standard deviation; fastest vibrato rate; slowest vibrato rate; median vibrato rate and the range of
vibrato rates i.e. fastest minus slowest vibrato rate) by time (pre-intervention and post-intervention). Data were subjected to analysis using the general linear model (GLM). Main effects for time and condition and interaction effects (time*condition) were calculated for each dependent measure.

A second set of analyses were conducted to assess the effect of order of intervention on the outcome of the six dependent measures. The analysis was a single factor within subject repeated measures design, with the difference score for each dependent variable calculated by subtracting pre-test from the post-test scores. All first, second and third presentation difference scores were compared to assess for possible order effects.

The distributions for each dependent measure were assessed for normality and outliers. Examination of skewness and kurtosis statistics indicated that the distributions were relatively normally distributed. Mauchly’s test of sphericity was assessed before interpreting the F statistics from the general linear model. Those variables with significance >0.05 were interpreted using the sphericity assumed statistics; those with significance ≤0.05 were interpreted using the Huynh-Feldt epsilon adjustment.

3.1.4.2 Perceptual analysis

Singer-subject data analysis

Singers’ scores from their self-rating of 18 qualities from 1 (=poor) to 10 (=excellent) were entered on Excel spreadsheets and any extra comments made by singer-subjects regarding their responses to the tasks undertaken were noted. The group mean score, standard deviation and 95% confidence intervals were extracted for each quality assessed in each condition. Paired t-tests were then conducted on singer-subject perceptual judgements of each quality and of each condition overall.

Inter-singer agreement was assessed from the individual ratings for each of the qualities assessed, as well as from the mean scores of each singer. Results were scrutinised for patterns of behaviour in the rating of individual singers, and for possible trends when the singers were divided into those with the most and those with the least singing experience. Singers’ perceptual judgements were also compared with the acoustic findings.
Listener-judge data analysis
Listener-judge scores which rated vocal qualities from 1 to 10 were entered on Excel spreadsheets. Any extra comments made by listener-judges were noted. Mean ratings for each vocal quality pre- and post-test and for each vocal sample pre- and post-test were ascertained and paired sample t-tests conducted for listener-judge perception. Listener-judges’ perceptual judgements were compared with the acoustic findings.

Inter-rater reliability was ascertained by considering how close all listener-judges’ scores were numerically, and also by noting whether pre- and post-intervention scores, when paired, registered a mean improvement, no change, or deterioration. Intra-rater reliability was assessed by comparing the scores from six repeated samples with the original scores.

3.1.5 Hypotheses
The hypotheses for study 1 were as follows:
1. Following the breathing imagery intervention, an improvement in vibrato quality will occur. Such improvement will take the form of more moderate and more consistent vibrato rates, and vibrato extents which are neither excessively narrow nor too broad.

2. Perceptually, both singer-subjects and listener-judges will rate vocal tone quality higher after the breathing imagery intervention than before. By contrast, lower perceptual ratings will be given to samples recorded after other interventions.

3. Following the alternate imagery intervention, which tests for the effects of imagery not related to traditional breathing imagery for singers, some acoustic change in vibrato, possibly reflecting increased relaxation, will ensue. Vibrato change will be greater than that registered following the non-imagery intervention where minimal change will occur, but will not necessarily reflect vocal improvement.

4. Singers will report a reduction in audible nervousness and a feeling of having vocally warmed up after the breathing imagery. Little, if any, improvement in these qualities will be noted after the other interventions.
3.2 STUDY 2: VOCAL WARM-UP

3.2.1 Tasks

3.2.1.1 Vocal excerpt
The study 2 vocal excerpt was taken from the Aria (Cantilena) from Bachianas Brasileiras No 5 by Villa-Lobos. This was the same solo as in study 1. See Section 3.1.1.1 for selection criteria and a description of the excerpt.

3.2.1.2 Vocal warm-up intervention
The study 2 intervention consisted of 25 minutes of set vocal warm-up exercises, presented by the researcher with the aid of a pre-recorded piano accompaniment. Although the literature suggests no specific time frame for vocal warm-up exercises to be effective, 25 minutes was chosen as study 1 interventions were of similar duration. Warm-up content, the same for each singer, was based on simple scale and arpeggio patterns commonly practised in Western classical singing. Exercises were commenced in a comfortable mid-range and extended semitone by semitone into the high range. As pedagogues disagree over vocal ranges deemed appropriate for each voice type, definitive ranges are not possible to stipulate (Collyer, 1998). However, by the conclusion of the warm-up, all singers had vocalised over a range considered viable for both soprano and mezzo-soprano tertiary singing students, spanning B₃ (247 Hz) to B₅ (988 Hz). The exercises used are presented in Figure 3.4.

3.2.1.3 Questionnaires
Both singer-subject and listener-judge questionnaires were the same as for study 1 (see Section 3.1.1.3 and Appendices 1.16 and 1.18). In addition, study 2 listener-judges were asked to indicate whether any change was perceived in the singer’s warm-up state (Appendix 1.19). That is, all samples in study 2 were presented such that two samples of the one singer were heard back-to-back.
Figure 3.4 Vocal warm-up exercises
3.2.2 Participants

3.2.2.1 Singer-subjects

Criteria for participation as a singer-subject and method of recruitment were the same as for study 1 (Section 3.1.2.1). See Appendix 1.9 for the recruitment advertisement. Twelve female singers fulfilled the criteria, chose a convenient time to take part and were successfully recorded. Table 3.2 presents the singer profiles. The mean age of singer-subjects was 24.6 years (S.D. 4.1) and mean years of vocal study 8.8 (S.D. 3.6). The singers, all tertiary singing students, came from a range of tertiary studios and were not students of the research team.

Table 3.2 Study 2 singer profiles

<table>
<thead>
<tr>
<th>Singer-subject</th>
<th>Age</th>
<th>Years of vocal study</th>
<th>Current education</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24</td>
<td>10</td>
<td>B.Mus (Hons)</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>6</td>
<td>B.Mus 3rd year</td>
</tr>
<tr>
<td>3</td>
<td>21</td>
<td>7</td>
<td>B.Mus 2nd year</td>
</tr>
<tr>
<td>4</td>
<td>24</td>
<td>7</td>
<td>B.Mus 2nd year</td>
</tr>
<tr>
<td>5</td>
<td>26</td>
<td>7</td>
<td>B.Mus (Hons)</td>
</tr>
<tr>
<td>6</td>
<td>21</td>
<td>10</td>
<td>B.Mus 2nd year</td>
</tr>
<tr>
<td>7</td>
<td>19</td>
<td>5</td>
<td>B.Mus 2nd year</td>
</tr>
<tr>
<td>8</td>
<td>27</td>
<td>6</td>
<td>Dip Opera 2nd year</td>
</tr>
<tr>
<td>9</td>
<td>30</td>
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<td>Dip Opera 2nd year</td>
</tr>
<tr>
<td>10</td>
<td>32</td>
<td>16</td>
<td>Dip Opera 3rd year</td>
</tr>
<tr>
<td>11</td>
<td>23</td>
<td>11</td>
<td>B.Mus 2nd year</td>
</tr>
<tr>
<td>12</td>
<td>28</td>
<td>15</td>
<td>B.Mus 3rd year</td>
</tr>
</tbody>
</table>

3.2.2.2 Listener-judges

Criteria for participation as a listener-judge and method of recruitment were the same as for study 1 (Section 3.1.2.2). See Appendix 1.10 for the recruitment advertisement. Six highly experienced listener-judges were recruited. All six were singing teachers and examiners, and three were also voice researchers.
3.2.3 Procedure

3.2.3.1 Recording and self-evaluation of singer-subjects

The method of recording and establishing each singer’s SPL was the same as for study 1 (Section 3.1.3.1). Pre- and post-intervention questionnaires filled out by singers were also the same (Appendix 1.16). However, for the study 2 intervention singers performed a 25 minute vocal warm-up. Post-intervention, when the excerpt was re-sung, singers were requested to sing as near as possible with the same amount of volume previously used.

3.2.3.2 Playback and listener-judge assessment

Playback and listener-judge assessment followed the same general procedure as for study 1 (Section 3.1.3.2). However, for study 2 each singer’s pre- and post-intervention vocal sample was played back-to-back with their order randomised. Three paired vocal samples were repeated at intervals throughout the assessment to determine intra-rater reliability. This gave 15 paired samples in total. In an effort to avoid rater fatigue samples were shortened to 22 seconds each, concluding with the 8th long held note as indicated in Figure 3.3, E₄ (330 Hz). Nevertheless, the samples displayed the full vocal range of the excerpt originally recorded.

Additionally, for study 2, after hearing each pair of vocal samples, listener-judges indicated whether any change in the singer’s warm-up state had been noticed. If this applied, listener-judges then chose whether sample 1 or sample 2 in the pair was more warmed up (Appendix 1.19).

3.2.4 Data analysis

3.2.4.1 Acoustic analysis

As 12 singers recorded the vocal solo twice each, 24 solos with their corresponding calibration tones were converted into graphic form. Spectrograms of the eleven sustained notes contained in each vocal solo, that is, of 264 sustained notes in total, were produced. Each vibrato cycle in the 264 spectrograms was assessed for rate and extent in the same manner as for study 1 (Section 3.1.4.1).
3.2.4.2 Perceptual analysis

Singer-subject data analysis
Singer-subject data analysis followed the same procedure as for study 1 (see Section 3.1.4.2).

Listener-judge data analysis
In addition to the procedure employed for listener-judge data analysis in study 1 (Section 3.1.4.2), tests for intraclass correlation coefficients for inter-judge reliability were undertaken. For listener-judges’ appraisals of each singer’s warm-up state, the number of correct appraisals out of a possible 15 were noted. Each judge’s 15 appraisals were entered on a spreadsheet, compared with those of each other judge and the percentage of inter-rater agreement calculated. The percentage of intra-rater reliability was calculated from the number of consistent appraisals from each listener-judge for the three repeated sample pairs.

3.2.5 Hypotheses
The hypotheses for study 2 were as follows:
1. Following the vocal warm-up, an improvement in vibrato quality will occur. Such improvement will take the form of more moderate and more consistent vibrato rates, and vibrato extents which are neither excessively narrow nor too broad.

2. Perceptually, both singer-subjects and listener-judges will rate vocal tone quality higher for those samples recorded after the vocal warm-up.

3. Listener-judges will consistently distinguish the warmed-up from the unwarmed-up sample of the same singer presented back-to-back.
4 RESULTS FOR STUDY 1: BREATHING IMAGERY

4.1 VIBRATO RATE ANALYSIS

Six singers each recorded a set eight bar solo (Figure 3.1) before and after three 25 minute interventions - a breathing imagery intervention (Intervention A), a Braille music code imagery intervention (Intervention B) and a non-imagery cloze passage (Intervention C), all of which allowed for vocal rest (Method 3.1.1.2). The order of interventions varied for each singer. Spectrograms were produced of the 11 long held notes in each solo, i.e. 396 notes in total. Each vibrato undulation was measured, and vibrato rate assessed for changes from one pre-intervention solo to its corresponding post-intervention solo, as well as for changes in the group of singers as a whole. See Section 2.1.6.2 for a discussion of what constitutes optimal vibrato and the degree of vibrato variability considered acceptable.

Additionally, as vibrato rate may be influenced by note duration (Prame, 1994), may increase somewhat as pitch rises (Titze, 1994), or may increase on loud tones and decrease on soft tones (Dromey et al., 2003; Winckel, 1953), vibrato rate was compared with note duration, fundamental frequency and singer dynamic intensity measured by sound pressure level (SPL).

4.1.1 Assessment of each group as a whole

Table 4.1 lists the mean vibrato rate per solo and the group mean vibrato rate per condition, in cycles/sec.

<table>
<thead>
<tr>
<th>Mean vibrato rate</th>
<th>Pre-A</th>
<th>Post-A</th>
<th>Pre-B</th>
<th>Post-B</th>
<th>Pre-C</th>
<th>Post-C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singer 2</td>
<td>5.869</td>
<td>5.521</td>
<td>5.906</td>
<td>5.685</td>
<td>5.796</td>
<td>5.796</td>
</tr>
<tr>
<td>Singer 3</td>
<td>4.904</td>
<td>5.011</td>
<td>4.963</td>
<td>4.923</td>
<td>4.910</td>
<td>4.861</td>
</tr>
<tr>
<td>Singer 4</td>
<td>5.346</td>
<td>5.416</td>
<td>5.436</td>
<td>5.257</td>
<td>5.363</td>
<td>5.338</td>
</tr>
<tr>
<td>Singer 5</td>
<td>5.739</td>
<td>5.583</td>
<td>5.755</td>
<td>5.548</td>
<td>5.560</td>
<td>5.571</td>
</tr>
<tr>
<td>Singer 6</td>
<td>5.604</td>
<td>5.428</td>
<td>5.349</td>
<td>5.290</td>
<td>5.373</td>
<td>5.378</td>
</tr>
<tr>
<td>Group mean</td>
<td>5.629</td>
<td>5.502</td>
<td>5.625</td>
<td>5.458</td>
<td>5.541</td>
<td>5.538</td>
</tr>
</tbody>
</table>

Data were assessed using a repeated measures ANOVA with a Huynh-Feldt correction. Pairwise contrasts were used to compare pre- and post- values for each of
the conditions. For the mean vibrato rate there was a significant overall effect between conditions (F=3.72, DF=3.7, P=0.02). For condition B there was a significant reduction in mean vibrato rate (mean change 0.17, P=0.01) but not for condition A (mean change=0.13, P=0.15) or condition C (mean change=0.0, P=0.87).

Table 4.2 lists the mean vibrato rate standard deviation per solo and the group mean standard deviation per condition.

Table 4.2 Mean vibrato rate standard deviations and the group mean standard deviation per condition

<table>
<thead>
<tr>
<th>Standard deviation</th>
<th>Pre-A</th>
<th>Post-A</th>
<th>Pre-B</th>
<th>Post-B</th>
<th>Pre-C</th>
<th>Post-C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singer 1</td>
<td>0.492</td>
<td>0.188</td>
<td>0.301</td>
<td>0.374</td>
<td>0.441</td>
<td>0.330</td>
</tr>
<tr>
<td>Singer 2</td>
<td>0.588</td>
<td>0.245</td>
<td>0.523</td>
<td>0.691</td>
<td>0.528</td>
<td>0.655</td>
</tr>
<tr>
<td>Singer 3</td>
<td>0.376</td>
<td>0.264</td>
<td>0.231</td>
<td>0.322</td>
<td>0.228</td>
<td>0.232</td>
</tr>
<tr>
<td>Singer 4</td>
<td>0.262</td>
<td>0.180</td>
<td>0.200</td>
<td>0.269</td>
<td>0.262</td>
<td>0.284</td>
</tr>
<tr>
<td>Singer 5</td>
<td>0.347</td>
<td>0.263</td>
<td>0.329</td>
<td>0.389</td>
<td>0.334</td>
<td>0.373</td>
</tr>
<tr>
<td>Singer 6</td>
<td>0.405</td>
<td>0.320</td>
<td>0.279</td>
<td>0.224</td>
<td>0.290</td>
<td>0.282</td>
</tr>
<tr>
<td><strong>Group mean</strong></td>
<td><strong>0.412</strong></td>
<td><strong>0.243</strong></td>
<td><strong>0.311</strong></td>
<td><strong>0.378</strong></td>
<td><strong>0.347</strong></td>
<td><strong>0.359</strong></td>
</tr>
</tbody>
</table>

For standard deviations of the vibrato rate there was a significant overall effect between conditions (F=3.82, DF=2.7, P=0.04). For condition A there was a significant reduction in the standard deviations (mean change 0.17, P=0.02). There was a marginally significant increase in the standard deviations for condition B (mean change=0.07, P=0.07) but no significant change for condition C (mean change=0.01, P=0.71).

Figure 4.1 illustrates, for the group as a whole, the mean vibrato rate and the fastest, slowest and median vibrato rates from 11 long held notes in the vocal excerpt under each condition.
Figure 4.1 The mean vibrato rate and the fastest, slowest and median vibrato rates from 11 long held notes in the vocal excerpt, assessed for the group as a whole under each condition.
As seen in Figure 4.1, after intervention A the range of vibrato rates for the group compacted and both the group median and mean vibrato rate were positioned somewhat more evenly between the average fastest and slowest vibrato rates. This was not the case after intervention B or C.

The results of the ANOVA showed that for the range of vibrato rates, calculated from the fastest minus the slowest vibrato rate, there was a significant overall effect between conditions ($F=3.62$, $DF=2.7$, $P=0.045$). For condition A there was a significant reduction in the fastest minus slowest vibrato rate (mean change $0.52$, $P=0.02$) but not for condition B (mean change $0.19$, $P=0.10$) or condition C (mean change $0.05$, $P=0.64$) both of which increased slightly.

For the fastest vibrato rate there was no significant overall effect between conditions ($F=2.56$, $DF=2.8$, $P=0.10$). For condition A there was a significant reduction in the fastest vibrato rate (mean change $0.53$, $P=0.04$), but not for condition B (mean change $0.08$, $P=0.43$) or condition C (mean change $0.05$, $P=0.50$). For the median vibrato rate there was a significant overall effect between conditions ($F=2.96$, $DF=4.4$, $P=0.04$). For condition B there was a significant reduction in the median vibrato rate (mean change $0.18$, $P=0.01$), but not for condition A (mean change $0.06$, $P=0.47$) or condition C (mean change $0.03$, $P=0.38$). For the slowest vibrato rate there was a significant overall effect between conditions ($F=3.63$, $DF=3.2$, $P=0.04$) but no significant effects for the planned contrasts – condition A (mean change $0.01$, $P=0.85$), condition B (mean change $0.27$, $P=0.08$) and condition C (mean change $0.0$, $P=1.0$).

4.1.2 Assessment of each solo

4.1.2.1 Mean vibrato rates

Figure 4.2 illustrates pre- to post-intervention change in the mean vibrato rate for each singer under each condition.
Figure 4.2. Mean vibrato rates for each of the six singers, before and after the three interventions.
As shown in Figure 4.2, singers 1 and 2 consistently had the fastest and second fastest pre-intervention mean vibrato rates for the group. Singer 3 consistently had the slowest pre-intervention mean vibrato rate of the group. Singers 1, 2 and 3 were vocally less experienced than singers 4, 5 and 6 who exhibited more moderate vibrato rates. (See Table 3.1 for singer profiles.)

After intervention A, the mean vibrato rates for the solos compacted; faster rates became slower and slower rates became faster. Singers 1, 2 and 3 produced vibrato rates closer to those of their more experienced counterparts 4, 5 and 6. After intervention B, all singers' vibrato rates slowed; the faster the pre-intervention vibrato rate the greater the slowing. After intervention C, the singers' mean vibrato rates remained disparate with little change.

Data were analysed using SPSS version 15.0. Repeated measures analysis of variance in the General Linear Model was used to test for statistically significant differences between the 11 conditions (11 notes per solo) and between the two time points (pre and post) for each of the three conditions. Univariate between-subject contrasts were used to test for between-condition differences and within-subject contrasts to test for differences over time. Table 4.3 shows the results of the repeat measures ANOVA.

<table>
<thead>
<tr>
<th>Intervention</th>
<th>p-value for change over time (pre versus post)</th>
<th>p-value for differences between 11 conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.001</td>
<td>0.013</td>
</tr>
<tr>
<td>B</td>
<td>&lt;0.0001</td>
<td>0.08</td>
</tr>
<tr>
<td>C</td>
<td>0.95</td>
<td>0.11</td>
</tr>
</tbody>
</table>

As reported in Table 4.3 there was a significant difference in vibrato rates pre- to post-A and also pre- to post-B. There was no significant difference pre- to post-C. There was also a significant difference pre- to post-A between the 11 notes assessed i.e. with some notes showing much more change than others. This was not the case for conditions B and C.
4.1.2.2 Standard deviation

Appendix 2.3 lists the mean vibrato rate, standard deviation and 95% confidence intervals with upper and lower limits per solo. Vibrato rate standard deviation in the 36 solos varied from 0.18 to 0.69 cycles/sec. This was calculated as ranging from 3.11% to 12.15% of the corresponding solo’s mean vibrato rate.

Figure 4.3 compares each singer’s vibrato rate standard deviation under each condition. Following intervention A, the standard deviation of the mean vibrato rates for every singer decreased to range from 3% to 6% of the singer’s mean vibrato rate (mean S.D. 4.46%). Singer 2 registered both the largest pre-A vibrato rate standard deviation and the largest post-A reduction - a decrease from 10.02% to 4.44% of her mean vibrato rate.

Post-B standard deviations ranged from 4% to 13% of singers’ mean vibrato rates (mean S.D. 6.87%). Singer 6, the most experienced singer in the group, registered a decrease in standard deviation from 5.22% to 4.23% of her mean vibrato rate. All other singers registered an increase. Singer 2 registered both the largest pre-B vibrato rate standard deviation and the largest post-B increase - from 8.86% to 12.15% of her mean vibrato rate.

Post-C standard deviations ranged from 4% and 12% of singers’ mean vibrato rates (mean S.D. 6.19%). The more experienced singers tended to retain very similar standard deviations pre- to post-C. The two least experienced singers were the least consistent and showed most variability in standard deviation pre- to post-C. Singer 2 again registered the largest pre-intervention vibrato rate standard deviation and largest post-intervention change with an increase from 9.11% to 11.30% of her mean vibrato rate.
Figure 4.3  Standard deviation of the solo’s mean vibrato rate for each singer
4.1.2.3 Range of mean vibrato rates

Figure 4.4 compares the range of mean vibrato rates for each solo (i.e. the fastest, slowest and median vibrato rates from 11 notes assessed per solo).

As seen in Figure 4.4, following intervention A, all singers displayed greater cohesion in the range of mean vibrato rates. The range of vibrato rates for singers 1 and 2, the two least experienced singers, compacted markedly and approached that of the more experienced singers. For each singer, their fastest and slowest mean vibrato rates for the solo were contained within a range of one cycle/sec, i.e. the smallest range covered 0.53 cycles/sec (singer 4) and the broadest range 0.97 cycles/sec (singer 6).

Following intervention B, vibrato rates broadened further for all except singer 6. Following intervention C, the range of vibrato rates showed little change. It was notable that under all conditions, the median vibrato rate was positioned somewhat equally between the fastest and slowest of the 11 mean vibrato rates only by the most acclaimed singer in the group, singer 6.
Figure 4.4 The range of mean vibrato rates and the median vibrato rate from 11 notes assessed per solo.

Note: The six vertical lines per chart represent, from left to right, singers 1, 2, 3, 4, 5, and 6.
4.1.2.4 Confidence intervals

Figure 4.5 presents the 95% confidence intervals for each solo.

Figure 4.5 The 95% confidence intervals for mean vibrato rate for each pre- and post-intervention solo

Note: Lines on the left of each pair show the pre-intervention confidence interval and those on the right show the post-intervention confidence interval.
As seen in Figure 4.5, vibrato rates pre- to post-A drew nearer 5.50 cycles/sec. This value was closest to that registered by singer 6, the most widely acclaimed singer in the group and as such, arguably the singer with the most exemplary vibrato. Pre- to post-B, the confidence intervals confirmed a slowing of all singers' vibrato rates. Pre- to post-C confidence intervals showed the least change and no notable trends regarding the slowing, quickening or range of vibrato rates.

4.1.3 Assessment of individual notes

4.1.3.1 Mean vibrato rates
Mean vibrato rates for each note assessed varied from 4.63 to 7.45 cycles/sec (Appendix 2.1). The less experienced singers produced the slowest and the fastest vibrato rates. Figure 4.6 compares the pre- and post-intervention vibrato rates for the 11 notes assessed per solo.
Figure 4.6 Variation in mean vibrato rates for each of the 11 notes assessed per solo
As shown in Figure 4.6, pre- to post-A changes in vibrato resulted in fewer very fast and very slow vibrato rates, and subsequently a somewhat smoother note-to-note progression of vibrato rates for all singers. This was neither the case pre- to post-B nor pre- to post-C.

Table 4.4 reports the t-test results for pre- to post-test differences in note pairs that registered either very slow or very fast vibrato. The music required vocal beauty combined with a calm, consistent, lyrical delivery and thus called for a moderate and even vibrato rate. Very slow vibrato is appropriate where tremendous grief, exhaustion or perhaps old age is portrayed in a role. Very fast vibrato is appropriate if the singer wishes to portray excitement, high energy, agitation, stress or fear. For singers in a research setting, Mürbe et al. (2007) classifies vibrato below 5.20 cycles/sec as slow, and vibrato above 5.80 cycles/sec as fast. This is consistent with Titze (1994) that a mean vibrato rate of 5.5 cycles/sec is generally perceived as desirable today. Therefore, to assess only for pre- to post changes that may indicate improvement or deterioration in note pairs and to exclude note pairs possibly within optimal limits, two subsets of the entire set of pairs of vibrato rates were chosen for statistical analysis. One subset consisted of vibrato rates below 5.00 cycles/sec, as these were regarded as too slow. The other subset comprised vibrato rates 6.00 cycles/sec and above, as these were regarded as too fast.
Table 4.4  Paired-t-test results for notes that pre- and/or post-intervention registered vibrato rates either slower than 5.00 cycles/sec, or 6.00 cycles/sec and faster

<table>
<thead>
<tr>
<th>A - Breathing imagery</th>
<th>Mean</th>
<th>N</th>
<th>Std deviation</th>
<th>Std error mean</th>
<th>Mean difference</th>
<th>Std deviation</th>
<th>t-value</th>
<th>Sig (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow vibrato rates</td>
<td>Before</td>
<td>4.739</td>
<td>9</td>
<td>0.075</td>
<td>0.025</td>
<td>-0.167</td>
<td>0.094</td>
<td>-5.308</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>4.905</td>
<td>9</td>
<td>0.130</td>
<td>0.043</td>
<td>-0.167</td>
<td>0.094</td>
<td>-5.308</td>
</tr>
<tr>
<td>Fast vibrato rates</td>
<td>Before</td>
<td>6.414</td>
<td>16</td>
<td>0.478</td>
<td>0.119</td>
<td>0.406</td>
<td>0.448</td>
<td>3.629</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>6.008</td>
<td>16</td>
<td>0.225</td>
<td>0.056</td>
<td>0.406</td>
<td>0.448</td>
<td>3.629</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B - Braille imagery</th>
<th>Mean</th>
<th>N</th>
<th>Std deviation</th>
<th>Std error mean</th>
<th>Mean difference</th>
<th>Std deviation</th>
<th>t-value</th>
<th>Sig (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow vibrato rates</td>
<td>Before</td>
<td>4.896</td>
<td>10</td>
<td>0.177</td>
<td>0.056</td>
<td>0.114</td>
<td>0.154</td>
<td>2.339</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>4.782</td>
<td>10</td>
<td>0.104</td>
<td>0.033</td>
<td>0.114</td>
<td>0.154</td>
<td>2.339</td>
</tr>
<tr>
<td>Fast vibrato rates</td>
<td>Before</td>
<td>6.367</td>
<td>16</td>
<td>0.378</td>
<td>0.094</td>
<td>0.222</td>
<td>0.631</td>
<td>1.405</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>6.146</td>
<td>16</td>
<td>0.504</td>
<td>0.126</td>
<td>0.222</td>
<td>0.631</td>
<td>1.405</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C - Cloze passage</th>
<th>Mean</th>
<th>N</th>
<th>Std deviation</th>
<th>Std error mean</th>
<th>Mean difference</th>
<th>Std deviation</th>
<th>t-value</th>
<th>Sig (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow vibrato rates</td>
<td>Before</td>
<td>4.877</td>
<td>12</td>
<td>0.183</td>
<td>0.053</td>
<td>0.002</td>
<td>0.278</td>
<td>0.019</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>4.875</td>
<td>12</td>
<td>0.255</td>
<td>0.073</td>
<td>0.002</td>
<td>0.278</td>
<td>0.019</td>
</tr>
<tr>
<td>Fast vibrato rates</td>
<td>Before</td>
<td>6.259</td>
<td>15</td>
<td>0.504</td>
<td>0.130</td>
<td>-0.125</td>
<td>0.644</td>
<td>-0.751</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>6.384</td>
<td>15</td>
<td>0.386</td>
<td>0.100</td>
<td>-0.125</td>
<td>0.644</td>
<td>-0.751</td>
</tr>
</tbody>
</table>
As reported in Table 4.4, condition A registered only nine of the 66 note pairs as having vibrato rates slower than 5.00 cycles/sec. Pre- to post-A, all nine note pairs registered faster vibrato rates. In condition B, ten note pairs registered vibrato rates slower than 5.00 cycles/sec. Pre- to post-B, the values of nine of these note pairs became slower, while one note pair registered a faster value. In condition C, 12 note pairs registered vibrato rates slower than 5.00 cycles/sec. Pre- to post-C, the values of ten of the note pairs became slower, while two note pairs registered faster values.

Table 4.4 also indicates that condition A and condition B each had 16 note pairs with vibrato rates 6.00 cycles/sec or faster. Both post-A and post-B, 14 note pairs with vibrato rates above 6.00 cycles/sec registered slower vibrato rates, while two note pairs registered faster vibrato rates. For condition C, 15 note pairs registered vibrato rates 6.00 cycles/sec or faster. Post-C, five of the note pairs registered slower values, while ten note pairs registered faster values.

The paired t-test results indicate that for condition A, note pairs with vibrato rates slower than 5.00 cycles/sec became significantly faster, while note pairs with vibrato rates 6.00 cycles/sec or faster became significantly slower. For condition B, note pairs with vibrato rates slower than 5.00 cycles/sec became significantly slower still, but no significant findings resulted for note pairs with vibrato rates 6.00 cycles/sec or faster. For condition C, no significant pre to post-test findings resulted.

4.1.3.2 Standard deviation

There was a degree of irregularity between virtually all individual vibrato undulations. Figures 4.7 and 4.8 show the spectrographic representation of less regular and of more regular vibrato undulations.
Both Figures 4.7 and 4.8 show the note F₅ (740 Hz) and, on the far right of each spectrograph, the note descending to the next pitch. Frequency is represented by the vertical axis. The horizontal axis shows time in seconds. Figure 4.7 shows the
frequency undulations spaced with poor metrical regularity along the horizontal (time) axis. The peaks of each undulation also do not occur consistently midway between the troughs. By comparison, Figure 4.8 shows the troughs, the peaks and each complete vibrato undulation more evenly spaced along the time axis, indicating greater metrical regularity in the vibrato rate.

Appendix 2.2 lists each note’s vibrato rate standard deviation. The two least experienced singers in the group produced the two largest standard deviations, i.e. 2.02 cycles/sec (singer 1) and 1.96 cycles/sec (singer 2). The largest values for singers 3 and 4 were 0.78 and 0.79 cycles/sec, and for singers 5 and 6, the most experienced singers in the group, 0.67 and 0.63 cycles/sec respectively. Thus, consistent with Bartholomew (1934), Sjöström (1948) and Sundberg (1995), the standard deviations provided an indication of singer level. Figure 4.9 shows vibrato rate standard deviations for each of the 11 notes assessed per solo, pre- and post-intervention.
Figure 4.9 Vibrato rate standard deviations for each of the 11 notes assessed per solo
As seen in Figure 4.9, the more experienced singers were noticeably more consistent in the regularity of their undulations within individual notes, irrespective of the condition. Singers 1 and 2, the two least experienced singers, were the least consistent and it is clear that intervention A impacted these singers the most. The more experienced singers, having less room for improvement, were less impacted. However, post-A, five of the six singers reduced their largest standard deviations at least to some extent, and all singers, regardless of experience, displayed a similar ability to maintain vibrato rates with standard deviations no greater than 0.50 cycles/sec. In contrast, after interventions B and C standard deviations remained roughly indicative of the different singer levels, with the two least experienced singers displaying the greatest difficulty in maintaining consistent, regular vibrato undulations. Within the broad range of values registered post-B, only singers 5 and 6 registered all standard deviations at or below 0.50 cycles/sec. Post-C, only singer 5 registered all values at or below 0.50 cycles/sec.

A subset of data, comprising all pre- to post-intervention note pairs with standard deviations greater than 0.50 cycles/sec, was selected from the entire set of pairs of vibrato rate standard deviations. This subset was selected in order to exclude note pairs with standard deviations that possibly fell within optimal limits, and assess for change that may indicate improvement or deterioration. Research is lacking as to how small standard deviations should be when singing is optimal. “The more skilled the singer, the more regular the undulations” (Sundberg, 1995, p. 39), yet even skilled singers display some variation in the rate of the cyclic undulations that comprise vibrato (Prame, 1994; Sundberg, 1995). Table 4.5 shows the paired t-test results for all notes that pre- and/or post-intervention registered vibrato rate standard deviations greater than 0.50 cycles/sec.
Table 4.5  Paired t-test results for notes that pre- and/or post-intervention registered vibrato rate standard deviations greater than 0.50 cycles/sec

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>N</th>
<th>Std deviation</th>
<th>Std error mean</th>
<th>Mean difference</th>
<th>Std deviation</th>
<th>t-value</th>
<th>Sig (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A - Breathing imagery</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard deviations</td>
<td>Before</td>
<td>0.775</td>
<td>13</td>
<td>0.415</td>
<td>0.115</td>
<td>-0.529</td>
<td>0.489</td>
<td>-3.897</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>0.246</td>
<td>13</td>
<td>0.145</td>
<td>0.040</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>B - Braille imagery</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard deviations</td>
<td>Before</td>
<td>0.674</td>
<td>18</td>
<td>0.487</td>
<td>0.115</td>
<td>-0.016</td>
<td>0.528</td>
<td>-0.125</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>0.858</td>
<td>18</td>
<td>0.458</td>
<td>0.108</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>C - Cloze passage</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard deviations</td>
<td>Before</td>
<td>0.566</td>
<td>18</td>
<td>0.403</td>
<td>0.095</td>
<td>0.192</td>
<td>0.743</td>
<td>1.098</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>0.759</td>
<td>18</td>
<td>0.521</td>
<td>0.123</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
As indicated in Table 4.5, of the 66 note pairs assessed in each condition, 13 pre-A notes registered standard deviations greater than 0.50 cycles/sec. No notes registered post-A standard deviations above 0.50. For condition B, while ten note pairs with pre-B values greater than 0.50 cycles/sec registered a reduction, eight note pairs registered values that increased to reach 0.50 cycles/sec or more. For condition C, while six note pairs with pre-C values greater than 0.50 cycles/sec registered a reduction, 12 note pairs registered values that increased to reach 0.50 cycles/sec or more. In all, a significant pre- to post-test reduction in note pairs with standard deviations greater than 0.50 cycles/sec was found for condition A, but not for conditions B or C.

4.1.4 Vibrato rate and dynamic intensity

Appendix 2.5 lists, for each singer and each condition, the mean vibrato rate and mean dynamic intensity measured by sound pressure level (SPL). Figure 4.10 illustrates mean SPL in relation to mean vibrato rate under all conditions.
Figure 4.10 Comparison of mean SPL and mean vibrato rate under all conditions
The pre- to post-A sections of Figure 4.10 indicate considerable independence between SPL and vibrato rate changes. Interestingly, rather than an incremental link between vibrato rate and SPL, singers 5 and 6 both produced pre- to post-A decreases in mean vibrato rates together with increases in mean SPLs.

However, the pre- to post-B sections of Figure 4.10 indicate a substantial decrease in SPL accompanied vibrato rate decreases for singers 1, 2, 3 and 4. Only the more experienced singers 5 and 6 registered no relationship between vibrato rate and SPL.

The pre- to post-C sections of Figure 4.10 show no consistent relationship between vibrato rate and SPL. While a positive correlation between the two was observed for some singers, singers 2 and 3 were notable exceptions. Singer 3 combined a vibrato rate decrease with an SPL increase and singer 2 combined stable vibrato rates with an SPL decrease.

### 4.1.5 Vibrato rate and fundamental frequency

The notes assessed in the solo were numbered from 1 to 11 (Figure 3.3). Table 4.6 lists the note with the fastest mean vibrato rate and Table 4.7 the note with the slowest mean vibrato rate in each solo.

#### Table 4.6 Notes from 1 to 11 with the fastest mean vibrato rate

<table>
<thead>
<tr>
<th>Fastest vibrato rate</th>
<th>Pre-A</th>
<th>Post-A</th>
<th>Pre-B</th>
<th>Post-B</th>
<th>Pre-C</th>
<th>Post-C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singer 1</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>Singer 2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Singer 3</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Singer 4</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Singer 5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Singer 6</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

#### Table 4.7 Notes from 1 to 11 with the slowest mean vibrato rate

<table>
<thead>
<tr>
<th>Slowest vibrato rate</th>
<th>Pre-A</th>
<th>Post-A</th>
<th>Pre-B</th>
<th>Post-B</th>
<th>Pre-C</th>
<th>Post-C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singer 1</td>
<td>6</td>
<td>11</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Singer 2</td>
<td>7</td>
<td>11</td>
<td>9</td>
<td>11</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>Singer 3</td>
<td>8</td>
<td>10</td>
<td>11</td>
<td>8</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>Singer 4</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>11</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Singer 5</td>
<td>6</td>
<td>11</td>
<td>11</td>
<td>10</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Singer 6</td>
<td>10</td>
<td>11</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>
No individual note produced either the fastest or slowest vibrato rate in all solos. However, the note with the highest fundamental frequency, note 1, had the fastest mean vibrato rate in 25 out of 36 solos (Table 4.6). The two most experienced singers, singer 5 and 6, produced the same highest-note-fastest-rate result under all conditions. Frequently, though not always, they produced all three highest notes in the solo, i.e. notes 1, 2 and 3, which had a descending order of fundamental frequency with correspondingly decreasing mean vibrato rates (Appendix 2.1).

Singers 1, 2, 3 and 4 sometimes produced a highest-note-fastest-rate result, but not consistently. However, after intervention A, all singers produced a highest-note-fastest-rate result. After intervention B, all except singers 1 and 3 produced a highest-note-fastest-rate result. After intervention C, all except singers 1, 2 and 3 produced a highest-note-fastest-rate result.

Notably, the post-A combination of highest-note-fastest-rate did not occur because the highest note’s post-A vibrato rate became faster. Instead, other notes adopted slower post-A vibrato rates. In fact, on all occasions following intervention A, the mean vibrato rate of the highest note slowed. This was not always the case after interventions B and C when the highest note produced the fastest vibrato rate.

No corresponding pattern occurred whereby the lowest fundamental frequencies regularly elicited the slowest mean vibrato rates. The lowest note assessed, note 8, only recorded the slowest mean vibrato rate twice out of 36 solos, and each time only for singer 3 (Table 4.7). Some factor or factors other than fundamental frequency generally appeared to influence slow vibrato rate in this solo.

4.1.6 Vibrato rate and note duration

As the same pre-recorded accompaniment was used for all solos, all singers produced notes of similar duration. Within the eight bar solo, the notes numbered 4, 6, 10 and 11 were all particularly long held notes, but once breathing time at the end of phrases and a slowing in the accompaniment towards the end of the solo were accounted for, notes 10 and 11, both notated as minimis, became the two longest notes.
For 23 out of 36 solos, the slowest vibrato rates were registered by notes 10 and 11. After intervention A, all singers produced their slowest mean vibrato rate on either notes 10 or 11 (Table 4.7). After intervention B, all except singers 1 and 3 produced a similar longest-note-slowest-rate result. After intervention C, all except singers 1 and 2 produced a similar longest-note-slowest-rate result. However, the converse pattern rarely occurred. That is, the note of shortest duration, note 3, recorded the fastest mean vibrato rate on only three of 36 occasions (Table 4.6).

4.1.7 Discussion

Study 1 acoustically measured the vibrato characteristics of six singers performing an eight bar excerpt from Villa-Lobos’ *Bachianas Brasileiras No 5*. The solo called for a calm, lyrical delivery and considerable vocal beauty for effective performance. As such, it required a fairly even, moderate vibrato rate. Group mean vibrato rates for each of the six conditions were between 5.46 and 5.63 cycles/sec, and were well within acceptable limits for vibrato as proposed by Titze (1994). Generally, vibrato rates below 5 cycles/sec are considered unacceptably slow (Sundberg, 1995) and tend towards a wobble (Prame, 1994), with vibrato near 4 cycles/sec clearly undulating rather than creating the impression of a constant pitch (Sundberg, 1995; Titze, 1994). Vibrato rates in the 6 to 8 cycles/sec range may often sound like a bleat (Titze, 1994), with those in the 7 or 8 cycles/sec range associated with tremolo (Doscher, 1994), vocal stress (Vennard, 1968), shrillness (Miller, 1996) and nervousness (Sundberg, 1995). Robison et al. (1994) found that the more beautiful the voice, the more a moderate vibrato rate is present. Indeed, while Mürbe et al. (2007) found that tertiary level training moderates vibrato, such that voices with vibrato faster than 5.8 cycles/sec acquire a slower vibrato and voices with vibrato slower than 5.2 cycles/sec gain a faster vibrato, Titze (1994) proposes that a mean rate of 5.5 cycles/sec falls midway in the region generally perceived as desirable today.

Nevertheless, considering the repertoire did not demand the portrayal of dramatically extreme emotions, mean vibrato rates for individual solos were less than optimal (4.86 to 6.34 cycles/sec), and values for individual notes displayed an even wider, more problematic range of vibrato rates (4.63 to 7.45 cycles/sec). The fact that optimal group mean values masked suboptimal vibrato within the subject pool highlights the need for
vibrato study to consider vibrato variation amongst singers and changes in vibrato patterns of individual singers more closely.

The six singers represented a range of ability levels from first year B.Mus to state opera soloist, and singer level was largely mirrored in the singers' vibrato rates. The more experienced members of the group, singers 4, 5 and 6, consistently had pre-intervention mean vibrato rates that were neither as fast nor as slow as the less experienced singers 1, 2 and 3. Also reflecting singer ability level, the more experienced singers tended to maintain greater vibrato rate stability. This was consistent with reports that although some variation in vibrato is present in the well-functioning voice, irregularity diminishes the more the singer is skilled (Bartholomew, 1934; Mürbe et al., 2007; Robison et al., 1994; Sjöström, 1948; Sundberg, 1987, 1995; Titze et al., 2002).

Singers 1, 2 and 3 often exhibited problematic vibrato, yet they did not always share the same flaws. Singer 1 had particularly fast mean vibrato, singer 2 had extremely unstable mean vibrato, and singer 3 had excessively slow mean vibrato. Overly fast and unstable vibrato rates are common problems amongst students at the commencement of vocal training (Mürbe et al., 2007; Titze et al., 2002). However, such problems are also typical acoustic indicators of muscular hyperactivity that occur in situations of high stress, excessive force and performance anxiety irrespective of singer level (Miller, 1996; Titze, 1994; Vennard, 1968). Excessively slow vibrato is associated with less able singers, where lethargy or poor muscle tone is present (Miller, 1996; Titze et al., 2002).

None of the three more experienced singers exhibited patent problems of extremely fast, slow or unstable vibrato. Yet for all six singers, vibrato rates adopted patterns of change according to the intervention undertaken and according to each singer's pre-existing strengths and weaknesses.

Intervention A breathing imagery produced three notable changes in vibrato rate: (i) more evenness in the cycle-to-cycle undulations comprising the vibrato rate of a note, (ii) more note-to-note stability when the vibrato rates of sustained notes in a solo are compared, and (iii) a moderating of excessively fast and excessively slow vibrato rates. These effects were greatest for those singers who lacked these qualities most. In this
study, conducted in a research laboratory away from the stresses of public performance, the student singers registered the greatest lack of these qualities. Nevertheless, the breathing imagery appeared to impact the acoustic signal of all six singers to some degree.

Pre- to post-A, a significant improvement in regularity was found for the cycle-to-cycle rate of undulations, with no note registering a standard deviation greater than 0.50 cycles/sec. The note-to-note mean vibrato rate values showed a significant improvement in stability, with pre-intervention values of 6.00 cycles/sec or faster becoming significantly slower, and pre-intervention values slower than 5.00 cycles/sec becoming significantly faster. Consequently, a more compact range of note-to-note vibrato rates resulted, and this occurred for all six singers. For every post-A solo each singer’s note-to-note vibrato rates were within a range (calculated from fastest minus slowest vibrato) of 1 cycle/sec. The average standard deviation of note-to-note vibrato rates reduced from 0.41 to 0.24 cycles/sec, with the post-A value matching that reported by Prame (1994) for professional recordings of Schubert’s Ave Maria. A solo-to-solo comparison of confidence intervals indicated that singers’ vibrato rates drew somewhat closer to 5.5 cycles/sec. This is a value that Titze (1994) believes falls midway in the region generally perceived as most aesthetically pleasing.

Following intervention A breathing imagery no significant change was found in the group mean vibrato rate, largely because both the fastest and the slowest mean rates for the solo tended to converge. The mean vibrato rate for the singer with the fastest vibrato decreased from 6.31 to 6.05 cycles/sec, the mean vibrato rate for the singer with the slowest vibrato increased from 4.90 to 5.01 cycles/sec, and even the mean vibrato rates of the more experienced singers contracted from between 5.35 and 5.74 cycles/sec (pre-A) to between 5.42 and 5.58 cycles/sec (post-A).

As opposed to the more regular, compact and moderate vibrato rates registered after intervention A, intervention B produced a significant reduction in the group mean and median vibrato rates for the solo, and notes with pre-intervention values already below 5.00 cycles/sec slowed significantly further. Slower vibrato was advantageous for singers 1 and 2, as their pre-B mean vibrato rates for the solo were very fast. For singer 3, however, her very slow pre-B vibrato slowed further below 5.00 cycles/sec.
towards an area where vibrato becomes a wobble (Prame, 1994). Even the more experienced singers registered slower vibrato rates.

Additionally, note-to-note and cycle-to-cycle vibrato rate irregularity increased after intervention B for all but the most acclaimed singer of the group. The largest standard deviation deterioration occurred for the singer with the least consistent pre-intervention vibrato rates. This was singer 2. Her pre- and post-B note-to-note standard deviation increased from 0.52 to 0.69 cycles/sec, or 8.86% to 12.15% with standard deviation expressed as a percentage of the solo’s mean vibrato rate. This stands in stark contrast to her pre- to post-A values of 0.59 to 0.25 cycles/sec, or 10.02% reducing to 4.44%.

The slower vibrato rates that occurred after both imagery interventions suggest an association between imagery and relaxation. Jung (1968) and Linklater (1976) stress that our imagination is linked to our subconscious functioning. That imagery and relaxation are often linked is a concept utilised in both clinical and sports psychology (Bakker and Kayser, 1994; Barr and Hall, 1992; De Francesco and Burke, 1997; Kendall et al., 1990; Perry and Morris, 1995; Sheikh and Jordan, 1983; Suinn, 1976). In fact, early electroencephalographic (EEG) recordings of brain wave patterns indicated a relationship between imagery and alpha activity associated with relaxed, resting states and the complete absence of stress (Short, 1953).

However, whereas the breathing imagery only slowed the fastest vibrato rates, the comprehensive slowing plus instability in note-to-note and cycle-to-cycle vibrato rates after Braille music code imagery for all but singer 6 suggests that the majority of singers did not cope particularly well with the amount of relaxation afforded by intervention B. It would seem that singer 6, the most accomplished singer in the group, was able to cope with relaxation without it influencing vibrato stability. For the other singers, a limit had been exceeded and although relaxation may sometimes be associated with improved execution of physical tasks, this was not the case for singers 1 to 5. The deterioration of vibrato brings to mind pedagogical warnings that although misplaced tension is to be avoided, complete relaxation is not the answer. Lamperti taught:

“Relaxation of mind and muscle – a quicksand that brings disaster ... Do not become rigid, but never relax” (Brown, 1957, p. 116).
A further difference between the two imagery groups was observed in the relationship between vibrato rate and dynamic intensity indicated by sound pressure level (SPL). Although all singers were asked to maintain, as far as possible, their same dynamic intensity for each recording, intervention B results uniquely linked slower vibrato rate with a decrease in dynamic intensity for singers 1, 2, 3 and 4. Again, this supports the concept that imagery and relaxation are frequent partners. It suggests that after the Braille imagery of intervention B, an increase in relaxation produced both a weaker dynamic range and slower vibrato rates for the less experienced singers. It also suggests that the two most acclaimed singers had found a means of voice production whereby vibrato rate was capable of functioning independently from dynamic level. To date no studies have investigated whether a link between vibrato rate and dynamic intensity may be dependent on the singer’s vocal technique. Nor have longitudinal studies investigated whether techniques for increasing dynamic intensity vary depending on a singer’s level of vocal accomplishment. The relationship between vibrato rate and vocal intensity is unclear. Some researchers have observed vibrato rate to be incrementally related to the dynamics used (Dromey et al., 2003; Winckel, 1953). However, other than in the pre- to post-B results, close consistent relationships between vibrato rate and SPL were not evident. Hence, in general, this study supported the concept, as reported by McLane (1985), Michel and Grashel (1980), Mürbe et al. (2007) and Shipp et al. (1980), that vibrato rate is not intrinsically a function of dynamic intensity.

As opposed to both imagery interventions, the non-imagery cloze passage of intervention C produced no significant changes in vibrato. Pre- to post-C mean vibrato rates for the solo showed the least change of any condition, and the note-to-note progression of vibrato rates and cycle-to-cycle regularity while fluctuating somewhat, showed no specific trends.

Trends have, however, sometimes been observed linking rising pitch with increased vibrato rate (Titze, 1994), and increased note duration with decreased vibrato rate (Prame, 1994). It is interesting that while the two most experienced singers matched their highest fundamental frequency with their fastest mean vibrato rate on all occasions, only after intervention A did all singers produced a highest-note-fastest-rate result. Yet this occurred, not because the highest note’s mean vibrato rate became faster, but because other notes assumed slower mean vibrato rates than the highest
note. Also after intervention A, the two longest held notes consistently produced the slowest mean vibrato rates.

The tendency for the highest note, note 1, to have the fastest mean vibrato rate and the longest held notes, notes 10 and 11, to have the slowest mean vibrato rate could, however, have resulted from a number of complex factors, including the singer’s emotional response to the music. For example, the singer’s sense of energy and possibly heightened stress level at commencing the solo on a relatively high note may have influenced the first note’s vibrato rate to be the fastest. Similarly for the final two notes, note 10 and 11, slow vibrato may have occurred as a result of the singers attempting to convey a quality of serenity and restfulness in the concluding notes.

Prame (1994) concedes that in addition to note length, the singer’s interpretation of a piece may affect vibrato rate. Titze et al. (2002) and Vennard (1968) also maintain that artistic interpretation and the singer’s emotional response to the music influence vibrato rate. Whether influenced by artistic interpretation, fundamental frequency, note duration or some combination of factors, it is interesting that uniform results among all singers as to which notes had the fastest and slowest mean vibrato rates emerged only after the breathing imagery. This outcome, combined with the fact that vibrato rates after the breathing imagery became more regular, compact and moderate, resulted in far more similarity among the six singers than was the case after the Braille music code imagery or the non-imagery cloze passage.

4.2 VIBRATO EXTENT ANALYSIS

Spectrograms of the eleven long held notes contained in each solo, i.e. 396 notes in total, were assessed for vibrato extent, and data scrutinised for recurrent differences following interventions A, B and C. Additionally, changes in vibrato extent were compared with singer dynamic intensity, measured by sound pressure level (SPL), as a relationship between these elements may exist (Bretos and Sundberg, 2002; Winckel, 1953).
4.2.1 Assessment of each group as a whole

Appendix 3.1 presents the mean vibrato extent for each note assessed. From these data, Table 4.8 lists the mean vibrato extent for each solo and for the group.

Table 4.8 Mean vibrato extent for each solo and each group, expressed in semitones both above and below the average fundamental frequency

<table>
<thead>
<tr>
<th>Mean vibrato extent</th>
<th>Pre-A</th>
<th>Post-A</th>
<th>Pre-B</th>
<th>Post-B</th>
<th>Pre-C</th>
<th>Post-C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singer 1</td>
<td>0.494</td>
<td>0.552</td>
<td>0.574</td>
<td>0.536</td>
<td>0.532</td>
<td>0.579</td>
</tr>
<tr>
<td>Singer 2</td>
<td>0.713</td>
<td>0.913</td>
<td>0.778</td>
<td>0.788</td>
<td>0.872</td>
<td>0.820</td>
</tr>
<tr>
<td>Singer 3</td>
<td>0.854</td>
<td>0.822</td>
<td>0.861</td>
<td>0.831</td>
<td>0.786</td>
<td>0.817</td>
</tr>
<tr>
<td>Singer 4</td>
<td>0.790</td>
<td>0.779</td>
<td>0.733</td>
<td>0.717</td>
<td>0.757</td>
<td>0.811</td>
</tr>
<tr>
<td>Singer 5</td>
<td>1.532</td>
<td>1.491</td>
<td>1.499</td>
<td>1.435</td>
<td>1.600</td>
<td>1.550</td>
</tr>
<tr>
<td>Singer 6</td>
<td>1.078</td>
<td>1.117</td>
<td>1.054</td>
<td>1.136</td>
<td>1.088</td>
<td>1.088</td>
</tr>
<tr>
<td><strong>Group average</strong></td>
<td>0.910</td>
<td>0.946</td>
<td>0.916</td>
<td>0.907</td>
<td>0.939</td>
<td>0.944</td>
</tr>
<tr>
<td><strong>Standard deviation</strong></td>
<td>0.359</td>
<td>0.324</td>
<td>0.326</td>
<td>0.324</td>
<td>0.370</td>
<td>0.338</td>
</tr>
</tbody>
</table>

As indicated in Table 4.8, group mean vibrato extents for each of the six conditions registered between ±0.91 and ±0.95 semitones from the perceived fundamental frequency. The largest pre- to post-intervention change, an increase of ±0.04 semitones, was registered after intervention A. Interventions B and C registered changes of ±0.01 semitones or less.

Standard deviation from the group mean vibrato extent decreased slightly following each intervention (Table 4.8). After intervention A, a decrease of ±0.04 semitones was registered. After intervention B, a decrease of ±0.01 semitones was registered, and after intervention C, a decrease of ±0.03 semitones.

4.2.2 Assessment of each solo

4.2.2.1 Mean vibrato extent

Figures 4.11 and 4.12 present spectrographic representations of small and large vibrato extents respectively.
Both Figures 4.11 and 4.12 show the note E₄ (approx. 330 Hz). The vertical axis indicates the frequency in Hertz, from which the fundamental frequency and upperpartials can be located. In Figure 4.11 the undulating lines of the partials, which showonly a small difference in frequency between each peak and trough of the vibratoundulations, give an indication of the small vibrato extent of singer 1. By comparison, inFigure 4.12 the same note sung by singer 5 displays greater variation in frequencyfrom the troughs to the peaks of each partial and hence a larger vibrato extent.
Figure 4.13 presents the mean vibrato extent for each solo.

Mean vibrato extent values ranged from ±0.49 semitones (singer 1) to ±1.60 semitones (singer 5). Variation in values from pre- to post-intervention for any individual singer was generally less than ±0.1 semitones. The sole exception was singer 2 who increased her mean vibrato extent from ±0.71 to ±0.91 semitones after intervention A. Overall, however, no distinct trends as a result of any intervention emerged.
4.2.2.2 Standard deviation

Vibrato extent standard deviation for the solos ranged from \pm 0.07 to \pm 0.26 semitones (Appendix 3.3). Pre-to-post changes included both increases and decreases in standard deviation irrespective of the intervention undertaken. Figure 4.14 indicates the vibrato extent standard deviation for each condition.

Figure 4.14 Standard deviation in relation to the mean vibrato extent for each solo

Note: Each of the six columns represent the mean vibrato extent of one solo by, from left to right, singer 1, 2, 3, 4, 5 and 6. The base of each column represents the perceived pitch. The double-headed arrows near the top of each column indicate the standard deviation.

As seen in Figure 4.14 once standard deviation was added to the mean vibrato extent, singer 5 had a particularly large vibrato extent exceeding \pm 1.5 semitones under every condition.
4.2.2.3 Confidence intervals

Figure 4.15 shows the 95% confidence intervals for vibrato extent.

Figure 4.15 The 95% confidence intervals for mean vibrato extent for each pre- and post-intervention solo

Note: Lines on the left of each pair show the pre-intervention confidence interval and those on the right show the post-intervention confidence interval.

Figure 4.15 confirms that although vibrato extent varied for each singer after every intervention, no clear trends regarding either the direction or size of variation were present.
4.2.3 Assessment of individual notes

The smallest mean vibrato extent for any individual note was ±0.14 semitones (Appendix 3.1). This was produced by singer 1, the youngest singer in the group. By contrast, singer 5, the oldest singer, regularly registered values above ±1.5 semitones, the largest being ±1.95 semitones. Mean vibrato extents generally varied only moderately from pre-to post-intervention. The response of singer 2, who notably registered more consistent note-to-note vibrato extents after intervention A, appeared to be atypical.

Figure 4.16 illustrates the standard deviation in relation to the mean vibrato extent for each note. As seen in Figure 4.16, once standard deviation was taken into account, singer 5, under every condition, produced some values exceeding ±2 semitones, i.e. more than one tone both above and below the average fundamental frequency. As the oldest singer, she consistently had both the widest vibrato extent and the widest standard deviations.
Figure 4.16 Mean vibrato extent and standard deviation for individual notes

Note: Each group of eleven columns represents the eleven mean vibrato extents assessed from each singer’s solo. The base of each column represents the target pitch. The double-headed arrows near the top of each column indicate the standard deviation.
4.2.4 Vibrato extent and dynamic intensity

Data were checked to determine whether a link existed between vibrato extent and the singer’s level of dynamic intensity indicated by sound pressure level (SPL). Appendix 3.4 lists mean SPL and mean vibrato extent for every solo. Figure 4.17 compares mean SPL and mean vibrato extent for each singer under every condition.

As seen in Figure 4.17, the pre-A and post-A mean vibrato extents appeared to be unrelated to mean SPL. Sometimes mean vibrato extent decreased while SPL increased. At other times the reverse occurred. Only once, for singer 6, did both mean vibrato extent and SPL increase.

From pre-B to post-B, both mean SPL and mean vibrato extent decreased for singers 1, 3 and 4. However, no such relationship between SPL and mean vibrato extent occurred for singers 2, 5 and 6.

From pre-C to post-C for singers 1, 2 and 3 the mean SPL and mean vibrato extent either both increased or both decreased. For singers 4 and 5, however, mean SPL and mean vibrato extent moved in opposite directions, while for singer 6 mean SPL increased and mean vibrato extent registered no change.
Figure 4.17 Comparison of mean SPL and mean vibrato extent under all conditions
4.2.5 Discussion

For study 1, the group mean vibrato extents for all six conditions were between ±0.91 and ±0.95 semitones from the perceived fundamental frequency. These average values seemed well within acceptable limits considering mean vibrato extents of between ±0.71 semitones from professional Lieder recordings (Prame, 1997) and ±1.4 semitones from professional opera singers (Shipp et al., 1980) have been documented.

Supporting the observation that beginner singers often display minimal vibrato extent (Titze et al., 2002), singer 1, at 19 years of age the youngest singer, registered the smallest mean vibrato extent in the group for all six conditions. Her smallest mean value for a solo was ±0.49 semitones, and her smallest mean value for an individual note, at ±0.14 semitones, was verging on a straight tone. By contrast, singer 5, at 49 years of age the oldest singer, registered the largest mean vibrato extent in the group for all six conditions. Singer 5's largest mean vibrato extent for a solo was ±1.60 semitones, and largest value for an individual note was ±1.95 semitones. She exceeded ±1.50 semitones for individual notes in all six conditions. This brought singer 5's vibrato extent into that area (±1.5 semitones and above) where Howes (2001) noted that listener-judges tended to rate singers negatively. Such large values, however, appeared to be beyond the control of singer 5 who expressed discontent with what she described as her increasing vibrato since the onset of menopause. This is consistent with findings that professional singers often experience increased vibrato extent as a result of aging (Sundberg et al., 1998).

None of the interventions appeared to influence vibrato extent in any systematic or pronounced way. Following the intervention A breathing imagery, the vibrato extent of singer 2 became more consistent from note-to-note and showed a mean increase for the solo from ±0.71 to ±0.91 semitones. However, this occurrence was atypical, and for most singers any change in mean vibrato extent, regardless of the intervention, was less than ±0.1 of a semitone. After intervention A, there was an increase in mean vibrato extent for three singers and a decrease for three singers. After intervention B, a small increase in mean vibrato extent occurred for two singers and a decrease for four singers. After intervention C, there was a small increase in mean vibrato extent for three singers, a decrease for two singers and no change for one singer. Overall, there was no indication that singer experience was related to these changes.
Although all singers were asked to maintain, as far as possible, their same dynamic level for each recording, some variation occurred. The existence of a relationship between dynamic level and vibrato extent is an unresolved issue amongst researchers, with some suggesting a link may exist (Bretos and Sundberg, 2002; Winckel, 1953), while others maintain there is either no such link (Michel and Grashel, 1980; Shipp et al., 1980) or at most an inconsistent connection often prone to considerable variation (Michel and Myers, 1991). Examination of the solos found that for interventions A and B, no close association between dynamic change and changes in mean vibrato extent was evident. However, intervention C findings suggested a possible relationship between vibrato extent, SPL and singer experience. That is, pre-C to post-C a positive correlation between mean SPL and mean vibrato extent occurred for the less experienced singers 1, 2 and 3. Notably, this did not occur for the more experienced singers 4, 5 and 6. This is not to suggest that these more experienced singers would refrain from using a combination of vibrato extent and SPL when the dramatic portrayal of artistic feeling is called for. Schoen (1922) maintained that emotional intensity may be signalled through increased vibrato extent, and Bretos and Sundberg (2002) measured concurrent increases in SPL and vibrato extent in emotionally intense repertoire. However, in the calm, lyrical Villa-Lobos excerpt used in this study, singers 4, 5 and 6 were able to produce vibrato extents that appeared to be independent of SPL. Hence, on the whole, the findings of this study concur with those of Michel and Myers (1991), Michel and Grashel (1980), and Shipp et al. (1980), who found no consistent change in vibrato extent when notes were sung at different dynamic levels.

In conclusion, irrespective of the intervention undertaken, no recognisable pattern occurred in singer responses regarding vibrato extent. On most occasions, change in vibrato extent was minimal and only rarely did vibrato extent appear to be related to SPL measurements. In cases where vibrato extent was excessively small or excessively large, this appeared to be neither under the control of the singers concerned nor resolved by any intervention.

### 4.3 SINGER-SUBJECT SELF-ASSESSMENT

Six female singers each recorded a set eight bar solo (Figure 3.1) without prior warming up, and self-assessed 18 qualities regarding their own performance (see
Qualities were rated from 1 to 10, with 1 indicating poor quality and 10 indicating excellence. Singers then undertook one of three 25 minute interventions based on either breathing imagery, Braille music code imagery or a non-imagery cloze passage on breathing (see Method 3.1.1.2). They then re-recorded the solo and completed further questionnaires (see Method 3.1.1.3). This procedure was repeated until each singer, using a different order for the interventions, had undertaken all three interventions. The singers each came from different studios, none of which incorporated the teaching of imagery as practiced in this project. Singers also had no prior knowledge of Braille music code and indicated that most of the information in the cloze passage on breathing was new. All singers reported being able to perform the intervention tasks as requested.

4.3.1 Group mean ratings

Of the 18 qualities rated, qualities i to vi were common to both singer-subjects’ and listener-judges’ questionnaires and related to tone colour. Figure 4.18 presents the singer-subjects’ mean ratings and 95% confidence intervals for qualities i to vi, and Table 4.9 lists the results of the corresponding paired t-tests for singer-subjects’ perceptual judgements. For condition A there was a significant difference pre- and post-test for “vibrato” and for “overall rating of classical vocal quality”, but not for “mellowness”, “brilliance”, “absence of vocal strain” and “overall rating of legit vocal quality”. For conditions B and C there were no significant differences pre- and post-test.
Figure 4.18 Singer-subject group mean ratings and 95% confidence intervals for qualities i to vi
Table 4.9 Group mean ratings of singer self-perception of qualities i to vi for conditions A (breathing imagery), B (Braille music code imagery) and C (non-imagery cloze passage), and paired t-test results

<table>
<thead>
<tr>
<th>Self-assessed qualities</th>
<th>Intervention</th>
<th>Group mean</th>
<th>Mean difference</th>
<th>Std. deviation</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(i) Mellowness</td>
<td>A</td>
<td>5.833</td>
<td>6.667</td>
<td>0.834</td>
<td>0.983</td>
<td>-2.076</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>6.167</td>
<td>6.500</td>
<td>0.333</td>
<td>1.033</td>
<td>-0.791</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>5.833</td>
<td>5.667</td>
<td>-0.166</td>
<td>0.983</td>
<td>0.415</td>
</tr>
<tr>
<td>(ii) Brilliance</td>
<td>A</td>
<td>5.333</td>
<td>6.667</td>
<td>1.333</td>
<td>1.506</td>
<td>-2.169</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>5.667</td>
<td>5.833</td>
<td>0.167</td>
<td>0.408</td>
<td>-1.000</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>5.833</td>
<td>5.667</td>
<td>-0.166</td>
<td>0.753</td>
<td>0.542</td>
</tr>
<tr>
<td>(iii) Absence of vocal strain</td>
<td>A</td>
<td>7.167</td>
<td>8.000</td>
<td>0.833</td>
<td>1.329</td>
<td>-1.536</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>7.333</td>
<td>7.000</td>
<td>-0.333</td>
<td>1.633</td>
<td>0.500</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>7.000</td>
<td>7.167</td>
<td>0.167</td>
<td>0.753</td>
<td>-0.542</td>
</tr>
<tr>
<td>(iv) Vibrato</td>
<td>A</td>
<td>6.000</td>
<td>7.000</td>
<td>1.000</td>
<td>0.894</td>
<td>-2.739</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>6.333</td>
<td>6.333</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>6.500</td>
<td>6.000</td>
<td>-0.500</td>
<td>0.837</td>
<td>1.464</td>
</tr>
<tr>
<td>(v) Overall rating of classical vocal quality</td>
<td>A</td>
<td>6.500</td>
<td>8.000</td>
<td>1.500</td>
<td>1.225</td>
<td>-3.000</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>6.667</td>
<td>6.833</td>
<td>0.167</td>
<td>0.753</td>
<td>-0.542</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>7.167</td>
<td>6.833</td>
<td>-0.334</td>
<td>0.516</td>
<td>1.581</td>
</tr>
<tr>
<td>(vi) Overall rating of legit vocal quality</td>
<td>A</td>
<td>6.167</td>
<td>6.667</td>
<td>0.500</td>
<td>0.548</td>
<td>-2.236</td>
</tr>
<tr>
<td></td>
<td>B</td>
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<td>6.333</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>6.333</td>
<td>6.333</td>
<td>0.000</td>
<td>0.632</td>
<td>0.000</td>
</tr>
</tbody>
</table>
Qualities vii to xii related to the singer’s psychological disposition and psychophysiological factors. Figure 4.19 presents the singer-subjects’ mean ratings and 95% confidence intervals for qualities vii to xii, and Table 4.10 lists the results of the corresponding paired t-tests for singer-subjects’ perceptual judgements. For condition A there was a significant difference pre- and post-test for “satisfaction with the way you sang” and for “energised alertness”, but not for “absence of performance anxiety”, “absence of audible nervousness”, “confidence” and “inner calmness”. For conditions B and C there were no significant differences pre- and post-test.
Figure 4.19 Singer-subject group mean ratings and 95% confidence intervals for qualities vii to xii
Table 4.10  Group mean ratings of singer self-perception of qualities vii to xii for conditions A (breathing imagery), B (Braille music code imagery) and C (non-imagery cloze passage), and paired t-test results

<table>
<thead>
<tr>
<th>Self-assessed qualities</th>
<th>Intervention</th>
<th>Group mean before</th>
<th>Mean difference</th>
<th>Std. deviation</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(vii) Satisfaction with the way you sang</td>
<td>A</td>
<td>4.500</td>
<td>6.500</td>
<td>2.000</td>
<td>1.095</td>
<td>-4.472</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>4.667</td>
<td>5.167</td>
<td>0.500</td>
<td>1.517</td>
<td>-0.808</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>5.167</td>
<td>5.333</td>
<td>0.166</td>
<td>0.983</td>
<td>-0.415</td>
</tr>
<tr>
<td>(viii) Absence of performance anxiety</td>
<td>A</td>
<td>8.667</td>
<td>8.833</td>
<td>0.166</td>
<td>0.408</td>
<td>-1.000</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>8.667</td>
<td>8.833</td>
<td>0.167</td>
<td>0.408</td>
<td>-1.000</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>8.833</td>
<td>8.833</td>
<td>0.000</td>
<td>0.000</td>
<td>1.000</td>
</tr>
<tr>
<td>(ix) Absence of audible nervousness</td>
<td>A</td>
<td>8.167</td>
<td>9.000</td>
<td>0.833</td>
<td>1.329</td>
<td>-1.536</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>8.167</td>
<td>8.333</td>
<td>0.167</td>
<td>0.408</td>
<td>-1.000</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>8.333</td>
<td>8.333</td>
<td>0.000</td>
<td>0.000</td>
<td>1.000</td>
</tr>
<tr>
<td>(x) Confidence</td>
<td>A</td>
<td>7.500</td>
<td>8.000</td>
<td>0.500</td>
<td>0.837</td>
<td>-1.464</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>7.333</td>
<td>7.667</td>
<td>0.333</td>
<td>0.516</td>
<td>-1.581</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>7.667</td>
<td>7.833</td>
<td>0.167</td>
<td>0.408</td>
<td>-1.000</td>
</tr>
<tr>
<td>(xi) Inner calmness</td>
<td>A</td>
<td>7.000</td>
<td>8.333</td>
<td>1.333</td>
<td>2.317</td>
<td>-1.938</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>7.167</td>
<td>7.333</td>
<td>0.167</td>
<td>0.408</td>
<td>-1.000</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>7.167</td>
<td>7.333</td>
<td>0.167</td>
<td>0.408</td>
<td>-1.000</td>
</tr>
<tr>
<td>(xii) Energised alertness</td>
<td>A</td>
<td>4.333</td>
<td>6.833</td>
<td>2.500</td>
<td>1.378</td>
<td>-4.443</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>4.833</td>
<td>5.000</td>
<td>0.167</td>
<td>0.753</td>
<td>-0.542</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>4.667</td>
<td>5.000</td>
<td>0.333</td>
<td>0.816</td>
<td>-1.000</td>
</tr>
</tbody>
</table>
Qualities xiii to xviii related in particular to singer perception of technical command and proprioceptive feedback from vocal technique. Figure 4.20 presents the singer-subjects’ mean ratings and 95% confidence intervals for qualities xiii to xviii, and Table 4.11 lists the results of the corresponding paired t-tests for singer-subjects’ perceptual judgements. For condition A there was a significant difference pre- and post-test for “sensation of being vocally warmed up”, “resonant voice sensations”, “vocal connection throughout the body” and “perception of ease”, but not for “concentration on appropriate technique” and “postural alignment for singing”. For condition B there was a significant difference pre- and post-test for “vocal connection throughout the body” but no significant differences for other qualities. For condition C there were no significant differences pre- and post-test.
Figure 4.20 Singer-subject group mean ratings and 95% confidence intervals for qualities xiii to xviii
Table 4.11 Group mean ratings of singer self-perception of qualities xiii to xvii for conditions A (breathing imagery), B (Braille music code imagery) and C (non-imagery cloze passage), and paired t-test results

<table>
<thead>
<tr>
<th>Self-assessed qualities</th>
<th>Intervention</th>
<th>Group mean</th>
<th>Mean difference</th>
<th>Std. deviation</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Before</td>
<td>After</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(xiii) Concentration on appropriate vocal technique</td>
<td>A</td>
<td>6.167</td>
<td>6.833</td>
<td>0.667</td>
<td>1.366</td>
<td>-1.195</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>6.500</td>
<td>6.667</td>
<td>0.167</td>
<td>0.753</td>
<td>-0.542</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>6.000</td>
<td>6.667</td>
<td>0.667</td>
<td>0.816</td>
<td>-2.000</td>
</tr>
<tr>
<td>(xiv) Sensation of being vocally warmed up</td>
<td>A</td>
<td>2.833</td>
<td>5.500</td>
<td>2.667</td>
<td>1.366</td>
<td>-4.781</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>3.333</td>
<td>3.833</td>
<td>0.500</td>
<td>0.548</td>
<td>-2.236</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>3.500</td>
<td>4.000</td>
<td>0.500</td>
<td>0.837</td>
<td>-1.464</td>
</tr>
<tr>
<td>(xv) Resonant voice sensations</td>
<td>A</td>
<td>5.000</td>
<td>7.167</td>
<td>2.167</td>
<td>1.602</td>
<td>-3.313</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>5.333</td>
<td>5.667</td>
<td>0.333</td>
<td>0.816</td>
<td>-1.000</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>6.000</td>
<td>5.333</td>
<td>-0.667</td>
<td>2.160</td>
<td>0.756</td>
</tr>
<tr>
<td>(xvi) Vocal connection throughout the body</td>
<td>A</td>
<td>3.333</td>
<td>6.667</td>
<td>3.334</td>
<td>1.633</td>
<td>-5.000</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>3.833</td>
<td>4.500</td>
<td>0.667</td>
<td>0.516</td>
<td>-3.162</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>4.667</td>
<td>4.667</td>
<td>0.000</td>
<td>0.632</td>
<td>0.000</td>
</tr>
<tr>
<td>(xvii) Perception of ease</td>
<td>A</td>
<td>4.833</td>
<td>7.333</td>
<td>2.500</td>
<td>2.074</td>
<td>-2.953</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>5.167</td>
<td>5.333</td>
<td>0.166</td>
<td>0.408</td>
<td>-1.000</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>6.333</td>
<td>6.167</td>
<td>-0.166</td>
<td>0.408</td>
<td>1.000</td>
</tr>
<tr>
<td>(xviii) Postural alignment for singing</td>
<td>A</td>
<td>5.000</td>
<td>6.167</td>
<td>1.167</td>
<td>1.329</td>
<td>-2.150</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>5.333</td>
<td>5.500</td>
<td>0.167</td>
<td>0.408</td>
<td>-1.000</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>5.667</td>
<td>6.000</td>
<td>0.333</td>
<td>1.033</td>
<td>-0.791</td>
</tr>
</tbody>
</table>
Comparing Figures 4.18, 4.19 and 4.20 it can be seen that the highest pre-intervention group mean scores were consistently registered for "absence of performance anxiety", which suggested that the singers as a group did not find the initial recording process particularly nerve-racking. The lowest pre-intervention group mean scores were consistently registered for "sensation of being vocally warmed up", reflecting the singers' compliance with the request not to warm up beforehand. Although all three post-intervention mean ratings showed an improvement in the "sensation of being vocally warmed up", the largest and only significant improvement in this quality was registered after intervention A breathing imagery.

Figure 4.21 presents the singer-subjects' mean ratings and 95% confidence intervals for each condition and Table 4.12 lists the results of the corresponding paired t-tests for singer-subjects' perceptual judgements.

![Figure 4.21 Singer-subject group mean ratings and 95% confidence intervals for each condition](image)

Overall, differences between pre- and post-A mean group scores varied from an increase of 0.17 to an increase of 3.33. Differences between pre- and post-B mean group scores varied from a decrease of -0.33 to an increase of 0.67. Differences between pre- and post-C mean group scores varied from a decrease of -0.67 to an increase of 0.67. As seen in Table 4.12, the one-tailed paired t-test results show a significant pre- to post-intervention difference for the entire sample across singers, pairs and quality for conditions A and B, but not for condition C.
Table 4.12 Group mean ratings of singer self-perception of all qualities combined for each condition, and paired t-test results

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Group mean</th>
<th>Mean difference</th>
<th>Std. deviation</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Breathing imagery</td>
<td>5.796</td>
<td>1.463</td>
<td>1.531</td>
<td>-9.930</td>
<td>0.000</td>
</tr>
<tr>
<td>B Braille music code imagery</td>
<td>6.046</td>
<td>0.213</td>
<td>0.724</td>
<td>-3.056</td>
<td>0.003</td>
</tr>
<tr>
<td>C Non-imagery Cloze passage</td>
<td>6.259</td>
<td>0.028</td>
<td>0.848</td>
<td>-0.340</td>
<td>0.734</td>
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</table>
4.3.2 Inter-singer agreement

Inter-singer agreement was assessed in two ways. Firstly, the mean scores for all 18 qualities were averaged before and after interventions A, B and C. Of the six singers, agreement was unanimous that a mean improvement occurred after intervention A breathing imagery (Appendix 4.1). By contrast, after intervention B Braille music code imagery only singer 6 rated a mean improvement. Singer 2 rated a mean deterioration and all others rated no change (Appendix 4.2). After the intervention C cloze passage on breathing only singer 3 rated a mean improvement. Singer 5 rated a mean deterioration and the others rated no change (Appendix 4.3).

Ratings were then assessed for agreement regarding each quality and considered to be in close agreement if a singer’s ratings differed by no more than ±1 from another singer’s ratings. From each singer’s 36 ratings (i.e. 18 ratings both pre- and post-intervention) the percentages that met this criterion were as follows:

Condition A agreement ranged from 36% to 83%, with a mean of 52% (S.D.12%).
Condition B agreement ranged from 17% to 72%, with a mean of 38% (S.D.16%).
Condition C agreement ranged from 6% to 64%, with a mean of 36% (S.D.18%) (Appendix 4.4)

4.3.3 Individual singer responses

Appendices 4.1, 4.2 and 4.3 list individual singers’ self-assessments for conditions A, B and C respectively. It shows that some singers registered the maximum possible for “absence of vocal strain”, “absence of performance anxiety”, “absence of audible nervousness” and “inner calmness” prior to every intervention, allowing no room for improvement irrespective of the activity undertaken. It also indicates that regardless of the order of the interventions, which changed for each singer, most rating increases occurred after intervention A breathing imagery.

The largest post-A increase was for “perception of ease” (singer 5) and “inner calmness” (singer 2) with an additional 6 points each. Pre- to post-A improvement was unanimously registered for “satisfaction with the way you sang”, “vocal connection throughout the body”, “energised alertness”, “sensation of being vocally warmed up” and “perception of ease”. Five of the six singers also registered stronger “resonant voice sensations”.

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Interestingly, for “postural alignment for singing” the less experienced singers 1, 2 and 3 registered no post-A improvement, yet the more experienced singers 4, 5 and 6 all registered rating increases. This tended to support the concept that postural awareness and the fine-tuning of spinal alignment may be linked with directional imagery once considerable vocal experience has occurred.

On the whole, a distinctly different pattern of responses emerged following interventions B and C. That is, in comparison to post-A ratings, increases were fewer and generally smaller, and agreement amongst singers regarding improvement was weaker.

After intervention B (Braille music code imagery) all singers rated most qualities as not changing. When change was registered, singers 4, 5 and 6 who were the more experienced singers of the group, noted only positive changes. This was not the case with singers 1, 2 and 3 who sometimes indicated that they did not cope as well with this intervention as the more experienced singers.

Intervention C (non-imagery cloze passage) also produced predominantly neutral responses. This time, most positive responses came from the less experienced singers in the group. Most negative responses came from more experienced singers. Interestingly, this intervention, with its shift of focus onto anatomy, was the only occasion that an improvement in posture was registered by any of the less experienced singers.

The variation between results from different singer levels after each intervention prompted a comparison of mean results of the three less experienced singers with the three more experienced singers. These data are descriptive only and are therefore included only in an Appendix for interest and to stimulate further interest in replication of the study on different groups of singers. There were too few participants to undertake statistical analyses or to draw definitive conclusions about the differential effects of these interventions on singers with differing characteristics (see Appendices 4.5, 4.6 and 4.7).

After assessing the 18 listed qualities, singers were asked if, in order to maintain the same dynamic level after the interventions as before, any vocal restraint was necessary. They were also given the opportunity to write any further comments they had. None of the singers felt vocal restraint was necessary after interventions B or C. Apart from singer 6 writing that intervention B seemed to have a relaxing effect, no
other comments were written from the other singers about intervention B. After intervention C, singer 1 wrote that the cloze passage on breathing gave “more mental focus on vocal technique”. Singer 5 wrote that after the cloze passage “I felt that I gave more effort but there was actually less projection”.

However, after intervention A, four of the six singers agreed that less effort was necessary to maintain the same volume. Singer 1 stated that this applied particularly to the highest notes, which had become much easier to produce after intervention A breathing imagery. Singer 1 also noted that post-A, the voice seemed “less breathy”, “the soft palate seemed to be warmed up for singing” and “much higher notes seemed possible if only the music asked for them”. Singer 2 wrote that “linking the two opposite directions for the breath was conceptually difficult, but afterwards I felt unusually calm” and that post-A “there was an easier legato line without trying”. Singer 3 wrote, “It seems strange that sensing the breath from the skull to the knees was quite easy to perform”. Singer 5 stated that whereas the voice had been “saggy and dull” before, after the breathing imagery “the voice was lifted up to where it should be. It had more shine and seemed capable of projecting louder with ease.” Singer 6 wrote that after the breathing imagery “the body felt ‘woken up’ for singing. Breathing to the absolute extremities (above the head and below the feet) was easier than the other breathing tasks. The image of breathing into roots below the stage floor is a fabulous grounding tool.” Hemsley (1998) defines “grounding” as “the feeling of a low centre of gravity … [that] will enable the singer to avoid tension and energy blockage in the midriff” (p. 103).

Singer 5, however, made the observation that she would have sung differently in a genuine performance because normally she would have to cope with nerves, yet with a research environment being so unlike a true performance, she was not nervous at all. In fact singers 3, 4, 5 and 6 generally reported no performance anxiety at all during the recording sessions of this project.

As previously indicated, all singers performed the interventions in a different order to counteract the possibility of the order of interventions influencing group mean results. Despite pausing after each pre- and post-intervention rendition of the solo before proceeding to the next pre- and post-intervention rendition, there was often some degree of carry-over effect apparent in each singer’s ratings. Thus, each singer’s pre-A, pre-B and pre-C ratings differed. In particular, as most rating increases were registered after intervention A (breathing imagery), whatever pre-intervention performance followed a post-A performance tended to reflect the post-A higher ranking. A carry-over
effect can clearly be seen with singer 5 who performed the interventions in the order B - A - C. After intervention B singer 5 rated many qualities as either remaining the same or slightly improved. Her pre-A ratings were then very similar. After intervention A she rated many qualities noticeably higher. Her subsequent pre-C ratings were similarly high. Interestingly, singer 5 said she felt so warmed up after the breathing imagery of intervention A that her voice was bound to remain that way all day irrespective of further interventions. Yet after the final intervention she expressed surprise at feeling she was not singing as well as she had after intervention A. This perception appeared to have an acoustic basis, as her vibrato rate had become more stable after intervention A, whereas after the final intervention her vibrato rate was less stable.

4.3.4 Comparison of acoustic and perceptual results

Relating the singers’ perceptual judgements to acoustic findings reported in Section 4.1, it is notable that despite pre- to post-intervention change in vibrato rate occurring for all singers, not all singers registered a perceptual change in vibrato. Singers 4 and 6, the only singers to each produce a mean vibrato rate between 5.20 and 5.60 cycles/sec under all conditions, and hence the singers exhibiting the most consistently moderate vibrato rates in the group, registered no perceived change in vibrato after any intervention.

All other singers noted an improvement in vibrato rate after intervention A breathing imagery, but no singers registered an improvement in vibrato after interventions B or C. The reason for the noted post-A improvement appeared to have an acoustic basis. That is, acoustically, all singers produced post-A vibrato rates that were more moderate and even from one sustained note to the next. Additionally, while some cyclic variation is necessary within the vibrato rate for each note, such variation generally decreased. However, it is unclear whether these singers were acutely perceptive of vibrato change or whether they rated vibrato as improving merely due to a sense an overall improvement in vocal quality after intervention A.

Singer self-perception did not always reflect an apparent acoustic basis. For example, singer 3 indicated the perception of greatest vocal improvement by her final rendition of the solo, although acoustic analysis of her vibrato rate indicated a progressive deterioration in vocal quality had taken place. Singer 3 performed the interventions in the order A – B – C and stated before commencing that over the course of the three interventions she presumed she would both warm-up and sing better at the end. By the
final rendition she registered greater satisfaction with the way she sang, that her classical tone quality had improved and that the quality of brilliance was at its best. Yet classical tone quality and brilliance deteriorate the more the vibrato rate slows below 5 cycles/sec (Miller, 1977; Prame, 1994), and singer 3’s vibrato rate slowed from 5.01 to 4.86 cycles/sec between the first and last intervention. Hence, singer 3’s ability to finely self-assess her own vocal quality was questionable. Interestingly, singer 3 also reported that normally the only vocal sensations she was aware of, were those in her throat from the position of her tongue. Compared with comments from Thomas Quasthoff (Holmes, 2003) and pedagogues Robison (2001) and Vennard (1968), who stress that a singer must sense the voice with the entire body, it would seem that the ability of singer 3 to assess her own vocal quality was restricted by limited use of proprioceptive feedback.

4.3.5 Discussion

All interventions were undertaken in a different order by each singer and involved the singer remaining silent for 25 minutes. Yet singers responded much more positively to some activities than to others. Singers’ registered unanimous agreement that a mean improvement occurred after intervention A (breathing imagery), whereas after interventions B (Braille music code imagery) and C (non-imagery cloze passage on breathing) the majority of singers’ mean scores registered no perceived change.

Intervention A breathing imagery produced a significant pre- and post-test difference for “sensation of being vocally warmed up”, “resonant voice sensations”, “vocal connection throughout the body” and “perception of ease”. These qualities related particularly to singer perception of technical command and proprioceptive feedback from vocal technique. Additionally, “energised alertness”, a quality strongly related to psycho-physiological disposition, produced a significant pre- to post-test difference after intervention A breathing imagery. This combination of results implied that a degree of relaxation resulted from the breathing imagery, but not so much that the musculature lacked tonus. That is, “effort and sensitivity are inversely related” and reducing tension increases proprioceptive sensitivity (Nelson and Blades-Zeller, 2002, p. 13) yet the body requires some degree of muscular tension in order to achieve muscular equilibrium (Doscher, 1994; Miller, 1996; Vennard, 1950). Hence, it would seem that the breathing imagery promoted “restful alertness”, a state associated with meditation (Stroebel and Glueck, 1978, p. 410).
That breathing influences muscular equilibrium and psycho-physiological disposition is noted by the medical fraternity (Bartley and Clifton-Smith, 2006; Grossman, 1983). Garlick (1990) maintains that “the quality of breathing is a good indication of the state of muscular equilibrium and psychological stress” (p. 41), and furthermore, “the more one stiffens or contracts one’s muscles the more it tends to make breathing more shallow and quicker or more irregular” (p. 37). It follows that if one breathes deeply (i.e. diaphragmatically) while maintaining an unhurried, regular rhythm, then muscles do not excessively tense, muscular equilibrium ensues and psychological stress, such as performance anxiety may reduce. Breathing imagery is frequently used in meditation, where it is associated with diaphragmatic breathing (Baeumer, 2004; Bartley and Clifton-Smith, 2006; Stoyva, 2000). Baeumer (2004) notes that the benefit of breathing imagery is that the person observes their own breathing more closely. She adds that because of this, stress related breathing patterns that may inadvertently occur are avoided. That is, the breath is not held, nor does it become irregular, or rapid and shallow. Moreover, Baeumer maintains that when imagery is used the breathing musculature is not consciously manipulated in a misguided effort to breathe “properly”.

Intervention A breathing imagery also produced significant pre- and post-test differences for “satisfaction with the way you sang”, “overall rating of classical vocal quality” and “appropriate vibrato”. These results may be explained by the close relationship between vibrato rate and optimal tone quality, and the role diaphragmatic breathing, muscular equilibrium and a state of restful alertness play not only in breathing imagery but also in regulating vibrato rate. That is, “breath management” is recommended by Miller as a means of both steadying an irregular vibrato rate (Miller, 2004, p. 122) and correcting excessively fast vibrato (Miller, 1996, p. 193). Relaxation exercises are also recommended when the vibrato rate is too fast (Titze et al., 2002). When vibrato is too slow, Miller (1996) cautions against poor muscle tone, lack of energy and the lethargic personality. Only when vibrato rate is neither too fast, too slow nor too irregular, may Western classical tone quality be optimal (Miller, 1977). Hence, it followed that after the breathing imagery, when vibrato rates became more moderate and regular, singers’ mean ratings showed unanimous agreement that improvement had occurred and significant differences were registered for “overall rating of classical vocal quality” and “satisfaction with the way you sang”.

As opposed to intervention A, most ratings following interventions B and C remained unchanged. On the whole, the reason for such strong differences in post-A, post-B and post-C results did not appear to be due to a particular intervention being any more or
any less distracting than another. The rating for “concentration on appropriate vocal technique” sought to determine whether singers felt distracted by the interventions or felt able to concentrate on whatever they deemed necessary for vocal proficiency. What constituted “appropriate technique” was not discussed between researcher and singer-subject, as singers often have personal concepts of what they need to do mentally at the time of a performance (Hines, 1982). At no time was the singer’s personal technique challenged; even the intervention C cloze passage on breathing only covered aspects of breathing which it stressed were beyond conscious control. Whether, for the subsequent recording of the solo, a singer sought to concentrate on vocal mechanics, proprioceptive feedback, “becoming the music”, legato line, feeling elated or any other aspect which may influence technique, was left to the discretion of the individual. Singers’ scores for “concentration on appropriate vocal technique” were consistently high, varying only marginally for all six conditions. Hence, that large differences between the scores for other rated qualities could be attributed to varying levels of singer concentration or distraction was not evident in singer self-assessments.

That differences in scores could be attributed to confidence possibly engendered by some interventions and not others was, likewise, not evident in singer self-assessments. “Confidence” was rated in the questionnaires because of the proposition that confidence is critical to successful performance, and any improvement attributed to imagery may merely be due to confidence increasing from appropriate task related imagery (Hall, 1995; Moritz et al., 1996; Woolfolk et al., 1985). This theory stems from sports performance and relates to imagery of the exact physical activity performed correctly. Certainly some vocal authorities approach breathing imagery as task related, even though not task identical. That is, even though breathing is not singing, the sensations from breathing imagery may mirror the sensations produced by the voice during speech or song (Linklater, 1976; Miller, 1977). Yet whether confidence gained from well performed breathing imagery could account for the pronounced rating increases specific to post-A self-assessments seems questionable. Scores for “confidence” only varied marginally between all six conditions, and paired t-test results showed no significant increases.

Following intervention B (Braille music code imagery), ratings sometimes differed according to singer level, and although “vocal connection throughout the body” registered a significant increase after intervention B, no increase was registered for this quality from the two least experienced singers. Interestingly, the most experienced singer in the group reported feeling particularly relaxed after intervention B, and indeed
relationships between imagery and relaxation (Sheikh and Jordan, 1983) and between relaxation and an increased kinaesthetic awareness (Nelson and Blades-Zeller, 2002) have been proposed. Singer mean scores suggest that the less experienced singers perhaps did not cope as well with increased relaxation compared to singers with more experience. The less experienced singers registered a worsening of “vocal strain”, while the more experienced singers showed an increase in “mellowness” ratings. Both are mentioned as relaxation related responses in vocal texts. That is, it has been noted that a predominantly “dark” tone linked to excessively slow vibrato (Miller, 1977) may stem from excessive relaxation and poor muscle tone (Titze, 1994). At the same time it has been noted that increased vocal strain may also result from misapplied relaxation, whereby relaxation of inappropriate muscle groups leaves other muscles to compensate by working too hard until straining results (Miller, 1996). For some singers, it seems that relaxation after the Braille imagery produced a lack of necessary muscular tone and muscular equilibrium vital to optimal singing.

Following intervention C (non-imagery cloze passage) rating also appeared to sometimes differ according to the singer level. While the less experienced singers judged the mechanistically based intervention C cloze passage, which covered the topic of basic breathing anatomy and function, as having a somewhat positive influence, it was judged as having a largely neutral or even detrimental influence by singers with more experience. Possibly of particular practical significance, the only time the less experienced singers registered improved postural alignment for singing was after the cloze passage. All three more experienced singers on the other hand, rated posture as either unchanged or deteriorating after this intervention and registered their strongest improvement in posture as occurring after the directional breathing imagery. This supports anecdotal reports that some aspects of imagery use may be related to vocal level and experience, as it suggests that at some point in a singer’s development once the broader mechanistic issues of posture have been addressed, postural awareness may change focus so that subtle adjustment may be facilitated through directional imagery.

However, the issue of how reliably singers can finely discriminate between aspects of their performance remains unclear. It cannot be ruled out that a singer’s anticipation of a particular outcome may have coloured self-rating responses. For example, a singer may presume that after a certain time, warm-up and hence better singing should have occurred, and allot marks according to this presumption. The problem of subjects judging their performance according to pre-conceived expectations is mentioned by
Suinn (1972) in his early research into imagery use to improve performance outcome. Furthermore, pedagogues point out that singers sometimes have poor judgement and need to be schooled in identifying appropriate sound and sensation before they can accurately determine for themselves whether improvement has occurred (Günter, 1992b). Singers lacking rigorous training may even be oblivious to the proprioceptive sense and its role in monitoring the finer distinctions of their performance (Brown, 2002; Günter, 1992b). A comparison of singer self-assessment and acoustic analysis tended to suggest that for at least one singer in the group, the ability to self-assess vocal quality was restricted – possibly limited by that singer’s lack of awareness of proprioceptive feedback.

Nevertheless, even singers well aware of proprioceptive feedback from singing are not meticulously conscious of their vibrato, at least under most circumstances. Hence, it is not surprising that asking singers to self-assess their own vibrato changes proved problematic. No singers registered any rating change in “appropriate vibrato” after intervention B (Braille music code imagery). This occurred despite post-B vibrato rates for all singers slowing and vibrato rate stability deteriorating for all except singer 6 who was the most acclaimed singer in the group and as such the singer most expected to produce greater consistency from one performance to another. One singer of less experience, who had notably slow vibrato, slowed her vibrato rate even further below 5 cycles/sec. Another singer whose vibrato rates were notably unstable, increased vibrato rate standard deviation to 12% of her mean vibrato rate. Both of these changes represent post-B deteriorations in vibrato, which were not perceived by the singer.

Yet most singers registered a perceived improvement in vibrato after intervention A breathing imagery when vibrato rates became more moderate; and notably, the only two singers who registered no perceived improvement in their own vibrato had the most moderate vibrato rates pre- and post-intervention. It is also interesting that the singer with the largest standard deviation in note-to-note vibrato rate – a problem that was only resolved after breathing imagery – specifically mentioned an improvement in her legato line after the breathing imagery. Miller (1966) states that legato is not possible if the vibrato rate is too variable, i.e. slow on one pitch and fast on another. It was not apparent that the singer noting improved legato related this to improved vibrato. Being analytically aware of vibrato is not part of singer training (Sundberg, 1994). Indeed, whether any singers who registered a post-A improvement in vibrato were acutely aware of vibrato, is questionable. It may be that for some singers, an overall sense of
improvement may have led to the presumption that virtually all aspects, including vibrato, improved.

It must not be overlooked that the singers in this project may have responded differently had they been in a genuine performance situation rather than a research environment. As singer 5 stressed, performance anxiety can alter a performance, and performance anxiety management may be central to success. Considering some surveys show that 70% of music students may experience debilitating performance anxiety (Mantel, 2003) and pedagogical literature tells us that “all artists experience some anxiety about performance” (Roland 1997, p. 3), it appears unlikely that the singers involved in this project would have lacked all performance anxiety in a genuine performance. Yet most singers in this project registered no performance anxiety or audible nervousness. While singers 1 and 2 were exceptions, their self-assessed improvement after breathing imagery does not provide a sufficient basis to assert that other singers in need of performance anxiety management may respond similarly. It may be that the breathing imagery of intervention A resembles meditational practice whereby stresses such as performance anxiety may be abated. Unfortunately with so few singers registering performance anxiety in this project it can only be speculated as to the effectiveness of intervention A breathing imagery in this area.

4.4 LISTENER-JUDGE ASSESSMENT

Listener-judges rated 24 randomly ordered vocal samples, each 35 seconds long, for six qualities - mellowness, brilliance, absence of vocal strain, vibrato, overall impression of classical vocal quality and of legit vocal quality (see Method 3.1.1.3). The samples presented a representative selection of singers from each condition based on the singers’ pre-intervention vibrato rates (see Method 3.1.3.2). There were nine pre-intervention samples, three each from condition A (breathing imagery), B (Braille music code imagery) and C (a non-imagery cloze passage), plus their corresponding nine post-intervention samples. Six samples were repeated to check for rater reliability. Qualities were rated from 1 to 10, with 1 indicating poor quality and 10 indicating excellence.
4.4.1 Appraisal of vocal quality

Appendices 5.1 to 5.6 present each listener-judge's ratings and Appendix 5.7 presents listener-judge group mean ratings. From these data, the group mean rating for each vocal quality pre- and post-test, and paired t-test results for listener-judge perception are presented in Table 4.13. As can be seen in Table 4.13, for condition A there were significant pre- to post-intervention differences for the perception of all six qualities. There was also a significant pre- to post-A difference for the entire sample across judges, pairs and quality. For conditions B and C no significant pre- to post-intervention differences were found.
Table 4.13 Group mean ratings for each vocal quality pre- and post-test, and paired t-test results for listener-judge perception

<table>
<thead>
<tr>
<th>Qualities assessed</th>
<th>Intervention</th>
<th>Group mean</th>
<th>Mean difference</th>
<th>Std. deviation</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Before</td>
<td>After</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mellowness</td>
<td>A ►</td>
<td>6.083</td>
<td>7.042</td>
<td>0.958</td>
<td>1.654</td>
<td>3.085</td>
</tr>
<tr>
<td></td>
<td>B ►</td>
<td>6.000</td>
<td>5.500</td>
<td>-0.500</td>
<td>2.284</td>
<td>-1.072</td>
</tr>
<tr>
<td></td>
<td>C ►</td>
<td>6.500</td>
<td>6.417</td>
<td>-0.083</td>
<td>1.248</td>
<td>-0.595</td>
</tr>
<tr>
<td>Brilliance</td>
<td>A ►</td>
<td>6.375</td>
<td>7.542</td>
<td>1.167</td>
<td>1.761</td>
<td>3.245</td>
</tr>
<tr>
<td></td>
<td>B ►</td>
<td>6.167</td>
<td>6.167</td>
<td>0.000</td>
<td>2.106</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>C ►</td>
<td>6.708</td>
<td>6.833</td>
<td>0.125</td>
<td>1.424</td>
<td>0.137</td>
</tr>
<tr>
<td>Absence of vocal strain</td>
<td>A ►</td>
<td>6.500</td>
<td>7.833</td>
<td>1.333</td>
<td>1.834</td>
<td>3.927</td>
</tr>
<tr>
<td></td>
<td>B ►</td>
<td>6.500</td>
<td>6.833</td>
<td>0.333</td>
<td>2.140</td>
<td>0.763</td>
</tr>
<tr>
<td></td>
<td>C ►</td>
<td>7.500</td>
<td>7.167</td>
<td>-0.333</td>
<td>1.606</td>
<td>-1.161</td>
</tr>
<tr>
<td>Vibrato</td>
<td>A ►</td>
<td>6.208</td>
<td>7.125</td>
<td>0.917</td>
<td>1.816</td>
<td>2.601</td>
</tr>
<tr>
<td></td>
<td>B ►</td>
<td>6.042</td>
<td>5.458</td>
<td>-0.583</td>
<td>2.062</td>
<td>-1.386</td>
</tr>
<tr>
<td></td>
<td>C ►</td>
<td>7.000</td>
<td>6.875</td>
<td>-0.125</td>
<td>1.116</td>
<td>-1.000</td>
</tr>
<tr>
<td>Overall rating of classical vocal quality</td>
<td>A ►</td>
<td>6.250</td>
<td>7.250</td>
<td>1.000</td>
<td>1.216</td>
<td>4.263</td>
</tr>
<tr>
<td></td>
<td>B ►</td>
<td>6.167</td>
<td>5.625</td>
<td>-0.542</td>
<td>1.783</td>
<td>-1.480</td>
</tr>
<tr>
<td></td>
<td>C ►</td>
<td>6.792</td>
<td>6.708</td>
<td>-0.083</td>
<td>1.139</td>
<td>-1.498</td>
</tr>
<tr>
<td>Overall rating of legit vocal quality</td>
<td>A ►</td>
<td>5.333</td>
<td>5.917</td>
<td>0.583</td>
<td>1.381</td>
<td>2.563</td>
</tr>
<tr>
<td></td>
<td>B ►</td>
<td>5.250</td>
<td>5.458</td>
<td>0.208</td>
<td>1.719</td>
<td>0.594</td>
</tr>
<tr>
<td></td>
<td>C ►</td>
<td>5.542</td>
<td>5.458</td>
<td>-0.083</td>
<td>1.176</td>
<td>-0.161</td>
</tr>
<tr>
<td>Mean of all assessments</td>
<td>A ►</td>
<td>6.125</td>
<td>7.118</td>
<td>0.993</td>
<td>1.610</td>
<td>7.947</td>
</tr>
<tr>
<td></td>
<td>B ►</td>
<td>6.021</td>
<td>5.840</td>
<td>-0.181</td>
<td>2.017</td>
<td>-1.069</td>
</tr>
<tr>
<td></td>
<td>C ►</td>
<td>6.674</td>
<td>6.576</td>
<td>-0.097</td>
<td>1.283</td>
<td>-1.661</td>
</tr>
</tbody>
</table>
Of all singers perceptually assessed, it was only singer 2 whose fast vibrato decelerated pre- to post-A and singer 3 whose slow vibrato accelerated pre- to post-A, for whom five listener-judges or more registered a post-intervention improvement. However, a significant perceptual improvement was only found for singer 2. Table 4.14 presents the mean assessments, the mean difference and the paired t-test results for listener-judge combined perception of condition A singer 2. Pre-A and post-A samples of singer 2 were each presented twice to check for listener-judge reliability. As indicated in Table 4.14, on both occasions a significant pre-A to post-A improvement in vocal quality was shown in the average ratings of the six listener-judges combined. Relating listener-judge perception to the acoustic findings (Section 4.1), it is notable that of the three condition A singers presented for listener-judge assessment, singer 2 displayed the fastest and the most uneven pre-A vibrato rate, as well as the most pronounced post-A acoustic change. The vibrato rate of singer 2 slowed from 5.87 to 5.52 cycles/sec and standard deviation reduced from 10.0% to 4.4% when expressed as a percentage of the vibrato rate. Indeed, all singers displayed more moderate and even vibrato rates after the intervention A breathing imagery. However, a significant perceptual improvement was only found for the singer who displayed the most pronounced acoustic change in the group, not for those singers with more even and relatively more moderate pre-A vibrato rates, for whom post-A acoustic change was less pronounced.
Table 4.14  Average rating of each listener-judge for singer 2, the mean difference (post-test minus pre-test) and the paired t-test results for listener-judge combined perception

<table>
<thead>
<tr>
<th>Breathing imagery rating</th>
<th>Before</th>
<th>After</th>
<th>Mean difference</th>
<th>Std. deviation</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singer 2 samples 3 &amp; 17</td>
<td>Listener-judge 1</td>
<td>4.667</td>
<td>6.333</td>
<td>1.417</td>
<td>0.391</td>
<td>8.879</td>
</tr>
<tr>
<td></td>
<td>Listener-judge 2</td>
<td>5.333</td>
<td>7.333</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Listener-judge 3</td>
<td>5.167</td>
<td>6.167</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Listener-judge 4</td>
<td>8.333</td>
<td>9.333</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Listener-judge 5</td>
<td>5.167</td>
<td>6.500</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Listener-judge 6</td>
<td>7.500</td>
<td>9.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Singer 2 samples 22 &amp; 23</td>
<td>Listener-judge 1</td>
<td>2.833</td>
<td>5.500</td>
<td>2.000</td>
<td>1.164</td>
<td>4.207</td>
</tr>
<tr>
<td></td>
<td>Listener-judge 2</td>
<td>5.167</td>
<td>5.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Listener-judge 3</td>
<td>5.167</td>
<td>7.667</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Listener-judge 4</td>
<td>7.167</td>
<td>9.167</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Listener-judge 5</td>
<td>5.000</td>
<td>8.167</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Listener-judge 6</td>
<td>7.000</td>
<td>8.833</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4.15 presents the mean assessments, the mean difference and the paired t-test results for listener-judge combined perception of condition B singer 3. Although no significant difference was found for the three condition B singers rated by listener-judges, Table 4.15 shows that singer 3 was perceived as producing a marginally significant pre- to post-B deterioration in vocal quality. Relating listener-judge perception to condition B acoustic findings (Section 4.1), it is notable while singer 3 displayed the slowest pre-B mean vibrato rate, intervention B produced a significant slowing of mean vibrato rates together with a marginally significant increase in vibrato rate standard deviations. Singers whose post-B vibrato rates remained above 5.00 cycles/sec were not perceived as deteriorating. However, singer 3’s already slow vibrato rate slowed even further below 5.00 cycles/sec, into a region often associated with a slow vibrato “wobble”, and was perceived as marginally deteriorating.
Table 4.15 Average rating of each listener-judge for singer 3, the mean difference (post-test minus pre-test) and the paired t-test results for listener-judge combined perception

<table>
<thead>
<tr>
<th>Singer 3 samples 21 &amp; 7</th>
<th>Braille imagery rating</th>
<th>Before</th>
<th>After</th>
<th>Mean difference</th>
<th>Std. deviation</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Listener-judge 1</td>
<td>7.000</td>
<td>5.833</td>
<td></td>
<td>-0.861</td>
<td>0.866</td>
<td>-2.436</td>
<td>0.059</td>
</tr>
<tr>
<td>Listener-judge 2</td>
<td>6.833</td>
<td>6.667</td>
<td></td>
<td>-0.167</td>
<td>0.866</td>
<td>1.187</td>
<td>0.247</td>
</tr>
<tr>
<td>Listener-judge 3</td>
<td>5.167</td>
<td>4.167</td>
<td></td>
<td>-1.000</td>
<td>0.866</td>
<td>-1.187</td>
<td>0.247</td>
</tr>
<tr>
<td>Listener-judge 4</td>
<td>9.167</td>
<td>8.167</td>
<td></td>
<td>0.861</td>
<td>0.866</td>
<td>1.187</td>
<td>0.247</td>
</tr>
<tr>
<td>Listener-judge 5</td>
<td>7.167</td>
<td>5.000</td>
<td></td>
<td>-2.167</td>
<td>0.866</td>
<td>-2.436</td>
<td>0.059</td>
</tr>
<tr>
<td>Listener-judge 6</td>
<td>6.333</td>
<td>6.667</td>
<td></td>
<td>0.333</td>
<td>0.866</td>
<td>0.389</td>
<td>0.700</td>
</tr>
</tbody>
</table>
For condition C vocal samples, no significant perceptual changes were registered by listener-judges, and neither were any significant pre- to post-C acoustic changes found. All non-significant paired t-test results for listener-judge combined perception of singers are presented in Appendix 5.8.

### 4.4.2 Inter-rater reliability

Table 4.16 presents the percentage of scores that differed by no more than ±1 from those of another listener-judge. This was calculated from each listener-judge’s 144 scores (i.e. 24 vocal samples rated for six qualities each).

<table>
<thead>
<tr>
<th>Listener-judges</th>
<th>Close agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 and 2</td>
<td>39%</td>
</tr>
<tr>
<td>1 and 3</td>
<td>53%</td>
</tr>
<tr>
<td>1 and 4</td>
<td>8%</td>
</tr>
<tr>
<td>1 and 5</td>
<td>52%</td>
</tr>
<tr>
<td>1 and 6</td>
<td>22%</td>
</tr>
<tr>
<td>2 and 3</td>
<td>49%</td>
</tr>
<tr>
<td>2 and 4</td>
<td>40%</td>
</tr>
<tr>
<td>2 and 5</td>
<td>51%</td>
</tr>
<tr>
<td>2 and 6</td>
<td>58%</td>
</tr>
<tr>
<td>3 and 4</td>
<td>27%</td>
</tr>
<tr>
<td>3 and 5</td>
<td>64%</td>
</tr>
<tr>
<td>3 and 6</td>
<td>36%</td>
</tr>
<tr>
<td>4 and 5</td>
<td>37%</td>
</tr>
<tr>
<td>4 and 6</td>
<td>65%</td>
</tr>
<tr>
<td>5 and 6</td>
<td>41%</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>43%</strong></td>
</tr>
</tbody>
</table>

Table 4.16 Percentage of inter-rater agreement based on rates that differ by no more than ±1

Table 4.17 presents the percentage agreement according to each quality rated.

<table>
<thead>
<tr>
<th></th>
<th>Close agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mellowness</td>
<td>46%</td>
</tr>
<tr>
<td>Brilliance</td>
<td>39%</td>
</tr>
<tr>
<td>Absence of vocal strain</td>
<td>40%</td>
</tr>
<tr>
<td>Vibrato</td>
<td>42%</td>
</tr>
<tr>
<td>Classical quality</td>
<td>45%</td>
</tr>
<tr>
<td>Legit quality</td>
<td>47%</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>43%</strong></td>
</tr>
</tbody>
</table>

Table 4.17 Percentage of inter-rater agreement for each quality rated

As seen in Table 4.17, despite considerable inter-rater disagreement, no individual quality stood out as being a dominant source of either disagreement or agreement.
Overall, the more the fine detail of rating was scrutinised, the more listener-judge disagreement was evident. For example, looking at individual listener-judge ratings for the six qualities (Appendices 5.1 to 5.6), it can be seen that on the rating scale of 1 to 10, sample 8 (singer 1 pre-B) was allotted one point for brilliance by listener-judge 1 and nine points by listener-judge 4, while vibrato was allotted one point by listener-judge 5 and nine points by listener-judge 6.

By contrast, when only the mean rate from each pre- and post-intervention vocal sample was assessed for agreement regarding improvement, deterioration or no change in mean rate, then inter-rater agreement increased. Table 4.18 lists, from each listener-judge’s 24 mean ratings (i.e. from 12 pre-intervention samples and their corresponding 12 post-intervention samples), the percentage of pairs that agreed in the direction of change.

<table>
<thead>
<tr>
<th>Listener-judges</th>
<th>Close agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 and 2</td>
<td>50%</td>
</tr>
<tr>
<td>1 and 3</td>
<td>58%</td>
</tr>
<tr>
<td>1 and 4</td>
<td>50%</td>
</tr>
<tr>
<td>1 and 5</td>
<td>67%</td>
</tr>
<tr>
<td>1 and 6</td>
<td>42%</td>
</tr>
<tr>
<td>2 and 3</td>
<td>58%</td>
</tr>
<tr>
<td>2 and 4</td>
<td>50%</td>
</tr>
<tr>
<td>2 and 5</td>
<td>75%</td>
</tr>
<tr>
<td>2 and 6</td>
<td>42%</td>
</tr>
<tr>
<td>3 and 4</td>
<td>42%</td>
</tr>
<tr>
<td>3 and 5</td>
<td>58%</td>
</tr>
<tr>
<td>3 and 6</td>
<td>50%</td>
</tr>
<tr>
<td>4 and 5</td>
<td>58%</td>
</tr>
<tr>
<td>4 and 6</td>
<td>42%</td>
</tr>
<tr>
<td>5 and 6</td>
<td>25%</td>
</tr>
</tbody>
</table>

Mean 51%

Furthermore, as seen in Appendices 5.1 to 5.6, when rates from conditions A, B and C were considered separately, listener-judge mean scores for singers as a whole registered unanimous agreement that improvement occurred after intervention A (breathing imagery). It was intervention B (Braille music code imagery) and intervention C (non-imagery cloze passage) that produced listener-judges disagreement when mean scores for singers as a whole were considered.
4.4.3 Intra-rater reliability

Figure 4.22 illustrates each listener-judge’s mean rates for the six repeated vocal samples.

The spread of marks in Figure 4.22 suggests that despite variation in both the ability level of the singers and in the marking standards of each listener-judge, there was a degree of consistency in the mean rates of each judge. Figure 4.23 illustrates the difference in mean rates between the first and second hearing of the six vocal samples plotted against their respective means, as per Bland and Altman (1986).
Figure 4.23 The difference in mean rates between the first and second hearing of six vocal samples plotted against their respective means, as per Bland and Altman (1986)

While the above figures represent intra-rater reliability when mean scores were considered, Table 4.19 presents intra-rater reliability for individual scores. It lists the percentage of individual rates that were within ±1 from the original rating.

<table>
<thead>
<tr>
<th>Listener-judge</th>
<th>Intra-rater reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>39%</td>
</tr>
<tr>
<td>2</td>
<td>69%</td>
</tr>
<tr>
<td>3</td>
<td>42%</td>
</tr>
<tr>
<td>4</td>
<td>58%</td>
</tr>
<tr>
<td>5</td>
<td>50%</td>
</tr>
<tr>
<td>6</td>
<td>81%</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>57%</strong></td>
</tr>
</tbody>
</table>

Table 4.19 Percentage of intra-rater reliability based on rates that differ by no more than ±1
Table 4.19 shows considerable variability (between 39% and 81%) within the six listener-judges when each listener-judge’s 36 repeated ratings (i.e. six repeated samples each rated for six qualities) were assessed for intra-rater reliability.

4.4.4 Discussion

Listener-judge ratings indicated that for condition A (breathing imagery) there were significant pre- to post-intervention differences for the perception of mellowness, brilliance, absence of vocal strain, vibrato, overall classical vocal quality and overall legit vocal quality. There was also a significant pre- to post-A difference for the entire sample across judges, pairs and quality. For conditions B (Braille music code imagery) and C (non-imagery cloze passage) no significant pre- to post-intervention differences were found. Listener-judges’ group mean ratings of the 24 samples registered a consistent pattern of improvement (mean increase of 0.99) after intervention A. This did not occur after intervention B (mean decrease of 0.18) or after intervention C (mean decrease of 0.10).

Paired sample t-test results for listener-judge combined perception showed a significant pre-A to post-A improvement for singer 2 whose vocal samples were each presented twice to check for listener-judge reliability. Of all condition A singers assessed by listener-judges, singer 2 had the least vocal experience and received the lowest pre-A listener-judge group mean score. Acoustically, she displayed a particularly uneven vibrato rate and had the fastest vibrato in the pre-A group of singers presented for assessment. After intervention A, singer 2 displayed the largest acoustic change; her vibrato rate became notably more even and slowed to a moderate rate. Indeed, acoustic analysis of all singers showed significant pre-A to post-A reductions in the fastest vibrato rate, in vibrato rate standard deviation and in the range of vibrato rates calculated from the fastest minus the slowest vibrato rate. However, despite all singers producing somewhat more moderate and even vibrato rates after intervention A breathing imagery, no significant pre- to post-test difference was shown in listener-judge combined perception for singers who exhibited more moderate and even vibrato rates from the outset.

Paired sample t-test results for listener-judge combined perception also showed a marginally significant pre-B to post-B deterioration for singer 3. Of all condition B singers assessed by listener-judges, singer 3 displayed the slowest pre-intervention vibrato. After intervention B, her vibrato rate slowed further towards an area where
vibrato tends to develop into a slow “wobble”. In fact, acoustic findings for condition B showed a significant reduction in all singers’ mean and median vibrato rates, and a marginally significant increase in mean vibrato rate standard deviations. Five of the six listener-judges agreed that the further deceleration of singer 3’s already slow vibrato produced an overall deterioration in vocal quality. By contrast, the more ambivalent response of listener-judges towards singer 1 who slowed her excessively fast mean vibrato after the Braille music imagery may be due to the greater unevenness of her vibrato rate after intervention B. That is, one fault was replaced by another.

Paired sample t-test results for listener-judge combined perception revealed no significant pre- to post-test differences for any condition C singers that were presented for assessment. Acoustic analysis also revealed no significant pre- to post-intervention change for condition C vocal samples.

However, while under some circumstances as mentioned above, listener-judges’ mean scores showed an awareness of perceptual change, it is doubtful whether listener-judges were genuinely able to distinguish between the six perceptual categories rated. Certainly, no one quality produced a universally greater rater consensus than any other, and individual listener-judges’ ratings for all six perceptual qualities per sample revealed considerable inter- and intra-rater unreliability - a common problem in perceptual studies (Callinan-Robertson et al., 2006; Erickson, 2009; Kent, 1996; Kreiman et al., 1993; Kreiman and Gerratt, 1998; Rothman and Timberlake, 1984; Vurma and Ross, 2002; Wapnick and Ekholm, 1997).

A degree of drift in the rating consistency of listener-judges may have stemmed from the very different vocal abilities presented, the order of samples and their random mixing rather than paired presentation of one singer (pre- and post-intervention) at a time. Rater fatigue may have also undermined concentration and increased rater drift. That is, although the number of samples had been reduced to 24 in an effort to reduce fatigue, at 35 seconds, the duration of each sample may, nevertheless, have promoted fatigue and rater drift. On the other hand, the high degree of inter- and intra-rater inconsistency in assessments of the repeated vocal samples of singer 1 (pre-B and post-B) suggests that listener-judges may require more than eight bars to familiarise themselves with a voice to the point at which it can be assessed reliably and consistently.
Inter-rater unreliability may also have stemmed from differences in individual listener-judges’ value systems. For example, although the terms to be rated were discussed with listener-judges and definitions agreed upon before rating, it appears listener-judges had their own personal criteria for what cues were relevant to the qualities rated. In addition, the importance of those cues could have varied according to the various singer ability levels heard. Some raters were more lenient towards less able singers in the group. One listener-judge, having finished rating, stated that the “potential” perceived in a voice influenced the rating.

Inconsistent rating may have sometimes reflected inconsistency within the individual singers. That is, within a single sample, raters were often exposed to a broad range of tonal qualities. One listener-judge commented that because the singer’s vocal quality was often inconsistent, rating only one bar, rather than eight, would have been less problematic. Indeed, Mitchell (2005) demonstrated that listener-judges can show considerable reliability when one single note per condition is presented for rating in paired vocal samples from the same singer.

Listener-judges’ group mean ratings for individual vocal samples did, however, reflect singer level of accomplishment fairly accurately. That is, singer 1 with the least performance experience was generally assessed lower than all other singers, whereas singer 6 with considerable performance experience and national acclaim registered the highest group mean rating. Group mean ratings for the other singers largely fell in line between singers 1 and 6 according to experience and level of vocal attainment.

Nevertheless, some exceptions to this general statement occurred. For example, singer 5 consistently received lower group mean ratings than her considerable experience may otherwise have suggested. This appeared to be due to her exceptionally wide vibrato extent which recurrently exceeded ± 1.5 semitones in every vocal sample. In fact, most listener-judges voiced displeasure at singer 5’s vibrato every time her samples were presented. Also singer 2, who had less vocal experience and acclaim than most other participants, while receiving a low pre-A mean group rating, received a very high post-A mean group rating. Indeed, strong acoustic change following the breathing imagery of intervention A placed the vibrato rate characteristics of singer 2 on a par with the more acclaimed singers in the project, and the positive listener-judge response to singer 2 post-A supported the principle that differences in vibrato rate may produce perceptible differences in vocal quality (Bartholomew, 1934, 1937; Miller, 1977, 1996; Robison, 2001; Robison et al., 1994).
For the majority of listener-judge assessments, however, it may be pertinent that while all listener-judges in this present study were highly experienced judges of the singing voice, Kreiman et al. (1990) found that the more highly trained and experienced the listener-judges, the greater the likelihood of inter-rater disagreement. This may stem from highly skilled listener-judges identifying various fine nuances in the vocal cues and, depending on the training and experience of each listener-judge, deeming some more relevant than others in the rating process. Such highly subjective judgements decrease inter-rater reliability, particularly in cases where change in the vocal signal is complex or subtle. Nevertheless, the ability to make fine distinctions between vocal qualities is prized amongst those in the singing profession.
5 RESULTS FOR STUDY 2: VOCAL WARM-UP

5.1 VIBRATO RATE ANALYSIS

Twelve singers each recorded a set eight bar solo (Figure 3.1) before and after a 25 minute vocal warm-up (Figure 3.4). Spectrograms were produced of the eleven long held notes contained in each solo, i.e. 264 notes in total. Each vibrato undulation was measured, and vibrato rate assessed for changes from one pre-intervention solo to its corresponding post-intervention solo, as well as for changes in the group of singers as a whole.

Vibrato rate was also compared with singer dynamic intensity measured by sound pressure level (SPL), with fundamental frequency and with note duration, as a relationship between these elements and vibrato rate may exist (Dromey et al., 2003; Prame, 1994; Titze, 1994; Winckel, 1953).

5.1.1 Assessment of the group as a whole

Appendix 6.3 presents the mean vibrato rate and the standard deviation from the 11 notes assessed per solo. From this, Table 5.1 presents the results of paired t-tests for the group mean vibrato rate and for the group mean standard deviation before and after vocal warm-up. As seen in Table 5.1 there was a significant pre- to post-test difference for both the group mean vibrato rate and the group mean standard deviation of the vibrato rate.

<table>
<thead>
<tr>
<th>Vocal Warm-up</th>
<th>Mean</th>
<th>Std deviation</th>
<th>N</th>
<th>t-value</th>
<th>p-value</th>
<th>Partial Eta Squared</th>
<th>Observed Power a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean vibrato rate</td>
<td>Before</td>
<td>6.090</td>
<td>0.779</td>
<td>12</td>
<td>7.980</td>
<td>0.017</td>
<td>0.420</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>5.903</td>
<td>0.611</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard deviation</td>
<td>Before</td>
<td>0.691</td>
<td>0.265</td>
<td>12</td>
<td>29.406</td>
<td>0.000</td>
<td>0.728</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>0.304</td>
<td>0.078</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5.2 presents the paired t-test results before and after vocal warm-up for the fastest, slowest and median vibrato rates, and the average range of vibrato rates (i.e. fastest mean minus lowest mean) for the group as a whole.
Table 5.2 Paired t-test results for before and after vocal warm-up comparisons for the fastest, slowest and median vibrato rates, and the average range of vibrato rates (i.e. fastest mean minus slowest mean) for the group as a whole.

<table>
<thead>
<tr>
<th>Vocal Warm-up</th>
<th>Mean</th>
<th>Std deviation</th>
<th>N</th>
<th>t-value</th>
<th>p-value</th>
<th>Partial Eta Squared</th>
<th>Observed Power a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fastest mean vibrato rate</td>
<td>Before</td>
<td>7.576</td>
<td>1.197</td>
<td>12</td>
<td>22.037</td>
<td>0.001</td>
<td>0.667</td>
</tr>
<tr>
<td>After</td>
<td>6.488</td>
<td>0.651</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slowest mean vibrato rate</td>
<td>Before</td>
<td>5.388</td>
<td>0.702</td>
<td>12</td>
<td>2.604</td>
<td>0.135</td>
<td>0.191</td>
</tr>
<tr>
<td>After</td>
<td>5.513</td>
<td>0.597</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median vibrato rate</td>
<td>Before</td>
<td>5.886</td>
<td>0.764</td>
<td>12</td>
<td>0.344</td>
<td>0.569</td>
<td>0.030</td>
</tr>
<tr>
<td>After</td>
<td>5.844</td>
<td>0.625</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vibrato rate range</td>
<td>Before</td>
<td>2.187</td>
<td>0.784</td>
<td>12</td>
<td>26.191</td>
<td>0.000</td>
<td>0.704</td>
</tr>
<tr>
<td>After</td>
<td>0.975</td>
<td>0.243</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5.2 shows that a significant pre- to post-intervention difference was found for the fastest mean vibrato rate and the vibrato rate range (i.e. fastest minus slowest mean vibrato rate), but not for the slowest mean vibrato rate and the median vibrato rate from the 11 long held notes in the vocal excerpt.

Figure 5.1 illustrates, for the group as a whole, the mean vibrato rate and the fastest, slowest and median vibrato rates from 11 long held notes in the vocal excerpt. As shown in Figure 5.1, after vocal warm-up the range of vibrato rates for the group reduced and both the group mean and median vibrato rate were positioned somewhat more evenly between the average fastest and slowest vibrato rates.

![Figure 5.1 The mean vibrato rate and the fastest, slowest and median vibrato rates from 11 long held notes in the vocal excerpt, assessed for the group as a whole](image-url)
5.1.2 Assessment of each solo

5.1.2.1 Mean vibrato rates

Figure 5.2 illustrates each singer’s mean vibrato for the solo before and after vocal warm-up.

As indicated in Figure 5.2, the mean vibrato rates for the solos varied between 4.63 and 7.66 cycles/sec with both these values registered prior to vocal warm-up. After vocal warm-up, vibrato rates consolidated towards an area of more moderate rate. The largest decrease in mean vibrato rate (0.46 cycles/sec) was exhibited by singer 4 who had the fastest initial mean vibrato rate. The largest increase (0.36 cycles/sec) was produced by singer 10, who had the slowest initial mean vibrato rate.

5.1.2.2 Standard deviation

Appendix 6.3 lists the mean vibrato rate, standard deviation and 95% confidence intervals with upper and lower limits for each solo. Before vocal warm-up, vibrato rate
standard deviations were between 0.26 and 1.33 cycles/sec (mean S.D. 0.69 cycles/sec). After vocal warm-up this value reduced to between 0.18 and 0.43 cycles/sec (mean S.D. 0.30 cycles/sec). This was calculated as ranging, pre-intervention, from 5% to 21% of the corresponding solo’s mean vibrato rate (mean S.D. 11.24%), and post-intervention from 3% to 8% of the corresponding solo’s mean vibrato rate (mean S.D. 5.16%). Figure 5.3 illustrates each singer’s standard deviation of the mean vibrato rate before and after vocal warm-up.

![Vocal warm-up graph](image)

Figure 5.3 Standard deviation of the solo’s mean vibrato rate for each singer

As seen in Figure 5.3 singer 9 had the largest pre-intervention vibrato rate standard deviation and largest post-intervention reduction - a decrease from 20.80% to 6.15% of her mean vibrato rate. Singer 10 had the smallest pre-intervention vibrato rate standard deviation and smallest post-intervention reduction in standard deviation - a decrease from 5.66% to 4.13% of her mean vibrato rate.

### 5.1.2.3 Range of mean vibrato rates

Figure 5.4 compares the range of mean vibrato rates for each solo (i.e. the fastest, slowest and median vibrato rates from 11 notes assessed per solo).
As shown in Figure 5.4, before vocal warm-up the smallest range of vibrato rates for the solo was 0.85 cycles/sec (singer 10) and the broadest was 3.80 cycles/sec (singer 9). After vocal warm-up, all vibrato rate ranges became more compact; the smallest was 0.47 cycles/sec (singer 5), the broadest was 1.32 cycles/sec (singer 11). This compacting mainly resulted from the fastest vibrato rates slowing. Singer 10 who had the slowest pre-intervention mean vibrato rate, was an exception – her fastest vibrato increased from 4.97 to 5.24 cycles/sec after vocal warm-up. These changes produced greater cohesion in the range of vibrato rates of all twelve singers.
5.1.2.4 Confidence intervals

Figure 5.5 shows the 95% confidence intervals for each solo.

![Figure 5.5](image)

Figure 5.5 The 95% confidence intervals for mean vibrato rate for each singer before and after the vocal warm-up.

Note: Lines on the left of each pair show the confidence interval before vocal warm-up and those on the right show the confidence interval after vocal warm-up.

Figure 5.5 illustrates that for singers with vibrato faster than 5.50 cycles/sec, vibrato rates compacted and became generally slower, while for singers with vibrato below 5.50 cycles/sec, vibrato rates compacted and became generally faster. Overall, vibrato rates tended to converge towards the region of 5.50 cycles/sec.

5.1.3 Assessment of individual notes

5.1.3.1 Mean vibrato rates

Appendix 6.1 lists mean vibrato rates for each note. Values varied from 4.12 to 9.30 cycles/sec before vocal warm-up, and 4.55 to 7.60 cycles/sec after vocal warm-up. Figure 5.6 compares vibrato rates for the eleven notes assessed per solo.
As seen in Figure 5.6, most singers registered their fastest vibrato rates early in each solo. This corresponded to the highest section of the solo. After the vocal warm-up the fastest vibrato rates slowed. Only singer 10, for whom all pre-intervention vibrato rates were slower than 5.00 cycles/sec, showed a quickening of vibrato rates for every note. Overall, changes in vibrato following vocal warm-up resulted in fewer excessively fast and excessively slow vibrato rates, and a more moderate progression of vibrato rates for every singer.

Table 5.3 reports the paired t-test results for two subsets of the entire set of pairs of vibrato rates. One subset consisted of vibrato rates below 5.00 cycles/sec, as these were regarded as too slow. The other subset comprised vibrato rates 6.00 cycles/sec and above, as these were regarded as too fast. The criteria for choosing these values were the same as for study 1 (see Section 4.1.3.1).
Table 5.3 Paired t-test results for notes that pre- and/or post-intervention registered vibrato rates either slower than 5.00 cycles/sec, or 6.00 cycles/sec and faster

<table>
<thead>
<tr>
<th>Vocal warm-up</th>
<th>Mean</th>
<th>N</th>
<th>Std deviation</th>
<th>Std error mean</th>
<th>Mean difference</th>
<th>Std deviation</th>
<th>t-value</th>
<th>Sig (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow vibrato rates</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>4.669</td>
<td>22</td>
<td>0.197</td>
<td>0.042</td>
<td>-0.337</td>
<td>0.218</td>
<td>-7.226</td>
<td>0.000</td>
</tr>
<tr>
<td>After</td>
<td>5.006</td>
<td>22</td>
<td>0.223</td>
<td>0.047</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fast vibrato rates</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>6.778</td>
<td>69</td>
<td>0.880</td>
<td>0.106</td>
<td>0.432</td>
<td>0.723</td>
<td>4.969</td>
<td>0.000</td>
</tr>
<tr>
<td>After</td>
<td>6.346</td>
<td>69</td>
<td>0.517</td>
<td>0.062</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As indicated in Table 5.3, of the 132 note pairs assessed, only 22 registered vibrato rates slower than 5.00 cycles/sec. Pre- to post-test, 21 note pairs with vibrato rates below 5.00 became faster and one slowed further. The paired t-test results confirm a significant pre- to post-test acceleration occurred for vibrato rates slower than 5.00 cycles/sec. Of the same 132 note pairs, 69 registered vibrato rates of 6.00 cycles/sec or faster. Pre- to post-test, 20 note pairs accelerated reaching 6.00 cycles/sec or more, however, 49 note pairs with vibrato rates above 6.00 cycles/sec became slower. In all, a significant pre- to post-test slowing occurred for note pairs with vibrato rates 6.00 cycles/sec and faster.

5.1.3.2 Standard deviation

The cyclic undulations that contributed to the vibrato of each note were always somewhat irregular in rate. See Appendix 6.2 for the mean vibrato rate standard deviation of each note. On average, values decreased from 0.82 to 0.53 cycles/sec after vocal warm-up. The largest decrease was registered by singer 11, with a standard deviation of 2.92 cycles/sec on note two reducing to 0.34 cycles/sec. Figure 5.7 illustrates standard deviations in the vibrato undulations for each of the 11 notes assessed per solo before and after vocal warm-up.

![Figure 5.7 Vibrato rate standard deviations for each of the 11 notes assessed per solo](image)

As seen in Figure 5.7, after the vocal warm-up all singers showed decreases in their largest vibrato rate standard deviations, with no values exceeding 1.66 cycles/sec. Research is lacking as to what a preferred range of standard deviations may be. However, while allowing for some variation even in skilled singing (Prame, 1994; Sundberg, 1995), the more skilled the singer, the more regular the undulations
(Bartholomew, 1934; Sjöström, 1948; Sundberg, 1995). Therefore, to assess only for changes after vocal warm-up that may indicate improvement or deterioration in note pairs and to exclude note pairs that possibly fell within optimal limits, t-tests were conducted on a subset of the entire set of pairs of vibrato rate standard deviations. A maximum limit of 0.50 cycles/sec was chosen, and only note pairs that fell outside this limit were statistically assessed for pre- to post-test change. Table 5.4 shows the paired t-test results for all notes that pre- and/or post-intervention registered vibrato rate standard deviations greater than 0.50 cycles/sec.
Table 5.4 Paired t-test results for notes that pre- and/or post-intervention registered vibrato rate standard deviations greater than 0.50 cycles/sec

<table>
<thead>
<tr>
<th>Vocal warm-up</th>
<th>Mean</th>
<th>N</th>
<th>Std deviation</th>
<th>Std error mean</th>
<th>Mean difference</th>
<th>Std deviation</th>
<th>t-value</th>
<th>Sig (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard deviations</td>
<td>Before</td>
<td>1.022</td>
<td>94</td>
<td>0.670</td>
<td>0.069</td>
<td>-0.402</td>
<td>0.720</td>
<td>-5.410</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>0.620</td>
<td>94</td>
<td>0.329</td>
<td>0.034</td>
<td>-0.402</td>
<td>0.720</td>
<td></td>
</tr>
</tbody>
</table>
As indicated in Table 5.4, of the 132 note pairs assessed, 94 registered pre and/or post-test standard deviations that exceeded 0.50 cycles/sec. Although 24 note pairs registered standard deviations that increased reaching 0.50 cycles/sec or more, 70 note pairs with pre-test standard deviations greater than 0.50 cycles/sec registered a post-test reduction. In all, a significant pre- to post-test reduction occurred for note pairs with standard deviations greater than 0.50 cycles/sec.

5.1.4 Vibrato rate and dynamic intensity

Appendix 6.5 lists each singer’s mean dynamic intensity measured by sound pressure level (SPL) and mean vibrato rate before and after vocal warm-up. Figure 5.8 shows mean SPL compared with mean vibrato rate. As seen in Figure 5.8, singer 3 paired decreases in both vibrato rate and SPL. However, for the majority of singers there was no consistent, positive correlation between singer dynamic intensity and vibrato rate.
Figure 5.8 Comparison of mean SPL and mean vibrato rate before and after vocal warm-up
5.1.5 Vibrato rate and fundamental frequency

The notes assessed in every solo were consecutively numbered from 1 to 11 (Figure 3.3). Table 5.5 lists the notes with the fastest and the slowest mean vibrato rates per solo.

Table 5.5 Notes from 1 to 11 with the fastest and slowest mean vibrato rates

<table>
<thead>
<tr>
<th>Singer</th>
<th>Vocal warm-up</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singer 1</td>
<td>Fastest mean vibrato rate</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Slowest mean vibrato rate</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Singer 2</td>
<td>Fastest mean vibrato rate</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Slowest mean vibrato rate</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Singer 3</td>
<td>Fastest mean vibrato rate</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Slowest mean vibrato rate</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>Singer 4</td>
<td>Fastest mean vibrato rate</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Slowest mean vibrato rate</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Singer 5</td>
<td>Fastest mean vibrato rate</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Slowest mean vibrato rate</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Singer 6</td>
<td>Fastest mean vibrato rate</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Slowest mean vibrato rate</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Singer 7</td>
<td>Fastest mean vibrato rate</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Slowest mean vibrato rate</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Singer 8</td>
<td>Fastest mean vibrato rate</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Slowest mean vibrato rate</td>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td>Singer 9</td>
<td>Fastest mean vibrato rate</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Slowest mean vibrato rate</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Singer 10</td>
<td>Fastest mean vibrato rate</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Slowest mean vibrato rate</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Singer 11</td>
<td>Fastest mean vibrato rate</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Slowest mean vibrato rate</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>Singer 12</td>
<td>Fastest mean vibrato rate</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Slowest mean vibrato rate</td>
<td>9</td>
<td>11</td>
</tr>
</tbody>
</table>

No single note consistently had the fastest or slowest vibrato rate. However, note 1, the highest note in the solo, recorded the fastest mean vibrato rate in 20 out of 24 solos. Nine of the twelve singers produced the same highest-note-fastest-rate result irrespective of vocal warm-up. After vocal warm-up eleven of the twelve singers recorded their fastest mean vibrato rate on the highest note (Table 5.5). Moreover, 13
of the 24 solos showed a pattern in which notes 1, 2 and 3, the highest, second highest and third highest notes in the solo, registered fast but progressively slower mean vibrato rates (Appendix 6.1). This occurred for six singers before and seven singers after vocal warm-up.

Generally, note 1 maintained the fastest mean vibrato rate despite slowing markedly after vocal warm-up. This was due to the vibrato rates of other notes also slowing. Singers 4 and 10 proved exceptions. Singer 4 had the fastest mean vibrato rate for the solo, and after the vocal warm-up despite her vibrato rate slowing at the beginning of the solo, by the end of the solo she had returned to a faster rate. Singer 10 had particularly slow vibrato, and increased the vibrato rates of all 11 notes, bringing them more in line with the other singers while still producing note 1, the highest note, with the fastest mean vibrato rate (Figure 5.6).

The lowest note assessed, note 8, displayed no corresponding link with slow vibrato rates. Note 8 only recorded the slowest mean vibrato rate twice out of 24 solos, both times prior to vocal warm-up.

5.1.6 Vibrato rate and note duration

Table 5.5 indicates that only notes 8, 10 and 11 registered the slowest vibrato rate before vocal warm-up more than once. After vocal warm-up, the only notes to register more than once were notes 10 and 11. These notes, both minimis, were not only the final two notes in the solo, they were also the two longest notes once breathing at the end of phrases and the slowing of tempo in the pre-recorded accompaniment were accounted for. After the vocal warm-up, eight of the twelve singers produced their slowest vibrato rates on either note 10 or 11, the longest held notes. Yet the converse pattern did not occur. That is, on no occasion did the shortest note, note 3, record the fastest vibrato rate (Table 5.5).

5.1.7 Discussion

Study 2 investigated the vibrato characteristics before and after vocal warm-up of 12 tertiary level singers. Acoustic data revealed three changes in vibrato rate which applied to all singers following vocal warm-up: (i) more regularity in the cyclic undulations comprising the vibrato rate of a note, (ii) more stability in the mean vibrato
rates from one sustained note to the next, and (iii) a moderating of excessively fast and excessively slow mean vibrato rates for the solos.

Firstly, it was found that individual notes with pre-intervention standard deviations of vibrato rate greater than 0.50 cycles/sec showed a significant reduction in cycle-to-cycle irregularity after the vocal warm-up. Prior to vocal warm-up, individual notes registered vibrato rate standard deviations as large as 2.70, 2.92 and 3.42 cycles/sec. The mean standard deviation was 0.82 cycles/sec. After vocal warm-up all standard deviation values were less than 1.66 cycles/sec and the mean standard deviation was 0.53 cycles/sec.

Secondly, it was found that because the fastest vibrato rates mostly slowed and the slowest rates mostly became faster after the vocal warm-up, the degree of note-to-note vibrato rate stability improved. Vibrato rates of 6.00 cycles/sec or faster significantly slowed, and vibrato rates slower than 5.00 cycles/sec became significantly faster. Overall, there was a tendency for vibrato to draw closer to the region of 5.5 cycles/sec. A more compact range of vibrato rates resulted for all singers, and while some singers had initially produced a range of vibrato rates as broad as 3.80 cycles/sec, after vocal warm-up no singer registered a range greater than 1.32 cycles/sec. The mean note-to-note vibrato rate standard deviation reduced from 0.69 to 0.30 cycles/sec. This post-intervention value of 0.30 cycles/sec for student singers compares quite favourably with that of 0.24 cycles/sec measured by Prame (1994) from commercial recordings of Lieder.

Nevertheless, allowing for the observation that singer 10 registered a particularly low vibrato rate standard deviation in combination with very slow vibrato rates, it was decided to calculate standard deviation as a percentage of each singer’s mean vibrato rate. This technique is adopted by Robison et al. (1994) on the grounds that it is not merely low standard deviation but a low value when standard deviation is expressed as a percentage of a singer’s mean vibrato rate that contributes to vocal beauty. Before vocal warm-up, vibrato rate standard deviations were between 5% and 21% (mean S.D. 11.24%) of the corresponding solo’s mean vibrato rate. These values reduced to between 3% and 8% (mean S.D. 5.16%) after vocal warm-up. Every singer produced a lower percentage of standard deviation following vocal warm-up.

Improved stability in the note-to-note progression of vibrato rates for singers with particularly fast vibrato resulted mainly from the highest notes attaining slower, more
moderate vibrato rates. For singers with particularly slow vibrato rates, improved note-to-note vibrato rate stability occurred after numerous notes, not necessarily the highest, attained faster, more moderate vibrato rates. Interestingly, that vibrato rates for all sustained notes in the solo subsequently became somewhat more evenly aligned resonates with comments from singers 2 and 6 that after vocal warm-up, they sensed an improved seamless blending across the range of notes and registers.

Finally, observing the mean vibrato rate for each solo, a moderating of excessively fast and excessively slow mean vibrato rates occurred after vocal warm-up for all singers. That is, prior to vocal warm-up, none of the 12 tertiary level singing students registered a mean vibrato rate for the solo between 5.00 and 5.70 cycles/sec. After vocal warm-up, singers with mean vibrato rates for the solo below 5.00 cycles/sec registered faster values, and singers with mean vibrato rates for the solo above 5.70 cycles/sec registered slower values. The largest increase in speed was registered by the singer with the slowest pre-intervention vibrato, and the largest decrease by the singer with the fastest pre-intervention vibrato. There was a significant reduction in the range of mean vibrato rates produced by the group of singers.

Overall, the finding that vibrato rates became more regular, compact and moderate suggests that vocal improvement occurred. The longitudinal study of Mürbe et al. (2007) found that vocal training produces more moderate vibrato rates, with vibrato below 5.20 cycles/sec becoming faster, and vibrato above 5.80 cycles/sec becoming slower. This is consistent with the observation by Titze (1994) that a mean vibrato rate of 5.5 cycles/sec is perceived as desirable by today’s audiences. Mürbe et al. (2007) and Titze et al. (2002) also note that training reduces the undesirable variability in singers’ vibrato rates; and providing that the music does not demand the dramatic juxtaposition of extreme emotions, then greater vibrato rate stability indicates greater vocal skill and vocal beauty (Bartholomew, 1934; Mürbe et al., 2007; Robison et al., 1994; Sundberg, 1987; Titze et al., 2002).

However, Dromey et al. (2003) and Winckel (1953) noted that vibrato rate may vary according to singer dynamic level: increasing when tones are loud, and decreasing when soft. All singers in this study were asked to maintain as far as possible the same dynamic intensity for both renditions of the solo, and no consistent, positive correlation between singer dynamic intensity and vibrato rate occurred. In fact, most often mean vibrato rate slowed to become more moderate after vocal warm-up while dynamic intensity increased to some extent. Hence, in general, the findings of this study concur
with Michel and Grashel (1980), Mürbe et al. (2007) and Shipp et al. (1980) that vibrato rate is not a function of dynamic intensity. This is not to say that the possibility of a link could be excluded on every occasion. Pedagogical wisdom suggests that how a singer achieves dynamic intensity varies depending on a singer’s technique and proficiency, and it follows that whether a relationship exists between dynamic intensity and vibrato rate may also vary according to individual technique and proficiency. In this study, however, most singers displayed no such link.

Instead, links between vibrato rate, pitch and note duration were observed, which became even more apparent following vocal warm-up. The slowest vibrato rates tended to be produced on the longest notes, lending support to the suggestion that vibrato rate is dependent on note duration (Prame, 1994). Yet on no occasion did the shortest note, note 3, record the fastest vibrato rate for any singer. Note 1, which had the highest pitch in the solo, $F_5$ (740 Hz), recorded the fastest mean vibrato rate in 20 out of 24 solos. This affirms reports that vibrato rate increases somewhat as pitch rises (Titze, 1994). Yet interestingly after vocal warm-up, the highest note often registered not only the fastest vibrato rate, but also a substantially slower vibrato rate than that registered prior to vocal warm-up. Furthermore, despite an apparent link between high pitch and vibrato rate, the lowest note assessed, $E_4$ (330 Hz) recorded the slowest mean vibrato rate only twice in 24 solos, on both occasions before vocal warm-up. So while there was a frequent link between vibrato rate and high fundamental frequency, at some point this link weakened and note duration exerted a stronger influence on vibrato rate.

Nevertheless, factors other than pitch and note duration may have contributed to creating the fastest and slowest vibrato rates. Musical interpretation and communication of feeling, anxiety levels, and each singer’s individual technical development also affects vibrato rate (Miller, 1996; Prame, 1994; Sundberg, 1987; Titze, 1994; Titze et al., 2002; Vennard, 1968). It cannot be discounted that as the solo commenced with the highest note in the excerpt, some degree of apprehension about commencing with less than optimal preparation may have contributed to the fastest vibrato rates being so consistently produced prior to vocal warm-up. The notes most often displaying the slowest vibrato rates, middle register notes on $B_4$ (494 Hz) and $A_4$ (440 Hz) were not only the two longest notes but also the final two notes of the solo. Musically these notes required a sense of calm repose and closure. Consequently, the particularly slow vibrato rates exhibited by most singers on these notes after vocal warm-up may have reflected the singers’ bodily response to the
emotional and artistic needs of musical interpretation. In fact, singer 10 reported that only after the vocal warm-up did she feel that the voice was capable of responding artistically to the music.

In summary, the vibrato rate of all singers changed in three ways following vocal warm-up. Regularity in the cycle-to-cycle undulations within individual notes, which is considered an indicator of singer skill, increased. Vibrato rates from one sustained note to the next, which cannot be too variable if a legato line is to be created, became more even. Overly fast vibrato, commonly associated with stress, nervousness and excessively bright tone, as well as overly slow vibrato, commonly associated with lack of muscle tone and excessively dark tone, became more moderate. Vocal warm-up was thus shown to be an important tool in refining the acoustic signal of each singer’s vibrato, bringing all singers closer to a region of more regular, compact and moderate vibrato rates associated with vocal accomplishment, the ability to maintain a legato line and create beautiful tone.

5.2 VIBRATO EXTENT ANALYSIS

Spectrograms of the eleven long held notes contained in each solo, i.e. 264 notes in total, were assessed for vibrato extent, and the data scrutinised for recurrent differences following the vocal warm-up intervention. Additionally, changes in vibrato extent were compared with singer dynamic intensity, measured by sound pressure level (SPL), as a relationship between these elements may exist (Bretos and Sundberg, 2002; Winckel, 1953).

5.2.1 Assessment of the group as a whole

Appendix 7.1 presents the mean vibrato extent for each note assessed. From these data, Table 5.6 lists the mean vibrato extents for each solo and for the group.
As indicated in Table 5.6, the group mean vibrato extent increased by ±0.01 semitones after vocal warm-up, from ±0.69 to ±0.70 semitones. Standard deviation from the group mean vibrato extent increased by ±0.02 semitones, from ±0.21 to ±0.23 semitones.

5.2.2 Assessment of each solo

5.2.2.1 Mean vibrato extent

Vibrato extent values ranged from ±0.40 to ±1.06 semitones. Following vocal warm-up, one singer produced no change in mean vibrato extent, five produced a decrease and six produced an increase. Changes ranged from a mean decrease of ±0.07 semitones to a mean increase of ±0.12 semitones, with no distinct trends emerging (Appendix 7.3). Figure 5.9 illustrates the mean vibrato extent for each solo.
Figure 5.9 Mean vibrato extent for each solo

Note: Each of the 12 vertical lines represents the mean vibrato extent of one singer. As vibrato extent refers to the pitch variation both above and below the average fundamental frequency, the midpoint of each vertical line represents the average fundamental frequency, i.e. the perceived pitch.

5.2.2.2 Standard deviation

Vibrato extent standard deviation for the solos varied from ±0.06 to ±0.25 semitones (Appendix 7.3). Pre-to-post changes included both increases and decreases in standard deviation. Figure 5.10 shows the standard deviation in relation to the mean vibrato extent for each solo.
Figure 5.10 Standard deviation in relation to the mean vibrato extent for each solo

Note: Each column represents the mean vibrato extent of one solo. The base of each column represents the perceived pitch. The double-headed arrows near the top of each column indicate the standard deviation.

Figure 5.10 indicates that even with standard deviation added to the mean vibrato extent, both pre- and post-intervention vibrato extents were always under ±1.5 semitones. That is, no singer produced excessively large and aesthetically undesirable vibrato extents (Howes, 2001; Sundberg, 1995).
5.2.2.3 Confidence intervals

Figure 5.11 illustrates the 95% confidence intervals for each solo’s vibrato extent.

![Graph showing 95% confidence intervals for mean vibrato extent for each singer before and after vocal warm-up.](image)

Note: Lines on the left of each pair show the confidence interval before vocal warm-up, and those on the right show the confidence interval after vocal warm-up.

Figure 5.11 confirms the absence of decisive trends in vibrato extent change following vocal warm-up. While a majority of singers displayed a somewhat more compact range of vibrato extents after vocal warm-up than before, both higher and lower values resulted.

5.2.3 Assessment of individuals notes

Appendix 7.1 lists mean vibrato extents for individual notes. The smallest mean vibrato extent for an individual note was ±0.17 semitones, and the largest was ±1.38 semitones. Though pre- and post-intervention vibrato extents differed, no specific patterns of change were evident. Appendix 7.2 lists the vibrato extent standard deviations for each note. Figure 5.12 illustrates the standard deviation in relation to the mean vibrato extent for each note.
Figure 5.12 Mean vibrato extent and standard deviation for individual notes

Note: Each group of eleven columns represents the eleven mean vibrato extents assessed per solo. The base of each column represents the perceived pitch. The double-headed arrows near the top of each column indicate the standard deviation.
Figure 5.12 shows that while some singers, for example, singers 3 and 11 produced more consistent vibrato extents and standard deviations after vocal warm-up, this response was not found in all singers.

5.2.4 Vibrato extent and dynamic intensity

Data were checked to determine whether a relationship existed between vibrato extent and the singer’s level of dynamic intensity indicated by sound pressure level (SPL). Appendix 7.4 lists mean SPL and mean vibrato extent for every solo. Figure 5.13 compares mean SPL and mean vibrato extent for each singer. Despite a tendency, as seen for example in singers 3, 4, 7 and 11 for a positive correlation between vibrato extent and SPL, there was no consistent link between changes in dynamic level and vibrato extent. Singers 1, 9 and 12, for example, show an increase in SPL and a decrease in vibrato extent.
Figure 5.13: Comparison of mean SPL and mean vibrato extent before and after the vocal warm-up.
5.2.5 Discussion

In study 2, the mean vibrato extent for the group of twelve singers increased from ±0.69 to ±0.70 semitones after vocal warm-up. These values are quite close to the group mean vibrato extent of ±0.71 semitones found by Prame (1997) in professional Lieder recordings. However, looking at singers individually, no consistent patterns of change emerged from vibrato extent data following vocal warm-up. Mean vibrato extent increased for some, decreased for others and occasionally remained the same. Change in vibrato extent did not favour any subsection of singers with similar vocal characteristics, for example, increasing for singers with small pre-intervention vibrato extents and decreasing for singers with large pre-intervention vibrato extents. While many singers produced a decrease in vibrato extent standard deviation after vocal warm-up, a minority of singers responded with either an increase or no change.

A positive correlation between vibrato extent and dynamic intensity was common to most singers, but it was not common to all. Michel and Grashel (1980), Michel and Myers (1991), and Shipp et al. (1980) assessed notes sung in an emotionally neutral context and failed to find a consistent link between vibrato extent and dynamic level. Nevertheless, an increase in loudness is often linked with strong emotions, and emotional intensity may be signalled through increased vibrato extent (Schoen, 1922). Bretos and Sundberg (2002) measured concurrent increases in SPL and vibrato extent in emotionally intense notes from recordings of the opera Aida. Hence, it cannot be discounted that those singers showing a positive correlation between SPL and vibrato extent perhaps used both vibrato extent and dynamic level to signal increased or decreased emotional intensity.

In conclusion, the variations in vibrato extent produced by singers in this study, rather than displaying a consistent pattern of change after vocal warm-up, illustrate that no two renditions of a piece ever share an identical voice signal. This broadly supports Prame (1997) who noted such diversity in vibrato extents that he judged it difficult to attribute a typical vibrato extent value to any individual singer.
5.3 SINGER-SUBJECT SELF-ASSESSMENT

Twelve female singers, from six different studios, each recorded a set eight bar solo (Figure 3.1) without first warming up, and self-assessed 18 qualities regarding their own performance (see Method 3.2.1.3). Each singer was then guided through a set list of vocal warm-up exercises for 25 minutes (Figure 3.4) and re-recorded the solo. Singers then reassessed the same 18 qualities and were given the opportunity to provide any further written comments. Qualities were rated from 1 to 10, with 1 indicating poor quality and 10 indicating excellence.

5.3.1 Group mean ratings

The first six qualities self-rated were the same tone colour qualities rated by listener-judges. Figure 5.14 shows the singer-subject mean self-ratings and 95% confidence intervals before and after vocal warm-up for qualities i to vi, and Table 5.7 presents the results of the corresponding paired t-tests for singer-subjects’ perceptual judgements. Table 5.7 shows that a significant pre- to post-intervention difference was found for “mellowness”, “brilliance”, “absence of vocal strain”, “vibrato” and “overall rating of classical vocal quality”, but not for “overall rating of legit vocal quality”. As seen in Figure 5.14, singers on the whole assessed their vocal quality before the vocal warm-up to be better suited to legit singing than to fully classical singing. After the vocal warm-up this judgement reversed, not so much due to a perceived deterioration in legit quality but more to a marked improvement in classical vocal quality. “Brilliance” showed the largest increase in mean self-rating and particularly compact 95% confidence intervals (Figure 5.14) indicating strong singer consensus that improvement had occurred after the vocal warm-up.
Table 5.7  Group mean ratings of singer self-perception of qualities i to vi before and after vocal warm-up, and paired t-test results

<table>
<thead>
<tr>
<th>Self-assessed qualities</th>
<th>Vocal warm-up</th>
<th>Mean difference</th>
<th>Std. deviation</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>i Mellowness</td>
<td>4.750</td>
<td>6.167</td>
<td>1.417</td>
<td>1.084</td>
<td>-4.529</td>
</tr>
<tr>
<td>ii Brilliance</td>
<td>3.583</td>
<td>6.917</td>
<td>3.333</td>
<td>1.073</td>
<td>-10.761</td>
</tr>
<tr>
<td>iii Absence of vocal strain</td>
<td>6.417</td>
<td>8.333</td>
<td>1.917</td>
<td>1.505</td>
<td>-4.412</td>
</tr>
<tr>
<td>iv Vibrato</td>
<td>6.083</td>
<td>7.833</td>
<td>1.750</td>
<td>1.765</td>
<td>-3.436</td>
</tr>
<tr>
<td>v Overall rating of classical vocal quality</td>
<td>4.500</td>
<td>6.667</td>
<td>2.167</td>
<td>1.267</td>
<td>-5.922</td>
</tr>
<tr>
<td>vi Overall rating of legit vocal quality</td>
<td>6.167</td>
<td>6.083</td>
<td>-0.083</td>
<td>2.353</td>
<td>0.123</td>
</tr>
</tbody>
</table>

Figure 5.14  Singer-subject group mean ratings and 95% confidence intervals for qualities i to vi
Qualities vii to xii related in particular to singer psychological disposition and psychophysiological factors. Figure 5.15 shows singer-subject mean self-ratings and 95% confidence intervals before and after vocal warm-up for qualities vii to xii, and Table 5.8 presents the results of the corresponding paired t-tests for singer-subjects’ perceptual judgements. As seen in Table 5.8 there were significant pre- to post-intervention differences for all qualities - “satisfaction with the way you sang”, “absence of performance anxiety”, “absence of audible nervousness”, “confidence”, “inner calmness” and “energised alertness”. “Energised alertness” registered the largest increase in mean self-rating combined with compact 95% confidence intervals (Figure 5.15) indicating strong singer consensus that improvement had occurred.
Table 5.8. Group mean ratings of singer self-perception of qualities vii to xii before and after vocal warm-up, and paired t-test results

<table>
<thead>
<tr>
<th>Self-assessed qualities</th>
<th>Before</th>
<th>After</th>
<th>Mean difference</th>
<th>Std. deviation</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>vii Satisfaction with the way you sang</td>
<td>4.083</td>
<td>6.417</td>
<td>2.333</td>
<td>1.497</td>
<td>-5.398</td>
<td>0.000</td>
</tr>
<tr>
<td>viii Absence of performance anxiety</td>
<td>7.333</td>
<td>8.667</td>
<td>1.333</td>
<td>1.497</td>
<td>-3.084</td>
<td>0.010</td>
</tr>
<tr>
<td>ix Absence of audible nervousness</td>
<td>7.250</td>
<td>8.833</td>
<td>1.583</td>
<td>8.500</td>
<td>-2.714</td>
<td>0.020</td>
</tr>
<tr>
<td>x Confidence</td>
<td>6.250</td>
<td>8.500</td>
<td>2.250</td>
<td>2.021</td>
<td>-4.864</td>
<td>0.000</td>
</tr>
<tr>
<td>xi Inner calmness</td>
<td>6.500</td>
<td>7.750</td>
<td>1.250</td>
<td>1.803</td>
<td>-3.563</td>
<td>0.004</td>
</tr>
<tr>
<td>xii Energised alertness</td>
<td>4.333</td>
<td>7.250</td>
<td>2.917</td>
<td>-3.924</td>
<td>0.000</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.15 Singer-subject group mean ratings and 95% confidence intervals for qualities vii to xii.
Qualities xiii to xviii related predominantly to singer perception of technical command and proprioceptive feedback from vocal technique. Figure 5.16 shows singer-subject mean self-ratings and 95% confidence intervals before and after vocal warm-up for qualities xiii to xviii, and Table 5.9 presents the results of the corresponding paired t-tests for singer-subjects’ perceptual judgements. As seen in Table 5.9 there were significant pre- to post-intervention differences for all qualities - “concentration on appropriate vocal technique”, “sensation of being vocally warmed up”, “resonant voice sensations”, “vocal connection throughout the body”, “perception of ease” and “postural alignment for singing”. “Sensation of being vocally warmed up” registered the largest increase in mean self-rating and compact 95% confidence intervals (Figure 5.16) reflecting the singers’ compliance with the request not to warm-up beforehand and the strong singer consensus that improvement was perceived after the intervention.
Table 5.9  Group mean ratings of singer self-perception of qualities xiii to xviii before and after vocal warm-up, and paired t-test results

<table>
<thead>
<tr>
<th>Self-assessed qualities</th>
<th>Vocal warm-up</th>
<th>Mean difference</th>
<th>Std. deviation</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>xiii  Concentration on appropriate vocal technique</td>
<td>4.667</td>
<td>7.500</td>
<td>2.833</td>
<td>1.642</td>
<td>-5.977</td>
</tr>
<tr>
<td>xiv   Sensation of being vocally warmed up</td>
<td>1.417</td>
<td>7.250</td>
<td>5.833</td>
<td>1.467</td>
<td>-13.776</td>
</tr>
<tr>
<td>xv    Resonant voice sensations</td>
<td>3.667</td>
<td>6.667</td>
<td>3.000</td>
<td>1.477</td>
<td>-7.036</td>
</tr>
<tr>
<td>xvi   Vocal connection throughout the body</td>
<td>3.333</td>
<td>6.833</td>
<td>3.500</td>
<td>1.834</td>
<td>-6.611</td>
</tr>
<tr>
<td>xvii  Perception of ease</td>
<td>5.000</td>
<td>7.500</td>
<td>2.500</td>
<td>1.679</td>
<td>-5.159</td>
</tr>
<tr>
<td>xviii Postural alignment for singing</td>
<td>4.417</td>
<td>6.833</td>
<td>2.417</td>
<td>1.929</td>
<td>-4.341</td>
</tr>
</tbody>
</table>

Figure 5.16  Singer-subject group mean ratings and 95% confidence intervals for qualities xiii to xviii
Of all 18 qualities, group mean self-assessments prior to vocal warm-up were highest for “absence of performance anxiety” and “absence of audible nervousness”, suggesting that the singers did not find the recording process particularly stressful. Self-assessments were lowest prior to vocal warm-up for “sensation of being vocally warmed up”, “vocal connection throughout the body”, “brilliance” and “resonant voice sensations”. On the whole, those qualities with low group ratings prior to vocal warm-up improved the most after warm-up and indeed had the most room for improvement. Figure 5.17 shows singer-subject mean self-ratings and 95% confidence intervals before and after vocal warm-up for all qualities combined, and Table 5.10 presents the results of the corresponding paired t-tests for singer-subjects’ perceptual judgements.

Table 5.10  Group mean ratings of singer self-perception of all qualities combined before and after vocal warm-up, and paired t-test results

<table>
<thead>
<tr>
<th>Vocal warm-up</th>
<th>Mean difference</th>
<th>Std. deviation</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before 4.986</td>
<td>After 7.333</td>
<td>2.347</td>
<td>1.940</td>
<td>-17.784</td>
</tr>
</tbody>
</table>

5.3.2 Inter-singer agreement

Inter-singer agreement was assessed in two ways. Firstly, the mean scores for all 18 qualities were averaged before and after vocal warm-up. Agreement was unanimous
among the 12 singers that an improvement occurred after the vocal warm-up (Appendix 8.1).

Ratings were then assessed for agreement regarding each quality and considered to be in close agreement if a singer’s ratings differed by no more than ±1 from another singer’s ratings. From each singer’s 36 ratings (i.e. 18 ratings both before and after vocal warm-up) the percentage that met this criterion ranged from 11% to 78% with a mean of 49% and standard deviation 15% (Appendix 8.2).

5.3.3 Individual singer responses

Appendix 8.1 lists individual singers’ self-assessments. After vocal warm-up, all singers registered improvement in the “sensation of being vocally warmed-up” as well as for “brilliance”, “overall rating of classical vocal quality”, “satisfaction with the way you sang”, “energised alertness”, “resonant voice sensations” and “vocal connection throughout the body”. Improvement in the “perception of ease” was registered by all except singer 4 who gave this quality 10 out of 10 both before and after vocal warm-up.

Singer perceptions varied regarding whether other qualities improved. Only four singers registered improvements in all 18 qualities rated. Some singers who registered no change for qualities such as “absence of performance anxiety” and “audible nervousness” had left little or no room for post-intervention improvement in their ratings. “Overall rating of legit vocal quality” registered the most disagreement amongst singers with five registering improvement, one registering no change and six registering a deterioration in legit quality.

After assessing the listed qualities, singers were also asked if, in order to maintain the same dynamic level after vocal warm-up as before, they felt any vocal restraint was necessary. Ten of the twelve singers (all except singers 2 and 7) stated that vocal restraint was necessary if they were not to sing louder after the warm-up.

In the space for optional comments, some singers noted the following vocal improvements after warming up. Singers 1, 3 and 12 wrote that in particular the higher notes were much easier to sing. Singers 7 and 10 commented that the voice became less “husky”. Singer 3 noted that sensations of “focus” and “placement” improved. Singers 2 and 6 felt the voice was more even when negotiating different registers.
Singer 10 commented that only after the vocal warm-up intervention was artistic control of the voice possible.

The following negative observations regarding the intervention were also made. Singer 8 wrote that the use of headphones in the study was a distraction that lessened her awareness of other sensations. Singers 5 and 11 expressed a heavy reliance on their own familiar set of warm-up exercises and wondered whether their vocal response following the new set of warm-up exercises in the intervention may therefore be less effective. Singer 5 particularly missed her “body awareness/breathing exercises” that she normally incorporated into a warm-up. Nine of the twelve singers (all except singers 3, 4 and 6) stated that for optimal singing they preferred to warm up for between 30 and 45 minutes rather than the 25 minutes allowed for in the intervention.

5.3.4 Comparison of acoustic and perceptual results

Relating the singers’ perceptual judgements to acoustic findings reported in Section 5.1, it is notable that singer 4 registered the largest perceptual change for “sensation of being vocally warmed-up” and showed considerable post-intervention change in vibrato rate. Singer 4 had the fastest mean vibrato rate of all singers prior to vocal warm-up, but after vocal warm-up her mean vibrato rate slowed, reducing from 7.66 to 7.20 cycles/sec. Her note-to-note mean vibrato rates that were originally between 6.90 and 8.73 cycles/sec compacted to between 6.66 and 7.60 cycles/sec. Also the individual undulations within each note showed greater regularity, with vibrato rate standard deviation originally between 0.29 and 2.42 cycles/sec, reducing to between 0.17 and 0.96 cycles/sec.

By contrast, singer 8 registered the least improvement for “sensation of being vocally warmed up” and, unlike other singers, most acoustic change occurred only on her highest note. This note was conspicuous for its fast vibrato rate and large standard deviation of vibrato rate before warm-up. After vocal warm-up the mean vibrato rate of her highest note slowed (from 7.83 to 6.63 cycles/sec pre- to post-intervention) and the standard deviation for that note reduced (from 2.70 to 0.49 cycles/sec). The range of vibrato rates in the solo compacted from between 5.62 and 7.83 cycles/sec before vocal warm-up to between 5.66 and 6.63 cycles/sec after vocal warm-up, but this was largely due to the slower vibrato of one note, the highest note.
Acoustic change was often greatest on the higher notes of the excerpt. Such change was particularly evident in the singer who registered the largest reduction in performance anxiety, singer 9. Her highest note exhibited the largest change in mean vibrato rate for any individual note (decreasing from 9.30 to 6.73 cycles/sec pre- to post-intervention), and her third highest note registered one of the largest decreases in standard deviation of vibrato rate (3.42 to 0.99 cycles/sec pre- to post-intervention). For the entire solo, she showed the largest improvement in vibrato rate standard deviation which, when expressed as a percentage of her mean vibrato rate, reduced from 21% to 6% after vocal warm-up.

Although the vibrato rate displayed consistent patterns of change for all singers after vocal warm-up, not all singers registered a perceived change in vibrato. Indeed, vibrato generally eludes the direct attention of singers, and even those singers who registered a change may have simply presumed vibrato had improved due to a general perception of vocal improvement. Nevertheless, singer 10, who had the slowest pre-intervention mean vibrato rate registered the largest self-assessed improvement in vibrato when it became faster after the vocal warm-up (4.63 to 4.99 cycles/sec pre- to post-intervention). The more vibrato slows below 5.00 cycles/sec, the more it is associated with a noticeable wobble (Prame, 1994). This increase in vibrato rate took singer 10’s undesirably slow vibrato closer to 5.00 cycles/sec and hence to a more aesthetically acceptable vibrato.

5.3.5 Discussion

All twelve singers stated that they relied on vocal warm-up for optimal singing, and singers’ mean ratings showed unanimous agreement that performance had improved after the 25 minute vocal warm-up intervention. This perceived improvement occurred despite comments from many singers that for optimal performance they preferred to warm up for a longer period of time, and from some singers that they relied heavily on their own personal set of warm-ups.

Singers did not always agree on which individual qualities improved. For some qualities, ceiling effects were evident. This occurred for qualities such as “absence of vocal strain” and “absence of audible nervousness” which were sometimes scored the maximum or close to the maximum prior to vocal warm-up so that minimal or no room for improvement was possible. Nevertheless, of the 18 qualities self-assessed by the
singers, significant pre- to post-test differences were found for all except the overall rating of legit vocal quality.

Pre- to post-intervention improvement was registered unanimously for “sensation of being vocally warmed up”, “brilliance”, “overall rating of classical vocal quality”, “satisfaction with the way you sang”, “energised alertness”, “resonant voice sensations” and “vocal connection throughout the body”. Of those singers who noted a lack of vocal ease prior to warm-up, all registered an improvement in “perception of ease” as well. The largest increases in group mean scores were for the perception of “brilliance”, “energised alertness” and for qualities xiii to xviii that related predominantly to singer perception of technical command and proprioceptive feedback from vocal technique - “concentration on appropriate technique”, “sensation of being vocally warmed up”, “resonant voice sensations”, “vocal connection throughout the body”, “perception of ease” and “postural alignment for singing”.

Legit quality, while being rated higher than classical quality prior to the vocal warm-up, was the only category to register no improvement for the group as a whole after vocal warm-up. As legit today does not usually require the voice to project unaided over the orchestra, it is possible that many singers felt that vocal projection had increased after the vocal warm-up and any less formally trained, lightness of timbre generally required of legit singing had decreased. Indeed, all singers rated their vocal quality as more resonant after the warm-up and most stated that vocal restraint was necessary when attempting to maintain the same dynamic level after the warm-up as before. However, to what extent practising specific vocal warm-ups, as opposed to mentally aiming for a particular vocal colour, plays a role in producing a legit “popera” or a fully classical tone quality needs further investigation.

Relating the singers' perceptual judgements to acoustic findings, not all singers registered a perceived improvement in vibrato, despite the vibrato rate of all singers displaying a consistent pattern of improvement after vocal warm-up. This was to be expected, as vibrato generally eludes the direct attention of singers, and even those singers who did register improved vibrato after vocal warm-up may have merely presumed this to be the case due to a general perception of vocal improvement.

The singer who produced the slowest mean vibrato rate of all singers registered the largest perceived improvement in vibrato, and the singer who produced the fastest mean vibrato rate of all singers registered the largest perceived improvement for the
“sensation of being vocally warmed up”. For both singers, as with all 12 singers, after vocal warm-up a more moderate mean vibrato rate resulted, the range of vibrato rates in the solo compacted, resulting in a reduced standard deviation of vibrato rate, and the individual undulations that comprised the vibrato rate of each note became more regular. However, the smallest perceived improvement in the “sensation of being vocally warmed up” was registered by a singer who, prior to vocal warm-up already produced somewhat more moderate vibrato rates and for whom acoustic change after vocal warm-up occurred largely at least, on one note, the highest note.

The vibrato rates of high notes in particular registered acoustic improvement after vocal warm-up. This appears to have played an important role in all singers feeling more warmed up. Nevertheless, some singers perceived that it was their audible nervousness that had improved most or mainly their feeling of performance anxiety that had diminished. Other singers registered no performance anxiety or audible nervousness either before or after the vocal warm-up, but registered particular improvement in “absence of vocal strain”, “resonant voice sensations” or “brilliance”, and commented that it took less effort to project the voice at a louder dynamic level. Acoustically, the moderating of fast vibrato rates on high notes tended to align the vibrato rates in the solo somewhat more evenly. Interestingly, this acoustic change resonates with the comments of singers that after vocal warm-up the sensation of seamless blending from lower middle to high registers of their voice improved.

Although the pre- to post-intervention singer self-assessments indicated the perception of improvement in many qualities following vocal warm-up, it cannot be concluded that vocal warm-up alone produced improvement. Sports psychologists suggest that once a skill is learnt, the most consistent major factor critical to successful performance is confidence (Gould et al., 1981; Heyman, 1982; Highlen and Bennett, 1983; Mahoney et al., 1987; Meyers et al., 1979; Moritz et al., 1996). Lack of confidence produces anxiety, which may show itself physically as a constriction of the throat. The word “anxiety” is derived from Greek and Latin roots meaning “strangling” and “constriction” (Marks, 1987). Optimal singing requires an “open” throat (Mitchell, 2005), not a strangled, constricted throat, and so it follows that optimal singing demands an absence of anxiety and instead a sense of confidence. Ten of the twelve singers registered increased confidence after the vocal warm-up, and interestingly, Miller (1990b) suggests that for some singers, the main advantage of vocally warming up is that it offers psychological security by assuring the singer that the voice is capable of functioning in the tasks ahead. Certainly, increased confidence may have contributed to singers rating their
performance after vocal warm-up as improved and contributed psycho-physiologically towards the acoustic improvement in singers' vibrato.

5.4 LISTENER-JUDGE ASSESSMENT

Listener-judges assessed 15 paired vocal samples, i.e. 30 samples in total, each 22 seconds long (see Method 3.2.3.2). The samples presented 12 singers prior to and after a 25 minute intervention consisting of vocal warm-up exercises (Figure 3.4). Each sample pair presented one singer, with the order of the singer’s warm-up condition randomly varied. Of the 12 singers’ paired samples, three were repeated to check for rater reliability.

Listener-judge assessment consisted of two sections. Firstly, six qualities as in study 1 were each rated from 1 to 10 (see Method 3.2.1.3). Then, after hearing each pair of samples, listener-judges registered whether any difference was perceived in the singer’s warm-up state and if so, whether the singer was more warmed up after the first or the second sample. All singers assessed had indicated they felt more vocally warmed up after the 25 minute vocalisation intervention (Appendix 8.1).

5.4.1 Appraisal of vocal quality

Appendices 9.1 to 9.6 present the perceptual ratings from each of the six listener-judges and Appendix 9.7 presents listener-judge group mean ratings. The difference in group mean ratings (post-intervention minus pre-intervention) and the paired t-test results for listener-judge perception are presented in Table 5.11.
Table 5.11  Group mean ratings and t-test results across all pairs for each vocal quality and for the entire sample across judges, pairs and quality pre- and post-test

<table>
<thead>
<tr>
<th>Qualities assessed</th>
<th>Vocal warm-up</th>
<th>Mean difference</th>
<th>Std. deviation</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mellowness</td>
<td>4.856</td>
<td>5.222</td>
<td>0.367</td>
<td>1.441</td>
<td>2.413</td>
</tr>
<tr>
<td>Brilliance</td>
<td>5.322</td>
<td>5.644</td>
<td>0.322</td>
<td>1.140</td>
<td>2.682</td>
</tr>
<tr>
<td>Absence of vocal strain</td>
<td>5.889</td>
<td>6.200</td>
<td>0.311</td>
<td>1.088</td>
<td>2.714</td>
</tr>
<tr>
<td>Vibrato</td>
<td>4.989</td>
<td>5.411</td>
<td>0.422</td>
<td>1.151</td>
<td>3.479</td>
</tr>
<tr>
<td>Overall rating of classical vocal quality</td>
<td>5.333</td>
<td>5.689</td>
<td>0.356</td>
<td>1.135</td>
<td>2.972</td>
</tr>
<tr>
<td>Overall rating of legit vocal quality</td>
<td>4.489</td>
<td>4.544</td>
<td>0.056</td>
<td>0.904</td>
<td>0.583</td>
</tr>
<tr>
<td>Mean of all assessments</td>
<td>5.146</td>
<td>5.452</td>
<td>0.306</td>
<td>1.155</td>
<td>6.150</td>
</tr>
</tbody>
</table>
As can be seen in Table 5.11, there were significant pre- to post-intervention differences for the perception of mellowness, brilliance, absence of vocal strain, vibrato and the overall rating of classical vocal quality, but not for the overall rating of legit vocal quality. There was also a significant pre- to post-intervention difference for the entire sample across judges, pairs and quality.

Table 5.12 presents the mean assessments, the mean difference (post-test minus pre-test) and the paired t-test results for listener-judge combined perception of singers 4, 5 and 10. As indicated in Table 5.12, the results of the paired t-tests show a significant pre- to post-test difference in listener-judge combined perception for singers 4, 5 and 10. Paired t-tests for the other singers (see Appendix 9.8) found no significant pre- to post-test differences. Relating listener-judge perception to the acoustic findings (see Section 5.1), the vibrato rates of singers 4, 5 and 10 were distinctly different from other singers. Of all singers in the group, singer 4 produced the fastest mean vibrato rate, singer 10 produced the slowest mean vibrato rate, and these singers received the two poorest listener-judge mean assessments prior to vocal warm-up. Apart from singer 9 who exhibited intonation problems, singer 5 displayed the most uneven mean vibrato rate in the group. After vocal warm-up all singers in the group produced vibrato rates that were significantly more moderate and even. A mean improvement was noted by all listener-judges for singer 10 (who registered a mean vibrato rate increase from 4.63 to 4.99 cycles/sec), and by five of the six listener-judges for singer 4 (who registered a mean vibrato rate decrease from 7.66 to 7.20 cycles/sec) and for singer 5 (who registered a vibrato rate standard deviation decrease from 13.55% to 3.01% of the mean vibrato rate). Listener-judge mean assessments of the other singers who possessed less extreme pre-test vibrato rates showed no significant pre- to post-test difference.
Table 5.12  Average ratings of each listener-judge for singers 4, 5 and 10, the mean difference (post-test minus pre-test) and paired t-test results for listener-judge combined perception

<table>
<thead>
<tr>
<th>Vocal warm-up rating</th>
<th>Before</th>
<th>After</th>
<th>Mean difference</th>
<th>Std. deviation</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singer 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>samples 7 &amp; 8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Listener-judge 1</td>
<td>4.167</td>
<td>5.000</td>
<td>0.417</td>
<td>0.293</td>
<td>3.478</td>
<td>0.018</td>
</tr>
<tr>
<td>Listener-judge 2</td>
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<td>3.667</td>
<td></td>
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</tr>
<tr>
<td>Listener-judge 3</td>
<td>4.333</td>
<td>5.000</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Listener-judge 4</td>
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<td>4.000</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Listener-judge 5</td>
<td>5.667</td>
<td>5.667</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Listener-judge 6</td>
<td>4.500</td>
<td>4.833</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Singer 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>samples 9 &amp; 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Listener-judge 1</td>
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<td>6.667</td>
<td>0.528</td>
<td>0.386</td>
<td>3.347</td>
<td>0.020</td>
</tr>
<tr>
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<td>6.333</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Listener-judge 3</td>
<td>5.667</td>
<td>6.500</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Listener-judge 4</td>
<td>5.667</td>
<td>5.833</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Listener-judge 5</td>
<td>4.333</td>
<td>5.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Listener-judge 6</td>
<td>6.000</td>
<td>6.500</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Singer 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>samples 21 &amp; 22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Listener-judge 1</td>
<td>4.000</td>
<td>4.833</td>
<td>1.056</td>
<td>0.544</td>
<td>4.751</td>
<td>0.005</td>
</tr>
<tr>
<td>Listener-judge 2</td>
<td>3.500</td>
<td>4.500</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Listener-judge 3</td>
<td>5.167</td>
<td>6.333</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Listener-judge 4</td>
<td>3.667</td>
<td>4.667</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Listener-judge 5</td>
<td>3.333</td>
<td>5.333</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Listener-judge 6</td>
<td>4.333</td>
<td>4.667</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.4.2 Appraisal of singers’ warm-up states

Table 5.13 shows the order in which each singer was presented and their state of vocal warm-up in the paired vocal samples.

<table>
<thead>
<tr>
<th>Singer number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>First time: Not warmed up</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Second time: Warmed up</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First time: Warmed up</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Second time: Not warmed up</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No change</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5.14 shows listener-judge appraisals of each singer’s state of vocal warm-up. As can be seen, the results ranged from four out of 15 correct to nine out of 15, with an average of six (i.e. 41%) correct. Considering listener-judges had three possible choices, 41% was somewhat better than a guess. As indicated in Table 5.14, the warm-up state of singer 10 was correctly assessed by five out of six listener-judges, and singer 4 by four out of six listener-judges. As mentioned, all singers produced more moderate vibrato rates after vocal warm-up but these two singers had produced the slowest (singer 10) and the fastest (singer 4) mean vibrato rates prior to the vocal warm-up. Correct appraisals of all other singers’ warm-up states were made by only three or fewer listener-judges.
Table 5.14 Perceived warm-up states in paired samples

<table>
<thead>
<tr>
<th>Singer number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>Total correct</th>
<th>Self-consistent judgements</th>
</tr>
</thead>
<tbody>
<tr>
<td>First time: Not warmed up</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Second time: Warmed up</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>First time: Warmed up</td>
<td>X</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Second time: Not warmed up</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>No change in the state of warm-up</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>First time: Not warmed up</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Second time: Warmed up</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>First time: Warmed up</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Second time: Not warmed up</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>No change in the state of warm-up</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>First time: Not warmed up</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<td>✓</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Second time: Warmed up</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>First time: Warmed up</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Second time: Not warmed up</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>No change in the state of warm-up</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>
5.4.3 Inter-rater reliability

Table 5.15 presents the intraclass correlation coefficients for inter-judge reliability.

Table 5.15 Intraclass correlation coefficients for inter-judge reliability

<table>
<thead>
<tr>
<th>Qualities assessed</th>
<th>Intraclass Correlation</th>
<th>95% Confidence Interval</th>
<th>S-value</th>
<th>df1</th>
<th>df2</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mellowness</td>
<td>0.32</td>
<td>-0.52 to 0.78</td>
<td>1.47</td>
<td>11</td>
<td>55</td>
<td>0.168</td>
</tr>
<tr>
<td>Brilliance</td>
<td>0.53</td>
<td>0.05 to 0.83</td>
<td>2.40</td>
<td>11</td>
<td>55</td>
<td>0.017</td>
</tr>
<tr>
<td>Absence of vocal strain</td>
<td>0.67</td>
<td>0.31 to 0.89</td>
<td>3.42</td>
<td>11</td>
<td>55</td>
<td>0.001</td>
</tr>
<tr>
<td>Vibrato</td>
<td>0.55</td>
<td>0.03 to 0.85</td>
<td>2.28</td>
<td>11</td>
<td>55</td>
<td>0.022</td>
</tr>
<tr>
<td>Classical quality</td>
<td>0.60</td>
<td>0.20 to 0.86</td>
<td>3.11</td>
<td>11</td>
<td>55</td>
<td>0.003</td>
</tr>
<tr>
<td>Legit quality</td>
<td>0.28</td>
<td>-0.15 to 0.69</td>
<td>1.73</td>
<td>11</td>
<td>55</td>
<td>0.092</td>
</tr>
<tr>
<td><strong>All qualities rated</strong></td>
<td>0.58</td>
<td>0.41 to 0.71</td>
<td>2.94</td>
<td>71</td>
<td>355</td>
<td>0.000</td>
</tr>
</tbody>
</table>

As indicated in Table 5.15 listener-judge assessments were most reliable for "absence of vocal strain" and "classical quality". Assessments were somewhat reliable for "vibrato" and “brilliance”, and least reliable for “mellowness” and "legit quality”.

Table 5.16 lists, from each listener-judge’s 30 mean ratings (i.e. from 15 pre-intervention samples and their corresponding 15 post-intervention samples), the percentage of pairs that agreed in the direction of change, i.e. showing improvement, deterioration or no change in the mean rate.

Table 5.16 Percentage of inter-rater agreement based on pre- to post-intervention pairs showing a mean improvement, no change, or deterioration

<table>
<thead>
<tr>
<th>Listener-judges</th>
<th>Close agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 and 2</td>
<td>40%</td>
</tr>
<tr>
<td>1 and 3</td>
<td>60%</td>
</tr>
<tr>
<td>1 and 4</td>
<td>53%</td>
</tr>
<tr>
<td>1 and 5</td>
<td>40%</td>
</tr>
<tr>
<td>1 and 6</td>
<td>53%</td>
</tr>
<tr>
<td>2 and 3</td>
<td>53%</td>
</tr>
<tr>
<td>2 and 4</td>
<td>47%</td>
</tr>
<tr>
<td>2 and 5</td>
<td>47%</td>
</tr>
<tr>
<td>2 and 6</td>
<td>33%</td>
</tr>
<tr>
<td>3 and 4</td>
<td>47%</td>
</tr>
<tr>
<td>3 and 5</td>
<td>80%</td>
</tr>
<tr>
<td>3 and 6</td>
<td>47%</td>
</tr>
<tr>
<td>4 and 5</td>
<td>47%</td>
</tr>
<tr>
<td>4 and 6</td>
<td>73%</td>
</tr>
<tr>
<td>5 and 6</td>
<td>53%</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>52%</strong></td>
</tr>
</tbody>
</table>

Table 5.16 shows considerable inter-rater disagreement. Yet when the scores of only singers 4, 5 and 10 were considered, listener-judges registered 89% agreement. These
singers each exhibited either exceptionally slow, exceptionally fast or exceptionally uneven mean vibrato rates prior to the vocal warm-up. Agreement was lowest for those singers that exhibited more moderate vibrato rates prior to warming up.

Nevertheless, when listener-judge ratings of singers as a whole were observed, listener-judge agreement was strong. Table 5.17 presents each listener-judge’s mean ratings of singers as a whole before and after vocal warm-up.
Table 5.17  Individual listener-judges’ ratings of singers as a whole before and after vocal warm-up

<table>
<thead>
<tr>
<th>Listener-judge</th>
<th>Warm-up condition</th>
<th>Absence of vocal strain</th>
<th>Brilliance</th>
<th>Mellowness</th>
<th>Classical quality</th>
<th>Vibrato</th>
<th>Mean rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Before</td>
<td>4.800</td>
<td>6.000</td>
<td>6.867</td>
<td>5.333</td>
<td>5.533</td>
<td>3.733</td>
<td>5.378</td>
</tr>
<tr>
<td>1 After</td>
<td>5.133</td>
<td>6.000</td>
<td>6.867</td>
<td>5.333</td>
<td>5.533</td>
<td>3.733</td>
<td>5.378</td>
</tr>
<tr>
<td>2 Before</td>
<td>4.800</td>
<td>6.000</td>
<td>6.867</td>
<td>5.333</td>
<td>5.533</td>
<td>3.733</td>
<td>5.378</td>
</tr>
<tr>
<td>2 After</td>
<td>5.133</td>
<td>6.000</td>
<td>6.867</td>
<td>5.333</td>
<td>5.533</td>
<td>3.733</td>
<td>5.378</td>
</tr>
<tr>
<td>3 Before</td>
<td>5.467</td>
<td>5.800</td>
<td>6.000</td>
<td>5.267</td>
<td>5.800</td>
<td>4.400</td>
<td>5.667</td>
</tr>
<tr>
<td>3 After</td>
<td>5.667</td>
<td>6.200</td>
<td>6.000</td>
<td>5.267</td>
<td>5.800</td>
<td>4.400</td>
<td>5.667</td>
</tr>
<tr>
<td>4 Before</td>
<td>4.667</td>
<td>5.200</td>
<td>5.400</td>
<td>5.125</td>
<td>5.733</td>
<td>4.333</td>
<td>5.278</td>
</tr>
<tr>
<td>4 After</td>
<td>5.000</td>
<td>5.600</td>
<td>5.400</td>
<td>5.125</td>
<td>5.733</td>
<td>4.333</td>
<td>5.278</td>
</tr>
<tr>
<td>5 Before</td>
<td>5.000</td>
<td>5.600</td>
<td>5.400</td>
<td>5.125</td>
<td>5.733</td>
<td>4.333</td>
<td>5.278</td>
</tr>
<tr>
<td>5 After</td>
<td>5.000</td>
<td>5.600</td>
<td>5.400</td>
<td>5.125</td>
<td>5.733</td>
<td>4.333</td>
<td>5.278</td>
</tr>
<tr>
<td>6 Before</td>
<td>5.933</td>
<td>6.067</td>
<td>6.000</td>
<td>5.267</td>
<td>5.800</td>
<td>4.400</td>
<td>5.667</td>
</tr>
<tr>
<td>6 After</td>
<td>5.933</td>
<td>6.067</td>
<td>6.000</td>
<td>5.267</td>
<td>5.800</td>
<td>4.400</td>
<td>5.667</td>
</tr>
</tbody>
</table>
Table 5.17 indicates that after vocal warm-up listener-judges unanimously registered mean rate increases for singers as a whole. As to the value of the vocal warm-up for legit vocal quality, listener-judges were equally divided. Of the other five qualities, mellowness, brilliance, absence of vocal strain, vibrato and classical vocal quality, none was unanimously perceived as improving markedly more than the others.

The perceptual appraisals of each singer’s warm-up state were also assessed for inter-rater agreement. From three assessment choices, namely (i) first warmed up and then not warmed up, (ii) first not warmed up and then warmed up, (iii) no change in the state of warm-up, Table 5.18 presents the percentage of listener-judge agreement.

<table>
<thead>
<tr>
<th>Listener-judges</th>
<th>Close agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 and 2</td>
<td>33%</td>
</tr>
<tr>
<td>1 and 3</td>
<td>40%</td>
</tr>
<tr>
<td>1 and 4</td>
<td>40%</td>
</tr>
<tr>
<td>1 and 5</td>
<td>40%</td>
</tr>
<tr>
<td>1 and 6</td>
<td>13%</td>
</tr>
<tr>
<td>2 and 3</td>
<td>27%</td>
</tr>
<tr>
<td>2 and 4</td>
<td>40%</td>
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<tr>
<td>2 and 5</td>
<td>27%</td>
</tr>
<tr>
<td>2 and 6</td>
<td>53%</td>
</tr>
<tr>
<td>3 and 4</td>
<td>27%</td>
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<tr>
<td>3 and 5</td>
<td>33%</td>
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<tr>
<td>3 and 6</td>
<td>20%</td>
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<tr>
<td>4 and 5</td>
<td>27%</td>
</tr>
<tr>
<td>4 and 6</td>
<td>33%</td>
</tr>
<tr>
<td>5 and 6</td>
<td>40%</td>
</tr>
</tbody>
</table>

As seen in Table 5.18, agreement varied between 13% and 53% with a mean of 33%. Given three choices, 33% agreement would also be likely were the responses random guesses.

### 5.4.4 Intra-rater reliability

Three pairs of vocal samples (i.e. six samples in total) were repeated to assess listener-judges’ self-reliability. Figure 5.18 compares the mean rate for each of the six vocal samples as assessed on two occasions.
As illustrated in Figure 5.18, although a rating scale of 1 to 10 was used, listener-judge mean rates tended to occupy only the middle third of the scale for the samples that were repeated.
Figure 5.19 illustrates the difference in mean rates of the six repeated vocal samples plotted against their respective means, as per Bland and Altman (1986).

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Figure 5.19 The difference in mean rates between the first and second hearing of six vocal samples plotted against their respective means, as per Bland and Altman (1986)
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However, neither of the above figures address the paired relationship, i.e. before and after the vocal warm-up, as perceived on two occasions. Figure 5.20 illustrates this relationship between sample pairs.
Figure 5.20 Mean ratings before and after vocal warm-up for singers whose vocal samples were repeated

Note: Repeated samples have the singer number in brackets.
Figure 5.20 shows that listener-judge 4 rated singer 3 much higher in the first assessment than the second, suggesting possible intra-rater unreliability. Yet, listener-judge 4’s perception of singer 3 is consistent in that on both occasions the paired samples were judged as improving after the vocal warm-up. By contrast, listener-judge 4 registered somewhat similar mean ratings for singer 7 before vocal warm-up, thus suggesting intra-rater reliability. Yet, after vocal warm-up listener-judge 4 perceived the singer as deteriorating on one hearing and improving on another hearing.

To establish the percentage of intra-rater reliability, scores of repeated samples were checked for numerical proximity to the original rating. From each listener-judge’s 36 repeated ratings (i.e. six repeated samples each rated for six qualities), those that differed by no more than ±1 from the original rating were considered in close agreement. Table 5.19 lists the percentage of scores that met this criterion.

Table 5.19 Percentage of intra-rater reliability based on rates that differ by no more than ±1

<table>
<thead>
<tr>
<th>Listener-judge</th>
<th>Reliability</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>75%</td>
</tr>
<tr>
<td>2</td>
<td>36%</td>
</tr>
<tr>
<td>3</td>
<td>56%</td>
</tr>
<tr>
<td>4</td>
<td>50%</td>
</tr>
<tr>
<td>5</td>
<td>58%</td>
</tr>
<tr>
<td>6</td>
<td>81%</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>59%</strong></td>
</tr>
</tbody>
</table>

Table 5.19 shows considerable variability (between 36% and 81%) within the six listener-judges regarding intra-rater reliability in the perception of vocal quality.

Intra-rater reliability regarding the perception of singers’ warm-up states was also determined from the three repeated vocal sample pairs. With six listener-judges there were a total of 18 appraisals to assess. Only 4 of the 18 appraisals were self-consistent (Table 5.14), which gave an average of 22% intra-rater reliability. However, only listener-judge 4 was both self-consistent and correct in appraising the warm-up state of any of the singers’ paired sample repeats (Tables 5.13 and 5.14) and this occurred on only one occasion.
5.4.5 Discussion

Listener-judge ratings indicated a significant pre- to post-intervention difference for the perception of mellowness, brilliance, absence of vocal strain, vibrato and the overall rating of classical vocal quality, but not for the overall rating of legit vocal quality. There was also a significant pre- to post-intervention difference for the entire sample across judges, pairs and quality.

Nevertheless, of the five qualities that showed significant improvement after the vocal warm-up, none was unanimously selected by listener-judges as improving the most, and when rating individual samples for specific tone qualities listener-judges showed considerable disagreement. This is consistent with the numerous studies that acknowledge that both inter- and intra-judge agreement on the perception of vocal tone colour is problematic (Kreiman et al., 1993; Rothman and Timberlake, 1984; Vurma and Ross, 2002; Wapnick and Ekholm, 1997) and even experts have difficulty in evaluating vocal quality (Erickson, 2009; Kreiman et al., 1993; Wapnick and Ekholm, 1997). Studies of both the spoken and the singing voice indicate that tone colour may be incapable of aural dissection into component parts as strong interrelationships between many factors contribute to tone colour (Ekholm et al., 1998; Kent, 1996; Kreiman and Gerratt, 1998; Wapnick and Ekholm, 1997), and judges agree less the more a detailed rating is requested (Kreiman and Gerratt, 1998). It is therefore important to consider listener-judges’ mean rates for each singer.

Observing the mean rates for each vocal sample, the singers in this study with the slowest and the fastest vibrato rates (singers 10 and 4 respectively) received the two poorest mean rates from listener-judges prior to vocal warm-up. Acoustically, after vocal warm-up all singers produced significantly more moderate and even vibrato rates, but paired sample t-tests for combined listener-judge perception did not find a significant pre- to post-intervention difference for most singers. Only three singers, namely those registering either the slowest vibrato rate (singer 10), the fastest vibrato rate (singer 4) and a particularly uneven vibrato rate (singer 5) prior to vocal warm-up, produced a significant pre- to post-intervention difference according to listener-judge combined perception. That is, for the singers who displayed the least acceptable vibrato rates prior to vocal warm-up, a significant level of mean improvement was perceived after vocal warm-up. For singers whose vibrato signals were more moderate
before the vocal warm-up, listener-judges’ mean assessments showed considerable disagreement.

The intraclass correlation coefficients for inter-judge reliability indicated that listener-judge assessments were most reliable for "absence of vocal strain" and "classical quality". Assessments were somewhat reliable for "vibrato" and “brilliance”, and least reliable for “mellowness” and "legit quality". Particularly low intraclass correlation coefficients for the assessment of legit quality suggest that there was no common understanding between listener-judges as to what they were looking for when assessing legit quality. That is, on the one hand, legit is described as sounding “decidedly classical” (Edwin, 2003, p. 431) and “unmistakably operatic” (Light, 1992, p. 13), and the role of Maria from West Side Story, a role sung by classical soprano Kiri Te Kanawa, is described as legit (Edwin, 2009). Yet Kiri Te Kanawa describes the legit voice of fellow New Zealander and “popera” singer Haley Westonra as belonging to a different world and explains this by disassociating her singing from that of singers that need a microphone to project over an orchestra (Adams, 2009). While singers of some legit roles may have a target sound that differs from that of other acclaimed legit singers, it is to be expected that the listener-judges had no single target sound in mind when assessing legit vocal quality. Clearly further investigation is needed into the perceptual parameters that differentiate “popera” legit from traditional legit as found in early musicals that required the voice to project unamplified over an orchestra, and furthermore, where the distinctions lie between this form of traditional unamplified legit and classical vocal quality.

Despite strategies being adopted to reduce listener-judge unreliability, it cannot be ruled out that reliability may have deteriorated due to procedural factors. That is, rater fatigue, a common cause of rater unreliability, had been addressed by reducing the duration of all samples to 22 seconds each. To manage rater drift, samples were not randomly mixed but presented in pairs that introduced one singer under both conditions. Additionally, singer-subjects were all tertiary trained singing students of somewhat uniform standard. Nevertheless, rater unreliability may have occurred due to fatigue from assessing 30 samples, causing a drift in raters’ attention spans. This is supported by the paired sample t-test results of listener-judge mean assessment that show a distinct decline in listener-judge agreement after the first ten vocal samples had been assessed. The fact, too, that singers were students not devoid of inconsistent
vocal quality may have affected rater reliability. Listener-judges commonly commented on the inconsistencies inherent in each singer’s voice, whereby qualities such as vibrato or mellowness were perceived as appropriate in one bar but not in the next. Two listener-judges remarked that, due to singer inconsistency, rating was influenced by when, during the sample, each of the six qualities came under consideration.

The presence of strong variation in the amount of mellowness within any one sample was, for example, often commented on by the listener-judges. Listener-judge 4 wrote:

"Mellowness, brilliance and strain varied over the course of each excerpt. In particular, higher notes lacked mellowness and were often shrill, whereas notes in a more comfortable mid-range were mellow. This made deciding on a score very difficult. It would have been easier to mark an individual note rather than a collection of notes."

This comment echoes the observations of Winckel (1960) who noted that tone colour changes with pitch, becoming brighter with ascending pitch and darker with descending pitch. Singer training attempts to equalise the balance of bright/dark or chiaroscuro tonal variation throughout the vocal range. In this study, however, it is suggested that poor listener-judge agreement for mellowness may have reflected the student status of the singers and a lack of intra-singer consistency of tone colour, rather than a lack of common understanding between listener-judges as to what mellowness in a voice sounds like.

Interestingly, listener-judges did not always consider that an improvement registered for the qualities rated was sufficient grounds to judge that the singer had warmed up. Instead, listener-judges indicated that factors other than those rated were important when appraising warm-up states. Two listener-judges commented that they were listening for change in the vocal onset, and one listener-judge for change in vocal offset. Two others commented that they were listening for change in how “breathy” or how “clean” the voice sounded throughout a phrase. One referred to listening for whether the voice was “falling back in the throat or not”, and another for how well the voice was “placed”. Yet even listening for such features as onset, breathiness and placement, why were listener-judges generally not able to correctly distinguish the singer’s warm-up state? Listener-judges as a group correctly appraised the singers’ warm-up states in only 41% of paired samples.
It is speculated that if the piece had a more extensive range, then the state of warm-up may have been more obvious. The excerpt covered a major 10th from the notes D⁴ (294 Hz) to F♯⁵ (740 Hz). Indeed, two of the singers commented that after the vocal warm-up they felt far more able to sing higher with ease, and that, had the repertoire been higher, their warm-up states would have been more apparent. For some listener-judges the vocal samples may have been too short. Each had been reduced to 22 seconds in duration in an attempt to minimise rater fatigue. One listener-judge commented that a longer period for familiarisation with any singer was required for reliable appraisal of vocal change, and that the basic character of the voice was still being discovered during the second sample. Another listener-judge mentioned that singer appraisal was hindered through a lack of visual cues. Miller (1996) also maintains that in singer assessment “the ear is assisted by the eye” (p. 193). Some listener-judges commented on singer discrepancies in intonation, rhythm and phrasing being off-putting. Perhaps such vocal faults were sufficiently irritating to listener-judges that neither sample in a pair was perceived as good singing, irrespective of the singer’s warm-up state. Certainly, Ekholm et al. (1998) found that faulty intonation was capable of adversely influencing all ratings, regardless of the specific quality under investigation.

At no time did all six listener-judges agree, correctly or otherwise, on the warm-up state of a given singer. However, five listener-judges correctly appraised the warm-up state of singer 10 who, with pre- to post-intervention mean vibrato rates of 4.63 to 4.99 cycles/sec respectively, displayed the slowest mean vibrato rate of any singer before vocal warm-up and the greatest increase in vibrato rate after vocal warm-up. Additionally, singer 10’s vibrato rate standard deviation reduced slightly after vocal warm-up. Interestingly, it was only singer 10 who received a higher mean score from every listener-judge after vocal warm-up.

Four listener-judges correctly appraised the warm-up state of singer 4, and five out of six listener-judges allotted her a higher mean score after vocal warm-up. Singer 4 had the fastest pre- and post-intervention mean vibrato rates of any singer, but slowed her mean vibrato rate from 7.66 to 7.20 cycles/sec. This represented the largest decrease in mean vibrato rate of any singer. Additionally, singer 4’s vibrato rate standard deviation reduced after vocal warm-up.
All remaining ten singers received correct appraisals of their warm-up states from only one to three listener-judges. They had mean vibrato rates between the excessively slow and excessively fast extremes of the two singers mentioned above. This suggests that the way judges determine whether the singer is warmed up is influenced by the quality of their vibrato, and that a moderate vibrato rate is an important indicator of a warmed-up voice. Furthermore, it suggests that when a singer’s vocal quality is assessed from recordings of short duration, perceiving whether that singer is or isn’t warmed up is more problematic the more the singer can produce a moderate mean vibrato rate without first vocally warming up.

This study also indicates that despite inter- and intra-rater inconsistencies, a majority of listener-judges could correctly assess as having warmed up, those singers displaying the greatest tempering of extremely fast and extremely slow vibrato rates. A majority of listener-judges also perceived a mean improvement of the qualities rated after vocal warm-up in those same singers.
6  OVERALL CONCLUSIONS

6.1 Review of the findings

The studies in this thesis have examined acoustic and perceptual change in the singing voice after vocal warm-up and after three non-vocal tasks. Acoustically, this research demonstrated that vibrato rates became more regular, compact and moderate after vocal warm-up and also after non-vocal breathing imagery based on traditional concepts found in singing literature. A non-vocal imagery task not based on traditional concepts found in singing literature produced less compact, predominantly slower and often irregular vibrato rates. A non-imagery silent task produced marginal change only. Vibrato extent remained largely unaffected by any intervention.

Perceptually, the results showed that singers felt more warmed up not only after the vocal warm-up but also after the non-vocal breathing imagery task. Listener-judge findings, however, showed considerable intra- and inter-judge unreliability in rating samples of approximately 28 seconds duration. Singers registering particularly pronounced acoustic change in vibrato tended to be noted by listener-judges as displaying a change in vocal quality; those displaying more subtle acoustic change appeared to be rated according to their overall level of training irrespective of a change in experimental conditions.

Although these studies pose a number of unanswered questions which need addressing in future research, they present an initial attempt to investigate the role of vocal and non-vocal pre-performance practices.

6.2 How these findings have addressed the research questions

Study 1 sought to address four main questions. Firstly, in what way may breathing imagery alter the acoustic signal of the singing voice? It was hypothesised that after the breathing imagery intervention, an improvement in vibrato quality would occur, indicated by more moderate and more consistent vibrato rates, and by vibrato extents that were neither excessively narrow nor too broad. The findings of study 1 support the first part of this hypothesis. That is, vibrato rates for all singers became more moderate and more consistent following the breathing imagery intervention. Specifically, three notable changes in vibrato rate occurred: (i) more regularity in the cyclic undulations
comprising the vibrato rate of a note, (ii) more stability in mean vibrato rates from one sustained note to the next, and (iii) a moderating of excessively fast and excessively slow mean vibrato rates for solos. The second part of the hypothesis, however, is not supported by the findings of study 1. That is, vibrato extent showed no consistent patterns of change as a result of any intervention.

The second question the study posed was whether breathing imagery enhanced vocal quality according to the singer and the listener. It was hypothesised that perceptually, both singer-subjects and listener-judges would rate vocal tone quality higher after the breathing imagery intervention than before, whereas lower ratings would be given to vocal samples recorded after other interventions. The singer-subjects’ results support, in general, this hypothesis. That is, when mean ratings were calculated, singers consistently registered higher self-ratings after the breathing imagery than after the other interventions. Listener-judges also registered higher mean group ratings after the breathing imagery intervention than other interventions. However, apart from when a singer displayed very pronounced acoustic change, listener-judges showed considerable intra- and inter-rater disagreement.

The third question posed by the study asked whether imagery not based on traditional vocal concepts had any effect on the voice. It was hypothesised that such imagery would produce change in the vibrato signal, possibly reflecting increased relaxation. However, while vibrato change would be greater than that registered after the non-imagery intervention where minimal change would occur, it would not necessarily reflect vocal improvement. This hypothesis found support in the findings of study 1. Following the imagery intervention based on Braille music code, the vibrato rates of all singers slowed and for all but the most accomplished singer became more unstable as well, whereas minimal change was registered following the non-imagery based cloze passage intervention.

Finally, the study asked whether breathing imagery served to both allay performance anxiety and function as a silent warm-up. It was hypothesised that singers would report a reduction in audible nervousness and a feeling of having vocally warmed up after the breathing imagery, and that little, if any, improvement in these qualities would be noted after the other interventions. Regarding performance anxiety, the hypothesis remains unanswered. What little performance anxiety was registered, basically by the two least
experienced singers in the group, showed most improvement after the breathing imagery intervention. However, with so few singers registering performance anxiety in this project, the role of breathing imagery in performance anxiety management for singers remains speculative. Regarding silent warm-up, the hypothesis was supported by the findings of study 1. That is, only after the breathing imagery intervention did all singers register the feeling of being more warmed up vocally.

Study 2 sought to clarify three questions. Firstly, in what way may vocal warm-up alter the acoustic signal of the singing voice? It was hypothesised that after vocal warm-up, an improvement in vibrato quality would occur, and that such improvement would take the form of more moderate and more consistent vibrato rates, and vibrato extents that are neither excessively narrow nor too broad. The findings of study 2 support the first part of this hypothesis. That is, vibrato rates for all singers became more moderate and more consistent after vocal warm-up. As with the findings following the breathing imagery of study 1, three notable changes in vibrato rate occurred: (i) more regularity in the cyclic undulations comprising the vibrato rate of a note, (ii) more stability in mean vibrato rates from one sustained note to the next, and (iii) a moderating of excessively fast and excessively slow mean vibrato rates for solos. The second part of the hypothesis, however, is not supported by the findings of study 2, as vibrato extent showed no consistent patterns of change as a result of vocal warm-up.

Study 2 also asked whether vocal warm-up enhanced vocal quality according to both the listener and singer. It was hypothesised that those samples recorded after the vocal warm-up would receive higher scores for vocal quality as rated on the questionnaires. The findings showed that for both singers and listener-judges, this was the case for overall scores. However, singers who produced excessively fast, slow or unstable vibrato rates before vocal warm-up self-rated their performance as improving more after warm-up than did those singers who produced more moderate and stable vibrato rates to commence with. Considerable listener-judge intra- and inter-rater unreliability was also registered, particularly when listener-judges were assessing less extreme acoustic change. This unreliability occurred despite acoustic verification that after vocal warm-up more moderate and more stable vibrato rates were produced by all singers.

Finally, study 2 asked if listener-judges could consistently distinguish warmed-up from unwarmed-up samples when the same singer was presented for back-to-back
assessment. The hypothesis that this would be possible proved incorrect. Under research conditions, listener-judges overwhelmingly failed to distinguish warmed-up from unwarmed-up voices, often citing factors not listed for rating as influencing their decision.

6.3 The significance of these studies

This has been the first study to investigate vibrato change after vocal warm-up and the first study to investigate vibrato change after both imagery and non-imagery tasks. As singers volunteered from a broad range of singing studios, it is believed that the results are not merely applicable to singers with a background in any one particular approach to the teaching of singing. The results, however, highlight the necessity of presenting singer-subject results individually so that valuable information is not lost in group averages.

These studies support the use of vibrato analysis as an effective analytical tool in the investigation of vocal practices. This is particularly important, as conventional Long Term Average Spectrum (LTAS) analysis, while indicating energy peaks, does not distinguish other changes in tone quality important to good singing technique (Mitchell, 2005). Furthermore, these studies support the validity of research into individual variation in vibrato amongst singers and changes in vibrato patterns, including the finer details of note-to-note and cycle-to-cycle vibrato rate stability.

Vibrato has a profound influence on tone quality (Bartholomew, 1934, 1937; Doscher, 1994; Miller, 1977, 1996; Seashore, 1932, 1947), yet vibrato rate in particular usually seems beyond the direct control of the singer (Bretos and Sundberg, 2002; Prame, 1994; Robison et al., 1994). These studies have shown that indirectly, both vocal warm-up and directional breathing imagery produce beneficial acoustic change in singers’ vibrato rates. While not disputing that vibrato is largely a “personal constant” (Sundberg, 1994, p. 117) or that years of training may be needed for vibrato to show lasting improvement (Björklund, 1961; Mürbe et al., 2007; Sundberg, 1987; Titze et al., 2002; Westerman, 1938), these studies nevertheless offer insight into the means by which vibrato may be fine-tuned before a performance.
These studies have also attempted to take a multidisciplinary approach to the investigation of singing practices. Vocal warm-up has been compared with warm-up for athletic performance, and the role of warm-up in stress management has been considered. Attention has been drawn to the fact that images of energy or of the breath directed both far above and far below the larynx such that a sense of elongation is encouraged are not unique to singing pedagogy. Similar images are employed in teaching speech and drama (Linklater, 1976; Rodenburg, 1992) and in the dance studio (Hanrahan et al., 1995) to aid expressive and technical capability. Related images of elongation are recommended by Sweigard (1975) to aid posture, and bear comparison with the principles of Alexander technique (Alcantara, 1997; Hudson, 2002a). Perhaps of particular note, similar images are found in meditation (Baeumer, 2004; Middendorf, 1995) - “a state of restful alertness” (Stroebel and Glueck, 1978, p. 410) in which a person may be so closely observing the breath that no negative self-talk or other distracting thoughts occur (Stoyva, 2000). Such intent focus of attention may be used in stress management (Langeheine, 2004; Mornell, 2002; Stoyva, 2000) for mitigating fight-or-flight responses which, importantly for singers, affect neuromuscular tremor activity and very possibly vibrato characteristics (Coleman et al., 1987; Schoen, 1922; Shipp et al., 1980, 1984; Stark, 1999; Titze, 1994; Titze et al., 2002; Westerman, 1938; Winckel, 1957).

As directional breathing imagery is found in meditation which encourages diaphragmatic breathing (Baeumer, 2004; Bartley and Clifton-Smith, 2006; Stoyva, 2000), study 1 appears to both validate the belief that diaphragmatic breath management may influence vibrato rate (Miller, 2004) and show that traditional breathing imagery used by singers is a means of achieving such diaphragmatic breath management. As highlighted by Baeumer (2004) when investigating Qigong, breathing imagery overcomes two major breathing pitfalls. Firstly, by encouraging the observation of the breath, it avoids the possibility of a person inadvertently falling into stress related breathing patterns - stress often being linked to rapid, irregular, shallow breathing as well as breath holding. Secondly, it avoids the equally harmful, conscious manipulation of respiratory muscles in a misguided attempt to breathe “properly”. That directional breathing imagery produces more moderate and consistent vibrato rates in singers, supports the view expressed by Titze et al. (2002) that relaxation exercises incorporating an imagery component may assist when excessive tension and lack of muscular equilibrium impinge negatively on vibrato rate.
The findings of study 1 do not lend support to the view that imagery used by singers must only represent physiological reality. One of the prime results not only of vocal warm-up but also of directional breathing imagery is the reduction of excessively fast vibrato rates on high notes. Such an adjustment of vibrato rate is important if a chiarauro tone quality is to be produced (Miller, 1977). Furthermore, it is tempting to speculate that vibrato rate adjustment may also be at the crux of “placement” or “focus” practices that involve directional imagery, and which singers of renown often use on their highest notes mid-performance in order to produce optimal tone quality (Hines, 1982; Patenaude-Yarnell, 2003a; Puritz, 1956; Yurisich, 2000a, 2000b).

However, more compact, moderate and even vibrato rates, as well as occurring after pre-performance breathing imagery and after vocal warm-up, also result from years of training (Mürbe et al., 2007). Hence study 2, when considered in relation to the longitudinal study of Mürbe et al. (2007), highlights the fact that in some pedagogical practices there may be no distinction between vocal warm-up exercises and the exercises that constitute a vocal lesson. Both these practices attempt to reduce undue stress, promote muscular equilibrium and in doing so, indirectly bring the singer closer to a better quality of vibrato. Eventually, if extensive vocal use is maintained, professional singers achieve a virtually permanent state of warm-up (Elliot et al., 1995) and, as evidenced in study 1, more consistent vibrato signals than those found in student singers. Nevertheless, Miller (1990b) suggests that a vocal warm-up also serves the purpose of providing the singer with psychological reassurance that the voice is functioning well. Such psychological reassurance is important for singers irrespective of their level of experience, as authorities concur that stress, whether muscular or emotional in origin, affects vibrato and hence tone quality (Coleman et al., 1984; Miller, 1996; Stark, 1999; Sundberg, 1987; Titze, 1994; Vennard, 1968).

With this in mind, it could be considered that vocal warm-up and directional breathing imagery may each offer different ways of working towards stress management. This is not to suggest that breathing imagery may replace vocal warm-up. Nevertheless, the findings of these studies suggest breathing imagery may provide a beneficial adjunct to vocal warm-up and serve as a means of reducing the time spent audibly warming up, or of maintaining a well warmed-up state when circumstances demand periods of vocal silence, for example, during the performance of an oratorio.
The results of both studies also highlight the divide between singer and listener perception. While singer self-ratings registered the sensation of being more vocally warmed up and of vocal quality generally improving after both breathing imagery and vocalisation, listener-judges showed considerable intra- and inter-judge unreliability in their perceptions of vocal change. Even with singers of somewhat similar standard, as in study 2, listener-judge responses showed a lack of reliability. It must be acknowledged, however, that inconsistent listener-judge ratings often reflected, quite accurately, that the singers themselves frequently produced a range of inconsistent vocal qualities throughout any one vocal sample. Indeed, the listener-judge response suggests that variation within any one vocal sample may be a key reason why listener-judge unreliability is particularly common, as noted by Vurma and Ross (2002) and Wapnick and Ekholm (1997), when vocal tone quality is rated.

On the whole, the listener-judge perceptual findings demonstrate that although the moderation of extremely fast, extremely slow or extremely irregular vibrato rates may be registered by listener-judges as an improvement in tone quality, those singers displaying more subtle changes in the vibrato signal are less likely to be noted as displaying a change in vocal quality. This latter category of singers is likely, irrespective of any change in experimental conditions, to receive high or low ratings according to their overall level of training. For study 1 in which both students and professional singers were assessed, listener-judge ratings reflected singer level with a fair degree of accuracy, apart from the ratings for one singer who registered particularly marked post-intervention improvement both acoustically and in listener-judge ratings.

As change in vibrato characteristics impinges on tone colour (Bartholomew, 1937; Miller, 1977; Robison et al., 1994), yet a reliable means of perceptually assessing subtle vocal change under research conditions is lacking, it is important that researchers have an objective measure by which change can be verified and assessed. Thus, the present study has supported the usefulness of acoustic analysis of vibrato in the study of vocal quality and in assessing the merit of different techniques singers use.
6.4 Limitations of the studies

In these studies, judgement of the singer’s true state of warm-up was based solely on singer self-perception. Physiological verification of whether the singer was indeed warmed up before or after any intervention was beyond the scope of this project. Moreover, the physiological correlates of a warmed-up voice are unclear and difficult to determine due to the physically invasive nature of any full investigation.

The use of only female singers in both studies is considered a methodological strength and the numbers in the singer-subject pool for study 1 were comparable to many other singing studies (Barnes, Davis, Oates and Chapman, 2004; Cleveland, Sundberg and Stone, 2001; Kenny and Mitchell, 2006; Thorpe, Cala, Chapman and Davis, 2001). Numbers in the singer-subject pool for study 2 were double again. Nevertheless, it is recommended that these studies be replicated for further verification, in particular using male singers to confirm the findings.

Caution is needed when interpreting the listener-judge perceptual findings of both studies. In an effort to reduce listener-judge fatigue in study 1, not all 36 samples acoustically analysed were presented to listener-judges. Nevertheless, a representative sample of singers was rated from each condition - one sample each representing fast, moderate and slow pre-intervention vibrato rates from conditions A, B and C, their corresponding post-intervention samples plus one repeated pre- and post-intervention sample from each of A, B and C to check for reliability. This gave 24 samples in total. Likewise in an attempt to avoid rater fatigue in study 2, although all samples plus three repeated pre- and post-intervention samples to check for reliability were played, giving 30 samples in total, listener-judge sample length was shortened from 8 to 5½ bars. However, the shortened samples still displayed the full vocal range covered in the complete 8 bar solo.

Furthermore, it must be considered that in these studies the research environment differed from a performance venue. Singers heard the pre-recorded accompaniment over headphones as this assured that tempo and pitch references were identical for all singers and only the singer’s voice was recorded for analysis. A microphone mounted on a head boom 7 cm from the singers’ lips had the advantage that it removed any effect of room reflections. However, the resultant perceptual recording, while benefitting acoustic analysis, lacked the sound quality of a voice recorded in a concert hall or
theatre, and sounded more similar to an unaccompanied voice heard while standing directly next to the singer in a teaching studio.

Even the singers sometimes expressed reservations about recording in a research environment that was so foreign to a genuine performance. Many remarked that although performance anxiety was minimal, in a genuine performance before an audience that would not be the case. As stress influences vibrato quality, it follows that in a genuine performance many singers may have shown a much greater need for - and a greater benefit from - strategies that rein in unruly vibrato. Unfortunately, while breathing imagery and warm-up are recommended in the management of performance anxiety (Langeheine, 2004; Mornell, 2002; Roland, 1994), the effect of these practices on performance anxiety indicators in the vibrato signal remains largely speculative, as so few singers registered performance anxiety in these studies.

6.5 Future directions

Although this body of work employed acoustic and perceptual methods of investigation, it is recommended that future studies of warm-up consider whether physiological verification of the singer’s warm-up state is also possible. This may be difficult due to the physiologically intrusive nature of such enquiry. Nevertheless, with the use of endoscopy and image analysis software, the question of whether the pyriform sinuses, the valleculae and sinus of Morgagni undergo physiological adjustments as a result of vocal warm-up exercises or imagery warrants investigation in future studies.

A major challenge which future studies must undertake remains the question of how to obtain reliable listener-judge perceptual ratings of tone quality under research conditions. Some listener-judges expressed the need for more than eight bars of singing to familiarise themselves with a voice to the point that it could be assessed reliably and consistently. Some commented that judging the tone quality of one bar or less would be easier as so many varied qualities were perceived within the one vocal sample. With time constraints barring thorough familiarity with a voice in most research situations, it is suggested that perhaps only single note samples be presented for paired comparison in future listener-judge perceptual studies. This suggestion is in line with the study of Ekholm et al. (1998) which concluded that reliability is better if there is only a very short segment to assess.
However, if no time constraints existed and listener-judges were to familiarise themselves fully with the singer’s voice, then extended samples in future may benefit from being recorded in both visual and aural formats. Clearly, listener-judges in study 2 relied on many cues other than those rated, when deciding whether a singer was warmed up or not. Although the experienced vocal assessor relies mainly on aural cues, some cues as suggested by listener-judges in study 2, may be visual. For example, spinal alignment, head position or facial expression in the region of the eyes in particular, may play a role in appraising a voice even a split second before a tone is uttered – much the same as a professional tennis player appraises where the ball will land from the opponent’s movement before the ball is hit (Syed, 2010).

In addition, as the literature suggests links between breathing imagery and meditation, which purportedly reduces unwanted stress and promotes muscular equilibrium (Plummer, 1982), and these factors influence vibrato rate (Miller, 1977, 1996; Sundberg, 1987; Titze, 1994; Vennard, 1968), then future studies are needed into other practices making similar claims of stress reduction and muscular equilibrium. For example, Qigong, the Feldenkrais method, Middendorf and Alexander techniques make such claims and are increasingly promoted amongst the music fraternity (Alcantara, 1997; Cheng, 1991; Dayme, 2005; De Graaff, 1994; Hartmann, 2004; Hudson, 2002a, 2002b; Middendorf, 1995; Nelson and Blades-Zeller, 2002; Pryor, 1997; Valentine, 2004). To date, however, acoustic investigation of whether and in what manner these activities influence vibrato rate has not been undertaken.

6.6 Conclusion

Singers may be the Olympians of the vocal folds, yet the strong research base into warm-up and imagery as practised by athletes stands in stark contrast to the limited research to date into similar practices used by singers. This thesis is an attempt to fill that void.

The acoustic effect of warm-up and imagery on singers’ vibrato, and the perceptual significance for both singers and listeners was investigated. Distinct patterns of response were identified. Following vocal warm-up and also following breathing imagery as mentioned in pedagogical literature, vibrato rates for all singers became more regular, compact and moderate. This was not the case after a non-imagery task
and after an imagery task not traditionally found in pedagogical literature. Listener-judges showed considerable intra- and inter-rater unreliability, although generally listener-judges assessed those singers with initially the fastest, the slowest or the most irregular vibrato rates as improving in tone quality after the vocal warm-up and breathing imagery tasks. All singer-subjects reported the sensation of having warmed up not only after the vocal warm-up task but also after the non-vocal breathing imagery.

These findings support the use of vibrato analysis in the investigation of pedagogical practices. Furthermore, they show that both imagery and vocal warm-up may produce measurable acoustic change. The findings indicate that the regulation of vibrato, which impacts on tone quality, is central to the singer’s use of both directional breathing imagery and vocal warm-up.

The history of singing teaching has sometimes been described as a history of conflict as to which approaches are most successful in developing the vocal capabilities of the singer. This thesis has explored two different pre-performance practices - breathing imagery and vocal warm-up – both of which have a long tradition in the discipline of singing. The thesis has found that each has a legitimate place alongside the many approaches used within the singing profession, each contributes to maintaining consistency in the vocal signal, and each ultimately influences performance outcome.
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