BODY MOVEMENT AND SOUND INTENSITY IN WESTERN CONTEMPORARY POPULAR SINGING

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… I was just a boy and they put me to working right alongside the men … Every man would be hollering … You might call them blues, but they was just made-up things … So you holler it. Sing it."

Howlin' Wolf, The Blue Line, p 496

But just because a record has a groove
Don't make it in the groove
But you can tell right away at the letter "A"
When the people start to move.

Sir Duke, Stevie Wonder

This way of life is so devised to snuff out the mind that moves
Moving with grace the men despise,
and women have learned to lose.
Throw off your shame or be a slave to the system.

The Sky is a Landfill, Jeff Buckley

PREFACE

In completing this thesis I, with appropriate supervisory support, conducted the literature review; designed the four studies presented in this thesis; prepared the ethics applications; collected, managed and analysed data; and presented the findings in thesis and journal article format (3 international, peer-reviewed journal articles).

One study in this thesis has been published in the international peer-reviewed journal *Musicae Scientiae*, another is currently in press with the same journal and a third has been accepted by the international peer-reviewed *Journal of New Music Research.* These papers are listed below:

- Turner, G. & Kenny, D. T. (2010). A preliminary investigation into the association between body movement patterns and dynamic variation in western contemporary popular singing. *Musicae Scientiae*, 14, 1, 143-164.

- Turner, G. & Kenny, D. T. (in press, 2011). Restraint of body movement potentially reduces peak SPL in western contemporary popular singing. *Musicae Scientiae*. SAGE Journals Online.

- Turner, G. & Kenny, D. T. (in press, Dec 2011). Voluntary restraint of body movement potentially reduces overall SPL without reducing SPL range in western contemporary popular singing. *Journal of New Music Research.*

Papers presenting the findings from this research have been given at two international conferences - the inaugural *International Conference on Music Communication Science* (ICOMCS) at the University of New South Wales in Sydney in 2007 and *The Second International Conference of Students of Systematic Musicology* (SysMus09) in Gent, Belgium in 2009 - and one national conference, *28th National Conference of the Musicological Society of Australia,* at the Sydney Conservatorium of Music in 2005. These conference papers are listed below.

- Turner, G., Kenny, D.T. (2009). The acoustic consequences of movement restraint on six professional western contemporary popular singers. *Proceedings of the 2nd International Conference of Students of Systematic Musicology*, Ghent, Belgium, November 18-20, 2009.

- Turner, G., Kenny, D.T. (2007). The relationship between sound pressure level and spontaneous body behaviour in western contemporary popular singing. *The inaugural International Conference on Music Communication Science* 5-7 December 2007, Sydney, Australia.

- Turner, G., Kenny, D.T., Alison, J. (2005). The relationship between spontaneous physical movements and vocal intensity in western contemporary popular singing styles. *28th National Conference of the Musicological Society of Australia,* 28 September – 1 October, Sydney, Australia.

The two in print papers and one abstract from the proceedings of these conferences are presented in Appendix A.

Declaration of Authenticity

I hereby declare that this thesis is my original work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person, except where due reference is made in the text. I have not submitted this material, either in full or in part, for the award of any other degree at the University of Sydney or any other educational institution. Any contribution of other people to my research has been acknowledged explicitly in the thesis.

This study project was approved by The University of Sydney Human Ethics Committee. The study followed all rules and regulations governing the conduct of clinical research involving humans.

SUPERVISOR'S CERTIFICATION

I certify the thesis of Gemma Turner entitled: *Body movement and sound intensity in western contemporary popular singing* to be suitable for examination.

Signed: Professor Dianna Kenny

Date: 18th April 2011

ABSTRACT

In western contemporary popular (WCP) singing, body movement is integral to stage performance. However, singers are often directed to stand still during recording sessions or in theatre productions, although no assessment has, prior to this thesis, been undertaken to determine whether singers produce the same sound levels under conditions of voluntary movement restraint. The way in which respiration, phonation and articulation, the physiological means by which singers control vocal sound intensity, interact with movement are not well understood.

This thesis explored the nexus between body movement, sound intensity and voice production in the practice of professional (WCP) singers. WCP singing, due to its highly idiosyncratic nature, presented particular issues and difficulties, not least in how to study it empirically while maintaining ecological validity from a practitioner and musicological perspective. This called for novel methods of observation, and a multidisciplinary perspective, drawing on musicology, physiology, biomechanics, acoustics, neurology and psychology.

The principal research questions addressed in the three major papers of this thesis were:

1. Are there specific body movements associated with vocal intensity variation in WCP singing?

2. What are the effects of voluntary body movement restraint in WCP singers on vocal peak intensity?

3. What are the effects of voluntary body movement restraint in WCP singers on overall vocal intensity and vocal range?

4. Is there an association between the laryngeal mechanism used, vocal style and body movement behaviour?

The initial question explored the means by which intensity variation in singing is physiologically controlled and whether it was associated with specific patterns of body movement employed by WCP singers. Study 1 investigated body movement patterns in six professional WCP singers during an R & B song, cross-referencing 3-D video footage and intensity measurements of their singing. The most common pattern was a

backwards torso movement that reached its maximum at the same time as the point of highest intensity (labelled the peak note), measured in decibels to yield a sound pressure level (SPL). This indicated that this movement, which has not been noted previously, may have a function in intensity control in these singers. The results of Study 1 indicated that more detailed acoustic analysis of the sound emitted by WCP singers in different movement conditions at the peak note point was warranted. Study 2 aimed to test the link between body behaviour and vocal intensity further by assessing whether voluntary restraint of body movement by WCP singers would reduce SPL at the peak note. The six professional WCP singers sang a section of a song in two performance modes: first, with the directive to perform as they normally would on a stage and then as if directed to stand still during their performance while a spotlight was on them. There was a reduction in SPL on the singers' peak note that was both statistically and acoustically significant in the 'no movement' condition. This suggested that restraint of movement was associated with reduced peaks in SPL. Possible reasons for the reduction proposed in this study included the inhibition of respiratory mechanisms for subglottal pressure production and interference with sensorimotor feedback mechanisms such as the autophonic response.

Given the effect of body movement restraint on peak SPL, the question arose as to why this effect had not been previously observed. What factors might be responsible both for the effect and its acoustic outcome? Further, did the effect pertain to the whole of the SPL output or was it just observed with respect to the peak intensity? Paper 3 addressed these questions by exploring the overall effects of movement restraint on SPL levels but also on the SPL range in a longer song sample. The calculation of percentiles revealed reductions in SPL in the no movement condition across all SPL levels for all singers. With respect to absolute range, contrary to expectation, the SPL minima were reduced by a degree equivalent to the reduction in SPL maxima in the majority of singers. To our knowledge, this phenomenon has not been noted previously, possibly because this compensatory effect disguised the overall reduction in SPL. This phenomenon may arise as a means whereby singers can maintain the dynamic range and therefore the expressive impact of their performance. Considering the slowness of hearing as a voluntary feedback mechanism and the fact that the SPL of one's own voice is regulated on a multisensory level via the autophonic response, it is likely that this effect is automatic and beyond the conscious control of singers. It remains to be studied whether this effect exists in other styles of singing and what aspect of movement restraint triggers this effect.

Finally, in a fourth study, three expert judges from different singing genres were asked to perceptually judge which laryngeal mechanism the six singers were using. The findings, although inconclusive, indicated that the perceived use of laryngeal mechanism may vary depending on the genre of popular music and the musical background of the judges.

These results have immediate practical implications for those working with singers in voice research, professional music recording and on stage in that verbal directions to curb body movement may have detrimental effects on acoustic output that may be insurmountable even in very experienced singers. It remains for future researchers and more highly controlled studies to explain the mechanisms behind these interesting phenomena.

Acknowledgements

I would like to express my deepest gratitude to Professor Dianna Kenny whose rigorous standards, unrelenting work ethic and firm but kind guidance supported me through extremely difficult times to completion. Without her professional and experienced supervision and statistical expertise, this thesis and the related journal publications would not have been completed.

I would also like to express my gratitude to other supervisors at various stages of my long candidature, A/Professor Pamela Davis, Dr. William Thorpe, A/Professor Jack Crosbie and, in particular, A/Professor Jenny Alison who helped me with the design of the initial movement study. I would also like to thank Dr Sally Collyer and A/Professor Simon Carlile who have been associate supervisors during this time.

I sincerely thank Professor Jack Crosbie for his continued professional advice and discussion concerning my movement study. There are many others whose professional advice was invaluable considering the wide-ranging nature of my research, Dr Helen Mitchell, Professor Joe Wolfe, Dr Densil Cabrera, Dr Maeva Garnier, Dr Sam Ferguson, Beth Willis, Tracey Bourne as well as the rest of my fellow postgraduate research students who kept this topic alive for me through discussion, good humour and collegiate and helpful attitude.

I sincerely thank the lively and talented group of singers who participated in this study. Without their generosity and curiosity about their art, my study would never have been possible. I would also like to thank Linda Marr and Dr Helen Mitchell for participating in my pilot study.

Special thanks go also to Peter Thomas whose intelligent and wide-ranging technical advice went well beyond his title of IT Facilities Manager.

Thanks also to world music broadcaster Jaslyn Hall for giving me access to her video collection at the beginning of my research.

Finally, I would like to thank my partner, Mark, and my son, Connor, for their loving support over the years of my research.

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List of abbreviations

AP	Antero-posterior
C4	Middle C in note plus octave name convention in which the note below is B3
dB	Decibel
df	Degrees of freedom
EMG	Electromyography
f.p.s.	frames per second
F0	Fundamental frequency
Hz	Hertz
JND	Just noticeable difference
M	Movement condition
m/sec	Millisecond
NM	Non-movement condition
PRAAT	Speech analysis software
Ps	Subglottal pressure
R & B	Rhythm and blues
SD	Standard deviation
SPL	Sound pressure level
WCP	Western contemporary popular

LIST OF PUBLICATIONS

Paper 1: Turner, G., Kenny, D.T. (2010). A preliminary investigation into the association between body movement patterns and dynamic variation in western contemporary popular singing. *Musicae Scientiae*, 14 (1), 143-164

Paper 2: Turner, G., Kenny, D.T. (in press). Restraint of body movement potentially reduces peak SPL in western contemporary popular singing. *Musicae Scientiae*

Paper 3: Turner, G., Kenny, D.T. (accepted with revisions). Restraint of body movement potentially reduces peak SPL in western contemporary popular singing. *Journal of New Music Research*

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Paper 5: Turner, G., Kenny, D.T. (2007). The relationship between sound pressure level and spontaneous body behaviour in western contemporary popular singing. *The inaugural International Conference on Music Communication Science* 5-7 December, Sydney, Australia

CHAPTER 1: INTRODUCTION

1.1 The nexus between body behaviour and vocal sound quality

1.1.1 Motivations for research

1.1.1.1 Ergonomic efficiency

I became interested in the interaction of body and voice while I was working for the Dutch Ergonomic Society in Amsterdam in the mid-1980s. By co-incidence this occurred at the time when I was deciding to make a career of singing in the area of contemporary and "world" musics. Ergonomics alerted me to the concept of movement efficiency and health, and subsequently to the role of posturing and movement as a tool for singing efficiency. This awareness grew alongside my developing singing skills and was very important since I was going through this process largely without the guidance of a teacher.

1.1.1.2 Rhythmic body movement

I was intrigued, as were my singing students, as to the reason why we were more easily able to sing strongly without vocal strain when using large, rhythmic body movements than when standing still. I originally experienced this during an exercise involving an imitation of a worksong used as a device to elicit "belt" voice in a workshop by the English folk singer Frankie Armstrong in 1986. I was startled by its effectiveness then, as are my students now when they realize that the optimizing effect disappears or reduces dramatically when they stop moving. Since my first encounter with this technique of using rhythmic body movement to optimize the singing voice, I have been curious to find out what mechanisms were at work behind it.

It has also been my experience that body movement in singing is linked to many other musical elements in addition to rhythm. Movement during the expression of emotion as well as for interactions with band and audience are obvious to most observers. However, I have also observed movement patterns in association with variations in pitch, dynamics and timbre, noting that these movements can have positive or negative effects depending on the musical style and context and what the singer is trying to achieve. My experience led me to the observation that some body movements seemed to allow advantageous physical processes to come into play to which I did not have conscious access and that they could be used to allow me to sing better and with more ease.

1.1.1.3 Effort

While recording a CD in 1994 ("On our way [Haza is kéne már menni]," 1994) I had another experience that reinforced the idea that increased body movement increased vocal ease. On one track, I had to sing while playing percussion with the heavy instrument hung around my shoulders. My body needed to be stationary in order to keep my mouth in line with the vocal microphone while my arms had to move vigorously while keeping the instrument in precise alignment with another microphone. It was a very awkward and physically difficult process. When I listened to all the tracks played back, I was surprised to find that this was the track on which I and other band members thought I sang best of all the tracks on the CD. I was surprised at the better result, which occurred without any awareness on my part. Surely, I thought, the extra physical effort needed to play the percussion instrument should have impeded the performance rather than enhance it. Later, I became aware of the pedagogical method of Jo Estill (Estill, 1996) and later Alison Bagnall (Bagnall & McCulloch, 2005), which placed emphasis on muscular effort as opposed to the relaxation suggested by most Western classical singing pedagogues (Monahan, 1978; Burgin, 1973). My own experience seemed to indicate that they were right, at least in the non-classical field in which I was working.

1.1.1.4 Learning music of other cultures

Finally, I became strongly aware through researching, performing and recording the songs of many cultures over a fifteen year period ("Blindman's Holiday: Traditional Vocal Music," 1989; Holiday, 1992, 1997) that some of the differences in sound colour produced in different singing cultures was due to physical factors such as body stance, degree and quality of movement, and head and neck configurations in addition to the favoured face and mouth shapes that were more obviously related to language differences. I found it easier to achieve these sound differences if I were able to watch singers and adopt their body behaviour rather than by modelling auditory information alone. Observing how different cultures learn and "do" music taught me about different approaches to musical practice. This led to greater understanding and better practice and provided me with principles that had immediate application in other musical paradigms.

Learning to play the music of other cultures illuminates the musical process. This phenomenon has been noted by ethnomusicologists who learn to play the music they are studying as part of their research method (Baily, 1985). Similarly, learning to play an instrument from a different culture requires attention to the accurate reproduction of the "body postures and movements that are usually used in its performance" (p. 242).

It is likely then that body behaviour is also important in learning to play music of one's own culture but that we are less conscious of this as part of the process in the same way that one is less aware of the workings of one's native language than of another language learnt later in life. For example, most contemporary popular singers are not subject to constraints and can move freely and idiosyncratically if they wish. Opera singers, on the other hand, who are playing particular roles must learn to control their urges to move spontaneously, as do music theatre singers, because of the constraints of stage blocking and direction. I perceived this constraint as having an impact on sound quality differences between styles and the way singers were able to achieve them. I wanted to know if that perceived difference in sound quality when body behaviour changed was measurable. It was with these personal observations in mind that I began to hone in on the subject of this thesis, to explore the nexus between body behaviour and vocal sound quality.

1.1.2 Preliminary observation of singing performances

1.1.2.1 Movement patterns related to style

For the past 20 years, I have systematically observed the body behaviour of singers in a range of contexts and styles, those in urban and remote regions of Australia, the Asia-Pacific region and in Europe. In Australia, this included the observation of traditional indigenous singing in the East Kimberley of Western Australia and collaboration with linguist Mark Richards on musical aspects of an applied linguistics program with the Mangarayi community in the Northern Territory that combined singing with language teaching (Richards, 1992). I also collected, with Mark Richards and Sally Corry (1993), recordings of vocal music from villages in the remote mountainous region of Gyimes in Romania.

I made notes on singing performances I had observed and added a small collection of videos of singers from ethnically diverse backgrounds. I used the terms "heavy mechanism" or "light mechanism" (Svec, Schutte & Miller, 1999) as a simple way to describe the general voice use patterns of the singers. Because so little research has been done on movement and singing, it seemed that the range of possible movements to observe would be too large to analyse within the confines of this thesis. In my initial informal observations, I hoped to narrow the focus of the types of movements observed to movements that related most closely to voice production rather than the communicative function of singing. I also hoped to narrow the focus onto musical aspects that were associated most closely to body movement. My own experience indicated that sound intensity would be the acoustic parameter most closely associated with body movement. I chose an ethnically wide range of singers to observe, hypothesizing that movement behaviours that appeared across cultures were those most likely to be fundamental and functional in relation to voice production rather than culturally or individually idiosyncratic movements. A similar but much more rigorous approach has since been adopted formally by some researchers and is known as the 'two-culture model', which is employed to identify universals in human behaviour (Sauter, Eisner, Ekman & Scott, 2010; Tracy & Robins, 2008).

A commercially available source that I used for this was the video "One World, One Voice" (Godley, 1993) featuring performances by a wide range of artists singing in a wide range traditional and contemporary styles from Africa, Europe, North and South America and Asia. Artists of particular note for this analysis who were observed in live performance include Zap Mama (Belgium), Ladysmith Black Mambazo (South Africa), Yungchen Llamo (Tibet), Nusrat Fateh Ali Khan (Pakistan), Yothu Yindi (Australia).

1.1.2.2 Body movement behaviour observed

Only movements that occurred during vocalization are noted here.

1. Repetitive rhythmic movement synchronized to musical beat

- hand-clapping
- foot tapping
- stepping pattern with bounce at the knees
- precise lateral movements of the head (isolations)
- swaying from side-to-side

2. Movements that was associated with the beginning or end of phrases and stressed syllables of lyrics

- head forward swoop
- jerking of hands downwards e.g. Nusrat Fateh Ali Kahn only
- bending of knees
- raising of the head higher than usual then bringing it down on emphasized beat
- arms raised (supplicating gesture) with jerk on beginning of phrase
- forward bending body movements (crunch)

3. Isolated movements which coincided with sudden increase in pitch

- back/upward move of head with or without wincing facial expression
- shoulder jerk downwards

4. Isolated movements which coincided with sudden increases in intensity level

- shoulder jerk downwards
- shudder (shoulder/neck). This was less common and was only observed in flamenco and West African singing

5. Stillness

- static posture

This occurred during:

- melismatic singing
- quiet passages
- all singing by some singers with light mechanism voices

1.1.1.3 Performances with lead and backing vocalists

In the performances I observed, choreographed rhythmic dance movements were only performed by vocalists who were accompanying or "backing" a lead vocalist. Lead vocalists were allowed to move freely and their movements had the appearance of being spontaneous and idiosyncratic and related to the lyrics. An example of this was Ladysmith Black Mambazo, whose lead vocalist Joseph Shabalala, would move around the stage with a handheld microphone using a wide range of movements, including many varied hand gestures that synchronized with word emphasis or demarcated the onset of phrases, all while singing long and complex vocal lines. His movements varied with each verse and seemed to be improvised. Meanwhile the other six singers performed precisely synchronized, choreographed athletic dance movements while singing shorter, more repetitive phrases that were focused on harmonic and rhythmic elements. Prior to this observation I had thought this pattern of the freely moving solo lead vocalist with choreographed backing vocalists was only a phenomenon of western contemporary popular music. Since observing this, I realized that this is common pattern in many cultures, which indicated a possible underlying cultural or physiological universal principle at work.

1.1.2.4 Lead or solo singer movements

The movement patterns were associated with variations in dynamics, pitch, rhythm, phrasing and melisma. The only movements that were not associated with these musical characteristics were the hand gestures of lead singers that were quite idiosyncratic and seemed to relate more strongly to communication. Actions 3-5 (listed above), which were associated with pitch, intensity and melisma, did not seem to be interchangeable and occurred repeatedly at the point described whereas actions 1 and 2, which were associated with rhythm, lyrics and phrasing were more variable and singers seemed to be able to have more freedom in the application of these movements implying that they were not associated with voice production. For example, the same singer who moved rhythmically most of the time would often stand still while singing melismas or a high note. My perception was that larger body movements coincided more often with heavy mechanism voice production e.g. Marie Daulne of Zap Mama when singing a reggae song, and stillness most often coincided with light mechanism voices e.g. Yungchen Llamo, Suzanne Vega.

An exception to the usual body/voice patterns was the now deceased, great singer of Sufi devotional music, Nusrat Fateh Ali Khan whose voice was both powerful and melismatic. His performances were in many ways different to the other singers, an important point being that he performed sitting down cross-legged so that his lower body was stationary. Like many other singers, however, he used strong arm/hand gestures on accented beats. He was also the only singer I observed who was not only famous internationally but considered to be "great" (Van Fleck, 2001). His ability to achieve elaborate melisma in a heavy mechanism voice may have been an indicator of his exceptional skill rather than indicating widespread or universal singer behaviour.

1.1.3 Choosing an acoustic parameter: Intensity

These preliminary observations indicated that my initial perception that acoustic phenomena might be associated with certain types of body movement seemed to be worth investigating further. The next step was to decide which of these acoustic elements to investigate. I was interested in one that would provide value-neutral empirically measurable information that could be clearly linked to voice function and in particular how this would relate to the singers' own experience of the process of singing.

The WCP music world places a high value on the excitement generated in an audience by the singer who produces a powerful sound. High sound intensity is an important part of the acoustic expression of emotion in both speech and singing, particularly of the strong emotions such as anger and happiness (Kotlyar & Morozov, 1976; Scherer, 1995) and lower levels conveying sadness (Sundberg, Iwarsson & Hagegård, 1995), fear or neutral emotional states (Kotlyar & Morozov, 1976). The variation of intensity levels is one of the main acoustic cues used by listeners to gauge emotional states, the other two variables being F0 (pitch) and sound spectrum (timbre) (Scherer & Oshinsky, 1977). The speed of variation is also important with faster variations conveying stronger emotions (Sundberg et al., 1995) or cueing the perception of certain emotions such as sadness (Kotlyar & Morozov, 1976) in the listener.

Short-term variability in sound pressure level (SPL) is also important to the expressiveness of speech and singing (Sundberg, Elliot, Gramming & Nord, 1993). The perceived emphasis in words (otherwise described as 'accent' in music and 'stress' in speech) is attributed to a combination of duration, fundamental frequency (F0), sound pressure levels (SPL), the vowel chosen and spectral balance (Sluijter, vanHeuven & Pacilly, 1997).

However, unlike spontaneous speech, in singing, the melody and lyrics largely dictate the fundamental frequency (pitch), vowel and duration characteristics. This leaves SPL and spectral balance (timbre) as the main variables that allow singers to express themselves. Both intensity and spectral balance can be recorded relatively easily without engaging in invasive procedures that could alter the behaviour of singers, allowing them to behave normally and with less self-consciousness. However, spectral balance is complex to interpret as it inevitably raises the issues of taste and style that are not directly quantifiable. By comparison, intensity is a simpler measure to interpret and there are many precedents for its use.

1.2 Music culture, body and voice production

In the following pages, I outline a large number of factors from the musicological and empirical literature that are relevant to the inter-relationship between musical style, intensity variation in voice production and body movement. Questions related to some of these factors are investigated in the empirical studies in this thesis. These are:

1. What are the movements that singers use in performance and how are these movements associated with intensity variations?

2. Does reduction of body movement affect intensity regulation within the vocal system and are those impacts acoustically and statistically significant?

3. Whether laryngeal mechanism differences vary according to style and intensity and can be perceived by expert listeners.

Others factors are discussed here for their importance with respect to understanding the complex inter-play between the multitudes of factors that influence movement production, voice production, and the effect of movement on vocal production. This required the marshalling of information of a wide-ranging and interdisciplinary nature, some of which to my knowledge has not been drawn into discussions of singing function before. These will be revisited in Chapter 6 in light of the findings from the four studies presented in this thesis.

1.2.1 Music as the end-product of movement

Body movement is essential to the creation of music (Baily, 1985; Dahl & Friberg, 2007). Despite this obvious fact, Baily identified a quarter of a century ago that, in the Western approach to the analysis of music, the motor control of music performance has been neglected or treated as "ultimately irrelevant" (Baily, 1985, p.238). This narrowed the study of music performance to the study of 'disembodied sound', reduced to the measurement of sine waves and the analysis of musical structures (Baily, 1985). Blacking (Rogers & Symons, 2005) observed that all the means by which musical sound is produced should be identified if music is to be understood fully (Baily, 1985).

Since these opinions were expressed, progress has been made in this arena. Gradual shifts in approach have been made that includes movement as an integral component to music research. This has been due, in part to the trend to inter- and multi-disciplinary music research such as that promoted under the discipline of systematic musicology (Honing, 2006; Cross, 2003) and partly to the advent of new technologies that allow movement and other physiological aspects of music performance to be studied quantitatively, such as in the studies of clarinettists' movements by Wanderley (Wanderley, 2002; Wanderley, Vines, Middleton, McKay & Hatch, 2005).

For singers, their body is their instrument. A Boolean Google search using the exact phrase "your body is your instrument" with variations on the word 'sing' 'singer' or 'singing' retrieved 29,100 web-pages, mostly from singing instruction websites. Despite this widespread and implicit understanding of the importance of the whole body to the production of a well-produced vocal sound, classical singing teaching, the dominant pedagogical method within the European tradition, has often not fully exploited a bodily approach to voice (Hudson, 2002). Research on the singing voice has acknowledged the importance of posture, primarily of the head and neck, in voice production (Wilson Arboleda & Frederick, 2006). Classical singing pedagogues have been divided on how or even whether to teach posture as part of technique (Burgin, 1973) but have tended to teach posture in terms of correct body positions (Burgin, 1973; Monahan, 1978) which can lead to the perception of posture as a static and invariable element: for example, in the often advocated 'noble posture' the same body position is maintained with no regard for whether the singer is in the inspiratory or expiratory phase of the breath cycle, a practice that can lead to rigidity in the body and thereby to inferior vocal results (Hudson, 2002; Li-de, 1995). Practices such as the Alexander technique advocated by Hudson, emphasize kinaesthetic awareness. Hudson laments the tendency of classical singers to 'remain relatively uneducated in the field of kinaesthetically developed body use' (Hudson, 2002, p.105).

1.2.2 Why study western contemporary popular singing?

It is widely recognized that most western contemporary popular (WCP) singers use high levels of movement in performance; not to do so in this style would be regarded as unusual or inappropriate (Meizel, 2009). Given that popular singing generates so much revenue, it is surprising that so little research has been conducted into this aspect of its performance. Consequently, little is understood with respect to how WCP performance practices affect voice function (Wilson, 2003). Australian contemporary singing pedagogue Pat Wilson has described the majority of working WCP singers as under-valued and undertrained with few teachers willing or knowledgeable enough to assist them. Sadly, such voices are often considered to be an expendable commodity by the music industry (Wilson, 2003). Young singers' voices are often pushed harder than they should be because the industry is aware that there is a ready supply of eager successors in the wings if they falter (Wilson, 2003). Wilson proposes more scientific research into the special physical demands of WCP singing so more assistance can be given to its practitioners. A lack of knowledge of vocal function and informed professional help for singers in this field has been attributed to their low socio-economic status (Gilman, Merati, Klein, Hapner & Johns, 2009). In my own experience as a singer and singing teacher, I have observed this to be true and that young artists are more likely to survive such pressures if they are clear about what their voices can do and learn to state clearly and authoritatively what the reasonable limits of the voice are. However, until the special demands placed on non-classical singers are fully understood, that authority can be difficult to summon and currently can only be gained by most singers through hard personal experience.

In addition to these environmental factors, there are risks inherent in the WCP singing culture. Most singers are self-taught and intuitive (Gilman et al., 2009) in their approach. There is a high value placed on individuality of style (Dibben, 2009) and what is widely described as *authenticity* in WCP music performance (Moore, 2002). Moore has defined several levels of the experience of authenticity but in the context of this thesis, I am most interested in his definition of *first person authenticity*, that is, the ability to communicate one's emotions to an audience directly and with integrity. This affects singing practice in that WCP singers are inclined to push themselves very hard to express emotion vocally in a way that may put vocal health at risk in a way more akin to an actor (Ryker, Roy & Bless, 1998) than to a classical singer. Further, in a tradition going back to jazz (Mackey, 2008) and gospel (Heilbut, 1985), creativity and spontaneity are highly valued and used to demonstrate musical prowess (Mackey, 2008) as shown by a singer's ability to improvise, write their own songs or to sing the songs of others in new and imaginative ways (Bowles, 1999; Potter, 2000b). The advantage of this adventurousness is that exciting new sounds can emerge and an enormous variety of vocal devices and timbres can be heard (Wilson, 2003; Hollien, 1983). The disadvantage is that this sometimes leads to injury and a promising career is cut short due to lack of good advice and support (Gilman et al., 2009; Wilson, 2003). The need for specifically tailored and systematized training for non-classical singers has been flagged for a long time (Hollien, 1983). It is a rare and relatively new phenomenon and acceptance of it within the world of singing pedagogy even newer (Lovetri, 2009; Gilman et al., 2009). As a result of its rarity, non-classical singers who feel the need of guidance will sometimes resort to attending singing lessons with teachers who have been trained within the western classical tradition in the hope that the techniques learned will be transferable to contemporary styles (Lovetri, 2009; Wilson, 2003). However, if, for example, a singer attempts to adopt body behaviour along the lines of the 'noble posture', they may find it difficult to move around the stage in the manner required for WCP music. Similarly, a self-taught singer who moves freely in performance may find it difficult to sing standing still when working in a recording studio. We do not know how these changes of body behaviour alter the sounds emitted by the singers or whether the act of moving while singing confers vocal advantage to the performer. Optimum singing practice while moving has not been studied empirically, and this is the focus of the body of work presented in this thesis.

The spatial configuration of any musical instrument in relation to the performer's body, influences the characteristics of music performance (Rogers & Symons, 2005)] and this principle also applies to vocal performance (Dibben, 2009). Baily (Baily, 1985) has suggested that the success of the particular spatiomotor behaviour used in music performance can be judged by the sonic results produced. This principle was applied in this thesis. The transfer of such a principle to singing was complicated by the fact that the instrument is also the singer's body and many aspects of the vocal instrument are not visible externally. This required a thorough understanding of the physiology of singing before this analysis could be undertaken. A major challenge facing researchers wishing to explore the relationship between the acoustic and spatiomotor elements in Western contemporary popular singing is to find an ecologically valid method for this analysis.

1.2.3 The historical and cultural origins of the integration of movement and in singing in western contemporary popular music

Neurologist Oliver Sachs has described the special nature of the rhythmic synchronization of singing with body movement. He recounts his use of singing with rhythmic movement when climbing down a mountain after sustaining a serious injury. He credits it with increasing his movement speed and stamina such that he was able to remove himself to safety in time to avoid death by hypothermia (Sacks, 1991, 2007). Likewise, the combination of rhythmic physical labour with singing, in the worksong, has been traditionally used the world over (Chalmers & Latham 2002) in pre-industrial cultures and are still practised in most parts of the world where outdoor, physical labour is the norm for the majority of people. The continent of Africa is one region where the worksong is still widely employed not only to entertain, but to allow the use of less force in physical labour, making for less fatigue (Smith, 1999). Dance-like body movement is apparent in many kinds of music playing originating in Africa, the conceptual link between dance and music being so strong that the word for music is inclusive of dance in some African languages (Baily, 1985). The historical lineage of western contemporary popular (WCP) music from its West African to African-American source is clear (Mosher, 2008; Nelson, 1999b; Headlam, 2002; Middleton, 2000) and its influence extends from ragtime, jazz and music theatre to rock, R & B and rap (Mackey, 2008; Potter, 2000a; Potter, 2000b; Banfield, 2000; Cooper, 1996). Bowles writes of the chain-gang songs of slaves and later convicts of in the US: "Rhythmic shouts and percussive beats combined to synchronize and empower hard, tedious labour" (Bowles, 1999). Chain-gang songs and the field holler, a type of improvised solo work song with or without words (Sackheim, 1969) were integral to the development of the most influential original African-American music forms, blues and gospel, making the worksong one of the most important ancestors of WCP music (Headlam, 2002). As in worksongs, in gospel, music, song and movement are closely linked, although for a religious purpose. In the African-American tradition, physicality in singing is exemplified by the traditional gospel 'shout'. The 'shout', which originated from West African ecstatic religious practice (Mosher, 2008), incorporated both dance and song, and was believed to be inspired by spirits (Heilbut, 1985). Originally, this was enacted by a group of people together in a circle but later became an individual form of expression that could take on any physical or vocal manifestation from walking to laughing to singing (Heilbut, 1985). Thus, the linking of WCP singing to body movement could be said to have its origins in lightening the load of hard physical labour, providing a diversion from pain, a balm for the soul and a form of entertainment. For these reasons, I am particularly interested in the origins of WCP singing in to the worksong. The existence of the worksong throughout the world and its linking of music to actions implies a physical function as well as a cultural one for this song form. Could worksongs have been employed consciously or unconsciously to trigger abdominal muscle support of the back during hard manual labour in the same way that a modern athlete consciously employs core body strength (Norris, 1997)? In addition, could this merging of song and body in African-American culture have affected not only the outward stylistic form of singing but also the internal vocal technique? Could the high level of physicality that exists with that tradition help explain the high level of vocal strength and virtuosity (Lovetri, 2002) passed on to its descendants, the so-called divas of WCP music today? Music that comes out of a historical and cultural context where the link between physicality and singing is strong will be likely to produce similar manifestations in newer art forms.

1.2.4 Western contemporary popular singing style

This thesis is concerned with a style of singing that I term western contemporary popular, abbreviated throughout as WCP. That it is a *western* style of popular singing is specified because there are many blocs of popular music styles in the world, some of which are far removed from the styles discussed here in terms of voice technique and timbre. Popular singing in Indian film is a good example of other such styles.

WCP embodies a range of styles that can include all types of rock, blues, Rhythm and Blues (R & B), Gospel, pop, hip hop and American style (Broadway) music theatre. A unifying feature of this diverse range of styles is that they have originated in and have been exported to the world from the Americas, in particular from the United States and particularly feature the influence of African-Americans, as discussed earlier.

There are many features of African musical traditions that travelled to the Americas and form the backbone of WCP music (Paymer, 1993). From its African lineage, WCP singing has inherited core values that emphasize physical and emotional authenticity and musical spontaneity in combination with the mastery of complex rhythm (Nelson, 1999a; Harvey, 1999; Bowles, 1999; Heilbut, 1985). The foundation blues singers whose style heavily influenced WCP vocalizations from Elvis Presley up to the present day (Potter, 2000a) were found "rarely sacrificing emotion to technique" (Brackett & Hoard, 2004). The gospel tradition, on the other hand, is famous for its singers whose technical skills rival those of opera singers (Heilbut, 1985) but still places authentic individual expression and inspiration higher in importance than technique, because its purpose is first and foremost a spiritual practice (Heilbut, 1985).

1.2.5 Musical features of western contemporary popular music

The following are aspects of the WCP music aesthetic that are relevant to the connections between singing and body movement to be discussed in this thesis. They are distinctly different from the musical aspects that are emphasized in the western classical tradition and as such may have considerable effects on how the embodied instrument is configured.

1.2.5.1 Complex rhythmic structures

It has been said that rhythm is to Africa what harmony is to Europe (Bowles, 1999). Rhythm is the 'primary improvisational tool' used in music of African-American origin. This involves several specific features:

a. The use of strict time and "grooves"

In European art music, alterations in tempo are an important expressive tool (Clarke, 1999; Palmer, 1989). Within WCP music, on the other hand, singers are expected to be aware of and keep to the beat and tempo to a much greater degree. This is meant to be internalized accurately but not necessarily sounded (Nelson, 1999b). For WCP singers, this does not mean that expressive timing does not exist but rather that they usually have to work within a much more strictly executed metrical structure. Playing with phrasing and syncopations rather than sitting directly on the beat are a part of a singer's improvisatory repertoire (Paymer, 1993). WCP musical time has become stricter over recent decades with the introduction of amplified instruments in combination with drum kits, click tracks and computerized backings. In addition to precise time, it is expected that there is a physical looseness or comfort within this strict metrical structure that allows for rhythmic tension, release and contrast that is known as "groove" (Harvey, 1999).

b. Polyrhythms and syncopation

There is a large range in the complexity of the layering of rhythms in WCP music from pop rhythms that are simple to highly complex jazz or Latin structures. The timing precision already described allows for this complexity and for syncopation. Syncopation is typified by the shifting of emphasis from a strong beat such as the first beat of a bar to a weak beat or the reducing of emphasis on normally strong beats thereby creating a violation of the expectation of the rhythmic structure (Large, 2000). This element of playing with rhythmic expectations is central to music of African lineage where irregularity is valued over regularity (Bowles, 1999).

1.2.5.2 Songs written without notation

True to its blues and gospel origins, the WCP song is a fluid structure that is usually composed without recourse to notation and performed with many variations (Paymer, 1993). The exceptions to this are music theatre songs and many popular songs, in particular written by professional popular songwriters in the period before rock and roll that have been notated but are also often varied by singers. An example of this would be the many songs that were originally from musicals that have become part of the jazz canon.

1.2.5.3 Improvisation

Jazz singer Billy Holiday was quoted as saying that she "couldn't stand to sing a song straight let alone the same song the same way twice" (Bowles, 1999). Spontaneity and improvisation in all musical aspects of song are a major part of WCP singing. It is a demonstration of individuality and musical mastery (Bowles, 1999). This can range from free interpretations on melodies with minor alterations of phrasing and timing to full-scale improvisations such as those found in jazz. Improvisation is based on implicit rather than explicit knowledge gained through experience and conscious practice but is not consciously recalled during the experience (Mackey, 2008) in the same way that speech is not created through conscious processes (LeDoux, 1998). Just because one is not aware of how the brain is functioning does not mean the brain is not at work (LeDoux, 1998). This lack of conscious awareness of the processes involved in complex tasks such as singing an improvised phrase of a demanding R & B song has created two unfortunate impressions of singers of the genre: first, that theirs is a mysterious and unlearnable skill that must be innate; and second, that it is not as demanding (Banfield, 1999) because it is often not learnt in a conscious, technical fashion during formal training. Partly because these perspectives on WCP singing, it is rarely accorded as high a status as an art form as classical singing.

1.2.5.4 Exploitation of varied vocal timbre

By its nature, contemporary singing does not employ only one method or aim for one aesthetic goal. In WCP singing a wide range of vocal techniques and timbres are used and considered acceptable (Wilson, 2003; Lovetri, 2009) sometimes within the course of one phrase or even one note. The western classical tradition favours a smooth transition between registers (Sundberg, 1987d) [see further explanation of these terms in the section on the larynx] with an audible jump between laryngeal mechanisms being considered a flaw in technique (Svec et al., 1999). By contrast, WCP singers often use register flips or jumps for expressive or dramatic purposes or to create musical contrast (Svec et al., 1999; Hollien, 1983). In combination with improvisation, this also means that vocal timbre may vary as well as pitch, rhythm and intensity. Changes in timbre can also be implied in the way the song is written. For example, high pitch, high intensity and belt voice quality often feature simultaneously at certain points in songs where a high level of drama or excitement is required because the increase in high frequency partials as belt voice quality goes higher generates more excitement. Music theatre songs often feature such points where a belt voice quality may be specified in the score and not be interchangeable with another voice quality (Lovetri, 2009).

1.2.5.5 The use of repetition and call and response

Repetitive devices such as choruses and riffs are usually the preserve of backing vocalists or instrumentalist with improvisatory elements being left for the most part with the lead vocalist. As such this element is not considered in this thesis (Paymer, 1993).

1.2.5.6 The importance of dance

This is a highly important element (Paymer, 1993) which has already been discussed.

1.3 The science of vocal sound level variation

It is necessary to understand the mechanisms, of which there are many, that underlying vocal sound level variation in singing in order to understand how they might relate to body movement. What follows is a brief overview of many of the factors that relate to phonation, vocalization and body movement. Although not all of the issues raised are dealt with directly in the research itself, they are included to better account for the methodology used and the results obtained and to provide direction for future research.

The source-filter theory of voice production is the widely accepted model for how vocal sound is produced and controlled with regard to intensity (sound energy), fundamental frequency (F0) and sound spectrum (Zemlin, 1998). In perceptual or musical terms these equate to loudness or dynamics, pitch and timbre. The source-filter model separates the physiological regions of the vocal instrument into three sub-systems. The first sub-system is power, which is initiated below the vocal folds in the respiratory system. The second sub-system is the source, which resides at the larynx where the vibrating vocal folds act as oscillator. The third is the filter, which is made up of the vocal tract that acts as resonator (Zemlin, 1998). The three sub-systems are also often described respectively as respiratory drive, phonation and articulation (Dromey & Ramig, 1998). Vocal intensity can be altered within each of these sub-systems (Titze, 1988). This three-fold system is involved not only with the overall sound intensity of a sung or spoken phrase but also the smaller and more subtle changes such as those found on stressed syllables within a word or accented musical beats (Newsom Davis & Sears, 1970; Fant, Hertegird & Kruckenberg, 1996).

These sound intensity controlling sub-systems will be described according to their locus within the body as follows:

1. Respiratory system
2. Larynx
3. Vocal Tract

Intensity is a measure of the area of energy flow multiplied by time (Zemlin, 1998). In the literature, sound intensity is used interchangeably with sound pressure level and measured in decibels (dB) (Isshiki, 1964). To avoid confusion between the colloquial use of the term intensity which often refers to emotion, I will use the term sound pressure level (SPL) from this point on.

1.3.1 *Respiratory system and singing: Subglottal pressure and how it is controlled*

Central to the operation of respiratory drive is control of subglottal pressure (Ps). Ps occurs below the vocal folds within the respiratory system and is sometimes referred to as lung pressure (Sundberg, 1987b) or alveolar pressure (Hixon, 1987). It is the main physiological factor affecting intensity in voice with higher pressure corresponding with greater intensity (Leanderson, Sundberg & von Euler, 1987; Sundberg, Titze & Scherer, 1993; Fant, 1982). This is true both in speech (Holmberg, Hillman & Perkell, 1988; Titze, 1988; Titze & Sundberg, 1992; Finnegan, Luschei & Hoffman, 2000; Björkner, Sundberg, Cleveland & Stone, 2005) and singing (Sawashima, Niimi, Horiguchi & Yamaguchi, 1988; Sundberg, Elliot et al., 1993). In speech, intensity increases 8-9 dB in speech per doubling of Ps (Finnegan et al., 2000; Tanaka & Gould, 1983; Isshiki, 1964). Because of the primary importance of Ps in the physiology of vocal intensity control, and an understanding of it underpins the research that follows, reference will be made to it throughout this thesis.

1.3.2 *Pitch and phonation threshold pressure*

Although laryngeal adjustment is the main determinant of fundamental frequency (F0) (as will be discussed in the section on the larynx) Ps is also a determinant of F0 (Sundberg, Titze et al., 1993). Singing requires extra control of Ps beyond the simple requirements of speech because of the precision and extremity of variations of SPL and F0 required by a melody (Sundberg, Leanderson, von Euler & Knutsson, 1991). High pitched and loud sounds, both requiring a surge in Ps, can occur at any stage of the musical phrase (Bouhuys, Proctor & Mead, 1966; Leanderson et al., 1987).

Phonation threshold pressure is the minimum Ps required to initiate the vibration of the vocal folds at a given F0 (Titze & Sundberg, 1992). It is most influenced by F0 and to a lesser extent laryngeal airway resistance and intensity (Plant, Freed & Plant, 2004). Singers double Ps when going up an octave in pitch (Sundberg, Titze et al., 1993). This is due to the vocal folds becoming stiffer as pitch increases, requiring a higher driving pressure both to initiate and maintain vocal fold vibration (Sundberg, Titze et al., 1993).

1.3.3 Subglottal pressure, sound pressure level and loudness

A doubling of subglottal pressure lead to ~ 8-9.5 dB increase in SPL, both in theoretical modelling (Titze, 1988; Fant, 1982) and direct measurement (Finnegan et al., 2000; Tanaka & Gould, 1983). Various studies have shown that there is a linear relationship between Ps and SPL (Van den Berg, 1956; Finnegan et al., 2000; Tanaka & Gould, 1983; Tang & Statholopoulos, 1995). It is assumed, therefore, that a variation in SPL reflects an equivalent variation in Ps (Van den Berg, 1956; Huber, 2007). The assumption of this is predicated, however, on other parts of the vocal mechanism, such as fundamental frequency and mechanism (determined at the larynx) and vowel shape (determined in the vocal tract), being kept constant. Perceptually, a 10 dB increase in SPL creates a doubling of perceived loudness (Stevens, 1955). Because of this correlation, SPL is also often given as an indicator of subjective loudness as well as acoustic intensity (Rasch & Plomp, 1999).

1.3.4 Inspiration and expiration

The control of Ps for singing, that is the control of respiratory drive, requires finely graded control of the respiratory muscles in order to achieve the desired effect (Newsom Davis & Sears, 1970) as for each new note a singer has to customize subglottal pressure with regard both intensity and fundamental frequency (Sundberg et al., 1991).

1.3.4.1 Inspiratory muscles

The main muscle of inspiration is the diaphragm and the external intercostals. When they contract, they reduce the alveolar (lung) pressure to lower than atmospheric pressure which creates an inward airflow (Hixon, 1987). In quiet inspiration only the diaphragm and the external intercostals are active with the diaphragm doing most of the work. The diaphragm is so efficient that it can perform this job on its own if need be (West, 2000). On inspiration, the diaphragm contracts and descends, gradually moving upwards on expiration. In normal tidal breathing the excursions of the diaphragm only extend to about 1 cm but on deeper inhalation can move up to 10 cms (West, 2000).

Although it has been commonly thought that the diaphragm is used actively in singing, it is only largely active during inspiration with its active contraction tapering off at the beginning of the onset of the tone (Bouhuys, Mead, Proctor & Stevens, 1968) after which the muscles of expiration become active. The thorax and abdomen represent two units of the respiratory system separated by the diaphragm (Leanderson et al., 1987). When the diaphragm is active, it creates a negative pressure while exerting a positive pressure on the abdomen pushing it outward unless opposed by the muscles of the abdominal wall (Leanderson et al., 1987). If the diaphragm is passive and slack, as during expiration, the thorax and abdomen unite to become the same unit in terms of pressure (Leanderson et al., 1987). This is true except when at low lung volume when a passive stretch of the diaphragm occurs, for example, toward the end of expiration (Leanderson et al., 1987). If the abdominal muscles are continually contracting during expiration they enhance the passive stretch of the diaphragm (de Troyer, 1983) which helps anchor the thorax for maintaining rib expansion allowing for airflow and pressure management. This also improves the efficiency of the contraction of the diaphragm on the subsequent inspiration since a previously stretched muscle has more contractile power (Cavagna, Dusman & Margaria, 1968).

Other muscles, known as accessory muscles of inspiration include the *pectoralis* major that raises sternum and ribs if the upper arm is fixed (Hixon, 1987), the scalenes which lift the first two ribs, the sternocleidomastoid which raises the sternum, the *alae nas*i, which flare the nostrils and various other minor small muscles of head and neck which are not normally active in quiet inspiration (West, 2000). It has been generally accepted by classical singing pedagogues that high effort in these accessory muscles has a negative effect on the larynx and pharynx and therefore on voice production (Pettersen & Westgaard, 2002) although as a blanket rule, this has been disputed by research indicating muscle effort in these areas is common among professional classical singers (Pettersen, 2005) as well as within some contemporary singing methods that emphasize specific muscular effort to increase vocal ease (Bagnall & McCulloch, 2005; Estill, 1996). It is not just muscle activity but the specific alignment of the structures of the head and neck that are important with respect to whether such muscle activity is damaging to the voice. The combination of hypertonicity of the sternocleidomastoid with the geniohyoid (an extrinsic laryngeal muscle) and a body posture weighted posteriorly is considered by speech therapists to be a predictor of voice problems (Kooijman et al., 2005).

1.3.4.2 Lung volume and intensity

Studies of respiration for speech have shown that high intensity phrases are initiated using a higher lung volume than low intensity phrases (Stathopoulos & Sapienza, 1993; Dromey & Ramig, 1998; Winkworth, Davis, Ellis & Adams, 1994). Conversely, Thorpe and colleagues found that in classical singing, phrases were not initiated at higher lung volumes in projected voice but ended at higher volume than unprojected voice since airflow is less in quiet phonation (Sawashima et al., 1988). One reason for this difference between speech and classical singing inspiration could be that phrases in the latter are much longer than in speech. In WCP songs, singers have the option to improvise and alter phrase lengths or alternate between short and long phrases. Short phrasing and the speech-like voice qualities that feature in WCP singing would indicate that we would be likely to see thoracic inspiratory strategies applied. This could alternate with abdominal inspiration strategies depending on phrase-length, the mechanism chosen, the singer's body or torso type and the musical context.

Within normal range the lung is very distensible (compliant) whereas at high pressure it is stiffer therefore the lung is easier to inflate at low volumes such as in quiet breathing but harder to inflate at the high lung volumes (West, 2000) that are required for high intensity singing.

The pressure is greater at the base of the lung than the upper (due to downward-acting weight forces gravity) which means that the lungs need support underneath them in order to maintain steady Ps (West, 2000) in singing. This is largely created by the diaphragm and the rib cage (West, 2000) on inspiration and the initiation of phonation followed by a gradual shift to activity by the expiratory muscles as lung volume drops.

1.3.4.3 Thoracic versus abdominal expansion

Most people will either expand both chest and abdomen or just chest when asked to take a deep breath (Iwarsson, 2001). It is thought that thoracic expansion while keeping the abdomen stable increases the efficiency of the diaphragm by stretching it to its optimal length (Iwarsson, 2001) and that this is efficient for phonation (Iwarsson, 2001). This research notwithstanding, many western singing pedagogues assert that thoracic inspiration leads to shoulder and neck tension and to a high larynx position, which is often associated with hyperfunctional voice (Iwarsson & Sundberg, 1998). However, Iwarsson found that abdominal expansion on inhalation led to a higher larynx position concluding that the important factor in larynx position was lung volume rather than inspiratory posture (abdominal versus thoracic expansion) (Iwarsson, 2001). WCP singers favour a high larynx position for belt voice compared with classical singers (Popeil, 1999) thus impacting on their lung volume and inspiratory posture.

1.3.4.4 Body type

Body type has implications for inspiratory strategies. Hoit and Hixon (Hoit & Hixon, 1987) compared the relationship between respiratory behaviour and body type using the Heath-Carter somatotype method (Fitt, 1988). Although lung volume was similar they found clear differences between endomorphs (tendency to be short with high proportion of body fat) and ectomorphs (tendency to be tall and lean) in terms of rib cage thoracic and abdominal contributions to inspiration for speech. They found that endomorphs favoured a high degree of abdominal participation whereas rib-cage involvement featured in the speech breathing of ectomorphs. They questioned the precision of body-typing, however, and suggested that torso proportions were more important to phonational breathing than general body type.

1.3.4.5 Expiratory muscles

The main expiratory muscles are the abdominal muscles comprising the *transversus abdominis*, the external and internal obliques and the *rectus abdominis*. The *transversus*, which is the deepest muscle of the three, is the most important muscle with regard to normal expiration as it always activates in both voluntary and involuntary contexts and is the first to activate in involuntary situations (de Troyer, Estenne, Ninane, Gansbeke & Gorini, 1990). It is always employed in speech and the obliques and *rectus abdominis* are employed most of the time in normal voluntary speech (de Troyer et al., 1990). There are major differences in abdominal muscle behaviour depending on whether it is voluntarily or involuntarily induced (de Troyer et al., 1990). The *transversus abdominis* activates at the onset of phonation and its activity gradually increases as lung volume declines (de Troyer et al., 1990). Structurally, the *transversus* is very strong and efficient, since the fibres of the horizontally encircle the abdominal cavity whereas the rectus and obliques run longitudinally from the lower rib cage to the pelvis (de Troyer et al., 1990).

1.3.4.6 Active respiration

In quiet breathing the accessory muscles of respiration are not activated and expiration is passive (West, 2000). When the demands on breathing become greater, the accessory muscles of respiration become involved and expiration becomes active. In normal tidal breathing the diaphragm has a movement range of about 1cm but on forced inspiration or expiration it can move up to 10cm (West, 2000). It makes sense therefore that the heavier the requirements of vigorous singing, the more muscle activity will be observed and that some of that will result in movement. It is still disputed, however, whether there are levels of muscle contraction that are potentially damaging to the voice and which muscle recruitment patterns might initiate such damage.

It used to be thought that the diaphragm had few receptors because it has few proprioceptors (Leanderson, Sundberg, Von Euler & Lagercrantz, 1984) compared to the high level in the intercostals, abdominal oblique muscles and limbs (Leanderson et al., 1984), however it is now known that there are many nerve endings in the diaphragm that behave like the muscle spindle afferents found in limb muscles (Gandevia, Allen, Butler, Gorman & McKenzie, 1998). In some instances, notably during voluntary arm movements, the diaphragm *can* be activated during expiration where it is assumed to play a role in stabilizing the torso (Hodges & Gandevia, 2000). Diaphragmatic activity can also be reduced during inspiration through the use of arm movements (Hodges & Gandevia, 2000). To my knowledge this behaviour, which was noted in studies of posture and movement not phonation, has yet to be tested during singing – no doubt because classical singers do not normally use vigourous arm movements – but does indicate that body movement could be used to voluntarily activate respiratory muscles during singing.

1.3.5 Respiratory drive

Subglottal pressure is the main phenomenon underlying vocal sound level variation. Singers control subglottal pressure within the respiratory system via respiratory drive. This section discusses how respiratory drive relates to posture and movement. This section finishes with an explanation of how the control of respiratory drive relates to the term "support", which is widely used by singers.

1.3.5.1 Respiratory drive control

Respiratory drive is not simply a question muscle contraction. Its control comprises the complex interplay of four factors (Sawashima et al., 1988; Sundberg et al., 1993b): (i) the elastic recoil of the lungs and rib cage (Sundberg et al., 1991); (ii) lung volume (Sundberg et al., 1991); (iii) contracting respiratory muscles (Bouhuys et al., 1966; Sundberg et al., 1991); and (iv) the force of gravity on the abdomen (Sundberg et al., 1991). Singers use various combinations of these four aspects of respiratory drive to control increase Ps. A singer or speaker may alter Ps either by starting with inspiring to a higher lung volume prior to the sung tone in order to take advantage of recoil pressure (Huber, Chandrasekaran & Wolstencroft, 2005) or by increasing expiratory muscle tension contraction to increase the driving pressure usually after residual volume has been reached (Leanderson & Sundberg, 1988) or both. The elastic recoil of the lung and chest is a passive force that is dependent on the state of the body's health (Elkins, Alison & Bye, 2005), and torso and body type (Cowgill, 2004; Hoit & Hixon, 1987). However, manipulation of this passive force can be achieved via strategic use of lung volume. High lung volume at the beginning of expiration generates a strongly expiratory force as the natural elasticity of the lungs and ribcage return the chest wall to its resting position (Sundberg et al., 1991). By starting phonation at a higher lung volume, one can take advantage of the passive recoil pressure produced (Leanderson & Sundberg, 1988), which is then transmitted to the abdomen (Bouhuys et al., 1966). However, the higher the pressures produced in this way, the more inspiratory muscles need to be recruited in a process known as inspiratory braking (Hill, Kaiser, J-Y & Rochester, 1985; Hixon, Mead & Goldman, 1976), which allows the slowing of airflow so it can be sufficiently maintained to the end of the phrase. Singers use this technique to maintain appropriate pressures and manage airflow especially for longer phrases (Leanderson et al., 1987).

Conversely, low lung volume exerts a strong inspiratory force (Sundberg et al., 1991), which exerts a negative pressure that is transferred to the abdomen and leads to a passive stretch of the diaphragm muscle (Bouhuys et al., 1966). Low lung volume at the end of exhalation, known as end-expiratory volume or EELV, facilitates the next inspiration by exerting a passive negative recoil pressure. Low EELV is mechanically advantageous to efficient breathing and is considered to be a positive gauge of respiratory function (Alison et al., 1998). Singers adapt normal breathing patterns to one in which inspiration is accelerated and expiration is prolonged (Bouhuys et al., 1966). The creation of low EELVs should therefore be an efficient practice for singing by increasing the ease and speed of inspirations.

In most people standing at rest, the abdominal muscles work tonically; that is, there is background muscle tone, but when more work is required, for example, for movement or phonation, the abdominal muscles actively contract (Leanderson et al., 1987). The amount of work occurring in the abdominal muscles is directly related to the degree of Ps generated (de Troyer, 1983). A steady, unchanging sung sound that is at the same intensity and F0, requires the maintenance of a constant Ps. Paradoxically, this requires continuously changing muscular recruitment patterns and effort levels because of the reduction of lung volume caused by the continuous airflow (Bouhuys et al., 1966). The level of positive respiratory muscular effort varies from the beginning to the end of a sung tone. However, in sustained high intensity sounds, pressure increases caused by positive expiratory muscle effort may be happening at all lung volumes, throughout the entire tone (Bouhuys et al., 1966) but with further increased muscular effort as the pitch goes higher in the melody or as sound levels go higher for expressive reasons. Keeping the abdominal muscles active at all stages, including during inspiration, may also reduce respiratory muscle work, since it may require more energy expenditure to end and or re-initiate muscle contraction than to maintain contraction (de Troyer, 1983).

A body action is called inhalatory when it facilitates inhalation and exhalatory when it facilitates exhalation, provided that it reduces the muscle work required for respiration, even if the action is not specifically respiratory in nature (Iwarsson, 2001). Some inhalatory and exhalatory actions can reduce the particular kinds of active respiratory muscular efforts required for singing. This is largely dependent on the force of gravity relative to the structures and pressures in the body (Sundberg et al., 1991). Abdominal muscles actively contribute to the high speed, precise and constantly varying pressures required for singing specific pitches and intensity levels (Leanderson et al., 1987). During rhythmic singing and octave pitch leaps abdominal muscles have been shown to act in synchrony with pressure changes and that activity increases as lung volume reduces (Leanderson et al., 1987). This shows that the muscles are actively working to change the Ps required for both intensity and fundamental frequency variation. Normal speech largely uses minimal active muscle requirements and passive forces (Sundberg, 1987b). Projected speaking voice and singing requires more active respiratory muscle work (Thorpe, Cala, Chapman & Davis, 2001).

There are two main muscle recruitment patterns used in these cases. The first pattern is the active contraction of the abdominals, which are the primary muscles of expiration, in particular, the *transversus abdominis* and obliques (Leanderson et al., 1987). The other pattern is the use the abdominal muscles to assist in anchoring the ribcage (Watson & Hixon, 1996) while the Ps variation is being enacted from the muscles in the ribcage such as the intercostals (Leanderson et al., 1987). These different muscle recruitment strategies are evoked in different phonational situations. For example, the oblique abdominal muscles are more active during either emotive speech or singing compared with speaking meaningless nonsense words (Leanderson et al., 1987). This is consistent with observations that variations in imagery cues to singers can trigger changes in respiratory strategies as evidenced in abdominal and ribcage dimensions and motions (Thorpe et al., 2001).

1.3.5.2 Gravity and centre of pressure and body position

Gravity exerts pressure on the abdominal contents. In an upright posture this means that the pressures against the abdominal wall are greater the lower in the abdomen. This affects muscle recruitment and the level of contraction (de Troyer, 1983). Major changes in the gravitational pull are not usually an issue for singers since they do not normally lie down during performance (Sundberg et al., 1991) or perform in zero gravity (Hoit, 1995; Kozlovskaya, Dmitrieva, Grigorieva, Kirenskaya & Kreidich, 1986) but minor changes that are enough to disrupt the fine motor control required for singing could occur if a singer is dancing or acting. Adopting a supine position makes exhalation less effortful, increasing inhalatory muscle work that is visible in movements of the abdomen (Sundberg et al., 1991) whereas in a standing position, more work by the muscles of the chest is visible in greater ribcage motion (Druz & Sharp, 1981). However, even minor changes of body position can create more muscle work by moving the centre of pressure in the body up or down (Bouhuys et al., 1966) affecting breathing mechanics (Hodges, Gurfinkel, Brumagne, Smith & Cordo, 2002) and breathing behaviour in general (Hoit, 1995). The effect of gravity on pressures also interacts with lung volume and muscle contraction effects (Bouhuys et al., 1966). For example, as body movement moves the centre of pressure in the abdomen upwards, muscle contraction can cause it to move back down again (Bouhuys et al., 1966). There is a hypothesis that alignment of a section of the lung with gravity will facilitate ventilation in that area, this being the principal of "postural drainage", a therapy used for patients suffering with respiratory ailments such as cystic fibrosis (Elkins et al., 2005). Generally, the more upright the posture is on expiration the higher the lung volume, lung pressure and airflow that can be obtained (Elkins et al., 2005). These are all factors that can facilitate higher sound levels in phonation. Because of these interactions, Hoit contends that body position has to be included in any discussion of breathing for speech or singing because each new body position requires a different muscular configuration and also because a change in position can involve different neural mechanisms (Hoit, 1995).

1.3.6 Support

Many singers reading the exposition thus far of respiration and singing will no doubt be wondering where "support" fits into this physiological picture. Defining the term "support" or "breath support" is problematic because it is a pedagogical and practitioner, rather than a scientific term and as such carries different meanings (Thorpe et al., 2001). Its precise physiological characteristics and their acoustic outcome have yet to be identified fully (Sand & Sundberg, 2005). Some pedagogues include the entire breath cycle in their definition of support behaviour; some only the expiratory phase while others leave this detail unstated (Burgin, 1973; Monahan, 1978). The simplest description of support is that it is the alteration of lung pressure to adapt to changing pitch conditions (Sand & Sundberg, 2005) but other definitions include SPL and spectral variation (Watson, 2009, p.124). This indicates that support relates to Ps in addition to some laryngeal and vocal tract characteristics (Griffin, Peak, Colton, Casper & Brewer, 1995; Sand & Sundberg, 2005). In spite of the lack of definitional clarity, the term is widely used, even in the empirical literature and therefore its definition requires attention. Thorpe et al offered a definition of "support" for singing which I will adopt here, that is, "support" is respiratory patterning, inspiratory or expiratory, which facilitates Ps control without interfering with vocal fold vibration (Thorpe et al., 2001).

1.3.7 The larynx and singing

There are four aspects of phonation that are controlled at the vocal folds, which together are the main determinants of voice quality (Henrich, d'Allessandro, Doval & Castellengo, 2005). These are:

1. vocal attack or onset
2. register or mechanism
3. glottal or vocal fold closure
4. fundamental frequency

The following is a description of these aspects and how they relate to intensity and healthy technique in voice production and WCP performance in general as well as how that use may differ in WCP singing compared with western classical singing.

1.3.7.1 Vocal onset or attack

There are three main approaches to initiating speech or singing, called onsets or attacks: 'breathy', where the air is released before the tone, 'simultaneous', which occurs when air is released at the same time as the vocal folds meet and 'glottal', where phonation begins with the vocal folds medially compressed (Zemlin, 1998). These have an impact on the voice quality. Breathy onset can lead to a weak, breathy voice quality while a glottal onset that is pushed too hard can lead to roughness in the voice (Zemlin, 1998). Because of these effects, simultaneous attack is the one most often recommended by vocal health professionals, although there seems to be a spectrum of healthy use from simultaneous to non-abusive glottal onsets (Zemlin, 1998). Simultaneous onset is the most often advocated for classical voice (Estill, 1995). All three onsets are used in WCP singing (Wilson, 2003). Even though the habitual use of breathy onset, is considered to be "ineffective" (Zemlin, 1998, p.149) because it results in a weaker voice quality, it can be a useable voice quality in live performance because of the amplification used by WCP singers (Edwin, 2001; Fielder, 1995). In addition, skillful use of microphone technique by singers can allow them to manually alter sound levels, which means that they can put voice qualities of varying strengths alongside each other and still have them heard by an audience to good advantage (Edwin, 2001). Glottal onset is the predominant onset used for shouting in speaking voice (Rostolland, 1982; Ryker et al., 1998) and in the strong voice quality used in WCP singing, known as belting (Estill, 1995).

1.3.7.2 Register or mechanism

There is, unfortunately, no agreement on the exact definition of the term 'register' as definitions depend on whether the register is defined in perceptual or physiological terms (Sundberg & Kullberg, 1999) depending on whether the author is representing a medical, scientific, pedagogical or practitioner's perspective (Roubeau, 2009). Over a period of more than 150 years, authors have defined between two and four registers, in some cases varying the number according to gender (Roubeau, 2009), which indicates a perceptual definition. To avoid contributing further to the confusion about this term, I chose instead to avoid the use of the word and substitute the model used by Roubeau (Roubeau, 2009) and Henrich (Henrich et al., 2005) which describes four vocal mechanisms. I chose this system because both authors make it clear that they define the mechanism as a physiological phenomenon based on intrinsic laryngeal musculature and because their definitions of these mechanisms are soundly based on direct measurements using electroglottography in conjunction with acoustic analysis of the spectrum of the sound output. Their definitions have been tested and confirmed using male and female (Henrich et al., 2005) and trained and untrained singers (Roubeau, 2009).

Their definitions of these mechanisms relate to existing terms for register as follows:

- Mechanism 0 – equivalent to glottal fry
- Mechanism 1 – equivalent to so-called chest or modal voice
- Mechanism 2 – equivalent to head, or falsetto voice
- Mechanism 3 – equivalent to whistle or flageolet register.

Mechanisms 1 and 2 are the most commonly used in singing and there is little disagreement on this (Roubeau, 2009). All four voice mechanisms are used by WCP singers (Wilson, 2003) although the use of Mechanism 1 predominates (Björkner et al., 2005). A source of great controversy that is relevant to vocal mechanism is the specific use of Mechanism 1 in the "belt" voice quality in WCP singing, to be discussed later.

1.3.7.3 Glottal or vocal fold closure

By changing the configuration of the muscles of the larynx, a singer can control whether a heavy (Mechanism 1) or light (Mechanism 2) vocal mechanism will be used and how much muscular effort will be applied to that vocal closure (Zemlin, 1998). The intrinsic muscles of the larynx are the main muscles responsible for this control of glottal (vocal fold) shape and vibratory pattern that designates the mechanism. Closure is the laryngeal action most strongly related to intensity levels. The muscle performing this task is the thyroarytenoid, which makes up the main mass of the vocal folds. It has been shown that the thyroarytenoid increases in activity with increases in intensity (Finnegan et al., 2000) It designates the amount of force used to bring the vocal folds together at the midline, an action known as medial compression or glottal closure, while being able to stretch the vocal folds, creating longitudinal tension (Zemlin, 1998). Without these actions any increase in subglottal pressure from the respiratory system would lead simply to increased airflow. Effort from the laryngeal and respiratory systems is mutual (Stathopoulos & Sapienza, 1993). Stronger vocal fold closure creates more resistance to airflow that requires higher subglottal pressure to blow the vocal folds apart thereby creating a more intense pulse of air being sent into the vocal tract. This leads to a change in the pattern of vocal fold vibration to one in which the open quotient is small but creates sharper glottal pulses, leading to an increase in sound intensity. The shorter open quotient in higher intensity sounds means that lower airflow accompanies louder vocal sounds (Schutte, 1983). This significantly affects respiratory behaviour in the form of breath management for singing. This coupling of respiratory drive with the laryngeal system is reflected in strong neural links between the two-subsystems (Davis, Zhang, Winkworth & Bandler, 1996). Increases in Ps automatically lead to increases in glottal closure because of a primitive reflex known as the laryngeal adductor response that is activated by mechanoreceptors in the laryngeal mucosa (Henriquez, Schulz, Bielamowicz & Ludlow, 2007). This is one of the reflexes that protect the respiratory system in the event of swallowing, coughing, vomiting and straining (Kim, Kang & Kim, 2009; Kirchner & Suzuki, 1968).

1.3.7.4 Fundamental frequency

Fundamental frequency (F0) or to use its musical descriptor, pitch, is finely tuned by internal laryngeal muscles that vary the length, thickness and tension of the vocal folds while they are vibrating. The vocal folds are under more tension the higher the pitch, which means higher driving (Cordo & Nashner, 1982) pressures are needed to overcome the resistance of the vocal folds (Sundberg, Titze et al., 1993). Subglottal pressure (Ps) doubles when F0 doubles, that is, expressed musically, when pitch is raised by an octave (Sundberg et al 1993). Thus, both F0 and Ps are determinants of intensity (Fant, Kruckenberg & Liljencrants, 2000). Care must be taken, therefore, when attempting to isolate causes of intensity variation with regard to Ps that comparisons are not made between samples of different F0 (Titze, 1988).

1.3.7.5 Glottal contributions to subglottal pressure

Glottal closure

Vocal fold behaviour in singing, in particular glottal closure, has a significant impact on Ps control and thereby on SPL. The thyroarytenoid (TA) muscle makes up the main mass of the vocal folds (Zemlin, 1998). It has been shown that it increases in activity with increases in intensity (Finnegan et al., 2000). Both glottal closure and respiratory drive increase in the production of higher intensities (Stathopoulos & Sapienza, 1993). In this regard, varying strategies are used to produce the same intensities in speech (Stathopoulos & Sapienza, 1993). In non-phonational breathing, increased Ps results in increased airflow because the glottis is open. However, in speech or singing, the relationship between Ps and airflow depends on the vibrational pattern of the vocal folds, which is dependent on factors such as laryngeal mechanism (Bouhuys et al., 1966). Stronger vocal fold closure creates more resistance to airflow, contributing to higher subglottal pressure,, which results in a shorter open quotient within the vibratory cycle (Schutte, 1983). This causes a more intense pulse of air being sent into the vocal tract to create sound (Schutte, 1983). Without vocal fold closure, any increase in subglottal pressure from the respiratory system would lead simply to increased airflow. In phonation, however, an increase in subglottal pressure leads to a change in the pattern of vocal fold vibration to one in which the open quotient is shorter but creates sharper glottal pulses, leading to an increase in sound intensity. For this reason, a short open quotient means that low airflow accompanies louder sounds (Schutte, 1983).

1.3.7.6 Respiratory drive or laryngeal adjustment?

With regard to the relative contributions of respiratory drive and laryngeal adjustment to intensity control, there are varying strategies used to produce the same intensities in speech (Stathopoulos & Sapienza, 1993). This is important in terms of drawing conclusions about the effects of movement on Ps. Care must be taken not to over-interpret the effect of movement on the sound in the studies if laryngeal factors were not taken into account in the protocol and analysis. In the past, it had been theorized that laryngeal control of pressure might be more efficient and quicker to use than pressure generated by respiratory drive (Titze, 1988; Winkworth, Davis, Adams & Ellis, 1995; Winkworth et al., 1994). This has been since refuted in speech through direct measurement (Finnegan et al., 2000). Finnegan et al (2000) tested this directly at different intensity levels and linguistic stress patterns in speech using tracheal puncture to measure Ps, EMG using bipolar hooked-wire electrodes inserted into the thyroarytenoid muscle and by measuring airflow. Using these measures they were able to calculate the relative amounts of pressure generated by respiratory drive and that created by laryngeal muscle activity. It was found that respiratory drive contributed 94% and laryngeal adjustment 6% of the Ps increase associated with raised vocal intensity in speech. It was also found that these relative contributions remained the same whether the intensity change was sustained over a long period or transient as in the case of linguistic stress.

Although the Finnegan (Finnegan et al., 2000) study was conducted with speakers, the study is significant for the understanding of intensity control in WCP singers, because they regularly move in and out of speech and speech-like modes when vocalizing. The other important point is that the relative contributions of respiratory drive to glottal closure remain reflexively the same in the same vocal mode. The proportional relationship between respiratory drive and glottal closure found in the Finnegan study is attributed to the automatic laryngeal closure mechanisms discussed above (Yamaguchi et al., 1993). This means that, even if the relative contribution of respiratory drive to glottis are different in another mechanism, for example, due to differences in airflow due to a longer open phase, respiratory drive can still be assumed to be the main driver of intensity change and it can be assumed that that will remain proportionally the same if the vocal mechanism does not change.

1.3.7.7 WCP voice qualities-belt

Laryngeal behaviour in WCP voice qualities

As previously mentioned, a wide range of voice qualities are used in WCP music. Koufman (Koufman, Radomski, Joharji & Russell, 1996) tested internal laryngeal muscle tension assessed by laryngoscopy in 100 singers from a broad range of western singing styles. By comparison to a range of classical styles tested, contemporary popular categories showed the most laryngeal work. Elevated laryngeal muscle tension was not seen as a sign of vocal dysfunction but a sign that the style demanded relatively more effort at the laryngeal level (Koufman et al., 1996 p. 535). WCP singers in this study were also grouped stylistically according to similar laryngeal biomechanics. Within the contemporary categories, Rock/Gospel showed the highest levels of laryngeal work, followed by Bluegrass/Country & Western, Musical Theatre and finally pop/jazz. The lighter laryngeal demands on the "pop" voice have been discussed in other studies (Miles & Hollien, 1990; Thalen & Sundberg, 2001) as has the high level of "pressedness" (a factor including glottal closure and Ps levels) in blues singing (Thalen & Sundberg, 2001).

Belt voice quality

Belt is one of the most commonly used voice qualities and is found worldwide (Popeil, 1999). The prevalence of the voice quality known as belt in rock, gospel and blues styles may account for the high levels of laryngeal work evident in these styles (Thalen & Sundberg, 2001). Belt is one of the strong voice qualities employed in WCP singing and although this is often seen as being in the domain of popular music only, it does also appear in operatic singing although to a lesser degree (Koufman et al., 1996). Pedagogically, belt has been described as a powerful "chest" voice taken above the pitch limits of speech range (Collyer, 1997; Lovetri, 2002). This description has also been supported empirically (Bestebreurtje & Schutte, 2000; Schutte & Miller, 1993). Although the reaching of a consensus on its characteristics among pedagogues has been difficult (Collyer, 1997) researchers are getting closer to a physiological definition of belt quality. Belt voice is an effortful voice quality involving more work at the larynx (Koufman et al., 1996) and higher Ps (Björkner et al., 2005; Sundberg, Gramming & Lovetri, 1993) resulting in higher sound pressure levels (SPL) than classical singing styles when compared at the same F0 (Sundberg, Gramming et al., 1993). This involves a long closed phase (>50%) of the vocal folds and a high larynx position (Schutte & Miller, 1993). This configuration amplifies the higher harmonics in the sound, contributing to its bright, loud, speech-like quality (Bestebreurtje & Schutte, 2000; Schutte & Miller, 1993; Stone, Cleveland, Sundberg & Prokop, 2003) especially above G4 (392Hz). The evidence of belt's strong glottal closure and long closed phase supports its definition as a Mechanism 1 voice quality (Bourne, Garnier & Kenny, 2010).

Belt is considered to traverse the F0 (pitch) range of roughly D4 – D5 (294-587Hz) in the female voice (Schutte & Miller, 1993) which means that belt goes beyond the usual upper limit of Mechanism 1 which is A4 (440Hz) in the female and G4 (392Hz) in male voices (Roubeau, 2009). In the speaking pitch range of Mechanism 1, SPL can be altered relatively easily by small changes in Ps (Sawashima et al., 1988), but as a singer moves up in F0, further increasing longitudinal tension, glottal closure and Ps, it becomes harder to remain in Mechanism 1, which is essential to maintaining belt voice quality. This is because the effort level at the larynx continues to increase as the upper ceiling of Mechanism 1 approaches and the vibrating vocal folds are stretched to their limit (Rothenberg, 1988; Sundberg, 1987d). The increased glottal resistance requires further increases in expiratory muscle effort to drive the air to maintain the vibration since passive recoil pressures of the ribcage alone are not be enough (Thorpe et al., 2001).

All of this incrementally increases the brightness of the sound as the upper limit of belt is reached, increasing the perception of loudness (Miles & Hollien, 1990). This acoustic effect and the excitement or awe it creates in audiences as the singer reaches the upper extremity of the belt range is much sought after by WCP singers. This upper limit in female voices has been placed at C5 (525Hz) (Miles & Hollien 1990) but the reality is that singers go considerably higher in practice. High pitch, high SPL and belt voice quality all require a high Ps. WCP songs are commonly written to feature high F0, high SPL moments in belt voice simultaneously at certain points in songs where a high level of drama or excitement are required. This is most easily demonstrated in the scores of the music theatre belt song repertoire where it may extend to F5 (698Hz) (Bourne et al., 2010) in the female voice. Such a combination of ever-increasing glottal closure and respiratory drive with increasing F0 in belt increases the vocal load (Hollien, 1983) or impact stress on the vocal folds (Jónsdottir et al., 2001) which can be harmful, depending on the singer's skill level in offsetting this effect (Hollien, 1983; Sataloff, Spiegel & Hawkshaw, 2003). These high level Ps requirements, which are potentially damaging, may produce physical phenomena that differ from other high SPL vocal styles such as opera. Respiratory drive, and to a lesser extent glottal adduction, are greater in belt than opera quality at the same fundamental frequency (Sundberg et al., 1993a; Stone et al., 2003). The singer using belt in the Sundberg study also achieved a sound level 10 dB higher than operatic quality at the same pitch (Sundberg, Gramming et al., 1993) which indicates a much higher Ps level. It has been noted elsewhere that high belt voice requires extremely strong abdominal breath support (Popeil, 1999) which also indicates high Ps.

It is at this extreme point of high F0, high SPL belt voice, in particular, that I have noticed body movement coming into play in WCP singers. Increasing expiratory muscle activity can reduce the stress on the vocal folds by increasing Ps. When Ps increases, it raises both loudness and F0, which must be counterbalanced by enough relaxation at the vocal folds to maintain the required F0 of the melody (Bouhuys et al., 1966). Knowledge of the intimate relationship between respiratory and laryngeal activity (Gould, 1971), gave rise to the hypothesis that the body movement of WCP singers may, at least in part, help to offset vocal fold impact stress by triggering a short burst of higher expiratory muscle activation. This speculation directed the focus in this thesis onto body movement during the production of high intensity, high F0 vocal tones in WCP singing.

1.3.8 The vocal tract and singing

The final component of the source-filter model is the filter or articulation, which is a function of the vocal tract. The vocal tract comprises the cavities of the nose, mouth and pharynx, which act as resonators. Changes to shape of the vocal tract can alter vowels, intensity and spectral balance through the muscular manipulation of the articulators: pharynx, mouth, tongue and velum (soft palate) (Fant et al., 2000; MacCurtain & Welch, 1983; Sundberg, 1987a; Sundberg, Gramming et al., 1993).

1.3.8.1 Sound pressure level and the perception of intensity

Sound pressure level (SPL) is also linked to spectral balance and F0 (measured in Hz) and their co-variation is complex and continually changing during phonation (Fant, 1982). It is via spectral balance that the vocal tract may contribute to increases in SPL. Loudness is the perception of sound intensity (Johnson, Turner, Zwislocki & Margolis, 1993). A sound has to be boosted more in the low F0 range than in the high F0 range for it to be perceived as louder (Suzuki et al., 2003). The ear perceives higher levels of high harmonics in the sound spectrum as increased loudness (Fant, 1982) or as projection (Thorpe et al., 2001).

1.3.8.2 Formants and formant tuning

How the sound is transmitted from the voice source to the mouth opening is known as the vocal tract's transfer function, which is dependent on its shape; more specifically, its width and length in relation to the vibrating vocal folds (Sundberg, 1987a). The sound frequencies that are transferred with the least difficulty by the vocal tract are known as formant frequencies and these are defined by the behaviour of the articulators (Sundberg, 1987a). The harmonics emanating from the vocal fold vibration that most closely match the formant frequencies of the vocal tract will have a higher amplitude in the sound radiated from the mouth opening. It is by this means that the vocal tract can affect intensity as well as spectral balance. The singer can regulate the height of the velum and the width and length of the pharynx (Honda, Hirai, Estill & Tohkura, 1995). The pharyngeal shape correlates with formant frequencies in singing (MacCurtain & Welch, 1983). The spectral balance of the voice is perceived as timbre and therefore contributes to the voice quality (Honda et al., 1995; Sundberg, Gramming et al., 1993). The intuitive alteration of the vocal tract shape to enhance the sound, in particular to increase intensity, is known as "formant tuning" (Carlsson & Sundberg, 1992; Miller & Schutte, 1990) or vowel modification (Miller & Schutte, 1990).

1.3.8.3 Vowels

Because vowels are longer in duration during singing than in speech, making them more dominant to the listener, they need to be formed with more care than in speech (Miller & Schutte, 1990). Each vowel position produces a distinctive frequency spectrum. Both the vocal tract positions adopted to create vowels and muscular alteration of the pharynx shape affect the spectral balance and intensity of the voice (Fant et al., 2000). For example, the sound "bar " produces a higher SPL than the sounds "bee" and "boo" at the same level of Ps (Ladefoged & McKinney, 1963).

1.4 Posture and movement interactions with vocal function

Movement disturbs equilibrium (Crenna, Frigo, Massion, Pedotti & Deat, 1988) by changing the body's geometry and centre of gravity. It is unlikely that an expert singer would choose to disturb that equilibrium unless it was advantageous in some way. In the previous section, the basic physiological mechanisms involved in intensity production were established and explained in relation to singing and more specifically WCP singing. This section outlines the means by which these vocal intensity mechanisms can interact with body movement and posture.

1.4.1 "Multipurpose" muscle function

Respiratory muscles are "multipurpose" in that they are also used for posture and movement and as a result their functions interact (Reed, 1989; Rimmer, Ford & Whitelaw, 1995). For example, the abdominal muscles are crucial for posture and movement and because of this relationship, these functions can enhance respiration in singers (de Troyer, 1983; Reed, 1989; Hoit, 1995; Rimmer et al., 1995). Similarly, any challenge to posture can negatively affect respiratory function(Gandevia, Butler, Hodges & Taylor, 2002). Of respiratory activities, speaking and singing require the greatest accuracy and control (Newsom Davis & Sears, 1970). Because of the necessity for precision in breathing behaviour for these activities, functional interactions become very important. Hoit goes so far as to contend that body position must be included in any discussion of speech or singing breathing because of the effects of the line of gravity on respiratory function (Hoit, 1995). The human motor system has evolved phylo- and ontogenetically to operate accurately in relation to gravity (Kozlovskaya et al., 1986). As a result, changes of body position produce alterations in body pressures, which in turn have respiratory effects such as increasing or reducing airflow in non-phonational breathing or subglottal pressure in phonation (Elkins et al., 2005). The degree of internal body pressure relates directly to the amount of work done by the abdominal muscles (de Troyer, 1983). This leads to the question regarding how body behaviour might be improved by the singer to facilitate an increase in sound pressure level (SPL). Since, as already stated, subglottal pressure (Ps) is the most important driver of intensity control, we would expect to see singers use body behaviours that manipulate that pressure, consciously or otherwise. Schneider contends that physical strength and good postural balance lead necessarily to better voice production and therefore suggests applying training principles of exercise physiology to vocal training via posture improvement (Schneider, Dennehy & Saxon, 1997). Many techniques used in voice and singing teaching make reference to postural connections with respiration for voice, for example, Alexander Technique (Hudson, 2002) and Accent Method (Bassiouny, 1998) although the reasons for their success is little researched. This question is pivotal to the research that follows, the principles on which it is grounded and the applications of the results.

1.4.2 Posture and voice

The relationship between posture and voice is considered to be so important that Gould described voice as a secondary function of the postural system of which the respiratory system is a part (Gould, 1971). Like the term "register", the word "posture" has a variety of meanings attributed it, some colloquial, some pedagogical and some scientific. In the literature, posture denotes several different aspects of body behaviour all of which are relevant to this discussion, and importantly to the central questions addressed in this thesis.

- Postural alignment
- Body position or attitude
- Postural control

1.4.2.1 Postural alignment

Colloquially, the word posture is usually associated with qualitative judgments such as the "good" posture of "sitting up straight" at school but this is not the meaning intended here. The implication of this popular image is that the spine needs to be made straight whereas, in fact, the spine needs to be curved and flexible in order to operate in a healthy manner as a spring-like shock absorber for the body (Norris, 1997). Postural alignment is a more explicit term than posture and is used by movement-oriented professionals such as physical therapists, Alexander teachers and dancers. Ideal postural alignment in a static model has been identified as one in which, in a normal upright position, a plumb-line allowed to fall from a point behind the ear would pass through the midpoint of the body anterior to the spine passing just anterior to the shoulder joint and just posterior to the hip joint finishing just anterior to the ankle joint (Schneider et al., 1997). It is this ideal that Schneider considers a productive goal for singers to improve their technique. In practice, good postural alignment is considered to exist when there is a stable, balanced relationship between different segments of the body, in which muscles are balanced in terms of length and tension around the joints and need only work minimally to maintain postural control (St. George, 1989; Wilson Arboleda & Frederick, 2006). This ideal postural alignment also involves a neutral spine (neither overly curved nor straight) when at rest.

Poor postural alignment can have negative effects on voice production (Bruno et al., 2007; Rubin, Blake & Mathieson, 2007). Kyphosis (abnormally convex thoracic spine) and cervical rectitude (permanently straightened neck) can be a hindrance to singing because such postures restrict neck movement and vocal tract changes required for pitch, timbre and resonance variation (MacCurtain & Welch, 1983; Scotto, 1998; Wilson Arboleda & Frederick, 2006). Kyphosis also restricts rib expansion and the descent of the diaphragm thereby reducing lung volume and airflow (Wilson Arboleda & Frederick, 2006). This results in reduced Ps and thereby to potentially lowered maximum sound intensity levels. Particular configurations of posture may therefore be detrimental to vocal intensity production. It follows that movement or dynamic posture (Gould, 1971) change can also either help or hinder the same vocal processes.

1.4.2.2 Body position or attitude

Another conventional meaning attributed to posture is body position or attitude, although this is an incomplete definition of posture in relation to voice production because it is static rather than dynamic (Gould, 1971). Body position is a useful neutral term in comparing and analysing changes from one moment to another, in the breath cycle (Hoit, 1995) or with reference to the respiratory effects of different body angles in relation to gravity (Elkins et al., 2005). Some singing studies compare gross differences in body position, for example, upright to supine (Sundberg et al., 1991). Body position significantly affects lung volume and expiratory pressures (Elkins et al., 2005). For example, in the treatment of lung disease, it is considered that the alignment of a bronchial segment of the lung with gravity will help clear that part of the lung faster (Elkins et al., 2005) indicating that the angle of the body in relation to gravity would be important to breathing for singing as well. The most advantageous body position for breathing is the upright standing position because higher lung volume can be achieved on inspiration and higher expiratory pressures can be attained on exhalation (Elkins et al., 2005). In an upright body position, ribcage motion increases (Druz & Sharp, 1981). This is because the upright position stimulates the contraction of both the diaphragm and the abdominal muscles, which together create a stiffened abdominal wall which together create a base that allows the ribcage to move more efficiently (Druz & Sharp, 1981). Therefore, it would seem that theoretically, this would be the best position to be in when attempting to achieve a high intensity moment in singing. Whether this is the case will be discussed in Chapters 2 and 3 in which acoustic intensity levels will be assessed with respect to body movement in WCP singers.

1.4.2.3 Postural control

Theoretical models of body behaviour may present ideal positions for voice production but the reality of the living human body is that it is never completely still. Posture has been defined as a dynamic interrelationship between muscle and skeleton (Gould, 1971). Even if the feet are motionless, the body is moving due to the effects of breathing, heartbeat and perturbations from the surrounding environment (Hodges et al., 2002). For this reason, what we perceive as standing still is really one end of a continuously operating movement spectrum. The purpose of postural control is to maintain balance of the body in the face of this continuous and varied movement. It is the system that maintains the stability of both the vertical and horizontal alignment of the body (Van der Kooij, Jacobs, Koopman & Grootenboer, 1999) in relation to the forces of gravity. Postural control is regulated by the central nervous system (CNS) using sensory information received from the eyes, the labyrinth of the ear, proprioceptors in the muscles and mechanosensors in the soles of the feet (Yasuda, Nakagawa, Inoue, Iwamoto & Inokuchi, 1999). Much of this occurs via reflexive behaviours and occurs unconsciously (Purves et al., 2001). An example of this is the vestibulo-oculo-motor reflex whereby the gaze remains forward in spite of body perturbations, drawing on visual information as a guide (Yates & Stocker, 1998).

Human postural control is therefore highly complex and although there are reflexive behaviours involved, it interacts strongly with training, experience and intent (Van der Kooij et al., 1999). Any voluntary interaction with an outside object, ranging from a change of floor surface to grabbing a microphone, changes the centre of gravity necessitating postural response which is not reflexive but generated high in the central nervous system (Cordo & Nashner, 1982). This may seem like a contradiction but it is now understood that there are varying levels of volition in relation to reflexes, ranging from reflexes that are completely involuntary to those that can be stopped consciously mid-action (Prochazka, Clarac, Loeb, Rothwell & Wolpaw, 2000). Complex behaviours such as playing music can harness simpler involuntary reflexes as part of training

(Prochazka et al., 2000). It is for this reason that it can be said that posture that contributes positively to voice production is not innate but comes through experience or conscious training and can thereby be altered and improved (Schneider et al., 1997). WCP styles are generally learned experientially by observation and imitation. As music of an oral rather than written tradition, body behaviour is then learned implicitly as part of the style (Mackey, 2008) rather than a separate approach known as "technique". It is feasible then that WCP singers could unconsciously adopt body positions and movements that increase their vocal efficiency so that body shifts could be part of implicit knowledge of how the sound is best produced. It is by such memorized approaches that singers are considered to alter their body schema (Scotto, 1998).

1.4.2.4 Vocal tract, neck posture and movement

The changes to articulators used in vowel formation and timbre variation, described earlier, are internal. However, pharynx shape and larynx position are also affected by external changes related to head and neck alignment (MacCurtain & Welch, 1983). During vocal tract changes due to pitch-related mechanism shifts (for example, in a shift from Mechanism 1 to 2), the extrinsic laryngeal muscles support the intrinsic laryngeal muscles (MacCurtain & Welch, 1983). Research observing neck position in singers has shown that changes to the external alignment of the head and neck have internal effects on the vocal tract that translate into alterations in the sound emitted (Bruno et al., 2007; Estill, Baer, Honda & Harris, 1984; MacCurtain & Welch, 1983; Popeil, 1999; Scotto, 1998; Wilson Arboleda & Frederick, 2006). Relaxation of shoulder and neck muscles has been seen as the healthy for the voice (Pettersen & Westgaard, 2005). A position in which the face is pushed forward in relation to the neck with the addition of neck muscle tension has clinically been associated with dysfunctional voice (Grini, Ouaknine & Giovanni, 1998; Grini-Grandval, Ouaknine & Giovanni, 2000). Bruno et al (2007) proposed that active contraction of the extrinsic laryngeal muscles and other muscles causing the head to be thrust forward while maintaining a posterior weight bearing position may cause an alteration of the body scheme, which produces a less effective postural strategy for phonation. However, in their study no difference in postural strategy was found between normal and dysfunctional voices in this regard. In deeper voluntary breathing it has been noted that the angle of neck to head increases (Hodges et al., 2002) although to my knowledge this has never been associated with voice dysfunction.

Kmucha et al (Kmucha, Yanagisawa & Estill, 1990) reported that classical singers attributed their high intensity singing to breath control, a low larynx, singing "in the mask" which Kmucha and colleagues observed as often involving hypernasality and relaxation of the head and neck area. Their findings contradicted the singers' subjective observation, suggesting that widening of the pharynx while simultaneously narrowing the aryepiglottic sphincter of the endolarynx was a major contributing factor to high intensity singing. Both these actions involve intrinsic and extrinsic muscular effort in the pharyngeal area. It is of interest to note that the widening of the throat discussed in this paper was compared to the sensation of laughing or sobbing, indicating an emotional association with the vocal tract configuration for high intensity singing. The tendency of WCP singers to sing high F0s in Mechanism 1 voice [belt] would indicate that this would have a further effect on muscular effort in the supra-glottal area. As one moves higher in pitch in Mechanism 1, the pharynx widens (MacCurtain & Welch, 1983). This would indicate that one would be likely to observe a movement in neck and head positioning, as the F0 is raised in a melody. This would be likely to be different positioning to that observed in classical singers who exhibit a gradual decrease in the anterior cricothyroid space as F0 increases, indicating increased activity of the cricothyroid muscle (Laukkanen, Takalo, Arvonen & Vilkman, 2002). Such a difference in the angle of head and neck between belt and classical voice has been noted as has the change of voice quality wrought by the resultant change of shape of the vocal tract (Popeil, 1999).

The mouth opening for belt voice is larger than for classical singing (Popeil, 1999). Intensity can be raised by increasing the mouth aperture (Huber & Chandrasekaran, 2006). Jaw opening also affects the pharynx. A larger mouth opening narrows the pharyngeal space boosting the higher harmonics contributing to a brighter sound (Sundberg & Skoog, 1997), which can increase acoustically measurable intensity as well as perceived loudness.

1.4.3 Movement and voice

In the empirical literature, movement is often described as a change in body position (Elkins et al., 2005), a shift of body posture or postural change (Bruno et al., 2007) rather than as a movement. Movement as observed in this thesis included subtle movements as well as the larger movements that may be more obvious to an audience. These subtle movements, which are often indeterminate in function, have been variously described in instrumentalist behaviour as non-obvious (Wanderley, 2002) or ancillary (Wanderley et al., 2005) movements or gestures (King, 2006) that may not always have an obvious causative link to sound. There are many physiological connections between movement and voice, including muscular and mechanical links and neural pathways:

1.4.3.1 Muscular linkage via common muscles

The most obvious link between voice and movement is either through the actions of muscles common to both activities or to muscles that interact through proximity or because they connect, for example by inter-digitating (the interweaving of the finger-like processes of one muscle with another). The list below provides examples of the most direct connections between torso movement and respiratory muscle interactions. They also relate to the actions observed in the singers in my preliminary observations on singer movement in the introduction. Movements of the torso are described below (Jensen, Schultz & Bangerter, 1983). Those in bold also double as primary expiratory muscles. It can be seen that all of the actions of the torso involve substantial expiratory muscle contraction and could therefore potentially increase Ps if unopposed (Goldman, Grassino, Mead & Sears, 1978), meaning that these actions could be used to increase vocal intensity.

1. **Flexion** (forward bend – not to be confused with hip flexion or forward bend from the hip)
    - ***Rectus abdominis***
    - **External oblique**
    - **Internal oblique**

2. **Extension** (straightening). This is the most powerful movement of the trunk and is used in almost any kind of performance.

- *Semispinalis*
- *Erector spinae (sacrospinalis)*
- ***Quadratus lumborum***
- *Multifidis* (which also extends the neck)

3. **Lateral flexion** (sideward bend) – Almost all flexor and extensor muscles are involved in this action on one side.

    - Flexor Muscles
    - **Rectus Abdominis**
    - **External Oblique**
    - **Internal Oblique**
    - Extensor Muscles
    - *Erector Spinae*
    - **Quadratus Lumborum**
    - *Semispinalis* (Thoracic)
    - *Multifidis*

4 **Trunk rotation** (shoulder turning)

- **External Oblique**
- **Internal Oblique**
- *Erector Spinae*
- *Semispinalis (Thoracic)*
- *Multifidis*

The observations of the actions of specific muscles in classical singing have been observed in the work of Pettersen and colleagues (Pettersen, 2005; Pettersen, Bjørkøy, Torp & Westgaard, 2005; Pettersen & Westgaard, 2002; Pettersen & Westgaard, 2004; Pettersen & Westgaard, 2004; Pettersen & Westgaard, 2005), who examined the activation levels of certain muscles of the neck (*trapezius*, sternocleidomastoid, scalenes and the posterior neck muscles), ribcage (intercostals) and abdomen (obliques, *rectus abdominis*) and how they related to the movement of the chest wall. It was found that the *trapezius*, intercostals, obliques and *rectus abdominis* muscles were activated in phase during expiration with increases during demanding singing. This trend was stronger in professional than student classical singers. It should be noted that the muscle behaviour may be different in WCP singers compared with classical singers. For example, it was noted that the activity of the *trapezius* was reduced in short breathing cycles and short phrases are more common in WCP songs than in classical songs. Thus, it cannot be assumed that all the muscle behaviour characteristics observed in this group of studies are universal to all singing styles. However, these studies do make clear that demanding singing at an expert level requires high levels of muscle activation.

Complex muscle relationships

It would be tempting to regard the behaviour of these muscles as having a simple, one-to-one causal relationship with vocal sound. However, this would be an oversimplification (van Soest & van Ingen Schenau, 1998). Pettersen noted a great deal of inter-subject variability in terms of muscle usage patterns in classical singers of similar quality (Pettersen & Westgaard, 2004). This highlights the fact that the relationship between muscles is not simple or linear (van Soest & van Ingen Schenau, 1998). The behaviour of one muscle can affect other muscles that it does not even intersect with, depending on position and movement constraints (van Soest & van Ingen Schenau, 1998). None of the actions of the torso can be performed with one muscle only because of their attachments and their angles and because any torso movement creates movements in the spine (Jensen et al., 1983); muscles act in concert and are controlled via complex neural pathways.

Indirect triggering of muscles and recruitment patterns

Different body actions provoke different recruitment patterns of the abdominal muscles (de Troyer et al., 1990). Whether an action is consciously or involuntarily evoked also changes the recruitment pattern (de Troyer et al., 1990). The deepest and strongest of the abdominal muscles, the *transversus abdominis*, is always activated, whereas other abdominals may not be. For example, abdominal muscle action is induced involuntarily by inducing postural muscle contraction by indirect means such as induced hypercapnia (excessive carbon dioxide in the bloodstream) (de Troyer et al., 1990). A voluntary non-respiratory movement can therefore induce an involuntary and unconscious respiratory effect by triggering automatic muscle responses. Therefore, a singer could be affecting SPL or F0 output unconsciously through movement.

Arm muscles

Arm movement has impacts on the larynx as discussed earlier with reference to glottal reflexes in the section on the larynx but also impacts respiratory behaviour. The part of the arm involved in movement determines its level of involvement in respiratory behaviour (Jensen et al., 1983): Arm movement has variable effects on respiration depending on position and action (Alison et al., 1998; Couser, Martinez & Celli, 1992). Upper arm movement involving the shoulder is strongly linked to respiration (Jensen et al., 1983) through its links to the pectoral, intercostal and abdominal muscles (Lee & Banzett, 1997). Peaks in intra-abdominal pressure (IAP) occur at the frequency of shoulder activity induced by arm movements (Hodges & Gandevia, 2000). Conversely, hand-gripping and wrist movement toward the thumb side have no muscular connections to respiration (Jensen et al., 1983). Other wrist and lower arm movements have weak or indirect links to respiratory muscles (Jensen et al., 1983). We would therefore expect that hand gesture that did not involve the upper arm would not have large impacts on respiration for singing.

1.4.3.2 Mechanical links between movement and voice

As discussed earlier, movements that are not specifically respiratory can indirectly cause the activation of muscles that have respiratory effects. This can occur via various mechanical pathways. The importance of the relationship between posture, movement and respiratory function can be seen in the various physical regimes used to treat lung and respiratory muscle diseases in which body position in relation to gravity and muscular actions are used to improve lung and respiratory muscle function(Alison et al., 1998; David, 1991; Elkins et al., 2005).

Movement activating and inhibiting respiratory muscle

Body movement is always preceded by postural muscle activity: The *transversus abdominis* muscle activates reflexively in anticipation of body movement (Hodges & Richardson, 1999), as do the internal obliques (Hodges, Gandevia & Richardson, 1997) and the diaphragm (Hodges & Gandevia, 2000). Exercise stimulates abdominal muscles (Loring & Mead, 1982) but even minor body movements are preceded by anticipatory postural muscle activity (Cordo & Nashner, 1982). Shifts of body position can stimulate (Hodges & Gandevia, 2000) or inhibit (Rimmer et al., 1995; Whitelaw, Ford, Rimmer & De Troyer, 1992) respiratory muscle. Increases in intra-abdominal pressure can in turn lead to further postural changes; for example, an increase in intra-abdominal pressure in response to a change in the centre of gravity can lead to an extension moment of the spine (Hodges, Cresswell & Thorstensson, 2004). Respiratory maneuvres can also affect postural tasks (Hodges et al., 1997).

Ribcage rotation

The intercostals are muscles of both respiration, posture and movement (locomotor) and they can either stabilize the ribcage by stiffening it or move the rib-cage depending on the task at hand (Rimmer et al., 1995; Whitelaw et al., 1992). Voluntary rotational movement of the ribcage produces phasic inspiratory intercostal muscle contraction (Rimmer et al., 1995).

Arm movements and respiratory drive

Arm movements originating from the shoulder trigger phasic *transversus abdominis* and diaphragm muscle activity leading to internal pressure changes as well as the stabilization of the torso (Hodges & Gandevia, 2000). The magnitude of the activation of the diaphragm increases with the velocity of the movement (Hodges & Richardson, 1999; Hodges & Gandevia, 2000). The diaphragm is the major inspiratory muscle but it is worth noting that the diaphragmatic activation discussed here increased on both the inspiratory and expiratory phase of respiration (Hodges & Gandevia, 2000). For a singer to take advantage of these increases they would therefore have to be carefully timed to occur when an increase was needed i.e. in the expiratory/singing phase of respiration rather than during the inspiratory phase when it could reduce lung volume or otherwise inhibit ventilation.

The deep *multifidus* (an important muscle for stabilizing the lumbar spine) and *transversus abdominis* are always activated by arm movement (Moseley, Hodges & Gandevia, 2002) but the direction of the arm movement results in the recruitment of additional muscles such as the superficial *multifidus* (Moseley et al., 2002). Activity of the trunk muscles is initiated in advance of rapid arm movement, and these muscles may therefore act in an anticipatory way to control reactive forces associated with limb movement. Repetitive movement as opposed to single movements also provokes different muscular responses (Moseley et al., 2002).

Arm movements and glottal closure

Pulling and lifting (elbow flexion) is one of the most powerful movements of the arms (Jensen et al., 1983). In the earlier section on laryngeal function, glottic closure, or the laryngeal adductor reflex was described. Arm movements have been shown to elicit laryngeal adductor reflexes (Naito & Niimi, 2000). This also may account, at least in part, for the use of arm movement on stressed syllables in speech (Masuda, 1996). Any action of the neck and upper arm, lifting and pushing can be used to trigger or increase reflexive glottal closure (Yamaguchi et al., 1993) and this has been used as a method for remediating glottal weakness in subjects with dysfunctional speaking voices by strengthening the vocal folds over time (Yamaguchi et al., 1993). The disadvantage of this method was that it also triggered ventricular fold constriction, another laryngeal reflexive response, which lead to damaging vocal fold impact stress. The researchers in this case offset this effect by introducing an unsounded hard laughing gesture to the exercises in the protocol. The hard laugh gesture is based on the theory that the extra work of the external laryngeal muscles may allow the internal vocal fold muscles to relax more (Estill, 1996; Estill et al., 1984) and may also offset laryngeal closure reflexes such as ventricular fold constriction (Kmucha et al., 1990). This strongly indicates that although arm movement links directly to vocal fold behaviour for vocalization that can be positive and efficient, other techniques may be required to offset the high level of vocal stress that may result.

Pre-phonatory posturing

So far the discussion has been mainly about the effects of posture and movement on the expiratory phase of respiration, that is, while vocalization is occurring. Body behaviour may also be linked to Ps through the inspiration phase of respiration. There is evidence that there are changes in posture during inspiration that may optimize chest wall mechanics for phonation. This is known as pre-phonatory posturing and has been noted in both speech (Wilder, 1983) and classical singing (Thorpe et al., 2001). Thorpe noted that pre-phonatory posturing occurred before sudden increases of either SPL of F0 and that sudden reductions in output were paired with sudden releases of muscle tension. This would indicate that the muscle recruitment required to build Ps may be visible to the naked eye. A range of pre-phonatory postures have been noted (McFarland & Smith,

1992) thoracic expansion being most often noted in slow singing (Griffin et al., 1995) and fast abdominal expansion has been associated with faster singing (Thorpe et al., 2001) and in combination with a high larynx (Iwarsson, 2001). Unfortunately, states of expansion of the thorax or abdomen are largely those described in such studies rather than body alignment or overall biomechanics although it has been suggested that different patterns of prephonatory posturing may be due to different posture or biomechanical properties of the chest wall (Wilder, 1983) or may be due to the speed of respiration required (McFarland & Smith, 1992).

Movement at extremes of lung volume

In a study using static posturography to compare body posture and movement behaviour during speech found that there was no significant difference between normal and dysfunctional speakers (Bruno et al., 2007). They asked them to remain upright. More antero-posterior (postural sway) movement was detected in all during voice production. A study of the effect of postural loading at lung volume extremes showed that muscle behaviour is not as influential at lung volume extremes as when the respiratory system is relaxed. At extreme high lung volume, spinal extension was found to be inspiratory, as expected, but spinal flexion had no influence, that is, was not expiratory or inspiratory in effect. At extreme low lung volume spinal flexion and extension both had the effect of increasing lung volume (Appel et al., 1986). This is contrary to the expiratory effect of flexion in quiet breathing. According to these principles, the phase of respiration is significant in terms of the function of singer movement behaviour,. For example, at the beginning of a phrase when lung volume is high a) spinal extension could slow airflow (inspiratory braking) to help manage breath for a longer phrase or b) the singer would be free to execute a spinal flexion without fear of losing control on pressure. Further, at the end of a phrase, when lung volume is very low, spinal movement in either direction could facilitate the following inspiration.

1.4.3.3 Neural links between body movement and voice

Interactions between body movement and respiration (Gandevia et al., 2002) and body movement, respiration and voice (Gould, 1971) are strong but require neural control mechanisms that can deliver the high levels of precision of pitch, timing, voice quality and intensity required by the singer. For example, respiratory muscles such as the diaphragm and *rectus abdominis* can be activated much more quickly in phonation via corticospinal pathways than via auditory feedback (Macefield, Gandevia, McKenzie & Butler, 1996) but if a singer cannot control this pathway, it could be more of a liability to performance than an advantage. Pathways between body behaviour and respiration and voice need to be mediated by the central nervous system. There is a physical difference between the breathing for phonation that occurs during movement between prone and upright body positions. This difference is not just due to biomechanical change due to the body's relation to gravity but because different neural systems are involved (Hoit, 1995). Similarly, an action performed standing is neurologically different to the same action performed sitting (Reed, 1989) and a slow action is neurologically different to one performed quickly (van Soest & van Ingen Schenau, 1998). Such factors are important in the designing of ecologically sound experimental protocols involving singers since interactions with technologies used to collect data can provoke uncharacteristic and sub-optimal control mechanisms for voice.

In this section I shall describe some of the models that are used to explain the coordination of the high level cognitive and motor skills required (Davidson, 2010) for singing. Motor control is complex in that there is not a linear relationship between neural activation and muscle force (van Soest & van Ingen Schenau, 1998). Other factors affect the biomechanical relationship such as muscle fibre characteristics, tendon elasticity, interaction between body segments and physical forces acting on the body from the environment such as gravity (van Soest & van Ingen Schenau, 1998).

Models of motor control of body movement

The style of movement used by many WCP singers and, in particular, R & B singers, involves explosive body movement, that is, they move quickly and powerfully from movement to movement or from stillness to movement and back again. Van Soest and van Ingen Schenau (1998) outlined the various models that have been put forward on how explosive body movements might be controlled. It is thought that motor control is made up of a hierarchy of processes with simpler tasks being handled by the lower sub-systems. These sub-systems from lowest to highest are as follows:

1. During movement, a muscle's force-length-velocity relationship forms a preflex, i.e. a sensory correction in anticipation of a bodily disturbance. This process can deal with small perturbations and, because they are counteracted in advance, there is no time delay.

2. Spinal reflex loops can deal with greater complexity but with a time-delay.

3. Supraspinal system – inputs to the motor neuron pool drawing on information from the musculoskeletal system, external forces, sensory input and movement goals.

How important these different levels are depends on the task. High-speed tasks can be dealt with by the lowest and instantaneous level whereas slower tasks are controlled by the higher level neural feedback loops which cause delays. Feedback from this system during movement is likely to produce time delays. Small errors in the supraspinal inputs can have a large effect on explosive movements (van Soest & van Ingen Schenau, 1998). For singers to take advantage of the mechanisms for increasing Ps, they have to carefully time them so that they would not conflict with the requirements of the song. The model described by Van Soest would indicate that the use of preflexes rather than spinal reflexes or sensory feedback would be the most advantageous for the rhythmic accuracy required in WCP music.

Kinematic models and timing

The part of the breath cycle in which a movement occurs is very important in terms of whether it is going to have a positive or negative effect on voice production. A change of leg position can have a negative impact on respiration by restricting expansion of the thorax on inspiration (Gould, 1971) whereas this might facilitate Ps on the sung phrase. For singers to take advantage of movement mechanisms for increasing Ps, they would have to carefully time them so that they would not conflict with the requirements of the song. The issue of the timing of body kinematics and its relation to rhythm has been discussed as being intrinsic to all high level motor skills but especially to musical skills (Shaffer, 1982). Recent theories of tau-guidance (Lee, Craig & Grealy, 1999; Lee, Georgopoulos, Clark, Craig & Port, 2001) address issues related to the co-ordination of multiple movements involving precise timing to achieve a desired goal. They also indicate a possible relationship between the communication of emotion in creative performances involving movement and tau-coupling information about how those kinematics are controlled; in particular, how they are intrinsically tau-guided. This theory might explain how a singer might be able to achieve the highly precise synchronization of respiratory to musical events required in singing. Originally used to explain the precision and timing of the movement behaviour in mammals and birds, this has been tested in humans with hand to mouth movement , infant regulation of sucking pressures in breastfeeding and time intervals (Lee et al., 1999). It puts forward the view that there may exist in some animals and humans an internal coordinative system for high-precision activities in which two factors, or taus, are collected via sensory input. The tau can be a distance, angle or force. By keeping the two taus in a constant ratio, an action known as tau-coupling, the subject can achieve a high level of accuracy when moving through space and dealing with physical forces simultaneously.

Body scheme

In another concept of motor control, multi-sensory inputs inform what is known as the body scheme. The body scheme is described as an internal body representation or model that allows humans to consciously perceive and control the body but also to process multisensory inputs unconsciously, such as those involved in the control of posture in response to movement (Gurfinkel, Levik, Popov, Smetanin & Shlikov, 1986). This includes precise knowledge of the length of body segments and their inertial properties and linkage sequences, muscle adjustment levels required and required responses to predictable perturbations (Gurfinkel et al., 1986).

Brainstem and vestibular system

Neurologically, movement mainly involves spinal nerves and speech mostly cranial nerves but both involve taction and proprioception (Borden, 1979). It is this commonality that is of note. The brainstem integrates what were formerly known as the voluntary and involuntary systems. Posture is an example of such integration since it requires adjustments in movement (voluntary) and the cardio-respiratory system (involuntary) (Yates & Stocker, 1998). How the brain integrates these two systems is illustrated in particular by certain human behaviours that require adjustments from both. Yates cites postural control as falling into this category of behaviour because it requires 1) muscular action to initiate movement 2) sympathetic nervous system activity to prevent blood pooling in the limbs and 3) changes in breathing to compensate for altered loading on respiratory muscles (Yates & Miller, 1998).

Postural control underpins controlled muscle movement including those involved in voice production (Gould, 1971) and proprioception is central to this. The central nervous system receives information from peripherally-located receptors also known as proprioceptors, located in muscle spindles. Some of these receptors relate more to conscious systems and some to the more automatic systems (Gould, 1971). When respiratory load changes suddenly proprioceptive reflexes activate in the same way as they do with limb movement (Newsom Davis & Sears, 1970). Tonic abdominal muscle activity changes with posture in this way (de Troyer, 1983). Movement can either cause muscle to activate or to stop working. For example, in a head down posture lower abdominal activity stops, showing that tonic activity depends largely on the proprioceptive information coming from the muscles (de Troyer, 1983). Proprioceptive neck afferents also affect respiration (Yates & Stocker, 1998) as does afferent input from the tendon organs and muscle spindles of the body although some of these inputs may not be significant (Rimmer et al., 1995).

The vestibular system regulates balance by receiving inputs from the labyrinth, visual and oculomotor system, proprioceptors in axial and limb muscles, and mechanoreceptors in the skin (Yasuda et al., 1999). Different head positions have an effect on respiration via the vestibular system (Yates & Miller, 1998) because vestibular nuclei have projections to the regions of the brainstem which regulate circulation and respiration (Yates & Stocker, 1998). The vestibular system can stimulate respiratory muscle activity, for example, that needed to maintain tidal volume in the standing position. A head-up position stimulates the respiratory system and head-down depresses it via the vestibular system whereas horizontal and ear to shoulder movements do not have any appreciable effect in this regard (Yates & Stocker, 1998).

Emotional motor system

From a respiratory system perspective, the larynx is sometimes regarded as merely a valve that protects the lungs from foreign bodies and regulates airflow. In its earlier, pre-phonatory stages of evolution, this is what it was. It is therefore of no surprise that the same neural structures are involved in the motor control of both respiratory and laryngeal muscles and that these are strongly coupled in their actions (Dromey & Ramig, 1998). Motor control via audition provides feedback too late to modify ongoing vocal behaviour (Borden, 1979). For this reason a control system that allows for the integration of the various body systems involved in speech and singing has been proposed and is known as the emotional motor system (EMS). In this model there two motor systems involved in speech production, one that is voluntary, involved specifically in speech production and the other is automatic or emotion-based system and organizes non-speech related vocalization, including singing (Holstege & Ehling, 1996). Both systems are required for a fully functional and integrated speech and vocal system (Holstege & Ehling, 1996). Indeed, it was the system's occasional malfunction that led to the observation that there were volitional and automatic pathways to vocalization (Holstege & Ehling, 1996). The voluntary system, which is mediated by Broca's area and the motor cortex of the brain, controls many of the muscles of articulation (Davis, Zhang & Bandler, 1996a). The emotional system, originating from the limbic system and the periaqueductal grey matter (PAG) of the mid-brain (Bandler, Keay, Vaughan & Shipley, 1996; Davis, Zhang & Bandler, 1996b), controls the laryngeal and respiratory muscles as well as some of the articulators including the soft palate muscles (Holstege & Ehling, 1996) thereby linking their actions together.

Emotion, automatic body movements and vocalization

Emotions are short in duration, complex and difficult to control compared with moods or traits and are usually generated unconsciously (LeDoux, 1998). Bodily responses are not integral to cognition but are essential to the process of feeling emotion (LeDoux, 1998). Emotions always involve bodily reactions, such as changes in respiration and heart rates (Averill, 1969). It is surprising therefore that there are only a small number of body movements originating from an emotion that are universal (Ekman, 2003). Although best known for his work on universals in facial expression, Ekman also identified a small number of emotional body postures or movements that do not have to be learned because they are "preset" and automatic and therefore exist across cultures (Ekman, 2003). These are

- Anger & enjoyment – movement toward the object that has triggered the emotion
- Fear – freezing to avoid detection or harm
- Disgust – similar to fear but less strong and may include turning away
- Sadness – overall loss of muscle tone resulting in postural slumping
- Contempt – impulse to look down at object of contempt
- Surprise/wonderment – fixed attention on the object
- Relief – relaxation of body posture
- Sensory pleasure – orientation to object, although no movement may occur
- Intense amusement- laughter

In recent research, the expression of pride has been added to this list, comprising a slight smile, the head tilted slightly back and an open posture with the hands on the hips (Tracy & Robins, 2008). This small set of simple, initial, rudimentary actions occur automatically (Ekman, 2003). The emotions expressed here are close to what have been named by various theorists as the "basic" emotions, that is, innate emotions that are common to all humans (LeDoux, 1998) such as anger, disgust, fear, joy, sadness, and surprise (Sauter et al., 2010). Non-verbal vocalizations and facial expressions corresponding to these emotions also occur universally and are recognized across cultures (Sauter et al., 2010). Although it is a short list, it contains emotions that are very important and intensely felt and therefore often expressed in singing (Kotlyar & Morozov, 1976; Sundberg et al., 1995). Beyond these, all other emotional body actions are learned (Ekman, 2003). This indicates that the forms taken by most of the body movement that we observe in singing performance is either determined by physiological function or is culturally determined. In other words, other body movements must either relate to the production of the sound (voice production) or to a culture-specific affective display (Ekman, 1977, 2003). Although movement originating from the experience of emotion and corporeal expressive display is not the focus of this thesis, it is important to attempt to recognize them in order to try to delineate as much as possible which movements are specifically related to voice production. The non-verbal behaviour of WCP singers is particularly idiosyncratic and complex making the process of delineation more difficult. This is further complicated by the fact that the same action can be simultaneously both functional and expressive in singing (Dahl & Friberg, 2007). The expression of some emotions can also be dysfunctional in terms of voice production by creating distress or levels of arousal that are too high for effective vocal performance (Pettersen & Westgaard, 2002). It could be presumed that the number of body movements relating to sound production would be limited because of the physical structures and processes involved, whereas expressive display would have unlimited manifestations that would change with culture, language, meaning, genre and context and the personality and transitory mood of the subject.

Automatic movement originating from real emotion may be different to expressive communication delivered by a performer. There are rules of display that exist within a culture (Ekman, 1977) but there is also an added layer of complexity within the physical display rules within particular style of music. The strong culture of "authenticity" and individuality of expression (Dibben, 2009; Moore, 2002) within the WCP music world is particularly relevant in this analysis. The non-verbal behaviour of several WCP performers have been observed in detail with regard to how non-verbal communication is a tool for providing meaning and information to the audience or fellow performers. Ways of categorizing display behaviour such as those devised by Ekman (Ekman, 1977) have been successfully used to describe the behaviours of Annie Lennox (Davidson, 2001), The Corrs (Kurosawa & Davidson, 2005) and Robbie Williams (Davidson, 2006). The focus on these papers was on non-verbal behaviour by singers as a communicative tool for adding meaning to performance (Davidson, 2001) rather than on function, authenticity of emotional expression or the vocal sound produced in relation to the behaviours exhibited by the singers. The "pop" sub-genre of WCP, to which the three acts above would be regarded as belonging, is considered to be the "most inauthentic music" (Moore, 2002). There is no way of knowing to what degree the WCP singers in the studies above are really feeling the emotions expressed and to what degree it is the appearance of emotion. The perceived authenticity of a singer's experience of emotion while singing is popularly used as a gauge of a singer's quality

(Dibben, 2009; Moore, 2002). Moore delineates different forms of "authenticity" in WCP music with "authenticity of expression" being the one of importance in this discussion, meaning performance of integrity and unmediated communication (Moore, 2002) although his discussion centres on the perception of authenticity by audience members rather than from the singer's own intention or experience.

In classical singing, engaging emotional connectedness as perceived subjectively by the singer has been shown to measurably change respiratory behaviour and the sound emitted as perceived by expert listeners (Foulds-Elliott, Thorpe, Cala & Davis, 2000). Physiologically, intention and task has an effect on the organization of expiratory muscle behaviour (Macefield et al., 1996). Strohl (Strohl, Mead, Banzett, Loring & Kosch, 1981) found that in speech, recitation, coughing and laughter the relative activity of the upper and lower abdomen became equal whereas in normal respiration tonic activity seems to be mainly in the lower abdomen with phasic activity in the upper abdomen. Significantly, when the intended end result of the subjects' behaviour changed so did the type of abdominal activity. Mental imagery has also been found to affect muscle recruitment patterns (Grimby, 1986). Through 'extraordinary motivation and training' recruitment patterns can be reversed and rewiring and chemical changes can occur in motor units which change their function (Grimby, 1986).

Thus, it can be seen that whether a vocal action is planned or involuntary, consciously practised or or implicit has a significant impact on the end result.

"Primal" vocal responses in singing: involuntary versus voluntary

Although there is disagreement on how speech developed in humans, it is considered that certain "vocal expressive-communicative signal(s)" such as moans, sighs, groans, cries and laughter (Ruch & Ekman, 2001) predated speech. These correlate with the universal body movement responses listed above, i.e. cry with sadness or anger, sigh with relief, moan with sensory pleasure, laugh with intense amusement. It is interesting that fear results in freezing, which we would associate with cessation of vocalization in an animal (to avoid detection) whereas fear and anxiety have negative effects on respiration (Suess, Alexander, Smith, Sweeney & Marion, 1980) and can lead to an inability to produce the voice properly in cases of stage-fright or performance anxiety

(Baumeister, 1984). Conversely, accessing reflexive universal human body-voice responses as a means to improving voice production is a method used by many singing teachers. Classical singing pedagogue Janice Chapman (Chapman 1986) uses what she calls primal voice to achieve vocal support. Jo Estill (Estill, 1996) uses sob, cry and laugh as imagery in her voice method for cueing specific physiological configurations that are good for voice production. In particular, she claims to use the sob and laugh to override the primitive closure reflexes governing the ventricular folds in the larynx (Kmucha et al., 1990). A true laugh is associated with reflexive body movement as well as being a neck and laryngeal event (Ruch & Ekman, 2001) and this is different to the voluntary control of the pharyngeal aspect of the laugh that Estill uses. This highlights the importance of both voluntary and involuntary behaviours in the process of singing. Neurologically, singing requires the use of the pariequeductal grey matter in the mid-brain and the tegmentum for the motor coordination of voice whereas the voluntary control of voice requires the forebrain (Jurgens, 2002). Chapman and Estill try to harness reflexive vocalization patterns in their methods but they also focus on voluntary control such as the use of specific torso muscle behaviour: Chapman places emphasis on the sudden release of abdominal muscles in the inspiratory phase (known by the acronym SPLAT for "singers please lose abdominal tension") (Chapman 1986) and Estill emphasizes contraction of the *lattisimus dorsi* in the expiratory/singing phase (torso anchoring) (Estill, 1996).

1.4.3.4 Locomotive movement and singing

Rhythmic locomotive movements are a common feature of WCP singing performance. The effects of locomotion on respiration demonstrate the integration of the various muscular, mechanical and neural effects of movement on respiration. As such, it shows how these different factors may interact during a singing performance. Locomotion produces a cyclic complex of actions performed by the legs, arms and torso, which can be divided into those that are expiratory and those that are inspiratory.

There are possible advantages and disadvantages of locomotion in terms of respiration in animals that might also apply to humans. (Lee & Banzett, 1997), Because the chest wall is used both for locomotion and respiration, these two functions can work either with or against each other:

1. *Locomotion may reduce the energetic cost of respiration:* The mechanism for this is as follows: in walking or running, energy is stored from cycle to cycle. In breathing this cyclic energy is normally expended on overcoming airway resistance or dissipates as heat. Transferring energy from locomotor activity to breathing might reduce the work of respiratory muscles while increasing the work in the limbs.

2. *Locomotive limb muscle activity may be increasing the maximum ventilation possible:* In locomotion the abdominal muscles are activated just before and during foot contact with the floor. The rigid, cylindrical structure created by the contraction of the muscles of the abdominal wall in combination with the sudden increase in vertical force allow a rise in intra-abdominal pressure that is quicker than that produced by muscle contraction alone (Newsom Davis & Sears, 1970). Also, the extension of the abdominal muscles during this action would create more muscle tension and therefore higher pressures than otherwise (Cavagna et al., 1968; Newsom Davis & Sears, 1970).

3. *Respiratory flow direction may be altered:*

    - The visceral piston mechanism causes inspiratory flows when displacing the diaphragm caudally and expiratory flows when displaced cranially

    - Spinal extension tends to cause inspiratory flows and lumbar flexion causes expiratory flows assuming trunk dimensions remain the same.

    - Acceleration moves the rib cage either up or down in both cases causing expiratory flows. Deceleration produces inspiratory flows.

4. *Small but frequent volume changes may reduce airway dead space to zero thereby increasing ventilation*

5. *Synchronizing breath to movement feels comfortable:* Runners find this. Extrapolating to singers, this may be a way of relating the rate of inspiration and pacing of expiration to the rhythm of the music.

6. *Limb impact to the ground creates a compressive force* on the ribcage that increases abdominal pressure, depending on the angle of the force in relation to the hinge axes of the ribs. This translates to increased Ps and potentially greater SPL in vocalization. Limb impact also caused phasic contractions of the abdominal muscles that are normally slow to react in voluntary maneuvers (Newsom Davis & Sears, 1970). These contractions can be useful in creating a rapid increase in pressure avoiding timing delays created by reflexes and electromechanical coupling (Grillner, Nilsson & Thorstensson, 1978).

Disadvantages of coupling respiration to locomotion

The mechanisms outlined above would indicate that walking movements could be advantageous to a singer who had to produce intensity peaks that rhythmically coincided with the stepping action. However, Lee and Banzett (1997) concluded that locomotion may increase the ease of respiration if used correctly but the difficulty of disengaging the two when needed might override the initial advantages of coupling the locomotion and respiration. In singing, the melody makes very specific Ps requirements that change from moment to moment (Sundberg et al., 1991). Entrainment could be counter-productive if the SPL peak required did not coincide with the sub-glottal pressure surge. Control of both F0 and SPL could both be lost in such a situation without a high degree of effort. Effort in singing, on the other hand, can indicate mastery (Bagnall & McCulloch, 2005). Also, where the main purpose is aesthetic and expressive, increased physical effort might be worthwhile if it creates the desired effect in the singer's performance, making singing by definition "inefficient" (Schutte, 1983). It will be of interest to note in the studies that follow, whether singers do employ locomotive movements and if they do, whether these are consistent throughout songs and present any patterns of note with regard to Ps.

1.4.3.5 Accent method

In light of the possible effects of locomotion on respiration, it is interesting to note the body of empirical research on the Accent Method, devised by Danish professor of Logopedics, Svend Smith. This pedagogic method, in which body movement is an important component, is used for improving singing and speech production and for the treatment of communication disorders such as stuttering. It employs rhythmic exercises involving exaggerated respiratory movements that coincide with emphasized syllables within rhythmic patterns. These are combined with rhythmic body and arm movements. A drum and a call-response style of delivering the exercises is used. It is noteworthy in light of the musical focus of this study on WCP music coming out of an African cultural source, that Smith drew inspiration from, and devised the drum patterns used in this method with, an African drummer from the ensemble of African-American singer and dancer Josephine Baker who visited Denmark during the 1930s. The physical actions of the Accent Method exercises are exaggerated versions of the actions of the breathing cycle involving phonation. That is, expansion of the abdomen and chest wall on inspiration and the forceful contraction of the abdominal muscles on the expiration/phonation part of the cycle. This can be seen as directly targeting the muscles that are used in respiratory drive.

In one study, Smith (Smith & Thyme, 1976) found that even a short-term series of 10 Accent method sessions improved 30% of their 80 subjects intensity levels in speech across the full frequency spectrum. It was found that the increases that were above 1kHz increased intelligibility and below 1kHz "convey the impression of a fuller voice". It is significant for singing that the strengthening and improvement of the speed and co-ordination of the respiratory muscles targeted by this method should improve intensity levels across the sound spectrum and not in just one region. This supports the conventional wisdom of singing and spoken voice pedagogy of the importance of support in achieving high intensity in combination with a vocal tone that has the depth or "fullness" of the lower frequency range and the clarity and intelligibility of the high frequency range. What is of significance to this study however is that these results are obtained using a method employing rhythm and body movement to achieve this aim. These are phenomena in keeping with the behaviour of singers of WCP music. So, while Western classical teaching pedagogy works within a paradigm in which the body normally remains still while singing in order achieve a good sound, the conventions of rhythmic movement and gesture of Western contemporary singers may be shown to be not unhealthy. It may in fact be necessary to achieve the goals of a contemporary singer without injury. This is born out in another study of the Accent method (Bassiouny, 1998) that included subjects with a range of both non-organic and organic voice disorders including hyper-functional voice and nodules. It was found that the Accent Method was significantly more successful than voice hygiene advice alone. Other studies have supported Accent Method's efficacy (Kotby & Fex, 1998) and its use, although up until now mainly confined to Germany and Scandinavia, is now spreading more widely (Messum, 1998). This indicates that the voice should be able to remain healthy and may even be made stronger within a vocal paradigm that incorporates body movement.

The literature demonstrates that there are means by which body posture, different types of movement and movement speed may be used to alter Ps and thereby influence the SPL of the sung sound. The movement in this context may not only be seen as a transitional phase between a series of carefully timed optimal postures but the transition phase itself may have positive effects on singing and general vocal health.

1.5 Methodological considerations

Western contemporary popular (WCP) singing presents special difficulties in experimental design because of the diversity of influences, individuality of its practitioners and variation in its performance that are at the core of its character. Many voice qualities are used; often within one song. Singers do not always sing a piece of music the same way: melodies are varied and ornamental notes added and subtracted. There is no one unanimously recognised, acceptable or desirable vocal timbre for WCP singing (Middleton, 2000). These characteristics make the comparisons which are necessary as part of empirical research difficult. Formal training, a criterion that is used in many classical singing studies as a baseline marker of a singer's quality, cannot be used as an indicator of quality with WCP singers since they are usually untrained. Better markers of the quality of a WCP singer include whether the singer is being paid to perform, gets good reviews in the media, attracts audiences or sells recordings.

1.5.1 Participants

1.5.1.1 Singing style

The singers recruited for this study fell within the style categories for music theatre and contemporary singing (Phyland, Oates & Greenwood, 1999). Phyland's contemporary category included jazz, folk, gospel, R & B and *a cappella* but excluded rock singers. Rock singers are noted for their use of textural effects in their singing such as glottal fry (Wilson, 2003) and distortion tones (i.e. like the distorted sound coming from an overdriven speaker) (Borch, Sundberg, Lindestad & Thalen, 2004). As in the case of belt, there are ways of minimizing vocal abuse while using these techniques (Hollien, 1983). However, at least some kinds of distortion tones, which are used, in particular, in metal styles, have been associated with vocal damage (Borch et al., 2004). As such, I deemed it best not to include singers who habitually used these sounds in this research and chose not to include rock singers for this reason.

1.5.1.2 Rhythm and blues/gospel expertise as common factor in participant choice

WCP music is a diverse genre; it can be difficult to identify characteristics that are identifiable in all practitioners. The Rhythm and Blues (R & B) style represents the genre's central musical characteristics. Thus, all the participants were chosen on the basis that they could sing skilfully in either R & B or gospel styles. Reasons for this methodological characteristic are described below:

a. Historically, R & B and gospel singing styles are musical "cousins" (Orgill, 2002) that relate to almost every contemporary singing style. Originally, R & B was the descriptor given to any music that appeared on the R & B commercial music charts from 1940 onwards and was defined as any music listened to by working class African-Americans in the United States (Potter, 2000a). It was multi-faceted, incorporating many singing styles and has been described as "the essence of 20th-century American popular music, not simply an amusing ethnic subset" (Cooper, 1996). It was white country artists such as Elvis Presley who spotted the expressive potential of R & B singing styles and started adding elements of it into their own performance contributing to the creation of rock and roll (Potter, 2000a). R & B's origins and early subdivisions were diverse and included blues, gospel and jazz (Cooper, 1996) and later transformed into rock and roll, soul and more recently rap (Potter, 2000a).

b. High technical vocal demands: R & B (Lovetri, 2002), gospel, soul and rock music feature rapid, variable dynamics and high sound levels and the physical demands are greater than in pop and jazz styles where voices tend to be lighter (Thalen & Sundberg, 2001; Koufman et al., 1996) and the demands of these styles are different (Koufman et al., 1996). R & B singers have strong, attractive voices (Lovetri, 2002) and are highly respected by their peers for their technical standards.

c. High level of variation in movement and vocal dynamics: R & B singers usually demonstrate a high degree of movement in performance. The high level of movement and large and sudden changes in dynamics of both movement and voice meant that, for the purposes of analysis, they were better subjects for observing correlations than singers of a style with a subtler dynamic palette.

1.5.1.3 Professional standing

Because of the lack of a "gold standard" of best practice in WCP singing, it was important that the participating singers were professionals with a proven track record. The singers recruited for this study fell within the definition of professional artist as defined by Throsby and Hollister (2003) in a major study of Australian artists. They defined professional artists as "serious, practising professional artists... [who are]...currently working or seeking to work in their chosen occupation" and operating by the" highest professional standards"(p.14). The taxonomy of singers proposed by Bunch and Chapman (2000) could not appropriately be applied to the local Australian performance situation due to limited professional opportunities, regardless of performer quality. It is often difficult for even high quality singers to make all of their living from singing performance if they work only in Australia, due to the small population and great distances between urban centres making touring expensive and difficult. This is also the reason for not employing the term Contemporary Commercial Music (CCM) proposed by Jeannette Lovetri (2007), since commercial implies good financial return.

1.5.1.4 Participant numbers

It is common for speech and singing studies to have six subjects (Cleveland, Stone, Sundberg & Iwarsson, 1997; Estenne, Zocchi, Ward & Macklem, 1990; Milstein & Watson, 2004; Shipp, 1975). Because the study design included "naturalistic" performances and because of the idiosyncratic nature of WCP performance, there was some risk that the data of some singers might not be useable for comparative purposes because like must be compared with like with regard to laryngeal mechanism, F0 and articulation if conclusions cannot be drawn about subglottal pressure characteristics. If singers improvised changes to the melody line or the words used on the section to be analysed, they would not be able to be compared acoustically to their other samples. For this reason, additional singers were recruited to ensure that there would be at least six usable data sets.

1.5.2 Research and non-notated music and improvisation

Most empirical music performance studies are based on notated music, which makes the goals of a performance clear (Palmer, 1997). This makes research easier to control than research focused on non-notated music for which the goals of performance may not be known or may shift throughout the performance (Palmer, 1997). Thus, the empirical music literature has been directed largely on the literate art music of Europe and the Americas (Baily, 1985). As discussed in the introduction, most WCP songs are written and performed without the use of notation; therefore, finding a method of data collection that produced measurable and analyzable data of any value, but that was also ecologically sound, that is, a method that did not impede the singers tendency to improvise, which would have undermined the very essence of the aesthetic driving the musical style, was difficult. Changes of register, dynamic and pitch all indicate alterations in the means of voice production. It was important, therefore, to find a way of confining the singer subjects' behaviour enough to acquire valid data for analysis while allowing the singers to feel unconstrained enough to perform well. For this reason, I decided not to direct the singers in their interpretation and to allow them to sing the song in the key of their choice. Forcing a singer out of his or her *tessitura* (the part of the pitch range which is easiest for the singer (Burgin, 1973)) could create vocal strain and change their characteristic spectral balance and SPL level, making it both ethically dubious as well as limiting the validity of the resulting acoustic data.

1.5.3 Cueing vocal and movement behaviour

The aim was to study intensity and body movement variation during natural, spontaneous, characteristic singing behaviour. How to achieve truly spontaneous behaviour under experimental conditions was challenging because psychological factors have a strong impact on respiration (Mead & Agostini, 1985-7). Various researchers have observed changes in respiratory kinematics after asking subjects to target specific phonational intensity level increases, some using external goals such as reaching a specific intensity using an SPL meter (Stathopoulos & Sapienza, 1993) or by perceptually monitoring the sound level of their own voices (e.g. by asking them to speak at four times their comfortable level (Dromey & Ramig, 1998)). Such methods require the subjects to use volitional control of sound level variation in a way that does not occur in spontaneous voice production (Huber, 2007). The manner of eliciting intensity variation has a major effect on the respiratory and laryngeal strategies adopted and the cues are linked to specific strategies (Huber, 2007).

Giving instructions to participants on how to behave during the inhalation phase of respiration can also alter involuntary laryngeal behaviours. In one study, phonating subjects were asked to expand their abdomens when they breathed in and the larynx was found to lower before vocalising (Iwarsson & Sundberg, 1998). In a later study with the same first author, when subjects inhaled without direction, the belly out position caused the larynx to rise (Iwarsson, 2001). The author attributed this paradoxical difference in result to the direction of breathing behaviour. Larynx height can have significant effects on the laryngeal mechanism as well as on vocal tract length, thereby affecting the sound spectrum and can even potentially affect vocal health (Iwarsson, 2001; Iwarsson & Sundberg, 1998).

In recognition of the sensitivity of respiration to even indirect instructions and in order to avoid cueing non-characteristic respiratory or laryngeal behaviours, Winkworth and Davis (1997) attempted to elicit automatic intensity increases in speech by using the Lombard effect, which is an automatic response whereby people increase their phonation intensity with increased ambient noise levels (Lane & Tranel, 1971; Siegel & Herbert, 1974). Huber (2007) considered this a more "natural" experimental method because of its automaticity but having the disadvantage of degrading auditory feedback to the subject. My aim was to create automaticity in intensity variation without degrading auditory feedback.

In order to create an environment where this automaticity occurred, I therefore chose, firstly, to give the singers something that they perceived as a musical rather than a technical task. I asked them to sing sections of songs rather than individual notes, as in many voice studies, so that there was more focus by the singers on musical and interpretative values to avoid inadvertently drawing their attention to the actual focus of the study which was body behaviour and respiratory drive. I also chose to use the musical term 'dynamics' when instructing the participants, rather than the term intensity or loudness since it has been shown that asking for increased loudness causes singers to resort to stronger laryngeal muscular effort rather than increased respiratory drive (Huber et al., 2005). Rather, I wanted them to think I was looking at musical contrast and variation. I was careful to avoid any terminology relating to any specific vocal technique that might confuse or change their perception of the task, in particular, anything that might make them conscious of breathing, it being particularly sensitive to cueing (Mead & Agostini, 1985-7).

1.5.4 Equipment and methods

1.5.4.1 Finding an ecologically valid procedure

Once I had decided that I wanted to look at the interaction of body movement and vocal intensity, there remained a large range of technical options for collecting acoustic and movement data and for designing the experimental protocol. It was a high priority that the information collected was meaningful to singers, as well as adding significant information to the body of knowledge about singing. To fulfil these criteria it was necessary to make ecological validity a high priority (Chaytor & Schmitter-Edgecombe, 2003). This involved designing tasks for the singers that were authentic to their professional experience and that simulated or resembled a real-life performance context.

Avoidance of invasive procedures

I experienced laryngeal endoscopy as a subject in a singing research study near the beginning of my candidature. This involves a flexible fiberoptic endoscope being introduced through the nasal passage and velum (soft palate) and then into the throat so that vocal fold activity can be viewed directly (Lim, Oates, Phyland & Campbell, 1998). It is performed after the administration of an anaesthetic nasal spray. I found the procedure extremely uncomfortable and distracting, while other participants in the study did not. I also considered that my own experience of singing while undergoing endoscopy was far removed from my usual performance behaviour. Every time I regained concentration for a moment and moved my head, neck, throat or jaw in the process of singing, the physical contact with the equipment brought me back to awareness of the equipment and my focus was taken away from singing. In the end, my usual behaviour altered to the extent that I maintained a rigid body position to minimize discomfort. In addition, although it was not a damaging procedure, it made me question the validity of the results collected when a singer is distracted by discomfort or fear of vocal damage. It also made me aware of the high level of variability in responses to invasive technologies used for data collection. Research has shown that laryngeal endoscopy changes vocal behaviour by altering frequency range and maximum phonation time (Lim et al., 1998). I decided to avoid highly invasive research methods that would cause discomfort or change vocal behaviour. In addition, since only high quality professional singers were recruited as subjects, I thought I would find it harder to recruit participants if they feared damage to the irreplaceable instrument on which their career was based (whether that fear was well-founded or not).

Electromyography

Early on, I considered collecting data on individual muscle activation during high SPL moments such as the classical singing studies of Pettersen and colleagues (Pettersen, 2005; Pettersen et al., 2005; Pettersen & Westgaard, 2002; Pettersen & Westgaard, 2004). The method most often used for this in singing studies has been electromyography (EMG), using either surface electrodes and or intra-muscular hooked wire electrodes (de Troyer et al., 1990). Numerous surface EMG studies of abdominal muscles have been conducted but their accuracy has been questioned compared to protocols in which intra-muscular electrodes were inserted using ultrasound for accuracy of placement (de Troyer et al., 1990). Such methods would be very distracting and invasive to singers.

Ultrasound

With assistance from staff from the Faculty of Health Sciences at The University of Sydney, I tried using ultrasound without EMG to observe my abdominal muscles while singing. Ultrasound presented interesting and subtle images of muscle behaviour but, although it produced no discomfort, there were signficant movement restrictions placed on the subject and the equipment was highly intrusive. In addition, I was advised that ultrasound is difficult to stabilize and that the images are difficult to interpret in an area like voice research where changes are subtle.

Inverse filtering

Since subglottal pressure (Ps) is the main driver of SPL variation, I also considered trying to directly measure Ps in order to track its relationship to body movement during singing. Direct measurement of Ps during phonation involves a transcutaneous puncture of the crico-thyroid membrane (Finnegan et al., 2000), a highly invasive procedure. For this reason the indirect method of inverse filtering has become common in singing research investigating Ps. In inverse filtering, oral pressure is recorded while the subject produces a voiceless plosive followed by a vowel, for example the syllable [pæ:], and from this the subglottal pressure is estimated (Plant et al., 2004; Sundberg, Titze et al., 1993). However, the validity of this method has been called into question (Plant et al., 2004; Plant & Hillel, 1998). Although, it can be accurate in measuring onset pressure and following a plosive consonant (Sundberg, Titze et al., 1993), it has been found to be inaccurate in the case of dynamic and extended phonation (Plant et al., 2004; Plant & Hillel, 1998). Also, this method would clearly not be possible to use during prolonged singing, especially one in which the subject is moving since the estimates of Ps are based on the presupposition that the vocal system is static during the analysis interval. In addition, such studies involve the use of flow masks (Sundberg, Titze et al., 1993), a form of equipment that would direct the attention of the singer to breathing. Face masks for monitoring breathing have also been shown to increase singers' perception of respiratory effort possibly due to altered muscle recruitment patterns (Collyer & Davis, 2006).

1.5.4.2 Advantages of SPL as an acoustic measure

There were two main approaches that could have been taken to measuring dynamic variation. One would be to take a perceptual approach and measure loudness variation using a perceptual measure such as phons (Zwicker & Fastl, 1999b). However, the main aim was to observe the intersection of movement behaviours with measurable sound output. This called for an acoustic measure. Voice data featuring sound pressure level (SPL), measured in decibels (dB), is widely available and quoted in the voice literature.

The use of this measure would allow for comparison with a large body of reputable research in voice.

1.5.4.3 Perceptual equivalence of sound pressure levels

SPL can also be used as a measure of perceived loudness (Sundberg, 1995) if other factors such as frequency are taken into consideration (Johnson et al., 1993; Stevens, 1972; Sundberg, 1987c; Suzuki et al., 2003; Zwicker & Fastl, 1999a). There are international standards determining loudness levels and their equivalence in decibels at specific fundamental frequencies, which have been calculated using discrete pure tones (Suzuki et al., 2003; Suzuki & Takeshima, 2004) or masked by noise (Johnson et al., 1993). The minimum difference in SPL that can be discerned by a listener, known as just noticeable difference (JND), of a pure tone is around 1dB (Zwicker & Fastl, 1999a) with a 10dB difference being perceived as a doubling of loudness (Stevens, 1972). Listening to a complex sound in context, such as music, is different to isolated pure tones. Among professional listeners of the music industry such as sound engineers and producers of recordings, it is considered that the minimum difference in SPL that can be discerned by a listener of a complex sound is around 1dB (D. Huber & Runstein, 2005).

1.5.4.4 Sound pressure levels as a gauge of the vocal health and fitness

WCP singers produce high sound levels in spite of the use of amplification (Borch & Sundberg, 2002) and it is popularly perceived as a measure of vocal prowess. SPL is used in the world of speech pathology as a gauge of physical vocal performance (Corthals, 2004) and efficiency (Tang & Statholopoulos, 1995). As discussed at the beginning of this introduction, the variation of SPL is a strong indicator of emotion to the listener (Scherer, 1995; Sundberg, 2000; Sundberg, Elliot et al., 1993; Sundberg et al., 1995). Therefore, vocal SPL would be a good measure of the overlap between physiological, acoustic and perceived performance quality, making it an ideal measure for preliminary and exploratory research into the acoustic output of the embodied voice.

1.5.4.5 SPL as surrogate measure of subglottal pressure

There is a further advantage of measuring SPL. As outlined in the section on glottal closure, the contributions of glottal closure (6%) and respiratory drive (94%) to Ps remain proportional throughout SPL variations (Finnegan et al., 2000) due to laryngeal reflexes in response to pressure change (Henriquez et al., 2007). Thus, a difference in SPL can be assumed to originate from changes in Ps, meaning that SPL could be seen as a surrogate measure of Ps change. This could then be analysed in relation to body movement that has been shown to affect respiratory drive. Surrogate measures or endpoints are used in clinical trials when a direct measure might be too invasive or uncomfortable to perform (Prentice, 1989). A surrogate measure, which must relate directly to the variable under scrutiny, replaces the variable of primary interest when it cannot be observed directly (Prentice, 1989).

Because of the complex interactions of the three sub-systems of voice production, if SPL were to be a surrogate measure of changes in subglottal pressure in the respiratory system, then this could only be validly compared if fundamental frequency, mechanism and articulatory variables were kept constant. Because of the co-variation of both pitch and intensity with Ps it is important that, with regard to Ps comparisons are only made within one subject on the same pitch (Titze, 1988). In a musical context, this meant the melody and lyric would have to be the same but also that the key would need to be the same to compare SPL as a surrogate measure of Ps across singers. Because the intention was to recruit only high quality professional singers, it was unlikely that they would be all of the same voice type, meaning that it would be unlikely that they would all choose to sing in the same key. This meant that although intra-subject comparisons with regard to Ps could be made, for example, between experimental conditions, inter-subject comparisons would be limited with regard to drawing conclusions about Ps.

1.5.4.6 Eliminating articulation as a variable

In studying intensity control, an issue worthy of consideration is whether the three parts of this vocal mechanism can be isolated for scrutiny since phonation can only be produced when all three are in operation. Of the three subsystems of voice production, respiration and phonation are more strongly linked than articulation (Dromey & Ramig, 1998). This is due to respiratory and laryngeal muscles sharing the same neural structures for metabolic respiration (Davis, Zhang, Winkworth et al., 1996). When intensity in speech changes significantly as a function of lung volume it has more effect on phonation than on articulation (Dromey & Ramig, 1998) indicating that if articulatory variables are kept constant that articulation can be largely removed as a consideration in terms of intensity. It is important, therefore, in the investigation of intensity controlling behaviours, that a bright-sounding vowel with greater amplitude of high harmonics, which may be both measurably of higher intensity and perceptibly louder, is not compared with a vowel in which lower harmonics dominate. Some vowels, such as [ee] an [oo], also require higher Ps to produce the same SPL level (Ladefoged & McKinney, 1963), due in part to the smaller mouth opening for these sounds (Van den Berg, 1956). Therefore, different vowels cannot be compared where the relationship between Ps and SPL is being observed with regard to vocal function. Fortunately, a song in itself provides this consistency of F0 and vowels.

1.5.5 Ecologically valid movement analysis

Quantitative methodologies measuring breathing activity through thorax movement require the rest of the subject's body to be completely still. For example, in a study on actors' voice use, a leaning board was used to stop postural change in order to view in the activity of the larynx in isolation (Ryker et al., 1998). The methodology used here aimed to allow postural change in order to see what working singers do in normal circumstances. Breathing for singing is often discussed as if it occurs within a static system. For example, Bouhuys' seminal, and still much quoted study of airflow and lung volume events in classical voice implies through its title, the "Kinetics of singing", that the singer is moving but the paper only deals with the "movement of the respiratory bellows", that is, the ribcage, in relation to how subglottal pressure is produced (Bouhuys et al., 1966). The singer's ribcage in the Bouhuys study was allowed to move freely, but the rest of the singer's body was enclosed in a wooden box up to the neck (body plethysmograph) and sealed around the neck with a rubber membrane to stop movement and create a seal so that a vacuum could be created in the box in order to accurately measure lung volume excursions. This method is used to observe lung function (Gould, 1971) and although much interesting data was collected, it is a study of the statics rather than dynamics of singing (Agostini & Mead, 1985-7). Within the study of respiratory physiology, a distinction is made between the static and the dynamic aspects of respiration (Agostini & Mead, 1985-7; Mead & Agostini, 1985-7). Statics concerns the volume-pressure relationships of respiration at various stages in the respiratory cycle (Agostini & Mead, 1985-7), whereas dynamics observe factors such as respiratory drive, the forces that result from it such as acceleration and the effect on gases and tissue (Mead & Agostini, 1985-7). Although the technology has improved considerably and the use of magnetometers and respiratory induction plethysmography (Respitrace) to measure rib-cage and abdominal dimensions have reduced the invasiveness of earlier methods, the technology still requires that the subject remain stationary during assessment. The equipment focuses the subjects' attention on their breathing because of its location on the body. It was for these reasons that I chose not to use magnetometers for this research although it had been used successfully in research into respiratory patterns in western classical singing (Thorpe, 2001), the postures of which are more static than those in WCP . Newer portable versions of Respitrace (Gastinger, 2010) and other motion capture technologies show promise for use in this area of research but were not available to us at the time of this study.

Since it is now known that breathing causes not only the thorax to move, but the entire torso or trunk (Hodges et al., 2002), it was important in the studies that follow to allow the singers' entire bodies to move freely, not just the thorax. Respiratory drive in a moving body during singing had not as yet been observed.

1.5.5.1 Visual observation of respiratory strategies

The breathing system provides possibilities for many different ways to both inhale and exhale, which means that the same Ps can be produced by different respiratory muscle recruitment strategies (Leanderson & Sundberg, 1988). Importantly, for the conduct of the studies that follow in this thesis, many of these 'can be detected by direct observation' (Leanderson & Sundberg, 1988). For example, the narrowing of the abdomen can indicate activity of the oblique muscles or the expansion of the ribcage can indicate an increase in lung volume (Thorpe et al., 2001). However, analysis of this kind is complex since ribcage or abdominal dimensions can also change without airflow occurring as in the case of an iso-volume maneuver in which the ventral wall of the abdomen is pulled inwards with the glottis closed (Konno & Mead, 1967). The validity of assuming a correlation between torso expansion and internal volume in singing has been questioned, especially when thoracic pressure is high or the torso is in movement (Thorpe et al., 2001). There are quantitative means of measuring video images of body movement (Gonçalves & Leonard, 1998) but this would be of little value without first principles to work from in analysing the images. Due to the preliminary nature of these studies, I chose, therefore, to do qualitative frame-by-frame analysis of movement during singing and to observe the associations between these and acoustic events.

1.5.5.2 Cueing in the second condition

I chose two movement conditions to observe changes in acoustic events: one with the direction to move freely as in performance one with the direction to stand still as if directed to do so in a stage performance. Alterations to cueing were expected to change the respiratory behaviour of singers since preparing not to move also has significant effects (Sterr, 2005). However, singers are often given such directions in their performing lives in recording and television studios, in large stage events where a stage director is involved and, of course, music theatre singers are highly experienced in receiving physical direction because they are also expected to act and dance. It was therefore assumed that the "no movement" instruction would constitute a normal performance requirement for the singers, although possibly not one that would be preferred by them. I also chose language and imagery evocative of the stage and stage direction in order to reinforce the non-movement condition's connection to the singers' performance experiences.

1.5.5.3 Degrees of freedom

In the study of normal human motor behaviour, there will be a high number of movement variables that are not necessary to the achievement of the main goal, an issue known as the degrees of freedom problem[1] (van Soest & van Ingen Schenau, 1998). However, the degrees of freedom problem is normally not an issue in the case of the optimization of an aspect of an expert level environment-specific goal such as an elite athlete sprinting a specific distance or, in this case, a professional singer singing a song. It is not a problem because there are a limited number of variables that can deliver such optimization (van Soest & van Ingen Schenau, 1998).

1.5.6 Protocol

1.5.6.1 Modelling in place of instruction

Because I had observed movement at points of high intensity in high belt range, a condition in which strong glottal adduction and high Ps occur (Björkner et al., 2005; Stone et al., 2003), I wanted to reproduce this condition in the protocol. However, I did not want to prompt the singer participants to sing in any particular way. Since belt has many definitions amongst practitioners and some never use the word, it was not appropriate to ask them for a particular voice quality. Instead I decided to use a recording of an expert singer as a model, which would allow them to learn the song in a manner familiar to them, that is, by listening and imitation, and secondly to avoid having to describe the voice quality in words that may have been confusing.

I chose a song that intentionally contained sections that were high in both F0 and SPL. This would allow the observation of expert singers performing at their physical limits

[1] The use of the term "degrees of freedom" in this context is different from the statistical definition of degrees of freedom.

while giving the singers the option to change the key to fit the song within the range of their *tessitura.* Good quality, high pitch tones have a small dynamic range that lie near the maximum possible sound level (Schutte, 1983, p.151). Voice range profiles also show that the dynamic range is reduced at the extremes of pitch in the different registers (Roubeau, Castellengo, Bodin & Ragot, 2004). Although these pitches described are at the upper pitch limit for belt voice, they are not at the upper limit of the entire vocal pitch range of all voice qualities (Schutte & Miller, 1993).

1.5.6.2 Choice of Aretha Franklin as a model

Aretha Franklin was chosen as the model for this study because of her "pyrotechnique" (Heilbut, 1985), for her significance as the singer who first brought R & B female singers to the attention of an international audience and her importance in the formation of contemporary popular vocal style and technique (Cooper, 1996). It is for these reasons that she became the first woman to be inducted into the Rock and Roll Hall of Fame (2007). Even very young contemporary singers, whom I have taught, male and female, are aware of her and have great respect for her. This is also, in part, due to the resurgence of R & B in recent years as a popular genre because of its association with rap. This was important because I expected the age-range of participants to range from young to middle-aged and the singing task needed to be attractive to all ages. The only danger was that the singers would be intimidated by being presented with a song modelled by someone of the stature of Aretha Franklin. To offset this, I chose the first part of the song, which was the least demanding in terms of belt pitch range and melisma (i.e. complex ornamentation), but still presented the very high vocal demands required of the study.

The early history of WCP demonstrated the ease with which a performer could move from blues, country, R & B and gospel to rock and roll due to the pervasive influence of the Pentacostal church movement (Mosher, 2008). Aretha Franklin was one of these artists. Pentacostalism emphasises spontaneity, strongly emotional singing accompanied by unbridled physical movement and has its origins in West African ecstatic spiritual practices (Mosher, 2008).

1.5.6.3 Warm-up in protocol

It is good singing practice to warm up the voice before singing at performance levels (Elliot, Sundberg & Gramming, 1995). Many WCP singers have a specific warm-up routine. I decided not to make a warm-up on-site a compulsory part of the protocol, partly out of respect for the singers' professional judgment, but also because they are less in need of warm-ups than amateurs since they are in a perpetually warmed up state (Elliot et al., 1995). Instead I decided to ask them if they needed time to warm up and allowed for that warm-up time within the protocol if they needed it. In addition, all singers were asked to provide two song excerpts from their own repertoire in addition to the one common song excerpt provided. This ensured that the singers were warmed up by the time they sang the target song.

1.5.6.4 Microphone technique

"Microphone technique" is a method whereby the singer moves a handheld microphone to varying distances from the mouth in order to control dynamic variation and to avoid distortion (Edwin, 2001). Although all WCP singers use microphone technique to some extent in live, amplified performance, its use varies widely depending on the response of the microphone they habitually use in performance, what they are hearing while they perform and interpretative and stylistic choices. The most common manifestations of this technique are for singers to move away from the microphone on high-pitched, loud notes and in closer on quieter notes. The effect of this vocal technique on the recorded signal is similar to compression, that is, dynamic range is reduced. Therefore, microphone technique had to be eliminated in order to get an accurate record of the dynamic variation. It was therefore decided that the microphone would be mounted on a headset to keep the singers' distance from the microphone constant. This method has been recommended for recording opera singers (Cabrera, Davis, Barnes, Jacobs & Bell, 2002), who do not use microphone technique and remain relatively stationary compared with WCP singers.

CHAPTER 2: CHARACTERISTIC SINGER MOVEMENTS AND SOUND PRESSURE LEVEL VARIATION

Singers perform so many functions that it is hard to know where to begin when observing them. The expressive behaviour of singers is varied and idiosyncratic and interacts in a complex way with verbal, body and musical language and cultural conventions. It is easy to lose sight of the fact that this communicative art involves an embodied instrument. This instrument must function optimally in the background at all times. We know this implicitly; in a sense, every listener is an expert since we are all players of the voice, even if only for speech.

Percussionists are aware of the importance of body movement in their playing in a way that singers may not. The percussionist's relationship to the instrument with regard to movement is clear and visible: an arm moves, a hand holds a drumstick that hits a drum that makes a sound. Even this relationship can become complicated in a musical context: an arm that is raised higher before hitting a drum can serve purposes both musical and physical: harnessing gravitational force to increase the impact to get a louder sound (Dahl, 2000) while the stretch created increases muscle power (Cavagna, Dusman & Margaria, 1968; Edman, Elzinga & Noble, 1978) and efficiency (Wilson, 1991). Analogous muscle actions are also occurring in the singer's body but in a way that is much less obvious to the observer, because the muscles activated in singing are less visible than those activated in the limbs.

An extreme and therefore illuminating, example of dramatic arm movement in instrumental playing is the athletic traditional drumming of Okinawa, Japan where large arm movements perform these functions but also take on a ritualistic aspect that can be also be viewed as a dance (Sutton, 1980). In this context, the ritual distracts the audience from the movement's function in the execution. Similar distractions from function exist in WCP singing where we may view various movements as stagecraft or affective gestures (Davidson, 2001, 2006; Kurosawa & Davidson, 2005).

Movement during singing can serve similarly complex purposes from the functional to the ritual but they are much harder to verify. The instrument is merged with and concealed within the body, making the task of identifying what is directly involved in making music much more difficult. Added to that, is the enormous complexity of the process of singing which makes it very hard to tease apart which aspect is instrument and which player. In the paper that follows, an attempt was made to delineate in particular which body movements, if any, were associated with sound pressure level (SPL) variations but also to observe the general trends in body movement that related to the other audible aspects of singing.

PAPER 1

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Please refer to the following 21 pages.

A preliminary investigation into the association between body movement patterns and dynamic variation in western contemporary popular singing

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• **Abstract**

This study assessed the presence of body movements that may be common to all western contemporary popular (WCP) singers that may be integral to both the physical production of the sung sound and to acoustic output, in this case sound pressure level variation. Since torso movement appears to be closely linked with dynamic variation in this style of singing, the study focused on the activity of the torso. 3-D video footage of the body movements of six professional WCP singers singing the same R & B song was collected. Antero-posterior (AP) torso movement direction frequency and characteristics at the point of maximum sustained SPL and $f0$ (peak note) on the vowel /ɛ/ were analysed. The most common movement of the torso was in a posterior direction, reaching its point of maximum displacement from the starting position on the peak note. Strong anterior torso movement on the peak note, which took the torso forward of its anatomical position was associated with the head forward position and vocal distortion, indicating that this movement at a point of high SPL may present a vocal health risk. These results indicate that the AP torso movement of WCP singers has a function in voice production and that not only body posture but the manner of movement from one body position to another is significant to vocal health and sound production, especially in styles where high sound levels must be achieved and where a high level of body movement is required in performance.

Keywords: Western contemporary popular singing, Body movement, Sound pressure level, Subglottal pressure, Dynamic variation.

Observations of the body movements of western contemporary popular (WCP) singers have largely focussed on their expressive and communicative functions (Davidson, 2001, 2006; Kurosawa & Davidson, 2005) although, in singing, the body is used simultaneously to both communicate meaning and produce music (Kurosawa & Davidson, 2005). Little observation of the possible voice production functions of body movements have been reported in the literature, although a wide range have been identified as being associated with other functions such as the communication of linguistic meaning (Goldin-Meadow & McNeill, 1999), the expression of emotion (Ekman, 2003) and some to performance or display behaviour that relates to the musical style or context, such as the posturing of an arena-style rock concert (Davidson, 2001, 2006). The use of spontaneous hand gestures with speech is universal (Feyereisen & de Lannoy, 1991), but the form of these gestures is individually, linguistically or culturally specific indicating a communicative (Goldin-Meadow & McNeill, 1999) rather than a voice production function. Beyond a small set of less than twelve universal emotional body postures, all other emotional body gestures are learned (Ekman, 2003). A combination of observation and empirical research (Cross, 2003) may allow the identification of movement behaviours during vocal performance that relate to both physical production and acoustic output. Because this is the first paper of its kind relating to WCP singing, our focus was on global, gross body movement patterns at points of maximal sound pressure level (SPL) that may provide a guide for more highly controlled studies of singers in the future.

The observation of the authors that trunk movement appears to be closely linked with dynamic variation in WCP singing provided the impetus for this study. Dynamic variation was defined as changes in sound level (Sundberg, Elliot, Gramming, & Nord, 1993). When singers of WCP music are constrained from moving spontaneously, the sound pressure level (SPL) of their singing is reduced significantly (Turner & Kenny, 2007). Reduced sound output as a result of movement restriction indicates that body movement of WCP singers may have a function in voice production. Most of our empirical knowledge of singing derives from studies involving singers who are immobilised by the technology used for data collection. One example is the body plethysmograph, in which the singer's body is enclosed up to the neck in an airtight box (Bouhuys, Proctor, & Mead, 1966). There are valid reasons for these restraints in the context of the study of voice, but as a result, little is known about the effect of natural body movement behaviour on singing (Dayme, 2006). More recent technology for measuring movement during phonation may preclude accurate sound synchronization or intimidate or distract singers (Giovanni *et al.*, 2006). Because the alteration of cues can trigger atypical respiratory (Huber, 2007) or body (Wilson Arboleda & Frederick, 2006) behaviours for voice production, we employed an observational design to study the body behaviours of expert singers, in order to minimise experimental interference with their normal performance style.

There are other linkages between body movement and dynamics than those proposed in this exploratory paper. Movement stimulates emotion (Dibben, 2004), integrates action and audition in the performance of complex skilled sequences (Pfordresher, 2005), and provides internal feedback about sound levels (Lane, Catania, & Stevens, 1961) to the singer that is faster than that provided via audition (Borden, 1979). This study focused on the linkages between body movement and its effect on respiratory kinematics for SPL regulation in singing.

To understand the relationship between movement and voice, one needs to discriminate between movements that contribute to the physical function of vocalisation and movements related to other functions outlined earlier, by observing the parts of the body involved, their multiple functions (Reed, 1989), mechanical links (Lee & Banzett, 1997) and the context of movement in relation to the three sub-systems — respiratory, laryngeal, vocal tract — within the source/filter model of phonation (Zemlin, 1998). Some movements collectively or individually affect each of these sub-systems. The primary focus of this study was on trunk movements and their relationship with respiratory drive and laryngeal behaviour in the generation of dynamic variation. Although posture is important to singing (Hoit, 1995; Wilson Arboleda & Frederick, 2006), trunk movement in singing has been little studied, with a few notable exceptions in the field of classical singing (Pettersen, Bjørkøy, Torp, & Westgaard, 2005). Existing studies focus on the thorax but do not explore how the body moves in space even though such movement is often required during performance.

A singer can voluntarily control SPL via the respiratory system in the inspiratory phase, by increasing lung volume to make use of passive recoil forces to increase subglottal pressure (Ps) on the subsequent sung tone; and, in the phonatory phase, by using muscle contraction to increase Ps (Dromey & Ramig, 1998; Leanderson & Sundberg, 988; Sundberg, Leanderson, von Euler, & Knutsson, 1991). Ps is the primary mechanism for regulating SPL in singing (Bouhuys, Mead, Proctor, & Stevens, 1968) (Leanderson, Sundberg, & von Euler, 1987). The degree of subglottal pressure is directly related to the work of abdominal muscles, which are the primary expiratory muscles (de Troyer, 1983), and the mode of phonation (Sundberg, Titze, & Scherer, 1993). The abdominal and intercostal muscles can be driven more strongly by voluntary postural movements than by respiratory manoeuvres alone (Gandevia, McKenzie, & Plassman, 1990). Postural changes prior to vocalisation in classical singers (pre-phonatory posturing), occur prior to sudden increases in SPL (Thorpe, Cala, Chapman, & Davis, 2001). Body movements during singing may therefore be related to management of lung volume and subglottal pressure for SPL regulation.

The popular notion that posture is static has influenced much singing teaching (Hudson, 202). However, even a stable quiet standing posture involves small compensatory movements that are essential to maintaining equilibrium (Hodges, Gurfinkel, Brumagne, Smith, & Cordo, 2002). In quiet standing, the body may perceptually appear to be still but is continuously moving to maintain equilibrium in the face of small periodic perturbations such as heartbeat (Sturm, Nigg, & Koller, 1980) and respiration, increasing with greater challenges such as deeper breathing (Hodges *et al.*, 2002). Antero-posterior (AP) torso movement direction also relates to respiratory phase, with spinal extension occurring on inspiration and spinal flexion on expiration (Hodges *et al.*, 2002). Lateral movements, on the other hand, may not be as strongly linked to respiration (Bruno *et al.*, 2007).

The body is not well adapted to maintaining a vertical posture (Hodges *et al.*, 2002) but remains stable through a combination of mobility and stability organised by the central nervous system. Compensatory changes in posture in response to respiration are created by phasic activation of the muscles of the hips and trunk, which increase with greater voluntary respiration (Hodges *et al.*, 2002) or during speech, where movement from the centre of gravity and AP movements of torso, thigh and head increase substantially with SPL increases triggered by the Lombard effect (Giovanni *et al.*, 2006). We therefore hypothesised that AP torso movement may have the most consistent relationship with dynamic variation in singing.

Respiratory muscles also have postural and movement functions, that can affect respiration (Reed, 1989) and thereby phonation. Non-respiratory actions activate the abdominal muscles (Hodges, Gandevia, & Richardson, 1997), producing either expiratory or inspiratory effects. Compensatory movements in reaction to respiration are variable even within subjects, in terms of pattern, direction and amplitude, as long as the contributions to the centre of pressure are similar (Hodges *et al.*, 2002). As observed in classical singers, training effects, and body or torso type (Hoit & Hixon, 1987) produce intra-subject variability in respiratory strategies (Lassalle, Grini, Amy de la Breteque, Ouaknine, & Giovanni, 2002). There may therefore be more than one movement strategy that is compatible with contemporary singing.

Because shoulder and thorax muscles are interconnected, upper arm movement affects respiration, whereas hand and most lower arm movements do not (Jensen, Schultz, & Bangerter, 1983). Though peaks in intra-abdominal pressure (IAP) occur at the frequency of shoulder activity induced by arm movements (Hodges & Gandevia, 2000), arm behaviour has variable effects on respiration depending on position and action (Alison *et al.*, 1998; Couser, Martinez, & Celli, 1992). We would therefore not expect to see consistent connections between dynamics and hand and arm movements.

Locomotion involves both arms and legs and is expiratory in action (Lee & Banzett, 1997) causing phasic contractions of the abdominal muscles (Saunders, Rath, & Hodges, 2004), which are normally slow to react (Newsom Davis & Sears, 1970). Such contractions may be advantageous in creating a rapid increase in pressure (Grillner, Nilsson, & Thorstensson, 1978), which may create small but significant surges in SPL (Zwicker & Fastl, 1999) required for rhythmic emphasis.

Such movements must be accurately synchronized to prevent musical inaccuracies. Additionally, during locomotion, leg actions are more strongly associated with expiration than arm actions (Alison *et al.*, 1998), which indicates that singers may need to use leg movements more cautiously than arm movements in order to manage airflow and Ps. Thus, the mechanical and neural links between movement and respiration can be both helpful and unhelpful to a singer (Lee & Banzett, 1997) depending on how and when they are applied. Locomotion lowers the energetic cost of respiration, such as the entrainment of breath to stride in running (Bernasconi & Kohl, 1993), but if the mechanical link is too strong for the ventilatory task, the cost of uncoupling the breath from movement can be greater than the advantage of entrainment (Lee & Banzett, 1997). Thus, the use of locomotive movements by singers may lead to problems maintaining that movement during passages of the song that present higher respiratory demands. We would therefore expect to observe limited use of the lower limbs outside of points where rhythmic emphasis or other peaks in dynamics occur.

We therefore hypothesized that there would be a consistent association between dynamic variation and AP torso movement, but little or no association with lateral torso movements, head, hand and lower arm movements.

Method

- **Participants**

Participants were six healthy, professional singers (1 male and 5 female) of WCP music (Table 1) aged between 21 and 46 years. By recruiting successful, established singers, it was unlikely that their habitual vocal behaviours created risk of vocal damage (Phyland, Oates, & Greenwood, 1999). This was important for recommendations arising from this study. All participants performed professionally in R & B style, music theatre, jazz, folk, gospel, Latin and blues styles. Rock singers were excluded because of their use of techniques that may affect vocal health (Borch, Sundberg, Lindestad, & Thalen, 2004). Four (Singers 2, 4, 5, 6) were experienced *a cappella* singers and all were experienced in recording studio conditions. Since participants were proficient in more than one WCP music style, they were asked to nominate their primary style (Table 1).

- **Considerations for experimental design**

To avoid using cues that might trigger atypical behaviours, verbal instructions were minimised. Participants were provided with a vocal model of a song on a sound recording (common song). The R & B/soul song *I Never Loved a Man (Like I Love You)* sung by Aretha Franklin (Franklin, 1998) was chosen because it provided a model singer with a powerful voice, delivering a high quality performance (Brackett & Hoard, 2004). The song spanned a 2-octave range, originally 175 Hz (F3) - 698 Hz (F5), and had wide variability in dynamics that permitted assessment of how

Table 1

Singer details and number of occurrences of torso movement in a posterior direction at the beginning of 36 peak notes (high SPL and $f0$) and 18 lower SPL and $f0$ notes, all on the vowel /ɛ/

Singer	*Sex*	*Primary Style*	*Years Professional Performance Experience*	*Song Range Hz/Pitch*	**Posterior Torso Movement**	
					High SPL & $f0$ (Peak Note)	**Low SPL & $f0$ Note**
1	F	Pop	5	196/G3 - 554/C#5	**2**	1
2	F	Latin	10	165/E3 - 659/E5	**6**	0
3	M	R&B	6	117/A#2 - 392/G	**4**	0
4	F	Music Theatre	10	175/F3 - 698/F5	**5**	2
5	F	R&B	18	175/F3 - 698/F5	**2**	0
6	F	Gospel	28	123.5/B2 - 494/B4	**5**	1
Total					**24/36**	4/18

the singers behaved in both high and low SPL conditions. This ensured that participants had to negotiate the higher part of their vocal range while engaging a strong voice quality and that even if they lowered the key substantially they would not be able to avoid the transition from chest to head register which in both male and female voice occurs between 294 Hz (D4) and 392 Hz (G4) (Callaghan, 1996; Titze, 1984). Singers were permitted to alter the key of the song to suit their habitual pitch range (Table 1).

A head-mounted microphone was used to keep the singers' distance from the microphone constant without restraining their movement. This was done to prevent the commonly used microphone technique which involves intentionally varying the distance of the mouth from the microphone (Edwin, 2001).

- **Performance tasks**

Lyrics and a recording excerpt (52 seconds) were provided for the common song for the singers to learn prior to data gathering. Singers were advised that they could personalize the song as they would any other song in their repertoire. However, they were requested to maintain a similar dynamic range to the original recorded version provided. They were asked to prepare two short additional song excerpts from their own repertoire with a similarly large dynamic range as the common song. No limitations were placed on $f0$ range, tempo or musical style and no other verbal instructions were given.

Participants sang unaccompanied in a large untreated room at the University of Sydney. Each of their three song excerpts was sung three times. Songs were recorded with a miniature omni-directional AKG C477 condenser microphone mounted on a headset. The signal went through a Behringer pre-amplifier to a Tascam DA-20 MK II DAT recorder.

Participants were videoed with two cameras front and side-on and the images were mixed to one screen using a Panasonic WJ-MX10 mixer. Singers were encouraged to sing and behave as if in performance while remaining within the range of the cameras, represented by a taped rectangle on the floor. The video was intended for later analysis but also to have the effect of making the singers more performance-aware and more likely to behave as if on stage throughout the protocol.

The self-chosen songs were used as a vocal warm-up and also as a means of helping the singers to feel at ease by singing familiar songs. The own-repertoire songs were also used to assess whether the samples taken of the common song represented the singers' usual vocal performance standard. Any takes not deemed to be of acceptable performance quality by the singer or researchers were re-recorded.

Measurement and Analysis

• Peak phrase and peak notes

Line 11 of the common song was the point at which all the singers most often reached and sustained their peak in SPL. This was on the first and third repetitions of the word *never* [original $f0$: 625 Hz]. These were also the highest sustained $f0$s of the song excerpt. This line was therefore referred to as the peak phrase since it represented the most demanding section of the song in terms of maximal voice production. The vowel of the first syllable of the word "never," the vowel /ɛ/ was referred to as the peak note in the subsequent analyses. The song excerpt was sung three times, which meant there were six instances of the peak note for analysis. The second occurrence in the peak phrase of the word *never*, which was a lower SPL, and $f0$, was also analysed for comparative purposes. A transcription of the phrase as sung by Aretha Franklin is shown in Figure 1.

The overall trends in movement were identified by viewing the entire video to ascertain whether movement corresponded to variations in rhythm, dynamics or phrasing and whether these patterns changed on peak notes. Both front and side-on views were observed in this way. An outline effect was added on the peak phrase video that made the singers' movements clearer for observation of movement and

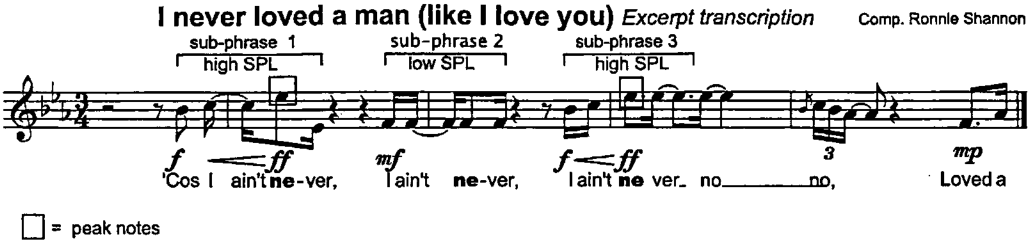

Figure 1.

Excerpt of performance by Aretha Franklin transcribed from the recording provided to the singers. Sub-phrases and peak notes analysed are marked.

also to disguise the identity of the singers. The peak phrase was edited into its three sub-phrases: high level 1, low level, high level 2. Each of the sub-phrases was viewed in slow motion and frame-by-frame (30 frames/second). Observation of the frequency and direction of types of AP movement that occurred on the peak notes was noted (Table 1) as well as on the quiet phrase. Inter-rater reliability on the occurrences of AP movement was assessed by asking an expert in biomechanics to examine the videos and stills of the performances and to indicate every instance of AP movement he observed. There was 100% agreement between the three raters on the type, direction and frequency of AP movement. A paired t-test analysis was conducted on the frequency with which the singers used a posterior movement on high SPL notes compared with low SPL notes.

Figures 2 to 4 show stills that were created from the video at four-frame intervals from one example of the first sub-phrase for each singer represented. Background objects not relevant to analysis were removed from the image using graphics software, Photoshop, and one vertical and one horizontal line were darkened for clarity. In cases where the singers moved farther away from the vertical line, making it hard to see the relationship, a second narrower line was created using a grid.

Results

• Main findings

All the singers performed small (Singer 1) to large (Singers 2-6) AP torso movements on the peak phrase. The most common pattern observed was a backward torso movement that reached its maximum amplitude on the peak note. Of the 36 high SPL notes across the six singers, there were 24 posterior movements on the high SPL notes (67%) compared with four posterior movements from a possible 18 (22%) on the low SPL notes. The mean number of posterior movements on high SPL notes across the six singers ($\mu = 4$, SD = 1.67) was compared with the mean number of posterior movements ($\mu = 0.67$; SD = 0.82) on the low SPL notes using a paired t-test analysis. The means were significantly different ($t = 4.66$, $df = 5$, $p = .006$).

This posterior torso movement in most cases was initiated at the beginning of the peak note, although three singers (1, 2, 4) regularly started the movement on the words at the beginning of the phrase just before the peak note. The posterior movement was followed by a gradual or sudden movement in an anterior direction until the singers were at (Figure 2) or forward of (Figure 3) their starting position. In some singers the backwards torso movement was intermittent (1, 5) or very short and fast (5, 6) (Figures 2, 3). In the case of singers 2, 3 and 4 torso movement was of longer duration and reached a greater distance from their anatomical position. Figure 2 shows Singer 2 who always used this movement pattern.

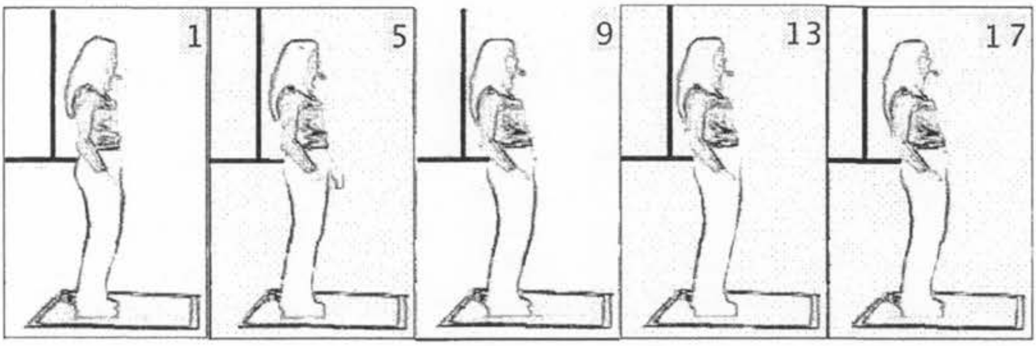

Figure 2.

Most common movement pattern shown at 4 frame (30 f.p.s.) intervals from onset to offset of peak note as demonstrated by Singer 2.

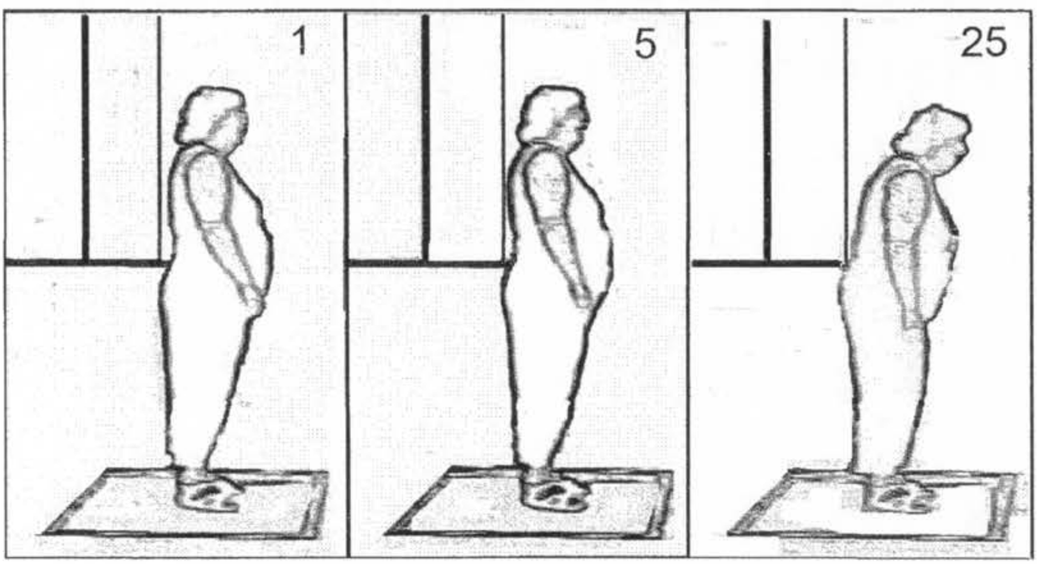

Figure 3.

Singer 6 shown at frames (30 f.p.s.) (1) Peak note onset, (5) maximum posterior torso displacement during peak note and (25) offset subphrase 1.

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Of the lateral movements visible from the front-view of the video, only one lateral torso movement coincided with one of the 36 peak notes analysed. The lower limbs mainly marked the periodic rhythm in most of the singers. Five singers (Singers 1, 2, 3, 5, 6) exhibited a range of lower limb movements (toe or heel tapping, stepping side-to-side, knee twitching, small lateral hip movements as a result of lower limb movement) that were synchronised to the musical beat. This caused small movements of the whole body that seemed to be postural compensations that were vertical, lateral or diagonal depending on the type of lower limb movement and whether both sides of the body were active. Singer 6 also occasionally stamped a foot on a peak note. Some singers made the rhythmic movements less forceful (Singer 2), went out of time (Singer 3) or sometimes suspended them altogether (Singer 2, 5, 6) on the peak notes.

- **Less common movement patterns**

Some singers, most notably singer 5 (Figure 4) also used visible downward shoulder movements in connection with peak notes but this was not universally the case. For example, Singer 3's shoulders and arms were passive throughout the protocol. Hand/lower arm movements were sometimes used in gestures that coincided with the emphasised syllable of a word or that marked a phrase. These were not consistent in movement amplitude, direction or character.

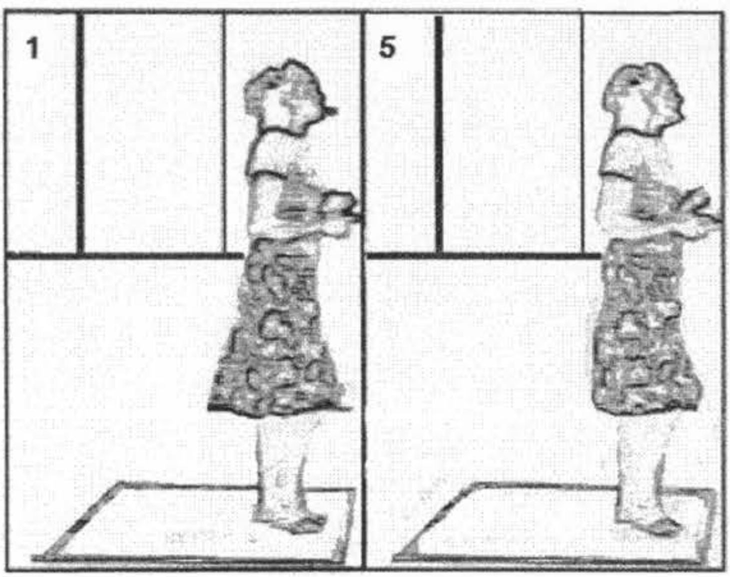

Figure 4.

Singer 5 shown at frames (30 f.p.s.) (1) Peak note onset and (5) maximum posterior torso with anterior pelvic displacement during peak note.

- **Idiosyncratic movement**

Singer 5 did exhibit some backward torso movements on the peak note (Table 1). Her characteristic movement on the peak note was that her pelvis tilted posteriorly and her shoulders moved back and down. Her movement was very fast so that the posterior movement was not visible until this was viewed frame by frame. This was also the case in terms of the pelvic movement. The amount of time between the onset of the peak note and the maximum posterior displacement was only 133 m/sec.

Singer 6 also moved very quickly into the posterior torso movement (Figure 3) but unlike the other singers began to lean forward quite early during the peak note. This meant that the torso was much farther forward by the end of the phrase and that she tended to push her head forward during the anterior torso movement when it moved past her anatomical position. Three of the six peak notes analysed for Singer 6 featured vocal distortion. Singer 1 also engaged in the posture of leaning forward, and similar distortion in the sung tone was observed. In singers 2-5, on the other hand, the gaze remained horizontal as the torso moved backward on the peak note. In these latter singers, no distortion was detected in the sound.

Discussion

In the majority of cases, the AP torso movement pattern showed consistent changes with the dynamics of the phrase, thus supporting our hypothesis that this movement is associated with dynamic variation. There was a significant association of torso movement in a posterior direction with the occurrence of the peak note. As hypothesized, the lateral torso movements did not coincide with the peak note except in one instance, indicating that they were not associated with the generation of high SPL at that $f0$.

Respiratory patterns in singing can be altered by the cueing of emotional connection thereby potentially altering sound levels (Foulds-Elliott, Thorpe, Cala, & Davis, 2000). There is no reason to assume that emotional connection was not present throughout the analysed phrase since the lyrical content was the same and the sub-phrases follow on very quickly from one to the other. Only the pitch and dynamic level changed. As such, the greater movement observed in the higher SPL sub-phrases is not likely to be associated with the presence or lack of emotional connection, though it may relate to the expression of different emotions. For example, higher sound levels are associated with the expression of anger and low levels with sadness in singing (Kotlyar & Morozov, 1976; Sundberg, Iwarsson, & Hagegård, 1995). If a particular movement, such as the posterior torso movement observed here, facilitates the delivery of higher sound levels via the increase of internal pressures in the body, it may be that these movements will be always linked to the expressions of specific emotions for the singer. As such, the AP torso movement serves both an expressive and a sound production function. It is perhaps this dual purpose that has disguised the movement's function in sound level regulation until now.

It can be assumed that the singers level of emotional arousal would be less than in performance due to the lack of accompaniment and the interactions with musicians and audience. In this respect, however, all the singers were equal in the protocol. The fact that four of the singers were experienced at performing unaccompanied and that all were used to performing in recording studios should have made it possible for them to achieve a behaviour close to public performance levels in the conditions experienced in this study. Future research into WCP singers AP torso movement in public performance situations is required to confirm this.

The hand and lower arm movements noted are of the type that have been designated by Ekman (Ekman, 1977) as *illustrators* in that they coincide with the emphasised syllable of a word (*batons*), or mark a phrase (*underliners*) but there was no specific gesture of this type that coincided with the peak note. Thus, hand movements seemed more closely related to the text rather than the musical dynamics of the song, indicating that hand/lower arm movements are not related to SPL regulation in voice production. Such gestures, have been noted previously in other analyses of WCP singer behaviour (Davidson, 2001, 2006). There was no hand/lower arm gesture of this type that occurred on the peak note. This is supported by the literature which indicates that the biomechanical connections between hand/lower arm movement and the musculoskeletal structures used in voice production are weak (Jensen *et al.*, 1983).

As hypothesized, the lower limbs were not used by all singers and when they were used, appeared to be associated with the rhythmic elements of the song. Lower limb movements have been associated with rhythm (London, 2006), marking time (Wanderley, Vines, Middleton, McKay, & Hatch, 2005) or to dancing, rather than as a physiological necessity for SPL regulation. The tendency of the singers to go out of time or stop these movements all together on the peak notes further supports our contention that such movements are not associated with the achievement or regulation of vocal SPL.

The backward torso movement is most commonly associated in respiration with the inspiratory phase (P.W. Hodges *et al.*, 2002). However, in these singers, this movement occurred on the expiratory phase. One explanation for this paradoxical finding may relate to inspiratory braking which occurs during the first part of expiration on phonation, when the passive expiratory recoil forces of the ribcage are strong. At this point it is necessary to balance these forces with inspiratory action in order to manage the breath and control the voice quality (Leanderson, Sundberg, & von Euler, 1987). Since the phrases in WCP songs tend to be short and speech-like (Potter, 2000) as here in the peak phrase, the singers may be using passive recoil to help generate subglottal pressure, which may have resulted in an over-pressure that required an inspiratory action to counter-balance it. If the backward torso action were performed to assist with inspiratory braking, it would be expected that the movement would be timed to occur from the beginning of the phrase rather than on the peak note. However, only three singers moved backwards at the beginning of the phrase, thus indicating that this was not the only possible function of this movement. The posterior torso movements in these cases peaked at or near the beginning of the peak note, indicating that this pattern of movement may relate to the generation of phonation threshold pressure (Sundberg, Titze *et al.*, 1993). Ps needed to initiate a tone at a given pitch is greater than the Ps needed to sustain it (Plant, Freed, & Plant, 2004). This timing of the action further indicates that this movement relates to Ps generation. As the abdominal muscles are slow to act (Newsom Davis & Sears, 1970), it may be preferable to perform the fine control of the opposing inspiratory and expiratory pressures by anchoring the abdomen and using the faster and more capable intercostals (Draper, Ladefoged, & Whitteridge, 1959). The intercostals also respond well in situations in which lung volume is changing quickly (Newsom Davis & Sears, 1970) as in this case.

With the backward torso movement, a stretch of the abdominal muscles was achieved. Lengthening a contracting muscle increases its force (Edman, Elzinga, & Noble, 1978) and this principle has been shown to apply to respiratory muscles (Gandevia, Gorman, McKenzie, & Southon, 1992; Gandevia *et al.*, 1990). An abdominal stretch added to the expiratory action of singing would allow the singers to increase Ps without having to further increase the expiratory muscle contraction. This would reduce the energetic cost of the Ps increase required while avoiding triggering tensions that might otherwise interfere with the fine control of singing (Wilson Arboleda & Frederick, 2006).

An abdominal stretch could also anchor the abdomen, thereby helping to keep the ribcage expanded (Konno & Mead, 1967) which would assist inspiratory braking. Projected voice in classical singing involves greater ribcage volume than unprojected voice (Thorpe *et al.*, 2001). The high number of proprioceptors in the intercostal muscles (Newsom Davis & Sears, 1970) would make them more effective for fine control of airflow in singing than the diaphragm. Alternatively, although the diaphragm is low in proprioceptors (Bouhuys *et al.*, 1966) it can be guided by intercostal-to-phrenic reflexes (Leanderson, Sundberg, & Von Euler, 1987) or interact with the abdominal muscles to vary internal pressures without altering neural drive (Gandevia *et al.*, 1990). Thus both the nature of this movement and its positioning in relation to the peak note indicated that it is associated with the management of lung volume and subglottal pressure and therefore worthy of future research employing direct measurement.

Some notable differences occurred amongst the singers in their torso behaviour during the peak note, although they served the common function of compressing the torso. In Singer 5, a pelvic tilt (antero-posterior) movement occurred at the same time as the shoulders moved back and down on the peak note. Both of these actions activate expiratory muscles, for example, the shoulder action involving the *pectoralis major* (Jensen *et al.*, 1983) which has been noted being used idiosyncratically by classical singers (Pettersen, 2006). This shoulder action may serve an idiosyncratic function for this singer also since Singer 3's shoulders and arms were passive throughout the protocol even though he reached very high sound levels. This indicates that if downward shoulder movement is a strategy to increase Ps for increasing SPL, it is not the only strategy.

Differences in movement speed were also noted in Singer 5. Changes in speed of locomotion alter respiratory muscle recruitment patterns (Saunders *et al.*, 2004), higher speed movement changes being associated with dysfunctional voice (Grini-Grandval, Ouaknine, & Giovanni, 2000). In this case, there was no evidence of vocal dysfunction and the singer gave the overall impression of being very relaxed physically and comfortable vocally.

Singer 6's anterior movement during the peak note ended forward of the anatomical position at the end of the phrase making the action a trunk flexion rather than just a return to the starting position as for the other singers. This movement appears functional given that trunk flexion allows maximal contraction of the abdominal muscles making it a powerful action, appropriate for increasing pressures in the thorax (Gandevia *et al.*, 1990). Singer 6 reached higher sound levels than the other female singers. However, she exhibited a head forward position and vocal distortion both of which may present vocal health risks (Borch *et al.*, 2004; Bruno *et al.*, 2007). Although this movement may allow for increased SPL, it may compromises the neck posture for phonation. That the posterior movements on the peak note in other singers were associated with horizontal gaze and no distortion may indicate that the posterior torso movement on the peak note may be advantageous to neck positioning, possibly for the widening of the vocal tract at higher pitch in the upper chest register (Hixon & Weismer, 1995). This indicates that further research into the connection between the posterior torso movement observed here and pitch-setting in contemporary singing is also indicated.

Singer 1's movements were smaller and different in character to those of the other singers. She also avoided holding the peak note, which meant the song was less stressful to sing, thereby altering the experimental condition. It is therefore difficult to draw conclusions from her style of movement. After data collection, Singer 1 disclosed that she had received advice from a classical singing teacher not to move when she sang, thus explaining the different style of movement.

Summary and conclusions

We observed the general body movement strategies of six professional WCP singers to inform us further as to what may be desirable, harmful or idiosyncratic in current WCP singing practice as well as to identify areas of focus for more controlled studies of the relationship between body behaviour and vocal output.

Our observation of the body movement strategies of these six singers indicated that posterior torso movements on moments of high SPL and pitch were common and appeared to support their production. Lower limb movement was largely associated with the rhythm and hand and head movement with the verbal aspects of the song. These movements appeared not to interfere with the execution of the song with exception of the head forward position. Lateral torso movements did not present any visually detectable trends in relation to sound levels. AP movement showed a strong relationship with the dynamic line, with movements of larger amplitude occurring at moments of higher sound level. Posterior torso movement occurred more consistently on the peak notes than on quiet lower pitch notes. Further research is needed to ascertain whether this was due to the high SPL or high $f0$ or a combination. This need for further clarification notwithstanding, since both higher $f0$ and higher SPL require higher Ps, and the locus of the movement indicates respiratory muscle involvement, it is likely that the movement is associated with Ps generation. This indicates that some of the body movement of WCP singers, such as AP torso movement, has a role in voice production and constraints placed on it may alter the sound produced by singers. This is a factor that should be taken into consideration by singing teachers, stage directors and professionals in recording studios as well as by the singers themselves.

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• **REFERENCES**

Alison, J. A., Regnis, J. A., Donnelly, P. M., Adams, R. D., Sullivan, C. E., & Bye, P. T. P. (1998). End-expiratory lung volume during arm and leg exercise in normal subjects and patients with cystic fibrosis. *American Journal of Respiratory and Critical Care Medicine, 158,* 1450-58.

Bernasconi, P., & Kohl, J. (1993). Analysis of co-ordination between breathing and exercise rhythms in man. *Journal of Physiology, 471,* 693-706.

Borch, D. Z., Sundberg, J., Lindestad, P. A., & Thalen, M. (2004). Vocal fold vibration and voice source aperiodicity in "dist" tones: a study of a timbral ornament in rock singing. *Logopedics Phoniatrics Vocology, 29*(4), 147-53.

Borden, G. J. (1979). An interpretation of research on feedback interruption in speech. *Brain and Language, 7*(May), 307-319.

Bouhuys, A., Mead, J., Proctor, D. F., & Stevens, K. N. (1968). Pressure-flow events during singing. *Annals of the New York Academy of Sciences, 155*(1), 379-81.

Bouhuys, A., Proctor, D. F., & Mead, J. (1966). Kinetic aspects of singing. *Journal of Applied Physiology, 21,* 483-96.

Brackett, N., & Hoard, C. (2004). Aretha Franklin. In *The New Rolling Stone Album Guide* (4th ed.). New York: Fireside.

Bruno, E., De Padova, A., Napolitano, B., Marroni, P., Batelli, R., Ottaviani, F., *et al.* (2007). Voice disorders and posturography: variables to define the success of rehabilitative treatment. *Journal of Voice, In Press.*

Callaghan, J. (1996). The Implications of Voice Science for the Teaching of Singing: Vocal registers. *Australian Voice,* 27-31.

Couser, J. I., Martinez, F. J., & Celli, B. R. (1992). Respiratory response and ventilatory muscle recruitment during arm elevation in normal subjects. *Chest, 101,* 336-40.

Cross, I. (2003). Music as biocultural phenomenon. *Annals of the New York Academy of Sciences, 999,* 106-11.

Davidson, J. W. (2001). The role of the body in the production and perception of solo vocal performance: a case study of Annie Lennox. *Musicæ Scientiæ, 5*(2), 235-56.

Davidson, J. W. (2006). She's the one: multiple functions of body movement in a stage performance by Robbie Williams. In A. Gritten & E. King (eds), *Music and Gesture*: Ashgate Publishing.

Dayme, M. B. (2006). An argument for whole body and holistic approaches to research and singing. *Journal of Singing, 63*(1), 59-64.

de Troyer, A. (1983). Mechanical role of the abdominal muscles in relation to posture. *Respiration Physiology, 53,* 341-53.

Dibben, N. (2004). The role of peripheral feedback in emotional experience with music. *Music Perception, 22*(1), 79-115.

Draper, M. H., Ladefoged, P., & Whitteridge, D. (1959). Respiratory muscles in speech. *J. Speech Hear. Res, 2,* 16-27.

Dromey, C., & Ramig, L. O. (1998). The Effect of lung volume on selected phonatory and articulatory variables. *Journal of Speech, Language, and Hearing Research, 41,* 491-502.

Edman, K. A. P., Elzinga, G., & Noble, M. I. (1978). Enhancement of mechanical performance by stretch during tetanic contractions of vertebrate skeletal muscle fibres. *Journal of Physiology, 281*, 139-55.

Edwin, R. (2001). Working with "Mike". *Journal of Singing, 58*(2), 171-172.

Ekman, P. (1977). Biological and cultural contributions to body and facial movement. In J. Blacking (ed), *The Anthropology of the Body* (pp. 39-84). London: Academic Press.

Ekman, P. (2003). *Emotions Revealed: understanding faces and feelings.* London: Weidenfeld & Nicholson.

Feyereisen, P., & de Lannoy, J. D. (1991). *Gestures and Speech: psychological investigations.* Cambridge/Paris: Cambridge University Press/Editions de la Maison des Sciences de l'Homme.

Foulds-Elliott, S. D., Thorpe, C. W., Cala, S. J., & Davis, P. J. (2000). Respiratory function in operatic singing: effects of emotional connection. *Logopedics Phoniatrics Vocology, 25*(4), 151-68.

Franklin, A. (1998). Aretha: Queen of Soul. The very best of Aretha Franklin: WEA International Inc.

Gandevia, S. C., Gorman, R. B., McKenzie, D. K., & Southon, F. C. G. (1992). Dynamic changes in human diaphragm length: maximal inspiratory and expulsive efforts studied with sequential radiography. *Journal of Physiology, 457*, 167-76.

Gandevia, S. C., McKenzie, D. K., & Plassman, B. L. (1990). Activation of human respiratory muscles during different voluntary manoeuvres. *Journal of Physiology, 428*, 387-483.

Gentilucci, M., Benuzzi, F., Bertoloani, L., Daprati, E., & Gangitano, M. (2000). Language and motor control. *Experimental Brain Research, 133*, 468-90.

Giovanni, A., Assaiante, C., Galmiche, A., Vaugoyeau, M., Ouaknine, M., & Le Huche, F. (2006). Forçage vocal et posture : études expérimentales chez le sujet sain [Vocal forcing and posture: experimental studies on normal subject] [French]. *Revue de Laryngologie Otologie Rhinologie, 127*(5), 285-91.

Goldin-Meadow, S., & McNeill, D. (1999). The role of gesture and mimetic representation in making language the province of speech. In M. C. Corballs & L. S.E.G. (eds), *The Descent of Mind: psychological perspectives on hominid evolution* (pp. 155-72). Oxford: Oxford University Press.

Grillner, S., Nilsson, J., & Thorstensson, A. (1978). Intra-abdominal pressure changes during natural movements in man. *Acta Physiologica Scandinavica, 103*, 275-83.

Grini-Grandval, M. N., Ouaknine, M., & Giovanni, A. (2000). Forçage vocal et variance de la vitesse : corrélation entre la vitesse de déplacement du centre de gravité et le travail des muscles posturaux (Forcing the voice: the correlation between the speed of displacement of the centre of gravity and the work of the postural muscles). *Revue de Laryngologie Otologie Rhinologie, 121*(5), 319-23.

Hixon, T. J., & Weismer, G. (1995). Perspectives on the Edinburgh study of speech breathing. *Journal of Speech and Hearing Research, 38*(1), 42-60.

Hodges, P. W., & Gandevia, S. C. (2000). Changes in intra-abdominal pressure during postural and respiratory activation of the human diaphragm. *Journal of Applied Physiology, 89*, 967-76.

Hodges, P. W., Gandevia, S. C., & Richardson, C. A. (1997). Contractions of specific abdominal muscles in postural tasks are affected by respiratory maneuvers. *Journal of Applied Physiology, 83*(3), 753-60.

Hodges, P. W., Gurfinkel, V. S., Brumagne, S., Smith, T. C., & Cordo, P. C. (2002). Coexistence of stability and mobility in postural control: evidence from postural compensation for respiration. *Exp Brain Res, 144*(3), 293-302.

Hoit, J. D. (1995). Influence of body position on breathing and its implications for the evaluation and treatment of speech and voice disorders. *Journal of Voice, 9*(4), 341-47.

Hoit, J. D., & Hixon, T. J. (1987). Body type and speech breathing. In T. J. Hixon (ed), *Respiratory Function in Speech and Song* (pp. 401-24). Boston: College-Hill Press.

Huber, J. E. (2007). Effects of cues to increase sound pressure level on respiratory kinematic patterns during connected speech. *Journal of Speech, Language, and Hearing Research, 50*(3), 621-34.

Hudson, B. (2002). The effects of the Alexander technique on the respiratory system of the singer/actor Part II: implications for training respiration in singer/actors based on concepts of Alexander technique. *Journal of Singing, 59*(2), 105-10.

Jensen, C. R., Schultz, G. W., & Bangerter, B. L. (1983). *Applied Kinesiology and Biomechanics* (3rd ed.): McGraw Hill.

Konno, K., & Mead, J. (1967). Measurement of the separate volume changes in rib cage and abdomen during breathing. *Journal of Applied Physiology, 22*(3), 407-22.

Kotlyar, G. M., & Morozov, V. P. (1976). Acoustical correlates of the emotional content of vocalized speech. *Soviet Physics Acoustics, 22*(January-December), 208-11.

Kurosawa, K., & Davidson, J. W. (2005). Non-verbal interaction in popular performance: The Corrs. *Musicae Scientiae, 9*(1), 111-33.

Lane, H. L., Catania, A. C., & Stevens, S. S. (1961). Voice level: autophonic scale, perceived loudness and effects of sidetone. *Journal of the Acoustical Society of America, 31*(2), 160-67.

Lassalle, A., Grini, M. N., Amy de la Breteque, B., Ouaknine, M., & Giovanni, A. (2002). Étude comparative des stratégies respiratoires entre les chanteurs lyriques professionnels et débutants [Comparative study of respiratory mechanisms between professional lyrical singers and beginners]. *Revue de Laryngologie Otologie Rhinologie, 123*(5), 279-89.

Leanderson, R., & Sundberg, J. (1988). Breathing for singing. *Journal of Voice, 2*(1), 2-12.

Leanderson, R., Sundberg, J., & von Euler, C. (1987). Breathing muscle activity and subglottal pressure dynamics in singing and speech. *Journal of Voice, 1*(3), 258-61.

Leanderson, R., Sundberg, J., & Von Euler, C. (1987). Role of diaphragmatic activity during singing: a study of transdiaphragmatic pressures. *Journal of Applied Physiology, 62*, 259-70.

Lee, H.-T., & Banzett, R. B. (1997). Mechanical links between locomotion and breathing: can you breathe with your legs? *News in Physiological Sciences, 12*(December), 273-78.

London, J. (2006). Musical rhythm: motion, pace and gesture. In A. Gritten & E. King (eds), *Music and Gesture*: Ashgate Publishing.

Newsom Davis, J., & Sears, T. A. (1970). Proprioceptive reflex control of the intercostal muscles during their voluntary activation. *Journal of Physiology* (209), 711-38.

Pettersen, V., Bjørkøy, K., Torp, H., & Westgaard, R. H. (2005). Neck and shoulder muscle activity and thorax movement in singing and speaking tasks with variation in vocal loudness and pitch. *Journal of Voice, 19*(4), 623-34.

Pfordresher, P. Q. (2005). Auditory feedback in music performance: the role of melodic structure and musical skill. *Human Perception and Performance, 31*(6), 1331-45.

Phyland, D. J., Oates, J., & Greenwood, K. M. (1999). Self-reported voice problems among three groups of professional singers. *Journal of Voice, 13*(4), 602-11.

Plant, R. L., Freed, G. L., & Plant, R. E. (2004). Direct measurement of onset and offset phonation threshold pressure in normal subjects. *Journal of the Acoustical Society of America, 116*(6), 3640-46.

Potter, J. (2000). Elvis Presley to rap: moments of change since the forties. In J. Potter (ed), *Cambridge Companion to Singing* (pp. 133-57). Cambridge: Cambridge University Press.

Reed, E. (1989). Changing theories of postural development. In M. H. Woollacott & A. Shumway-Cook (eds), *Development of Posture and Gait across the Life Span* (pp. 2-20): University of South Carolina Press.

Saunders, S. W., Rath, D., & Hodges, P. W. (2004). Postural and respiratory activation of the trunk muscles changes with mode and speed of locomotion. *Gait and Posture, 20,* 280-90.

Sturm, T., Nigg, B., & Koller, E. A. (1980). The impact of cardiac activity on triaxially recorded endogenous microvibrations of the body. *European Journal of Applied Physiology and Occupational Physiology, 44,* 83-96.

Sundberg, J., Elliot, N., Gramming, P., & Nord, L. (1993). Short-term variation of subglottal pressure for expressive purposes in singing and stage speech: a preliminary investigation. *Journal of Voice, 7*(3), 227-34.

Sundberg, J., Iwarsson, J., & Hagegård, H. (1995). A singer's expression of emotions in sung performance. In O. Fujimura & M. Hirano (eds), *Vocal Fold Physiology: Voice Quality Control* (pp. 217-31). San Diego, CA: Singular Publishing Group.

Sundberg, J., Leanderson, R., von Euler, C., & Knutsson, E. (1991). Influence of body posture and lung volume on subglottal pressure control during singing. *Journal of Voice, 5*(4), 283-91.

Sundberg, J., Titze, I. R., & Scherer, R. (1993). Phonatory control in male singing: a study of the effects of subglottal pressure, fundamental frequency, and mode of phonation on the voice source. *Journal of Voice, 7*(1), 15-29.

Thorpe, W. C., Cala, S. J., Chapman, J., & Davis, P. J. (2001). Patterns of breath support in projection of the singing voice. *Journal of Voice, 15*(1), 86-104.

Titze, I. R. (1984). *Influences of subglottal resonance on the primary register transition.* Paper presented at the 13th Symposium on care of the Professional Voice, Juilliard School. New York City.

Turner, G., & Kenny, D. T. (2007). *The relationship between sound pressure level and spontaneous body behaviour in western contemporary popular singing.* Paper presented at the International Conference on Music Communication Science, Sydney, Australia.

Wanderley, M., Vines, B., Middleton, N., McKay, C., & Hatch, W. (2005). The musical significance of clarinetists' ancillary gestures: an exploration of the field. *Journal of New Music Research, 34*(1), 97-113.

Wilson Arboleda, B. M., & Frederick, A. L. (2006). Considerations for maintenance of postural alignment for voice production. *Journal of Voice, In press.*

Zemlin, W. R. (1998). *Speech and Hearing Science: anatomy and physiology* (4th ed.). Boston: Allyn and Bacon.

Zwicker, E., & Fastl, H. (1999). Rhythm. In E. Zwicker & H. Fastl (eds), *Psycho-acoustics: facts and models.* Springer.

• Una investigación preliminar en la asociación entre modelos de movimiento corporal y variación dinámica en los cantantes populares occidentales contemporáneos

Este estudio evaluó la presencia de movimientos corporales comunes a los cantantes occidentales contemporáneos populares (WCP) que pueden ser integrales tanto a la producción física del sonido cantado como a su salida acústica, en este caso la variación del nivel de presión del sonido. Ya que el movimiento de torso parece estar estrechamente relacionado con la variación dinámica en este estilo de canto, el estudio se ha centrado en la actividad del torso. Se ha grabado un video en tres dimensiones con los movimientos corporales de seis cantantes profesionales WCP que cantaban la misma canción R&B. Se analizaron la dirección y la frecuencia de los movimientos antero-posteriores (AP) de torso, y características como el punto de máximo sostenimiento, SPL, y la *f*0 (nota pico) sobre la vocal /e/. El movimiento más común del torso fue en dirección posterior, alcanzando su punto de desplazamiento máximo de la posición de partida sobre la nota pico. Un fuerte movimiento de torso en dirección anterior sobre la nota pico realizado por el torso desde su posición anatómica se asoció con la posición avanzada de la cabeza y la distorsión vocal, indicando que este movimiento en un punto de alto SPL puede presentar un peligro para la salud vocal. Estos resultados muestran que el movimiento AP del torso de cantantes WCP tiene una función en la producción de voz y que no sólo la postura del cuerpo sino la forma del movimiento de una posición del cuerpo a otra es significativa para la salud vocal y la producción del sonido, especialmente en estilos donde se deben alcanzar altos niveles sonoros, que requieren, además, un alto nivel de movimiento corporal.

• Uno studio preliminare sull'associazione tra alcuni pattern del movimento del corpo e la variazione dinamica nel canto della musica leggera contemporanea occidentale

Il presente studio ha indagato la presenza di movimenti del corpo comuni a tutti i cantanti di musica leggera contemporanea occidentale (WCP) che possono essere parte integrante sia della produzione fisica del canto sia del risultato acustico, in questo caso la variazione del livello della pressione sonora. Dal momento che il movimento del torso sembrerebbe essere strettamente legato alla variazione dinamica in questo tipo di musica, il nostro studio si concentra sull'attività del torso. Sono state raccolte sequenze video 3-D dei movimenti del corpo di sei cantanti WCP professionisti durante l'interpretazione di una stessa canzone R & B. Sono state analizzate la frequenza della direzione anteroposterioe (A.P.) nel movimento del torso e le caratteristiche nel momento di massima SPL sostenuta e *f*0 (nota di picco) sulla vocale /ε/. Il movimento più comune del torso era nellà direzione posteriore, raggiungendo il punto di massima distanza dalla posizione di partenza nella nota di picco. Un deciso movimento anteriore del torso sulla nota di picco che riportava il torso in avanti rispetto alla posizione anatomica era associato alla posizione della testa in avanti e alla distorsione della voce, indicando che questo movimento nel punto di alta SPL può presentare un rischio per la salute della voce. Questi risultati indicano che il movimento del torso anteroposteriore dei cantanti di musica leggera contemporanea occidentale ha una funzione nella produzione della voce e che non solo la posizione del corpo ma anche il modo di muoversi da una posizione ad un'altra è significativo sia per la salute della voce che per la produzione del suono, soprattutto nei generi dove si raggiungono alti livelli di suono e dove è richiesto durante l'esecuzione un movimento del corpo considerevole.

• Recherche préliminaire sur l'association entre les formes de mouvement corporel et la variation dynamique chez des chanteurs populaires occidentaux actuels

Cette étude évalue la présence de mouvements corporels qui pourraient être communs à tous les chanteurs populaires occidentaux actuels (CPO), mouvements qui pourraient être intrinsèques à la fois à la production physique des sons chantés et à leur sortie acoustique, dans ce cas la variation du niveau de pression sonore. Comme les mouvements du torse semblent être étroitement liés avec la variation dynamique, dans ce style de chant, l'étude s'est centrée sur l'activité du torse. On a rassemblé des images vidéo en 3D des mouvements du corps de six chanteurs professionnels CPO chantant la même chanson de R&B. On a analysé la fréquence des mouvements antéro-postérieur (AP) du torse et ses caractéristiques au point maximum de niveau de pression sonore soutenu SPL et *f0* (note culminante) sur la voyelle /e/. Le mouvement le plus courant du torse était vers l'arrière, atteignant son point maximum de déplacement sur la note culminante. Le fort mouvement antérieur du torse sur la note culminante, qui emmenait le torse loin de sa position anatomique, était associé à la position en avant de la tête et l'altération vocale, indiquant que ce mouvement, à un point élevé de pression sonore, peut présenter un risque de santé pour la voix. Ces résultats indiquent que le mouvement antéro-postérieur des chanteurs CPO a une fonction dans la production vocale et que, non seulement la position du corps mais aussi la manière de bouger d'une position à une autre, importantes pour la santé vocale et la production de son, particulièrement dans des styles musicaux où de hauts niveaux sonores doivent être produits et qui requièrent un niveau élevé de mouvance corporelle.

• Eine vorläufige Untersuchung über Zusammenhänge zwischen Körperbewegungsmustern und dynamischen Varianten im zeitgenössischen westlichen Popgesang

Diese Studie untersuchte das Auftreten von Körperbewegungen, die möglicherweise bei allen zeitgenössischen westlichen Popsängern (ZWP) zu beobachten sind. Die Bewegungen könnten integrale Komponenten sowohl der physischen Produktion des gesungenen Klangs als auch des akustischen Ergebnisses sein (hier: die Variation des Schalldruckpegels). Da Rumpfbewegungen eng mit der dynamischen Variabilität in diesem Gesangsstil verbunden zu sein scheinen, fokussierte diese Studie die

Aktivitäten des Rumpfes. 3D-Videos der Körperbewegungen von sechs professionellen ZWP-Sängern, die alle denselben RnB-Titel sangen, wurden aufgezeichnet. Dabei wurden die Richtungsfrequenz der anterior-posterioren (AP) Rumpfbewegungen sowie Charakteristika zum Zeitpunkt des maximal anhaltenden Schalldruckpegels und der *f0* (beim höchsten gesungenen Ton) auf dem Vokal /ɛ/ analysiert. Die häufigsten Rumpfbewegungen waren in posteriorer Richtung und erreichten die maximale Ausschwenkung von der Startposition auf der höchsten Note. Starke anteriore Rumpfbewegungen auf der höchsten Note, die den Rumpf nach vorn aus seiner anatomischen Position brachten, hingen mit nach vorn gerichteten Kopfbewegungen und stimmlichen Beeinträchtigungen zusammen. Das deutet darauf hin, dass zu Zeitpunkten mit hohen Schalldruckpegeln diese Bewegungen ein Risiko für die stimmliche Gesundheit darstellen könnten. Diese Ergebnisse zeigen, dass die AP-Rumpfbewegungen der ZWP-Sänger eine Rolle in der Stimmproduktion spielen, und dass nicht nur die Körperhaltung, sondern auch die Art der Bewegungen von einer Körperposition in eine andere bedeutsam für die Stimmgesundheit und Klangproduktion ist. Besonders trifft dies auf Gesangsstile zu, in denen hohe Lautstärken erreicht werden müssen und ein hohes Maß an Körperbewegungen in der Performanz erforderlich sind.

This paper was designed to study the characteristic stage performance movement patterns of WCP singer. What remained was to observe the effects on the sound levels when singers were not moving.Otherwise, it could be said that these variations were merely co-incidental associations within a style of performance that encourages idiosyncratic behaviour. In the next chapter, an attempt will be made to further quantify the difference in the acoustic effect between the characteristic body behaviour noted in this chapter and a situation in which that movement is restrained.

Chapter 3: Body movement and peak sound pressure level

"Live Act"

Many artists in the music industry are characterized by the expression "live act" or "only a live act". This usually means that they are at their best in live performance but sometimes that they are not able to reach the same high standard in a recording studio as on a stage. In a sub-genre such as jazz in which improvisation is so important, this can be seen as a compliment. In a sub-genre such as "pop" this can mean that they are an act that is hard to market because the magic just does not happen in the recording studio. This can have dire consequences for a singer's career because it is usually on the basis of recordings that concert bookings are made and recording contracts offered.

The studies discussed in last chapter showed that there is a relationship between torso movement and sound pressure level (SPL). If high SPL vocal sound conveys emotion, effort and excitement, as indicated in the literature, could the inability of some singers to produce great recordings incorporating high SPL sounds originate from the restriction of their behaviour in the recording studio? Just as dysfunction often informs medical practice as to how healthy functioning occurs, it is often that which does nott work for singers that tells us how good singing occurs.

The paper that follows represents an attempt to verify further the nexus between body movement and SPL by exploring SPL in a condition in which singers could not move.

PAPER 2

Turner, G., Kenny, D.T. (in press). Restraint of body movement potentially reduces peak SPL in western contemporary popular singing. *Musicae Scientiae*

3.1 Abstract

In western contemporary popular (WCP) singing, body movement is integral to overall stage performance. However, singers are often directed to stand still while singing during recording sessions or music theatre productions. No assessment has been undertaken by sound engineers or directors to determine whether singers can produce the same sound levels under conditions of voluntary movement restraint. The aim of this investigation was to assess the impact of body movement restraint on sound pressure levels (SPL) levels in WCP singing. Six professional WCP singers sang a section of a song in two performance modes: first with the directive to perform as they normally would on a stage and then when directed to stand still during their performance. The recordings were analysed for SPL and the results of the two conditions were compared. There was a significant reduction in the sound pressure level recorded by the singers both statistically and acoustically in the 'no movement' condition. This result suggests that restraint of movement during WCP singing is associated with reduced peaks in SPL. Possible reasons for this reduction include the inhibition of respiratory mechanisms for subglottal pressure production and interference with sensorimotor feedback mechanisms such as the autophonic response.

3.2 Introduction

The sound levels in the live performance of western contemporary popular (WCP) music are high and need to be high in order to satisfy audiences (Dibble, 1995). The singer who can achieve high SPL during live performance is greatly appreciated. High sound pressure levels (SPL) are an important part of the perception of the acoustic expression of emotion in both speech and singing, particularly for strong emotions such as anger and happiness (Kotlyar & Morozov, 1976; Scherer, 1995). More rapid changes in SPL convey stronger emotion and also cue the perception of certain emotions such as sadness (Kotlyar & Morozov, 1976; Sundberg, Iwarsson & Hagegård, 1995). However accomplished, high sound levels are physically taxing for the voice especially when delivered at high fundamental frequency (F0) (Schutte, 1983) (Jónsdottir et al., 2001), potentially leading to functional problems with the voice in the long-term if not executed with the appropriate technique (Hollien, 1983). As a result, singers want to know how to master control of high vocal sound levels for stylistic, expressive and technical purposes and need to know how to achieve them safely, efficiently and sustainably. There are many aspects of singing that may be affected by movement restriction. SPL was chosen for investigation because of health risks posed by peak SPL production and its importance in the perception of WCP singing.

In WCP singing, body movement is integral to overall stage performance. This movement takes three forms: the spontaneous movement, of which the singer is not consciously aware, which may have a function in sound production (Turner & Kenny, In Press; Wanderley, 2002); planned or choreographed movement and language related gesture (Davidson, 2001, 2006; Kurosawa & Davidson, 2005). This study focussed on spontaneous movement. When singers who normally move spontaneously during concert performance go to a recording studio, the conditions can alter dramatically. In recording studios, singers may be told to stand still, or maintain their position according to markings on a floor to avoid background noise created by movement or to keep an optimum microphone distance. Similarly, an artist accustomed to the physical freedom of fronting a band who moves into music theatre may have difficulties with the strictures of stage direction. There is an assumption that singers should be able to reproduce their usual stage standard in terms of vocal performance while adopting different body behaviour. This study challenges this assumption on the basis of knowledge of the interactions of upper body behaviour with respiratory (Gandevia, Butler, Hodges & Taylor, 2002; Thorpe, Cala, Chapman & Davis, 2001), laryngeal (Kooijman 2005) and vocal tract function (Honda, Hirai, Masaki & Shimada, 1999; MacCurtain & Welch, 1983). We hypothesized that the restriction of body movement in singers of contemporary popular music would alter the sound produced.

SPL can be voluntarily altered on three levels – above, at, and below the larynx (Titze, 1998): (1) above the larynx in the vocal tract through factors such as changing vowel shape (Ladefoged, 1963) and formant tuning (Titze & Sundberg, 1992); (2) at the larynx via fundamental frequency (F0) regulation (Titze & Sundberg, 1992) and the register used (Henrich, d'Allessandro, Doval & Castellengo, 2005); and (3) below the larynx via respiratory drive (Ladefoged, 1963, Isshikki, 1964). Subglottal pressure (Ps) which is altered through a combination of changes in the larynx and respiratory drive, is considered to be the most important factor in vocal SPL generation both in speech (Björkner, Sundberg, Cleveland & Stone, 2005; Finnegan, Luschei & Hoffman, 2000; Holmberg, Hillman & Perkell, 1988; Titze, 1988; Titze & Sundberg, 1992) and singing (Sawashima, Niimi, Horiguchi & Yamaguchi, 1988; Sundberg, Titze & Scherer, 1993). There is a linear relationship between SPL and Ps (Tanaka & Gould, 1983; Tang & Statholopoulos, 1995) whereby an increase or reduction in SPL can be assumed to be accompanied by an equivalent alteration in the level of Ps (Finnegan et al., 2000), the majority of which is generated by respiratory drive (Finnegan, Luschei & Hoffman, 1998).

Respiration always creates compensatory antero-posterior motion of the trunk and lower limbs that in quiet breathing is less than 1° in amplitude but which increases when respiration deepens (Hodges, Gurfinkel, Brumagne, Smith & Cordo, 2002). These compensatory changes in posture are created by phasic activation of the muscles of the hips and trunk and this movement increases with greater voluntary respiration (Hodges et al., 2002). In speech, movement from the centre of gravity and antero-posterior movements of torso, thigh & head increase substantially with SPL increases triggered by the Lombard effect (Giovanni et al., 2006). Posterior torso movements on notes of high SPL and pitch are common and appear to support the production of these notes with movements of larger amplitude occurring at moments of higher sound level (Turner & Kenny, In Press). On the basis that antero-posterior trunk movement in WCP singers may be related to either subglottal pressure generation via respiratory drive or a compensatory postural response to the deeper respiration required for higher SPL production, we hypothesize that singers will have difficulty maintaining their usual SPL levels if they eliminate body movement.

3.3 Method

3.3.1 Participants

Participants were six singers of contemporary popular music (Table 1), 1 male and 5 female, ranging in age from 21 to 46 years. They were all professional singers by the standards defined by Throsby and Hollister (Throsby & Hollister, 2003). By recruiting participants who had demonstrated skill in stage and recording studio performance over a period of years, it was less likely that the behaviours exhibited would cause vocal damage (Phyland, Oates & Greenwood, 1999). This was an important issue in terms of recommendations arising from the findings of this study.

Table 3.1: Singer details and peak note (PN) means

Singer	Sex	Primary Style	Years Professional Performance Experience	Mean PN SPL (dB) Movement	Mean PN SPL (dB) Non-Movement	Mean PN SPL (dB) Difference
1	F	Pop	5	110.33	108.42	1.90
2	F	Latin	10	109.41	107.95	1.45
3	M	R&B	6	115.65	112.60	3.05
4	F	Music Theatre	10	105.14	104.17	0.96
5	F	R&B	18	105.57	103.32	2.25
6	F	Gospel	28	113.30	108.69	4.60
				111.49	108.61	2.88

Participants were music theatre and contemporary music singers using styles including jazz, folk, gospel, R & B and *a cappella.* Rock singers were excluded because of their use of techniques that may affect vocal health (Borch, Sundberg, Lindestad & Thalen, 2004). All participants were able to sing skilfully in either R & B or gospel styles. Since most of the participants were proficient in more than one contemporary music style, they were asked to nominate the style they considered to be their primary area of expertise (Table 1).

3.3.2 Experimental design

To avoid using cues that might trigger atypical SPL output strategies (J. E. Huber, Chandrasekaran & Wolstencroft, 2005) or body postures (Wilson Arboleda & Frederick, 2006), verbal instructions were minimised. Singers were therefore provided with a vocal model of a song on a recording that all participants sang (referred to as the common song). The R & B/soul song *I Never Loved a Man (Like I Love You)* sung by Aretha Franklin (Franklin, 1998) was chosen as it spanned a 2-octave range, originally 175 Hz (F3) – 698Hz (F5). This would allow the demonstration of: (i) wide variability in dynamics in order to demonstrate how the singers behaved in both high and low SPL conditions (ii) a song with a large enough F0 range to ensure that the participants had to negotiate the higher part of their vocal range while engaging a strong voice quality; (iii) provision of a model singer with a powerful voice, delivering a high quality performance (Brackett & Hoard, 2004).

Singers were permitted to alter the key of the song to suit their habitual F0 range. The large F0 range of the common song ensured that even if the singers lowered the key substantially they would not be able to avoid the transition from chest to head register (also known as the *primo passagio*), which in both male and female voice occurs between 294 Hz (D4) and 392Hz (G4) (Callaghan, 1996; Titze, 1984).

Most WCP singers who do not dance as part of their performance use a hand-held or stand-mounted microphone in performance that allows them to use microphone technique. This involves intentionally varying the distance of the mouth from the microphone (Edwin, 2001). A head-mounted microphone was therefore used to keep the singers' distance from the microphone constant.

3.3.3 Performance tasks

All singers prepared three short song excerpts, two of their own choice from their own repertoire, in addition to the song excerpt provided by the researchers.

Lyrics and a recording were provided for the common song for the singers to learn prior to data gathering. The excerpt was 52 seconds long. Singers were advised that they could sing the song in the key of their choice and could personalize the song as they would any other song in their repertoire (F0 and equivalent musical note ranges chosen by the singers are shown in Figure 1). However, they were requested to maintain a similar dynamic range to the original recorded version provided to them.

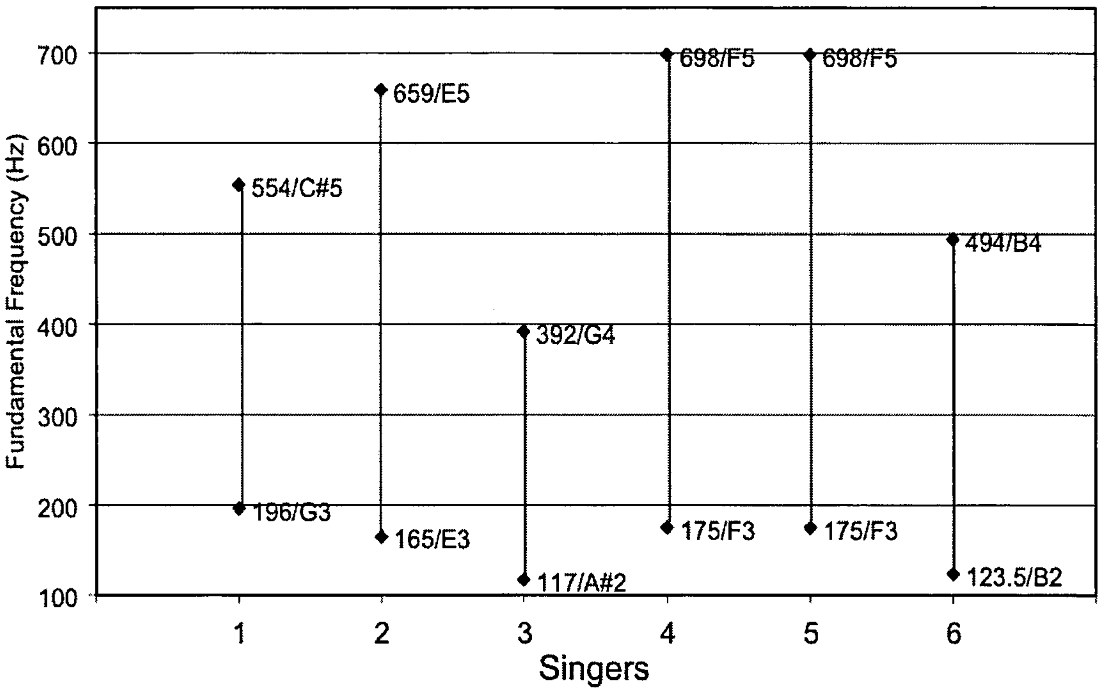

Figure 3.1: Fundamental Frequency and equivalent musical note range of common song excerpt, Singers 1-6

Singers were asked to choose two other song excerpts with a similarly large dynamic range as the song provided to them. No limitations were placed on F0 range, tempo or musical style and no other verbal instructions were given. These familiar songs served as a vocal warm-up, as a means to assist singers to feel at ease in the experimental setting, and to assess whether the samples taken of the common song represented the singers' usual vocal performance standard.

All singers sang unaccompanied in a large untreated room at the Faculty of Health Sciences, The University of Sydney. The inclusion of three sample phonations have been found to most reliably define a singer's vocal SPL profile although the first sample most closely represents the "usual" voice (Sihvo, Laippala & Sala, 2000; Zwicker & Fastl, 1999c). Therefore, the singers sang each of their three song excerpts three times. The starting pitch (F0) of each song was nominated by the singer and was played on a pitch pipe before each recording. Songs were recorded with a miniature omni-directional AKG C477 condenser microphone mounted on a headset. The signal went through a Behringer pre-amplifier to a Tascam DA-20 MK II DAT recorder. The levels for each participant were set separately with two calibration tones recorded using a sound generator and an SPL meter. Conditions such as microphone distance and the pre-amplifier's microphone sensitivity settings varied for each subject in order to avoid clipping.

Participants were videoed simultaneously with two video cameras from the front and side and the images from the two cameras were mixed to one screen using a Panasonic WJ-MX10 mixer. Singers were encouraged to sing and behave as if in performance. A taped rectangle on the floor represented the range of the cameras and singers were advised that they could move as they wished within this space. The video was intended for later analysis but also to give the singers a focus for their performance in the absence of an audience, thus making them more likely to behave as if on stage throughout the protocol.

When the first part of the protocol in which the singers performed in their usual manner [called the movement condition] was concluded, singers were requested to sing the songs again, behaving as if they had been given the instruction "by a director as part of a large-scale staged event to remain still, and that the spotlight was on them". This imagery, and the wording describing it, were chosen to provide a musical rationale for a stationery performance that would be realistic to singers who would normally not stand still in performance, since the manner of eliciting voice change can affect the mechanisms used (J. E. Huber et al., 2005). All three songs were then sung again under this non-movement condition. In the second condition, the two own-repertoire songs served as a training period for the common song. The protocol took no more than 40 minutes for all participants, and constituted a personal and vocal demand well within the capacity and usual practices of contemporary popular singers.

Five of the six singers were recorded with the microphone at the same distance of eight centimetres from the centre of the lips. Singer 4's voice was so strong that this protocol caused constant clipping. The sensitivity of the microphone had to be adjusted and the microphone was gradually moved away until it reached a distance of 12 cm prior to commencing the protocol. SPL is reduced proportionally to the increased distance from the sound source (Warren, 1977; Zwicker & Fastl, 1999b). Most of the change in microphone distance was taken into account in the calibration but there may have been some small alterations to the spectrum of the sound recorded because of the difference in the angle of the microphone to her mouth. This may have resulted in her absolute dB levels recording lower than they in fact were. However, the relationship between the two conditions, which was the focus of this study, remained the same for this singer.

3.3.4 Measurement and analysis

3.3.4.1 Peak note levels

For the analysis, it was necessary to find the point at which all the singers most often reached and sustained their peak in SPL in the common song. On the original recording, this was found to be Line 11 on the first and third repetitions of the word *never* [original F0: 625Hz]. Preliminary analysis showed that this was also the case for the singers in this study. Line 11 was therefore referred to as the peak phrase since it represented the most demanding section of the song in terms of maximal voice production, containing notes of both high F0 and SPL. The notes of highest SPL within the peak phrase were referred to as peak notes in the subsequent analyses. The peak note occurred on the first syllable of the word "never," the vowel /ɛ/, was measured for mean dB in PRAAT (Boersma & Weenink, 1996) from the offset of the sound /n/ to the onset of the /v/. Thus, the peak note represents the same F0, vowel and register in both conditions. The note boundaries were identified by a combination of listening to the recording and visual observation of the spectrum and F0 contour in PRAAT. This was done for all three takes in each condition at the same point.

3.3.4.2 Assessment of statistical differences

A one sample t-test was conducted to assess the null hypothesis that there would be no difference between the movement and non-movement conditions; that is, the difference in peak note SPL between the two conditions would not be significantly different from zero. A paired t-test assessed the averaged differences over the three takes in each condition for all six singers between the movement and non-movement conditions. A linear transformation of SPL values was conducted prior to analyses.

3.3.4.3 Assessment of acoustic differences

The Just Noticeable Difference (JND) in SPL of a pure tone is considered to be ~1dB (Johnson, Turner, Zwislocki & Margolis, 1993; Zwicker & Fastl, 1999a), an increase of 3dB constitutes a doubling of power (energy) (Zwicker & Fastl, 1999b) with a 9dB increase being perceived as a doubling of perceived loudness (Stevens, 1972). Listening to a complex sound in context, such as music, can be different to listening to isolated pure tones, but in the music recording industry, it is considered that the minimum difference in SPL that can be noticed by a listener is also ~1dB (D. M. Huber & Runstein, 2005). One decibel was therefore used as the criterion for determining significant acoustic differences in this study.

3.4 Results

Figure 3.2 shows the SPL attained on the PN in both conditions for each singer. For all singers, the maximum SPL attained on a PN occurred in the M condition.

SPL values and difference scores (M-NM) were consistently lower in the NM condition for each singer. The hypothesis tested by the one-sample test was not confirmed. The mean difference was 2.37dB (SD=1.3); t=4.46 (df=5), p (two-tailed) =.007. The paired t-test assessing the averaged differences for all six singers between the M and NM conditions, averaged over the three takes in each condition (Table 1) showed that the mean difference of 2.87dB (SD=1.3) was statistically significant [t=4.42 (df=5), p (one-tailed) =.039].

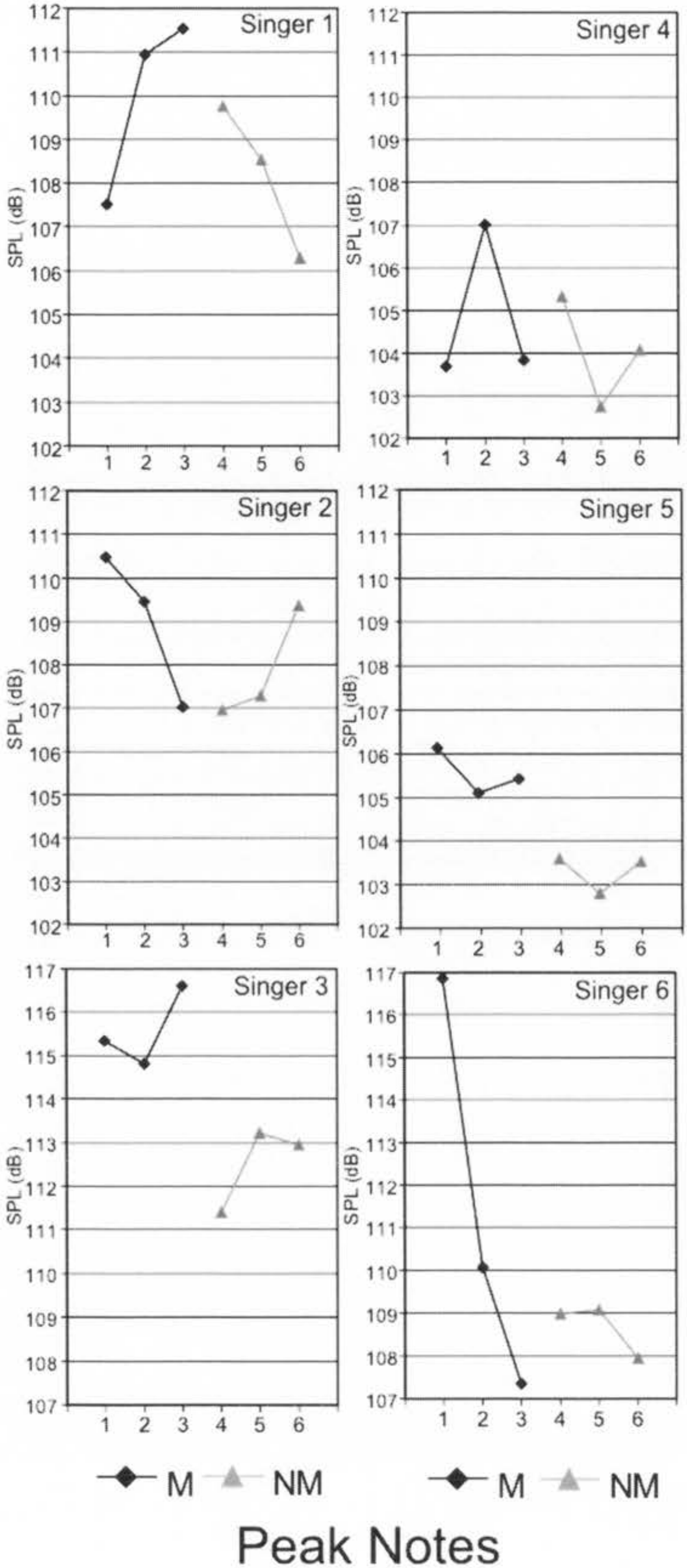

Figure 3.2: Sound pressure level (dB) on peak notes in movement (M) and no movement (NM) conditions

Figure 3.3 shows contours representing the SPL for the entire peak phrase normalised for time. It can be seen that the singers varied their performances dynamically and with respect to phrase length both within and across conditions. In spite of this, reductions of SPL in the NM condition can be seen at many points in all singers. The maximal amplitude differences between conditions are most apparent for Singers 5 and 6 and smallest for Singers 1 and 4. For Singers 2 and 3 it is clear that the maximum SPL attained was in the M condition and was significant, but to a lesser degree than for Singers 5 and 6 where reductions of up to 10dB were visible. Some singers reached the same SPL but for a shorter period of time in the NM condition, for example, in the first sub-phrase for Singers 2 and 4.

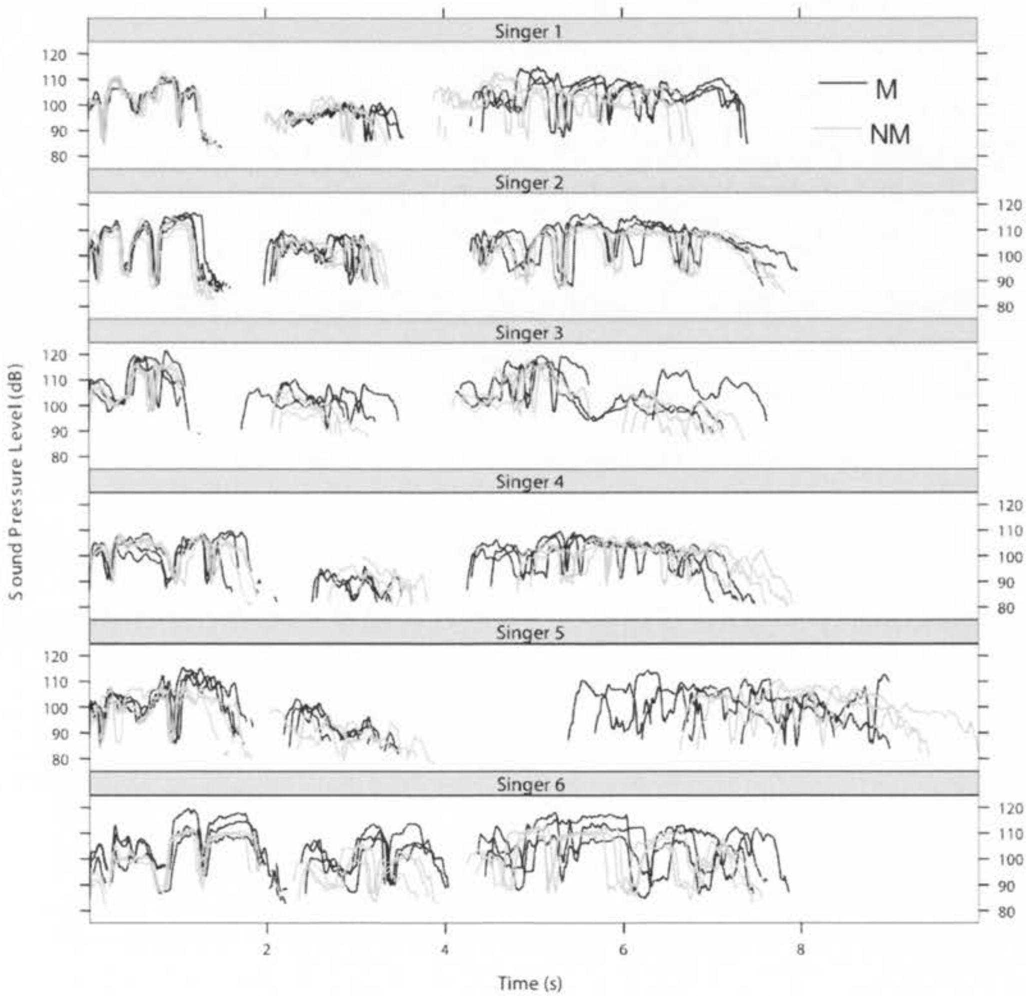

Figure 3.3: Sound pressure level (dB) tracings peak phrase in movement (M) and no movement (NM) conditions, normalized for time: *"I ain't never/ I ain't never/ I ain't never, no, no"*

It should be noted that all of the singers had difficulty in the second condition, which they either commented on between takes, or was visible on the video footage in facial expressions and gestures showing displeasure, perplexity or frustration. It should be noted that only Singer 5 anticipated difficulties singing while standing still. She initially objected to performing in the NM condition commenting that it was "all about emotion" but agreed to continue with the protocol with the pre-judgement that it would not sound good.

3.5 Discussion

There are many possible explanations for the phenomena observed in this study. The results suggest a number of possible explanations. Further studies will need to replicate the findings before firm explanations can be offered. Larger samples exploring the impact of gender, voice type and the different WCP vocal styles will assist in determining whether the results reported here pertain to the range of singers that comprise the WCP genre. Some of the more likely possible explanations that may account for the observed change in sound output as a result of body restraint are discussed below.

3.5.1 Automatic execution model of skilled performance

According to the automatic execution model of skilled performance (Baumeister, 1984), making a person conscious of what they are doing during an activity that they normally accomplish automatically can impair performance. Although being required to limit their body movement while singing was not a novel experience, the singers in this study were not able to adapt to the NM condition with respect to producing the same SPL levels as in the movement condition, even after the training period of having sung their other two songs in the NM condition prior to the common (assessed) song. A loss of SPL indicates that functionally there has been a loss of vocal efficiency (Tang & Statholopoulos, 1995), and that musically, within the expectations of this musical genre, there has been a reduction in performance quality (Dibble, 1995) (Todd & Cody, 2000). The singers may have compensated qualitatively in other ways but this was not specifically assessed in this study. The possible explanations for the loss of SPL in the no movement condition are discussed below.

3.5.2 *Inhibition of subglottal pressure production*

The theory of skilled performance does not account specifically for the loss of SPL in the no movement condition. Sataloff states that even minor dysfunction in any body system can adversely affect the singing voice (Sataloff, Spiegel & Hawkshaw, 2003). Likewise, postural control is an automatic multi-sensory process that includes visual, vestibular, somatosensory and proprioceptive inputs, the latter of which includes kinaesthetic and vibrational sensations (Yasuda et al., 1999). Restraint of movement may interfere with either of the two voluntary means of generating Ps in the respiratory system (Leanderson & Sundberg, 1988); that is, deeper inspiration prior to a sung phrase, which causes greater AP movement (Hodges 2002) or stronger expiratory muscle contraction on the sung phrase which would also cause changes in posture (Gandevia et al., 2002). Any change in body posture changes the centre of pressure (Hodges et al., 2002). Hence, such direct mechanical interference as change in body posture affects voice production by interfering with Ps, which is the main controlling factor in SPL production.

The other physical areas involved in SPL control are the larynx and the vocal tract. The restraint of movement may have changed neck postural adjustments that would normally occur as the vocal tract widens at the higher F0s attainable in the chest register (MacCurtain & Welch, 1983). However, Singer 6, who chose a lower F0 for the song, still experienced reduced SPL in the NM condition, suggesting that other mechanisms may be contributing to the loss of SPL in non-movement conditions, even at lower F0s within the range.

3.5.3 *Autophonic response*

The consistency of the singers' loss of SPL in the NM condition may lie not in vocal or auditory malfunction but in other sensory feedback. Reflexive responses to auditory feedback in relation to the regulation of intensity of vocal SPL have been documented (Chang-yit, 1975; Fulton & Spuehler, 1962): the Lombard effect (Lane & Tranel, 1971; Winkworth & Davis, 1997) whereby speakers raise their sound level with increases in background noise; and the sidetone effect whereby speakers lower their vocal level if the auditory feedback of their own voice is artificially increased (Fulton & Spuehler, 1962; Lane, Catania & Stevens, 1961). There is also evidence that an automatic mechanism for regulating voice SPL exists but that it is only accurate for changes up to 1dB (Bauer, Mittal, Larson & Hain, 2006). In auditory studies related to the perception of SPL in the speaking voice (Lane et al., 1961) found that the subjective numerical estimation of one's own vocal loudness, called the autophonic scale, was invariant enough to be calculated and more accurate than that of an outside listener.

Lane et al hypothesized that singers used means other than air-conducted sound to measure loudness, such as perception of muscular effort. Subjects were found to be able to ignore auditory feedback more easily than other sensorimotor feedback. It was concluded that muscular effort was a major factor in SPL estimation and that hearing air-conducted sound was a minor factor in own-voice loudness judgement. Although the autophonic scale was confirmed in subsequent research, the importance placed by Lane on non-auditory sensory feedback in own-voice SPL perception was disputed (Warren, 1962) until recent research on Parkinson's disease (Ho, 2000) and stuttering (Ingham, Warner, Byrd & Cotton, 2006) that has vindicated the original theory that sensorimotor feedback is the most important factor in the judgement of own-voice SPL levels. This effect could explain the consistency of response of the singers to the NM condition since the effort sensations would be considerably altered both in level and location due to changes in muscle recruitment patterns.

3.5.4 Vestibular system

Another physical link between sound level production and postural control is the vestibular system. Research has indicated that the desire to listen to music at high sound levels, a phenomenon described as the "rock and roll threshold" may have a physiological basis in the vestibular system whereby high SPL levels evoke pleasurable sensations manifested in body movement (Todd & Cody, 2000). Though the vestibular system is integral to posture and balance, we do not normally have conscious perceptual access to it (Purves et al., 2001). This may explain the singers' perplexity and surprise at not being able to control their dynamic levels in the NM condition.

3.5.5 Emotional connection

The presence or lack of emotional stimulus affects abdominal muscle recruitment (Pettersen & Bjørkøy, 2007) and respiration (Foulds-Elliott, Thorpe, Cala & Davis, 2000) in classical singing. Singer 4's objection to the NM condition as being related to emotion implied that, for her, movement was strongly connected with both emotional expression and her singing. It is possible that the NM condition interfered with the singers' emotional connection and thereby with Ps production, since intent is a factor in the control of both posture (Van der Kooij, Jacobs, Koopman & Grootenboer, 1999) and the initiation of phonation (Foulds-Elliott et al., 2000) as well as with expressive timing (Palmer, 1989).

3.5.6 Effects of musical style

All the singers had reduced SPL in the non-movement condition of this study but the degree to which it affected them varied. Internal laryngeal effort levels have been found to vary with WCP styles (Friberg & Sundberg, 1999), with rock and gospel having the highest, music theatre being in the middle range, and pop and jazz featuring the lowest levels of intrinsic laryngeal effort (Koufman, Radomski, Joharji & Russell, 1996). A similar scaling exists in this study with R & B (not specifically featured in the Koufman study though closely related stylistically to rock and gospel) and gospel singers (Singers 3, 5, 6) being most affected by movement restraint, and music theatre, Latin and pop being less affected (Table 1). The division of the subjects along stylistic lines indicates that there may also be different patterns of body behaviour linked to voice use within WCP music.

Preliminary analysis of the video footage revealed an association between the degree of posterior torso displacement and higher SPL levels within the M condition (Turner & Kenny, In Press). Such phenomena may also exist in Western classical singing in a different form. For example, Cabrera, Davis, Barnes, Jacobs & Bell (2002) reported significant involuntary antero-posterior movement in a highly skilled classical singer. There may not be one universal style of body behaviour that can be called good or healthy for all singing styles. Future studies of body movement patterns during singing within specific WCP sub-genres such as R & B, jazz, music theatre and rock styles observing larger numbers of expert singers are therefore indicated.

3.5.7 Timing

Timing also seems to have been affected by the NM condition. A slowing of execution can be observed in Figure 3 even though it was normalised for time. This could indicate interference with respiration, such as the inhibition of the reduction of end expiratory lung volume (EELV) thereby slowing the following inspiration (Alison et al., 1998). Thorpe et al. (2001) noted a correlation between faster inspiration times and higher sound levels in classical singing that they related to pre-phonatory posturing. It could also be due to the accumulation of neural delays in estimating body orientation (Van der Kooij et al., 1999). We observed in our earlier study that lower limb movement was associated with marking rhythm in the singers (Turner & Kenny, 2010), a phenomenon also observed in clarinettists (Wanderley, Vines, Middleton, McKay & Hatch, 2005). The restriction of leg movement, therefore, may account for the changes in phrase duration and may therefore not relate to SPL variation. A future study similar to this one but incorporating controls for the restriction of movement in different body regions would clarify the role of different body regions in SPL variation.

3.6 Conclusion

There was a significant reduction in the sound pressure level recorded by the singers both statistically and acoustically in the 'no movement' condition. This indicates that the restriction of movement during WCP singing is associated reductions in peak SPL, though by what means is yet to be determined. The consistency of the differential effect was surprising considering that the participants were allowed a high degree of freedom in execution, indicating that the SPL reduction effect of movement restraint was robust. It would have been reasonable to expect more idiosyncratic changes in SPL output because of the individualistic nature of WCP singer behaviour and because the singers sang songs rather than individual notes. The results of this study have implications for those working with singers in theatres or recording studios in that the placement of physical constraints on singers may have detrimental effects on acoustic output that may be insurmountable even in very experienced singers.

3.7 Acknowledgements

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3.8 References

Alison, J. A., Regnis, J. A., Donnelly, P. M., Adams, R. D., Sullivan, C. E. & Bye, P. T. P. (1998). End-expiratory lung volume during arm and leg exercise in normal subjects and patients with cystic fibrosis. *American Journal of Respiratory and Critical Care Medicine, 158*, 1450-1458.

Bauer, J. J., Mittal, J., Larson, C. R. & Hain, T. (2006). Vocal responses to unanticipated perturbations in voice loudness feedback: an automatic mechanism for stabilizing voice amplitude. *Journal of the Acoustical Society of America, 119*(4), 2363-2371.

Björkner, E., Sundberg, J., Cleveland, T. & Stone, E. (2005). Voice source differences between registers in female musical theater singers. *Journal of Voice, In press.*

Boersma, P. & Weenink, D. (1996). *PRAAT, a system for doing phonetics by computer, version 4.6.38* (No. 132): Institute of Phonetic Sciences of the University of Amsterdam.

Borch, D. Z., Sundberg, J., Lindestad, P. A. & Thalen, M. (2004). Vocal fold vibration and voice source aperiodicity in 'dist' tones: a study of a timbral ornament in rock singing. *Logopedics Phoniatrics Vocology, 29*(4), 147-153.

Brackett, N. & Hoard, C. (2004). Aretha Franklin. In *The New Rolling Stone Album Guide* (4th ed.). New York: Fireside.

Callaghan, J. (1996). The Implications of Voice Science for the Teaching of Singing: Vocal registers. *Australian Voice*, 27-31.

Chang-yit, R. (1975). Reliability of sidetone amplification effect in vocal intensity. *Journal of Communication Disorders, 8*, 317-324.

Davidson, J. W. (2001). The role of the body in the production and perception of solo vocal performance: a case study of Annie Lennox. *Musicae Scientiae, 5*(2), 235-256.

Davidson, J. W. (2006). She's the one: multiple functions of body movement in a stage performance by Robbie Williams. In A. Gritten & E. King (Eds.), *Music and Gesture*: Ashgate Publishing.

Dibble. (1995). Hearing loss and music. *J. Audio Eng. Soc., 43*(4), 251–266.

Edwin, R. (2001). Working with "Mike". *Journal of Singing, 58*(2), 171-172.

Finnegan, E. M., Luschei, E. S. & Hoffman, H. T. (1998). Estimation of alveolar pressure from direct measures of tracheal pressure during speech. *NCVS Status and Progress Report*(June), 1-10.

Finnegan, E. M., Luschei, E. S. & Hoffman, H. T. (2000). Modulations in respiratory and laryngeal activity associated with changes in vocal intensity during speech. *Journal of Speech, Language & Hearing Research, 43*(4), 934-950.

Foulds-Elliott, S. D., Thorpe, C. W., Cala, S. J. & Davis, P. J. (2000). Respiratory function in operatic singing: effects of emotional connection. *Logopedics Phoniatrics Vocology, 25*(4), 151-168.

Friberg, A. & Sundberg, J. (1999). Does music performance allude to locomotion? A model of final *ritardandi* derived from measurements of stopping runners. *Journal of the Acoustical Society of America, 105*(3), 1469-1484.

Fulton, R. T. & Spuehler, H. E. (1962). Effects of frequency filtering on delayed sidetone on vocal responses. *Journal of Speech and Hearing Research, 5*, 382-386.

Gandevia, S. C., Butler, J. E., Hodges, P. W. & Taylor, J. L. (2002). Balancing acts: Respiratory sensations, motor control and human posture. *Clinical and Experimental Pharmacology and Physiology, 29*(1-2), 118-121.

Giovanni, A., Assaiante, C., Galmiche, A., Vaugoyeau, M., Ouaknine, M. & Le Huche, F. (2006). Forçage vocal et posture: études expérimentales chez le sujet sain [Vocal forcing and posture: experimental studies on normal subject] [French]. *Revue de Laryngologie Otologie Rhinologie, 127*(5), 285-291.

Henrich, N., d'Allessandro, C., Doval, B. & Castellengo, M. (2005). Glottal open quotient in singing: measurements and correlation with laryngeal mechanism, vocal intensity, and fundamental frequency. *Journal of the Acoustical Society of America, 117*(3), 1417-1430.

Ho, A. K. (2000). Volume perception in Parkinsonian speech. *Movement Disorders, 15*(6), 1125-1131.

Hodges, P. W., Gurfinkel, V. S., Brumagne, S., Smith, T. C. & Cordo, P. C. (2002). Coexistence of stability and mobility in postural control: evidence from postural compensation for respiration. *Exp Brain Res, 144*(3), 293-302.

Hollien, H. (1983, 1985). *Report on vocal registers.* Paper presented at the Stockholm Music Acoustics Conference, Stockholm.

Holmberg, E. B., Hillman, R. E. & Perkell, J. S. (1988). Glottal airflow and transglottal air pressure measurements for male and female speakers in soft, normal, and loud voice. *Journal of the Acoustical Society of America, 4*(2), 511-529.

Honda, K., Hirai, H., Masaki, S. & Shimada, Y. (1999). Role of vertical larynx movement and cervical lordosis in F0 control. *Language and Speech, 42*(4), 401-411.

Huber, D. M. & Runstein, R. E. (2005). *Modern Recording Techniques* (Sixth Edition ed.): Focal Press/Elsevier.

Huber, J. E., Chandrasekaran, B. & Wolstencroft, J. J. (2005). Changes to respiratory mechanisms during speech as a result of different cues to increase loudness. *Journal of Applied Physiology, 98*(6), 2177-2184.

Ingham, R. J., Warner, A., Byrd, A. & Cotton, J. (2006). Speech effort measurement and stuttering: investigating the chorus reading effect. *Journal of Speech, Language, and Hearing Research, 49*(3), 660-670.

Johnson, J. H., Turner, C. W., Zwislocki, J. J. & Margolis, R. H. (1993). Just noticeable differences for intensity and their relation to loudness. *Journal of the Acoustical Society of America, 93*(2), 983-991.

Jónsdottir, V., Laukkanen, A.-M., Illomäki, I., Roininen, H., Merja, A.-B. & Vilkman, E. (2001). Effects of amplified and damped auditory feedback on vocal characteristics. *Logopedics Phoniatrics Vocology, 26*, 76-81.

Kotlyar, G. M. & Morozov, V. P. (1976). Acoustical correlates of the emotional content of vocalized speech. *Soviet Physics Acoustics, 22*(January-December), 208-211.

Koufman, J. A., Radomski, T. A., Joharji, G. M. & Russell, G. B. (1996). Laryngeal biomechanics of the singing voice. *Otolarygology – Head and Neck Surgery, 115*, 527-537.

Kurosawa, K. & Davidson, J. W. (2005). Non-verbal interaction in popular performance: The Corrs. *Musicae Scientiae, 9*(1), 111-133.

Lane, H. L., Catania, A. C. & Stevens, S. S. (1961). Voice level: autophonic scale, perceived loudness and effects of sidetone. *Journal of the Acoustical Society of America, 31*(2), 160-167.

Lane, H. L. & Tranel, B. (1971). The Lombard sign and the role of hearing in speech. *J. Speech Hear. Res., 14*, 677-709.

Leanderson, R. & Sundberg, J. (1988). Breathing for singing. *Journal of Voice, 2*(1), 2-12.

MacCurtain, F. & Welch, G. (1983). *Vocal tract gestures in soprano and bass: a xeroradiographic-electro-laryngographic study.* Paper presented at the SMAC (Stockholm Music Acoustics Conference) 83.

Palmer, C. (1989). Mapping musical thought to musical performance. *Journal of Experimental Psychology: Human Perception and Performance, 15*, 331 – 346.

Pettersen, V. & Bjørkøy, K. (2007). Consequences from emotional stimulus on breathing for singing. *Journal of Voice, In Press.*

Phyland, D. J., Oates, J. & Greenwood, K. M. (1999). Self-reported voice problems among three groups of professional singers. *Journal of Voice, 13*(4), 602-611.

Purves, D., Fitzpatrick, D., Augustine, G. J., Katz, L. C., Williams, S. M., McNamara, J. O., et al. (2001). *Neuroscience* (2nd ed.). Sunderland, Mass: Sinauer Assoc.

Sataloff, R. T., Spiegel, J. R. & Hawkshaw, M. J. (2003). History and physical examination of patients voice disorders. In *Diagnosis and Treatment of Voice Disorders* (pp. 137-170). Australia;UK: Delmar Learning.

Sawashima, M., Niimi, S., Horiguchi, S. & Yamaguchi, H. (1988). Expiratory lung pressure, airflow rate, and vocal intensity: data on normal subjects. In O. Fujimura (Ed.), *Vocal Physiology: voice production, mechanisms and functions* (pp. 416-422). New York: Raven Press Ltd.

Scherer, K. R. (1995). Expression of emotion in voice and music. *Journal of Voice, 9*(3), 235-248.

Schutte, H. K. (1983). *The efficiency of voice production.* Groningen: Kemper.

Sihvo, M., Laippala, P. & Sala, E. (2000). A study of repeated measures of softest and loudest phonations. *Journal of Voice, 14*(2), 161-169.

Stevens, S. S. (1972). Perceived Level of Noise by Mark VII and Decibels (E) *Journal of the Acoustical Society of America*, 575-601.

Sundberg, J., Iwarsson, J. & Hagegård, H. (1995). A singer's expression of emotions in sung performance. In O. Fujimura & M. Hirano (Eds.), *Vocal Fold Physiology: Voice Quality Control* (pp. 217-231). San Diego, CA: Singular Publishing Group.

Sundberg, J., Titze, I. R. & Scherer, R. (1993). Phonatory control in male singing: a study of the effects of subglottal pressure, fundamental frequency, and mode of phonation on the voice source. *Journal of Voice, 7*(1), 15-29.

Tanaka, S. & Gould, W. J. (1983). Relationships between vocal intensity and noninvasively obtained aerodynamic parameters in normal subjects. *Journal of the Acoustical Society of America, 73*(4), 1316-1321.

Tang, J. & Statholopoulos, E. T. (1995). Vocal efficiency as a function of vocal intensity: a study of children, women and men. *Journal of the Acoustical Society of America, 97*(3), 1885-1891.

Thorpe, W. C., Cala, S. J., Chapman, J. & Davis, P. J. (2001). Patterns of breath support in projection of the singing voice. *Journal of Voice, 15*(1), 86-104.

Throsby, D. & Hollister, V. (2003). Don't give up your day job: an economic study of professional artists in Australia [Electronic Version] from http://www.ozco.gov.au/arts_resources/publications/dont_give_up_your_day_job_report/.

Titze, I. R. (1984). *Influences of subglottal resonance on the primary register transition.* Paper presented at the 13th Symposium on care of the Professional Voice, Juilliard School. New York City.

Titze, I. R. (1988). Regulation of vocal power and efficiency by subglottal pressure and glottal width. In O. Fujimura (Ed.), *Vocal Physiology: voice production, mechanism and function* (pp. 227-238). New York.

Titze, I. R. & Sundberg, J. (1992). Vocal intensity in speakers and singers. *Journal of the Acoustical Society of America, 91*(5), 2936-2946.

Todd, N. P. M. & Cody, F. W. (2000). Vestibular responses to loud dance music: A physiological basis of the "rock and roll threshold"? *Journal of the Acoustical Society of America, 107*(1), 496-500.

Turner, G. & Kenny, D. T. (In Press). A preliminary investigation into the association between body movement patterns and dynamic variation in Western contemporary popular singing. *Musicae Scientiae.*

Van der Kooij, H., Jacobs, R., Koopman, B. & Grootenboer, H. (1999). A multisensory integration model of human stance control. *Biological Cybernetics, 80*, 299-308.

Wanderley, M. (2002). Quantitative analysis of non-obvious performer gestures. In I. Wachsmuth & T. Sowa (Eds.), *Gesture and sign language in human-computer interaction* (pp. 241-253). Berlin: Springer Verlag.

Wanderley, M., Vines, B., Middleton, N., McKay, C. & Hatch, W. (2005). The musical significance of clarinetists' ancillary gestures: an exploration of the field. *Journal of New Music Research, 34*(1), 97-113.

Warren, R. M. (1962). Are 'autophonic' judgements based on loudness? *American Journal of Psychology, 75*(3), 452-456.

Warren, R. M. (1977). Subjective loudness and its physical correlates. *Acustica, 37*, 334-346.

Wilson Arboleda, B. M. & Frederick, A. L. (2006). Considerations for maintenance of postural alignment for voice production. *Journal of Voice, In press.*

Winkworth, A. L. & Davis, P. J. (1997). Speech breathing and the Lombard effect. *Journal of Speech, Language, and Hearing Research, 40*(February), 1-11.

Zwicker, E. & Fastl, H. (1999a). Just-Noticeable Sound Changes. In E. Zwicker & H. Fastl (Eds.), *Psycho-acoustics: facts and models* (pp. 176): Springer.

Zwicker, E. & Fastl, H. (1999b). Loudness. In *Psychoacoustics: facts and models* (pp. 203-238): Springer.

Zwicker, E. & Fastl, H. (1999c). Stimuli and procedures. In *Psycho-acoustics: Facts and Models* (pp. 1-15): Springer.

CHAPTER 4: BODY MOVEMENT AND OVERALL SOUND PRESSURE LEVELS AND RANGE

A core concept of this thesis is that there are patterns of body movement that are associated with subglottal pressure (Ps) generation and that these directly relate to SPL output. The peak notes chosen for analysis in the previous chapter represented points at which both SPL and F0 were high – that is the point at which there are two acoustic aspects of vocal sound production that require high Ps. In the previous study body movement restraint was associated with reduced peak SPL. However, it was noted in the SPL tracings of the peak phrase (Chapter 3, Figure 3.3) in the previous study that there was a decrease in the SPL levels in the NM condition in evidence at many points in the melody – not just at the points of high sound level and pitch. This indicated that movement restraint may have broader effects than originally hypothesised. The paper that follows addressed these questions by exploring the overall effects of movement restraint on SPL levels and also on SPL range in a longer song sample. The possible reasons for the results are discussed in terms of various feedback, control and compensatory mechanisms involved in voice production.

PAPER 3

Turner, G., Kenny, D.T. (in press, December 2011). Voluntary restraint of body movement potentially reduces overall SPL without reducing SPL range in western contemporary popular singing. *Journal of New Music Research*

4.1 Abstract

Voluntary restriction of body movement is associated with the reduction of sound pressure level (SPL) peaks in western contemporary popular singing. This paper investigated whether overall SPL and SPL range are affected when singers voluntarily restrain their movement during performance. Six professional singers performed a section of a song in two performance modes: first with no constraints placed on their body behaviour and again when directed to stand still. Overall SPL and SPL range were compared for the two conditions. The calculation of percentiles revealed reductions in SPL in the no movement condition across all SPL levels for all singers. With respect to absolute range, contrary to expectation, the SPL minima were reduced by a degree equivalent to the reduction in SPL maxima in the majority of singers. To our knowledge, this phenomenon has not been noted previously, possibly because this compensatory effect disguises the overall reduction in SPL. This effect may be automatic and beyond the conscious control of singers. It remains to be studied whether this effect exists in other styles of singing and what aspect of movement restraint triggers this effect. Verbal directions to curb body movement may have detrimental effects on acoustic output even in experienced singers.

4.2 Introduction

High sound levels and high levels of body movement are both characteristic of western contemporary popular (WCP) singing performance but the potential relationship between these factors has only recently begun to be documented. WCP singers produce high vocal sound levels even when using amplification (Borch & Sundberg, 2002) and it is popularly perceived as a measure of vocal prowess. Torso movement in a posterior direction is associated with moments of high sound pressure level (SPL) in WCP singing (Turner & Kenny, 2010). Both acoustically and statistically significant reductions in SPL were associated with these same points when body movement was restrained (Turner & Kenny, in press, June 2011). These two prior papers focused on moments where both high fundamental frequency (F0) and high SPL occurred simultaneously. High F0 and SPL both require high levels of Ps (Sundberg, Leanderson, von Euler, & Knutsson, 1991; Sundberg, Titze, & Scherer, 1993). In the first paper, we proposed that the posterior torso movement could signal expiratory muscle contraction or other biomechanical enhancements to the generation of Ps required for the singing of a high, powerful note. In the second paper, we suggested that the reduction of SPL when movement was restrained may have been due to the inhibition of the movement's positive contribution to Ps generation. It was noted in this second paper that there seemed to be similar reductions in SPL in other parts of the phrase when movement was restrained. The aim of this study was to observe the relationship between WCP singer body movement, restraint of body movement, and overall SPL and SPL range in longer song samples.

The use of SPL, measured in decibels (dB), fulfilled many functions in this study. Firstly, voice data featuring SPL is widely available in the voice literature. Thus, the use of this measure allows comparison with a large body of reputable voice research with regard to many aspects of vocal performance. In addition, SPL is a strong indicator of emotion to the listener (Scherer, 1995; Sundberg, 2000; Sundberg, Elliot et al., 1993; Sundberg et al., 1995) making its variation and range an important part of the expressive art of singing. It is also useful as a gauge of vocal health: speech pathologists use SPL as a gauge of physical vocal performance (Corthals, 2004) and efficiency (Tang & Statholopoulos, 1995). SPL can be also be used as a measure of perceived loudness (Sundberg, 1995) if other factors such as frequency are taken into consideration (Johnson et al., 1993; Stevens, 1972; Sundberg, 1987c; Suzuki et al., 2003; Zwicker & Fastl, 1999a). SPL is also often given as an indicator of subjective loudness as well as acoustic intensity (Rasch & Plomp, 1999). Therefore, vocal SPL was chosen as a measure of the overlap between physiological, acoustic and perceived performance quality, making it an ideal measure for preliminary and exploratory research into the acoustic output of the embodied voice.

The highly important singing technique commonly known as support has been linked to torso behaviour, concomitant variations in Ps and thereby to sound output (Thorpe, Cala, Chapman, & Davis, 2001). However, direct measurement of Ps during phonation involves a transcutaneous puncture of the crico-thyroid membrane (Finnegan et al., 2000), a highly invasive procedure. Spontaneous respiratory behaviour is highly sensitive to cueing (Mead & Agostini, 1985-7). The minimization of intervention during data collection was therefore highly desirable in terms of ecological validity (Chaytor & Schmitter-Edgecombe, 2003) if characteristic singer behaviour was to be elicited during the protocol. The only non-invasive method currently used to measure Ps during phonation is inverse filtering (Plant et al., 2004; Sundberg, Titze et al., 1993). However, the validity of this method has been questioned (Plant et al., 2004; Plant & Hillel, 1998). Although it can be accurate in measuring onset pressure and following a plosive consonant (Sundberg, Titze et al., 1993), it has been found to be inaccurate in the case of dynamic and extended phonation (Plant et al., 2004; Plant & Hillel, 1998). This means that it is not suitable for analyzing longer samples, especially those in which the subject is moving because the estimates of Ps are based on the presupposition that the vocal system is static during the analysis interval.

Thus, there is a further advantage of measuring SPL, which is to use it as a surrogate measure of Ps. Surrogate measures or endpoints are used in clinical trials when a direct measure might be too invasive or uncomfortable to perform or to expose the research participant to unacceptable risk (Prentice, 1989). A surrogate measure, which must relate directly to the variable under scrutiny, replaces the variable of primary interest when it cannot be observed directly (Prentice, 1989). Various studies have shown that there is a linear relationship between Ps and SPL (Van den Berg, 1956; Finnegan et al., 2000; Tanaka & Gould, 1983; Tang & Statholopoulos, 1995). Data obtained during direct measurement of Ps during phonation has shown that the contributions of glottal closure (6%) and respiratory drive (94%) to Ps remain proportional throughout SPL variations (Finnegan et al., 2000) due to laryngeal reflexes in response to pressure change (Henriquez et al., 2007). It can be assumed, therefore, that a variation in SPL reflects an equivalent variation in Ps (Van den Berg, 1956; Huber, 2007), making SPL suitable as a surrogate measure of Ps change. The assumption of this is predicated, however, on other parts of the vocal mechanism, such as fundamental frequency and mechanism , determined at the larynx (Roubeau, 2009; Henrich, d'Allessandro, Doval, & Castellengo, 2005) and vowel shape, determined in the vocal tract (Honda, Hirai, Estill, & Tohkura, 1995; Sundberg, 1987), being kept constant. Unlike speech, these factors are kept constant in singing by the melody and lyrics of the song. These are comparable as long as the keys are the same in the samples compared. The use of SPL as a surrogate measure in this case allowed for an ecologically sound method of collecting acoustic data without interfering with the physical behaviour of the singers participating.

The aim of this investigation was twofold: to assess whether movement restraint in WCP singing leads to reductions of SPL throughout a sung passage rather than just at individual points of high output and to assess its impact on SPL range. Singing at low SPL and low F0s places lower subglottal pressure (Ps) requirements on a singer than high SPL and F0 (Sundberg et al., 1993). This alters the activity of the respiratory muscles (Leanderson, Sundberg, & von Euler, 1987) which also function as muscles of posture and movement (Rimmer, Ford, & Whitelaw, 1995). If antero-posterior torso movement in WCP singers is used to increase muscle power for generating high Ps for increasing SPL and F0 as has been suggested (Turner & Kenny, 2010) it would be expected that movement restraint would not alter the minimum SPL. It would be expected that the mid-range dynamics would be variable depending on musical interpretation but that there might be more use of the mid-range to compensate for losses at the peaks. It was therefore hypothesized that the absolute range would be reduced due to lower maxima with minima remaining the same as in the movement condition due to the lower Ps requirements for producing this sound.

4.3 Method

4.3.1 Participants

Participants were six singers of contemporary popular music (Table 4.1), 1 male and 5 female, ranging in age from 21 to 46 years. As formal and systematized training in the field of WCP singing is a rare and relatively new concept (Gilman, Merati, Klein, Hapner, & Johns, 2009; Hollien & Schoenhard, 1983; J. Lovetri, 2009; Wilson, 2003), participants were chosen instead on their professional status rather than on their vocal education background. They were all professional singers by the standards defined by Throsby and Hollister (Throsby & Hollister, 2003). By recruiting participants who had demonstrated skill in professional performance over a period of years, it was more likely that the behaviours exhibited would be healthy, sustainable and of high quality (Phyland, Oates, & Greenwood, 1999).

Table 4.1: Singer details and fundamental frequency/pitch ranges of common song

Singer	Sex	Primary Style	Years Professional Performance Experience	Song Range – Hz/Pitch
1	F	Pop	5	196/G3 – 554/C#5
2	F	Latin	10	165/E3 – 659/E5
3	M	R&B	6	117/A#2 – 392/G4
4	F	Music Theatre	10	175/F3 – 698/F5
5	F	R&B	18	175/F3 – 698/F
6	F	Gospel	28	123.5/B2 – 494/B4

Participants were music theatre and contemporary music singers using styles including jazz, folk, gospel, R & B and *a cappella.* Rock singers were excluded because of their use of techniques that may affect vocal health (Borch, Sundberg, Lindestad, & Thalen, 2004). All participants had the robust voices required for the R & B genre (Jeannette Lovetri, 2002) and sang skilfully in R & B or gospel styles. Since most of the participants were proficient in more than one contemporary music style, they were asked to nominate the style they considered to be their primary area of expertise (Table 4.1).

4.3.2 Experimental design

To avoid using cues that might trigger atypical SPL output strategies (Huber, Chandrasekaran, & Wolstencroft, 2005) or body postures (Wilson Arboleda & Frederick, 2006), verbal instructions were minimised. Singers were therefore provided with a vocal model of a song on a recording that all participants sang (referred to as the common song). The R & B/soul song *I Never Loved a Man (Like I Love You)* sung by Aretha Franklin (Franklin, 1998) was chosen as it spanned a 2-octave range, originally

175 - 698 Hz (F3 - F5). This would allow the demonstration of: (i) wide variability in dynamics in order to demonstrate how the singers behaved in both high and low SPL conditions (ii) a song with a large enough F0 range to ensure that the participants had to negotiate the higher part of their vocal range while engaging a strong voice quality; (iii) provision of a model singer with a powerful voice, delivering a high quality performance (Brackett & Hoard, 2004).

Singers were advised that they could alter the key of the song to suit their habitual F0 range. The large F0 range of the common song ensured that even if the singers lowered the key substantially they would not be able to avoid singing within range of the transition from chest to head register (also known as the *primo passagio*), which in both male and female voice occurs between 294 and 392Hz (D4 - G4) (Callaghan, 1996; Titze, 1984).

All contemporary popular singers use microphone technique to some degree if they use a microphone that is hand-held or on a stand. This involves intentionally varying the distance of the mouth from the microphone (Edwin, 2001). Significant antero-posterior movement was noted in a study involving a highly trained opera singer as subject. She had difficulty stopping this movement in spite of direction by the researchers. This indicated that even classical singers may move more than previously thought, leading the researchers to recommend that head-mounted microphones be used to keep singers' distance from the microphone constant for the purposes of measurement (Cabrera, Davis, Barnes, Jacobs, & Bell, 2002;Svec & Granqvist, 2010).

4.3.3 Performance tasks

Prior to data gathering, all singers prepared the common song excerpt from the recording and lyrics sheet provided by the researchers plus two song excerpts of their own choice from their own repertoire with a similarly large dynamic range as the song provided to them. The duration of the recording of the common song excerpt provided to them was 52 seconds. A musical transcription of the part of this recording analysed in Figure 4.3 is provided in Figure 4.1.

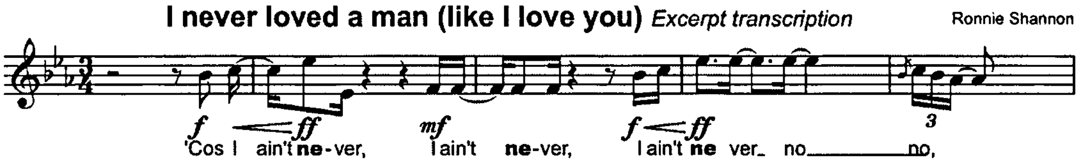

Figure 4.1 Transcription of the peak phrase as performed by Aretha Franklin on the recording provided to the singers.

No limitations were placed on F0 range, tempo or musical style; however, they were requested to maintain a similar dynamic range to the original recorded version provided to them. No other verbal instructions were given. F0 and equivalent musical note ranges chosen by the singers are shown in Table 4.1.

All singers sang unaccompanied in a large untreated room at the Faculty of Health Sciences, The University of Sydney. The singers sang each of their three song excerpts three times as recommended in the literature (Sihvo, Laippala, & Sala, 2000; Zwicker & Fastl, 1999c). The starting pitch (F0) of each song was nominated by the singer and was played on a pitch pipe before each recording. Songs were recorded with a miniature omni-directional AKG C477 condenser microphone with a flat response (Svec & Granqvist, 2010) mounted on a headset. This microphone position increases the signal-to-noise ratio such that acoustic reflections and background noise are not problematic to acquiring accurate measurement (Ferguson, Kenny, & Cabrera, 2010). The signal went through a Behringer pre-amplifier to a Tascam DA-20 MK II DAT recorder. Conditions such as microphone distance and the pre-amplifier's microphone sensitivity settings varied for each subject in order to avoid clipping. Separate reference tones were recorded for each participant using a sound generator and an SPL meter placed to match each singer's microphone distance.

Participants were videoed simultaneously with two video cameras from the front and side and the images from the two cameras were mixed to one screen using a Panasonic WJ-MX10 mixer. Singers were encouraged to sing and behave as if in performance. A taped rectangle on the floor represented the range of the cameras and singers were advised that they could move as they wished within this space. The video was analyzed in a separate study (Turner & Kenny, 2010) but also intended to have the effect of making the singers more performance-aware and more likely to behave as if on stage throughout the protocol.

When the first part of the protocol in which the singers performed in their usual manner [called the movement condition] was concluded, singers were requested to sing the songs again, behaving as if they had been given the instruction “by a director as part of a large-scale staged event to remain still, and that the spotlight was on them”. This imagery, and the wording describing it, were chosen to provide a musical rationale for a stationary performance that would be realistic to singers who would normally not stand still in performance, since the manner of eliciting voice change can affect the voice production strategies used (J. Huber et al., 2005). All three songs were then sung again under this non-movement condition. The protocol took no more than 40 minutes for all participants, and constituted a personal and vocal demand well within the capacity and usual practices of WCP singers.

The self-chosen songs were used as a means of warming up the voice, helping the singers to feel at ease by singing familiar songs and providing a training period in the second condition. They were also used to assess whether the samples taken of the common song represented the singers’ usual vocal performance standard. Any takes not deemed to be of acceptable performance quality by the singer or researchers were re-recorded (inferior takes were not analysed).

Five of the six singers were recorded with the microphone at the same distance of eight centimetres from the centre of the lips. Singer 4’s voice was too strong causing constant clipping. The sensitivity of her microphone had to be adjusted and the microphone distance increased to twelve cm prior to commencing the protocol. SPL is reduced proportionally to the increased distance from the sound source (Warren, 1977; Zwicker & Fastl, 1999b). Most of the change in microphone distance was taken into account in the calibration but there may have been some small alterations to the spectrum of the sound recorded because of the difference in the angle of the microphone to her mouth. This may have resulted in her absolute dB levels recording lower than they in fact were. However, as explained in the introduction, the intra-subject differences between the two conditions were the focus of study and given this focus, it was not deemed to be a problem.

4.3.4 Measurement and analysis

4.3.4.1 Peak phrase levels

To analyse the dynamic range, it was necessary to find a phrase during which all the singers reached and sustained both high and low levels of SPL. On the original recording, this was found to be Line 11, which contains 3 short sub-phrases, two of which demonstrate high SPL levels (the first and third) and one sub-phrase with low SPL levels (the middle sub-phrase). Line 11 was therefore chosen for analysis and referred to as the peak phrase since it represented the most demanding section of the song in terms of maximal voice production, containing notes of both high and low F0 and SPL. Thus, the peak phrase represents the same F0, vowel and register sequence in both conditions. Sound pressure levels were calculated at 10 millisecond intervals using PRAAT, generating decibel (dB) calculations for the entire peak phrase. All silences, unvoiced sounds and sounds that fell below the minimum SPL range of the singers' voiced sounds were eliminated from calculations via scripting. This was done for all three takes in each condition at the same point.

4.3.4.2 Absolute SPL ranges

The absolute minimum and maximum for each recording of the Peak Phrase were extracted from the dB calculations generated by PRAAT.

4.3.4.3 SPL percentile levels

SPL percentile values were calculated from the dB listings generated, in order to show the entire dynamic range of the Peak Phrase. The percentile levels indicate which SPL levels had been exceeded between 1% and 99% of measurement time.

The performance of WCP singers is characterised by idiosyncrasy and variability (Bowles, 1999). The use of SPL percentiles, that is, the amount of time spent on different levels within the phrase analysed, were judged a more realistic gauge of singers' SPL generating behaviour than the absolute range alone, which may indicate what was achieved for only a very short period of time. The limitation of the percentile measure is that it does not incorporate the fundamental frequency at the moment of a given SPL, but does describe the entire dynamic range and better gauges ability/disability than the measurement of single vowels (Corthals, 2004) .

4.3.4.4 Assessment of acoustical differences

The Just Noticeable Difference (JND) in SPL of a pure tone is considered to be ~1dB (Johnson, Turner, Zwislocki, & Margolis, 1993; Zwicker & Fastl, 1999a). Although listening to a complex sound is different from listening to isolated pure tones, in the music recording industry, it is considered that the minimum difference in SPL that can be noticed by a listener is also ~1dB (Huber & Runstein, 2005). One decibel was used as the criterion for determining the minimum significant SPL difference in this study.

4.3.4.5 Assessment of statistical differences

A two-tailed paired t-test was conducted on the three averaged SPL range calculations for each singer in each condition to determine whether the differences in SPL across the two conditions were statistically significantly different.

4.4 Results

4.4.1 Absolute SPL ranges for all songs

Figure 4.2 shows the maximum and minimum decibel levels for each take of all the songs. Contrary to our hypothesis, SPL minima decreased when SPL maxima decreased in the no movement (NM) condition. For four of the six singers (Singers 2, 3, 4 and 5), the highest and lowest SPL occurred in parallel. This allowed singers to maintain a consistent dynamic difference in SPL throughout the song. This also meant that even though the same singers in our previous study had significant reductions in peaks (Turner & Kenny, in press, 2011) this was compensated for in terms of maintaining the dynamic variation by an equivalent reduction in minimum SPL.

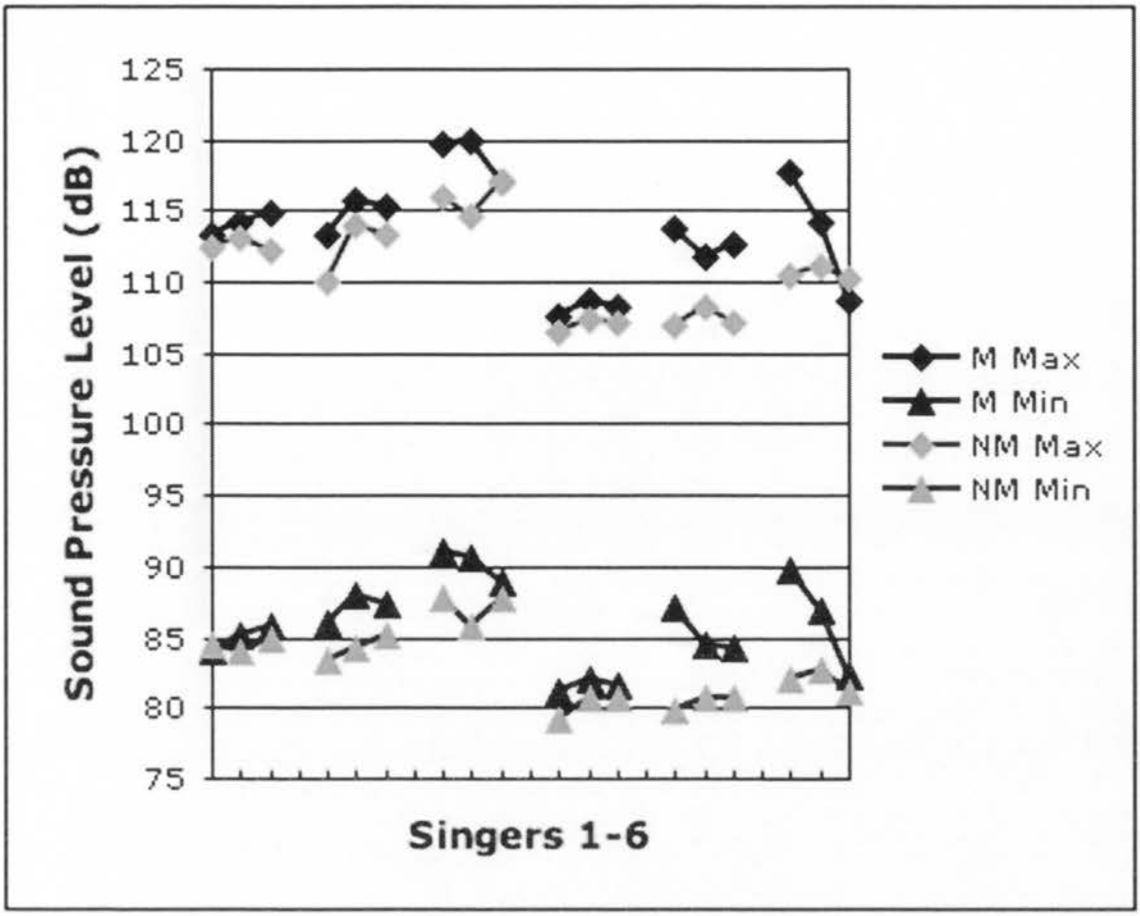

Figure 4.2: Absolute SPL ranges for the entire common song, singers 1- 6, three takes each in movement (M) and non-movement (NM) conditions

4.4.2 Dynamic range and statistical differences

Contrary to our expectation, there was much less variation within and across singers and conditions in SPL range extent compared with the absolute SPL range shown in Figure 4.2. All singers maintained a dynamic range at ~30dB in both conditions. There was no statistically significant difference between the two conditions with respect to differences in SPL range ($p=0.325$).

4.4.3 Percentile levels

Figure 4.3 shows graphs representing percentile levels (L) 1-99 for all singers in both conditions. The calculation of percentiles revealed reductions in SPL in the NM condition across all SPL levels for all singers. This gives a clearer picture of overall

SPL behaviour, showing that some singers spent more time in the mid range SPL in the NM conditions (Singers 1, 2 and 4).

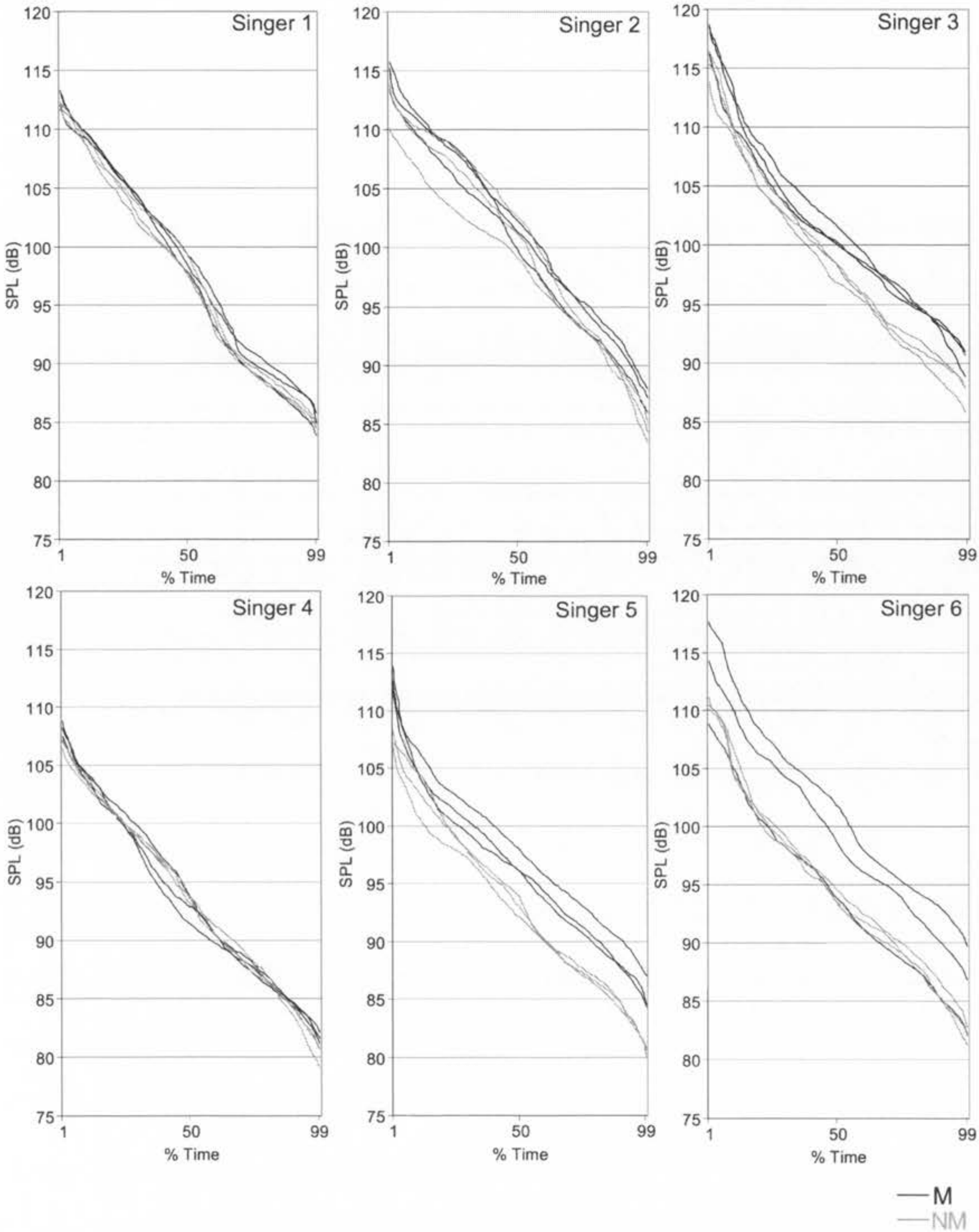

Figure 4.3: SPL percentile levels for peak phrase of common song singers 1-6, three takes each in movement (M) and non-movement (NM) conditions

The graphs show higher SPL levels in the M condition at the extremes of the dynamic range in most cases. In all singers, the maximum L99 attained was in the M condition. Singers 3, 5 and 6 showed larger differences between conditions at all percentiles. Singer 5 showed the phenomenon of parallelism of SPL most clearly, with a ~3dB gap between the lowest M percentile line and the highest NM percentile line up to the 40th percentile area, with some crossing over at ~L80-90. The percentile chart shows that overall SPL levels for these singers were very high. Thirty-five of the 36 takes across both conditions showed levels greater than 80dB for 99% of the duration of the song excerpt.

Some singers had more difficulty complying with the NM condition than others. Singer 2 was cautioned after the second take that she was starting to move again but was unable to stop and even increased her movement more on the last take. The NM takes where the SPL levels were higher on the percentile graph represent the takes where she moved more (Takes 2 & 3). All of the singers had difficulty in the second condition, which they either commented on between takes, or which was visible on the video footage in facial expressions and gestures showing displeasure, perplexity or frustration in between takes. Five of the six singers specifically and spontaneously commented on the difficulty of performing while remaining stationary.

4.5 Discussion

Overall SPL levels reduced significantly across the entire dynamic range in all singers under conditions of voluntary movement restraint as evidenced by the SPL percentile levels (Figure 4.3). However, the varying patterns from singer to singer revealed by the percentile curves show the complexity of the reaction to the NM condition, presenting a more detailed view of SPL than the absolute range alone (Figure 4.2). There were two main responses to the NM condition following the same subject grouping as shown in Figure 4.3: the first, as revealed by Singers 3, 5 & 6, produced a similar pattern of SPL but with all values reduced by approximately the same amount in the NM condition. The second response demonstrated in Singers 1, 2 and 4 showed reductions in SPL at the range extremes with more time spent in the mid-range.

The reduction of minima in parallel with maxima, shown most clearly in Figure 4.2, was an unexpected result and does not support our hypothesis that the minima would remain at the same level. Further, our expectation that SPL range in the NM condition would be reduced compared with the movement condition was also not supported. Possible explanations for the reductions in peak SPL under the conditions of movement restriction were covered in detail in our previous paper (Turner & Kenny, in press, 2011). These results indicated that movement restriction is associated with the reduction of overall SPL not just SPL peaks.

These mechanisms involved in vocal intensity control are still not fully understood. Changes in the mechanisms used to regulate SPL may be triggered by the use of different cues for loudness change, which are the result of neural control being affected by an internal loudness target (Huber et al., 2005). Movement patterns may be linked to loudness targets since limb movements also provide information for internal targeting (Gentilucci, Benuzzi, Bertoloani, Daprati, & Gangitano, 2000). Importantly, consistent with the findings of this current study, singers rely more strongly on internal models than auditory feedback for F0 regulation than non-singers (Jones & Keough, 2008). Similar strong internal models may also exist for SPL in singers.

Contrary to expectation, SPL percentiles at the low end of the dynamic range reduced in proportion to the reductions shown at the maximum end. This was the case even in Singer 6 who had dramatic differences between the maxima obtained on the first two takes in the M condition and the NM takes: her SPL range remained ~30dB. The singers in this study were asked to sing with a large dynamic range but remained consistently within ~30dB, the dynamic range possible in most healthy speaking voices at the pitch of ordinary speech (Colton, 1984). This range is substantially different to the potential decibel range exhibited in voice range profiles that demonstrate a physiological range in untrained singers of 60 dB (female) and 58 dB (male)(Hacki, 1999) as well as from the ~15 dB dynamic range of classical singers within a song noted by Schutte, Stark, & Miller (2003).

Range extent may have been consciously controlled by the singers in their desire to maintain the dynamic range and therefore the expressive values of the performance. Reducing the minimum to keep the dynamic range similar would be a practical option for maintaining dynamic range when the maximum must be reduced. By decreasing the minimum level, the maximum sounds louder to the listener. This allows the singers to give the impression that there is no reduction in the maximum in the NM condition by keeping the extent of the range the same. A possible explanation for this phenomenon is potentially provided by Baltes (1997), who described the phenomenon of compensation for loss of function in which the aging pianist Arthur Rubinstein heightened the perception of speed in fast movements by slowing his minimum tempi in the slow movements of concertos and sonatas.

This does not however explain the precision of the drop in SPL minima in this study nor the consistency of the effect regardless of singer experience, gender, training or stylistic background (Table 4.1). It is unlikely that simple mechanical interference with Ps production alone would cause this since the Ps demands were not equally great throughout the song phrase. These remain exciting questions for future research.

The precision of the maintenance of SPL range extent in the NM condition is noteworthy and to our knowledge has not been previously reported, possibly because this compensatory effect disguises the perception of the reduction of the SPL minimum. It is unlikely that singers are consciously controlling this, considering the precision of the reduction of the minimum and the slowness of auditory feedback alone as a mechanism for voluntarily monitoring and modifying speech (Borden, 1979). Although the interference with usual body behaviour created by the NM condition interfered with the setting of the maximum levels, surprisingly, it did not destabilize the singers' capacity to maintain SPL range.

Various mechanisms may be associated with this effect. As noted earlier, the speed as well as the amplitude of sound level variation is a key indicator of the vocal expression of emotion (Sundberg et al., 1995). The participants may have been more focused on the rate of loudness change rather than the less perceptible absolute SPL in the NM condition. This seems to be a plausible explanation considering that human perception of loudness is linked to sound level duration (Moore, 2003; Zwicker, 1999). A crescendo or diminuendo may need a certain sound level change rate as well as a certain magnitude. Thus, it is possible that if the participants were able to precisely maintain the rate of loudness change in the NM condition, this may have led to the same loudness extent.

The operation of an automatic compensatory mechanism may also be indicated. The SPL of one's own voice is, at least in part, regulated on a multisensory level via the autophonic response (Ho, 2000; Ingham, Warner, Byrd, & Cotton, 2006; Lane, Catania, & Stevens, 1961). Recent evidence indicates that automatic compensatory mechanisms are involved in the stabilizing of vocal SPL (Bauer, Mittal, Larson, & Hain, 2006;

Heinks-Maldonado & Houde, 2005; Liu, Zhang, Xu, & Larson, 2007) and fundamental frequency (F0) (Liu et al., 2007) in speech. The SPL range regulation observed in this study may be part of such automatic regulatory behaviour, since it would be very unlikely that singers would be able to consciously control the SPL range so precisely during performance. That the dynamic range extent is automatically regulated is also supported by the consistency of this result across singers and conditions regardless of the stylistic background of the singers, or the key in which they chose to sing. Differentiating reflexive or automatic from voluntarily controlled behaviour can be difficult, but the characterisation of behaviour as reflexive is constantly being modified as new evidence comes to light (Prochazka, Clarac, Loeb, Rothwell, & Wolpaw, 2000). The definition used here is that a reflex "appears automatic and hard to suppress" (Prochazka et al., 2000, p. 430). A voluntary behaviour, in this case, singing or body movement, can be a complex, conscious activity that may also harness simpler more reflexive behaviours beyond the conscious control of the instigator (Prochazka et al., 2000). Posture and respiratory control involve such reflexes and can enhance or interfere with one another (Gandevia, Butler, Hodges, & Taylor, 2002; Rimmer et al., 1995) such that respiratory muscle adjustment required by postural change cannot occur, thereby altering vocal output. Building on research concerning the autophonic response, it has now been found that a combination of auditory and kinaesthetic feedback is also important for F0 control (Larson, Altman, Lin, & Hain, 2008). This is a possible explanation for the singers' problems in overcoming the difficulties presented by altered kinaesthetic feedback when movement was restrained.

It is possible that the nature of the protocol alone had effects on acoustic output through the inducement of a change in attentional focus that interfered with what normally would be automatic behaviour. According toconstrained-action hypothesis , there are two types of attention: internal focus in which conscious attempts to control outcomes are made using kinaesthetic, kinematic or somatosensory information and external focus in which outcomes are the focus and which harnesses automatic motor processes (Wulf, McNevin, & Shea, 2001). In the context of this study, external focus would be attention on acoustic output of the voice (Maas et al., 2008). There is evidence that external focus leads to better performance and this has been shown to operate also within the oral-motor system (Freedman, Maas, Caligiuri, Wulf, & Robin, 2007). There was an attempt made in this study to keep attention externally focussed during the protocol by using directed imagery of a performance situation and this was further supported by the use of microphones and video cameras. However, according to the Schema Theory of motor control, the nature of the change in focus created by the altered acoustic feedback would have drawn the singers' attention onto sensory information as they tried to adapt to the unfamiliar situation. Schema Theory (Schmidt, 2003) posits that there are bodily memory representations of goal-oriented actions and their consequences based on past experience of that situation. For optimum adaptability, the motor system must record the relationships between the conditions, the motor commands generated, their sensory consequences and the outcome of the movement process. These relationships are called schema and can be recalled, recognized and adapted as required. When there is a mismatch between the expected and actual outcome of an action, the schema must be updated with the new sensory and movement information. For this reason, it is likely that the singers became conscious of the changes in kinaesthetic information as they tried to adapt to the NM condition in which both sensory and acoustic outcomes were changing, thereby shifting attention to an internal focus. However, if this were the only factor, and again following the reasoning of Schema theory, because of the singers' high levels of expertise, it would be expected that the singers would then adapt and improve their performance. This did not occur. Instead, five of the singers did not exhibit a learning effect by returning to their M condition sound level maxima. Initially, it appeared that Singer 2 seemed to be returning to her movement condition SPL in the NM condition, which was interpreted as a learning effect. However, on returning to view the video footage of her performance it became apparent that this improvement occurred at the same time as an (unintentional) increase in movement. This highlights again the association of the control of SPL with body movement.

Finally, research examining the special role of high sound levels in WCP music has shown that a pleasurable sensation of self-motion is induced when the sound of music is 90dB or above (Dibble, 1995; Todd & Cody, 2000). This phenomenon, described as the "rock and roll threshold" may be due to the effect of high sound pressure levels on the vestibular system (Todd & Cody, 2000) and may account for the dissatisfaction expressed by musicians and audiences when amplification sound levels are not kept high enough by sound engineers (Dibble, 1995). This may also account, at least in part, for the strong association of movement with dynamic variation in WCP singing. The minimum levels of these singers were already relatively high, the lowest (Singer 4 at 81.2dB at L1) being ~20dB higher than the ~60dB (Schutte, 1983) minimum level found in classical singers. All the singers in this study produced sound levels above 90dB most of the time (Figure 3) although these levels dropped considerably in the NM condition especially in singers 3, 4 and 6. It is possible that some of the displeasure expressed by the singers in the study at their sound production in the NM condition occurred because their minimum level had dropped below that threshold. We have perceptual access to the vestibular system only through the consequences of its activity (Purves et al., 2001). This may explain why the singers were surprised that standing still made singing so difficult and resulted in what they determined to be suboptimal performances. These phenomena should now be studied quantitatively in more closely controlled conditions to determine whether the SPL reducing effect of movement restraint exists in other styles of singing and what aspect of movement restraint triggers this effect.

Professional Implications

Control of SPL range by singers is important in professional singing contexts such as recording studios or when amplification is used in performance where unexpected high levels can lead to clipping or distortion or excessively low levels may not be adequate for a quality recording signal (Fielder, 1995). Singers in these contexts are often directed to stand still, based on the underlying assumption that if they are good singers they will be able to produce the same sound output. These results indicate that professionals such as voice coaches, sound engineers and directors need to be cautious in directing WCP singers to change their body behaviour, knowing that this may affect their sound output negatively.

4.6 Summary and conclusion

Two phenomena were observed in this study. The first was that SPL amplitude reduced throughout the dynamic range, not just at the peaks as previously demonstrated, when movement was restrained. This may occur due to interference between the postural and respiratory systems, since respiratory drive is the main factor in Ps production for SPL regulation. Movement restraint may also inhibit interactions between auditory and kinaesthetic feedback for SPL control.

Secondly, reduction of the SPL maxima was coupled with a parallel lowering of SPL minima that allowed the singers to maintain an SPL range at around 30dB even in the face of the robust SPL-reducing effect of movement restriction. To our knowledge, this phenomenon has not been noted previously, possibly because compensatory downward shift in SPL disguises the reduction in SPL maxima. This result was contrary to our expectation and indicates that there may be automatic mechanisms involved in this effect. This is supported by recent research that indicates that there are automatic compensatory responses to perturbations in phonation amplitude feedback that regulate SPL output. The difference in this case was that the perturbations provided in the protocol were not in auditory but in kinaesthetic feedback.

The consistency of these effects are surprising considering that the participants were permitted a high degree of freedom in execution in a singing genre known for its variability, indicating that both the SPL-reducing effect of movement restraint and the SPL range maintenance effect were robust. The results of this study also have significant practical implications for those working with singers during the conduct of voice research, in professional recording studios and on stage in that the placement of physical constraints on singers may have detrimental effects on acoustic output that may be insurmountable even in very experienced singers.

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4.7 References

Baltes, P. B. (1997). On the incomplete architecture of human ontogeny: selection, optimization and compensation as foundation of developmental theory. *American Psychologist, 52*(4), 366-380.

Bauer, J. J., Mittal, J., Larson, C. R., & Hain, T. (2006). Vocal responses to unanticipated perturbations in voice loudness feedback: an automatic mechanism for stabilizing voice amplitude. *Journal of the Acoustical Society of America, 119*(4), 2363-2371.

Borch, D. Z., Sundberg, J., Lindestad, P. A., & Thalen, M. (2004). Vocal fold vibration and voice source aperiodicity in 'dist' tones: a study of a timbral ornament in rock singing. *Logopedics Phoniatrics Vocology, 29*(4), 147-153.

Borden, G. J. (1979). An interpretation of research on feedback interruption in speech. *Brain and Language, 7*(May), 307-319.

Bowles, J. (1999). A rap on rhythm. In A. M. S. Nelson (Ed.), *"This is how we flow": Rhythm in Black Cultures* (pp. 5-14). Columbia, South Carolina: University of South Carolina Press.

Brackett, N., & Hoard, C. (Eds.). (2004). The New Rolling Stone Album Guide (4th ed.). New York: Fireside.

Cabrera, D., Davis, P. J., Barnes, J., Jacobs, M., & Bell, D. (2002). Recording the operatic voice for acoustic analysis. *Acoustics Australia, 30*(3), 103-108.

Callaghan, J. (1996). The Implications of Voice Science for the Teaching of Singing: Vocal registers. *Australian Voice*, 27-31.

Chaytor, N., & Schmitter-Edgecombe, M. (2003). The ecological validity of neuropsychological tests: a review of the literature on everyday cognitive skills. *Neuropsychology Review, 13* (4), 181-197.

Colton, R. H. (1984). *Glottal waveform variations associated with different vocal intensity levels.* Paper presented at the 13th Symposium Care of the Professional Voice.

Corthals, P. (2004). Sound pressure level of running speech: percentile level statistics and equivalent continuous sound level. *Folia Phoniatrica et Logopaedica, 56*(3), 170-181.

Dibble, K. (1995). Hearing loss and music. *Journal of the Audio Engineering Society, 43*(4), 251–266.

Edwin, R. (2001). Working with "Mike". *Journal of Singing, 58*(2), 171-172.

Ferguson, S., Kenny, D. T., & Cabrera, D. (2010). Effects of training on time-varying spectral energy and sound pressure level in nine male classical singers. *Journal of Voice, 24*(1), 39-46.

Fielder, L. D. (1995). Dynamic-range issues in the modern digital audio environment. *Journal of the Audio Engineering Society, 43*(5), 322-339.

Franklin, A. (1998). Aretha: Queen of Soul. The very best of Aretha Franklin.: WEA International Inc.

Freedman, S., Maas, E., Caligiuri, M., Wulf, G., & Robin, D. A. (2007). Internal versus external: oral-motor performance as a function of attentional focus. *Journal of Speech, Language, and Hearing Research, 50*, 131-136.

Gandevia, S., Butler, J. E., Hodges, P., & Taylor, J. L. (2002). Balancing acts: Respiratory sensations, motor control and human posture. *Clinical and Experimental Pharmacology and Physiology, 29*(1-2), 118-121.

Gentilucci, M., Benuzzi, F., Bertoloani, L., Daprati, E., & Gangitano, M. (2000). Language and motor control. *Experimental Brain Research, 133*, 468-490.

Gilman, M., Merati, A. L., Klein, A. M., Hapner, E. R., & Johns, M. M. (2009). Performer's attitudes toward seeking health care for voice issues: understanding the barriers. *Journal of Voice 23*(2), 225-228.

Hacki, T. (1999). [Vocal capabilities of nonprofessional singers evaluated by measurement and superimposition of their speaking, shouting and singing voice range profiles]. *Hals-, Nasen-, Ohren- Heilkunde, 47*(9), 809-815.

Heinks-Maldonado, T. H., & Houde, J. F. (2005). Compensatory responses to brief perturbations of speech amplitude. *Acoustics Research Letters Online, 6*(3), 131-137.

Henrich, N., d'Allessandro, C., Doval, B., & Castellengo, M. (2005). Glottal open quotient in singing: measurements and correlation with laryngeal mechanism, vocal intensity, and fundamental frequency. *Journal of the Acoustical Society of America, 117*(3), 1417-1430.

Ho, A. K. (2000). Volume perception in Parkinsonian speech. *Movement Disorders, 15*(6), 1125-1131.

Hollien, H., & Schoenhard, C. (1983). The riddle of the middle register. In *Vocal Fold Physiology: Biomechanics, Acoustics and Phonatory Control.*

Honda, K., Hirai, H., Estill, J., & Tohkura, Y. (1995). Contributions of vocal tract shape to voice quality: MRI data and articulatory modeling. In O. Fujimura & M. HIrano (Eds.), *Vocal Fold Physiology: voice quality control* (pp. 23-38). San Diego, CA: Singular Publishing Group.

Huber, D., & Runstein, R. (2005). *Modern Recording Techniques* (Sixth Edition ed.): Focal Press/Elsevier.

Huber, J., Chandrasekaran, B., & Wolstencroft, J. (2005). Changes to respiratory mechanisms during speech as a result of different cues to increase loudness. *Journal of Applied Physiology, 98*(6), 2177-2184.

Ingham, R. J., Warner, A., Byrd, A., & Cotton, J. (2006). Speech effort measurement and stuttering: investigating the chorus reading effect. *Journal of Speech, Language, and Hearing Research, 49*(3), 660-670.

Johnson, J. H., Turner, C. W., Zwislocki, J. J., & Margolis, R. H. (1993). Just noticeable differences for intensity and their relation to loudness. *Journal of the Acoustical Society of America, 93*(2), 983-991.

Jones, J. A., & Keough, D. (2008). Auditory-motor mapping for pitch control in singers and nonsingers. *Experimental Brain Research, 190*, 279-287.

Lane, H. L., Catania, A. C., & Stevens, S. S. (1961). Voice level: autophonic scale, perceived loudness and effects of sidetone. *Journal of the Acoustical Society of America, 31*(2), 160-167.

Larson, C. R., Altman, K. W., Lin, H., & Hain, T. (2008). Interactions between auditory and somatosensory feedback for voice F0 control. *Experimental Brain Research, 187*, 613-621.

Leanderson, R., Sundberg, J., & von Euler, C. (1987). Breathing muscle activity and subglottal pressure dynamics in singing and speech. *Journal of Voice, 1*(3), 258-261.

Liu, H., Zhang, Q., Xu, Y., & Larson, C. R. (2007). Compensatory responses to loudness-shifted voice feedback during production of Mandarin speech. *Journal of the Acoustical Society of America, 122*(4), 2405-2412.

Lovetri, J. (2002). Contemporary commercial music: more than one way to use the vocal tract. *Journal of Singing, 58*(3), 249-252.

Lovetri, J. (2009, 7/12/09). Going a new way. From www.blogger.com/profile/0435893414631644578

Maas, E., Robin, D. A., Hula, S., Freedman, S., Wulf, G., Ballard, K., et al. (2008). Principles of motor learning in treatment of motor speech disorders. *American Journal of Speech-Language Pathology, 17*, 277-298.

Mead, J., & Agostini, E. (1985-7). Dynamics of breathing. In *The Respiratory System.*

Moore, B. C. J. (2003). The Perception of Loudness. In *An Introduction to the Psychology of Hearing* (Fifth ed., pp. 27-161). San Diego: Academic Press.

Phyland, D. J., Oates, J., & Greenwood, K. M. (1999). Self-reported voice problems among three groups of professional singers. *Journal of Voice, 13*(4), 602-611.

Prochazka, A., Clarac, F., Loeb, G. E., Rothwell, J. C., & Wolpaw, J. R. (2000). What do *reflex* and *voluntary* mean? Modern views on an ancient debate. *Experimental Brain Research, 130*, 417-432.

Purves, D., Fitzpatrick, D., Augustine, G. J., Katz, L. C., Williams, S. M., McNamara, J. O., et al. (2001). *Neuroscience* (2nd ed.). Sunderland, Mass: Sinauer Assoc.

Rimmer, K. P., Ford, G. T., & Whitelaw, W. A. (1995). Interaction between postural and respiratory control of human intercostal muscles. *Journal of Applied Physiology, 79*, 1556-1561.

Roubeau, B. (2009). Laryngeal vibratory mechanisms: the notion of vocal register revisited. *Journal of Voice, 23*(4), 425-438.

Schmidt, R. (2003). Motor schema theory after 27 years: reflections and implications for a new theory. *Research Quarterly for Exercise and Sport, 74*(4), 366-375.

Schutte, H. (1983). *The efficiency of voice production.* Groningen: Kemper.

Schutte, H., Stark, J. A., & Miller, D. G. (2003). Change in singing voice production, objectively measured. *Journal of Voice, 17*(4), 495-501.

Sihvo, M., Laippala, P., & Sala, E. (2000). A study of repeated measures of softest and loudest phonations. *Journal of Voice, 14*(2), 161-169.

Sundberg, J. (1987). Articulation. In *Science of Singing* (pp. 93-133). DeKalb, Illinois: Northern Illinois University Press.

Sundberg, J., Iwarsson, J., & Hagegård, H. (1995). A singer's expression of emotions in sung performance. In O. Fujimura & M. Hirano (Eds.), *Vocal Fold Physiology: Voice Quality Control* (pp. 217-231). San Diego, CA: Singular Publishing Group.

Sundberg, J., Leanderson, R., von Euler, C., & Knutsson, E. (1991). Influence of body posture and lung volume on subglottal pressure control during singing. *Journal of Voice, 5*(4), 283-291.

Sundberg, J., Titze, I. R., & Scherer, R. (1993). Phonatory control in male singing: a study of the effects of subglottal pressure, fundamental frequency, and mode of phonation on the voice source. *Journal of Voice, 7*(1), 15-29.

Svec, J., & Granqvist, S. (2010). Guidelines for selecting microphones for human voice production research. *American Journal of Speech-Language Pathology, 19*, 356-368.

Thorpe, W. C., Cala, S. J., Chapman, J., & Davis, P. J. (2001). Patterns of breath support in projection of the singing voice. *Journal of Voice, 15*(1), 86-104.

Throsby, D., & Hollister, V. (2003). Don't give up your day job: an economic study of professional artists in Australia [Electronic Version] from http://www.ozco.gov.au/arts_resources/publications/dont_give_up_your_day_job_report/.

Titze, I. R. (1984). *Influences of subglottal resonance on the primary register transition.* Paper presented at the 13th Symposium on care of the Professional Voice, Juilliard School. New York City.

Todd, N. P. M., & Cody, F. W. (2000). Vestibular responses to loud dance music: A physiological basis of the ''rock and roll threshold''? . *Journal of the Acoustical Society of America, 107*(1), 496-500.

Turner, G., & Kenny, D. T. (2010). A preliminary investigation into the association between body movement patterns and dynamic variation in Western contemporary popular singing. *Musicae Scientiae, 14*(1), 143-164.

Turner, G., & Kenny, D. T. (2011, in press). Restraint of body movement potentially reduces peak SPL in western contemporary popular singing. *Musicae Scientiae, SAGE Journals Online.*

Warren, R. M. (1977). Subjective loudness and its physical correlates. *Acustica, 37*, 334-346.

Wilson Arboleda, B. M., & Frederick, A. L. (2008). Considerations for maintenance of postural alignment for voice production. *Journal of Voice, 22*(1), 90-99.

Wilson, P. (2003). Sinful modern music: science and the contemporary commercial singer. *Australian Voice, 9*, 12-16.

Wulf, G., McNevin, N., & Shea, C. H. (2001). The automaticity of complex motor skill learning as a function of attentional focus. *Quarterly Journal of Experimental Physiology, 54*(4), 1143-1154.

Zwicker, E., & Fastl, H. (1999). Examples of Application. In *Psychoacoustics: facts and models* (pp. 315-319): Springer.

Zwicker, E., & Fastl, H. (1999a). Just-Noticeable Sound Changes. In E. Zwicker & H. Fastl (Eds.), *Psycho-acoustics: facts and models* (pp. 176): Springer.

Zwicker, E., & Fastl, H. (1999b). Loudness. In *Psychoacoustics: facts and models* (pp. 203-238): Springer.

Zwicker, E., & Fastl, H. (1999). Stimuli and procedures. In *Psycho-acoustics: Facts and Models* (pp. 1-15): Springer.

Are R & B specialist singers different to other WCP singers?

The research reported in Chapter 4 further supported the hypothesis that there is an association between body movement and dynamic variation and that movement may be needed for SPL control in WCP singing styles and that it may enhance the technique known by singers as support. In addition, it became clearer that movement restraint might have been having a greater negative impact on SPL in those singers who nominated themselves as primarily R &B/gospel singers than on those who, though adept at singing R & B, did not nominate it as their primary style. In Chapter 3 (Figure 3.2), two of the R&B/gospel specialists (Singers 3 and 6) reached higher sound levels than the other singers in the original condition and had bigger decreases in the NM condition. Although Singer 5, the other R &B/Gospel singer, demonstrated levels that were not as high initially, she had a significant drop in the NM condition (Fig 3.2). Singers 3, 5 and 6 had SPL reductions over the whole song in the NM condition – not just at the most demanding points in terms of Ps. This raises the question of whether there is something different about the voice production techniques used by R & B/gospel specialists that make *not* moving more difficult. This question is pursued further in Chapter 5.

CHAPTER 5: LARYNGEAL MECHANISMS USED BY WESTERN CONTEMPORARY POPULAR SINGERS

In the studies outlined in the previous chapters, the singers sang a song excerpt that they had learned, modelled on a recording of Aretha Franklin. In my judgment, most of that model recording was sung by Franklin in Mechanism 1 (defined in section 1.3.7.2). Although all the singers sang R & B/gospel styles professionally, it appeared that not all of the singers adopted the same mechanism as the model recording. When the participants sang, I perceived those singers who achieved the highest SPL were those most obviously singing in Mechanism 1 with a straight tone (Singers 3 and 6). These were also the singers who had the most difficulty maintaining their intensity when they were asked to stand still. Singers 3 and 6 were also two of the three singers who defined themselves as primarily R & B/gospel singers. I also judged that some of the remaining singers were using a lighter mechanism (Mechanism 2) voice at the higher pitches rather the Mechanism 1 voice of the recording they modelled.

As discussed earlier in the section on the larynx (1.3.7, in particular 1.3.7.7), near the upper pitch limit of Mechanism 1, the vibrating vocal folds are stretched to their physiological limit (Rothenberg, 1988). Concurrently, the subglottal pressure required at greater F0 in Mechanism 1 is greater than that using Mechanism 2 at the same pitch (Stone, Cleveland, Sundberg & Prokop, 2003; Sundberg, Gramming & Lovetri, 1993). For these reasons, a singer will often move from a heavy to light voice quality as the pitch of the melody rises. A transition to the lighter mechanism means that the activity of the *cricothyroid*, *lateral cricoarytenoid* and *vocalis* muscles may be reduced (Sundberg, 1987b). High F0 sung in lighter voice is accompanied by much lower Ps (Schutte, 1983). There is evidence that pitch is controlled by laryngeal muscular activity in Mechanism 1, whereas in Mechanism 2, it may be regulated by airflow (Sundberg, 1987b). Such a change of mechanism is one way of reducing stress on the voice at high pitch. Therefore, a high note in Mechanism 2 will require lower levels of respiratory drive than a high note in Mechanism 1. It is for this reason that the mechanism is significant to the discussion of the possible functional role of movement for altering Ps during singing.

Western classical training minimises body movement (Pettersen, 2005) in contrast to WCP singing. The degree to which body movement is associated with vocal SPL variation may depend on the physical demands placed on the voice source for the style. In observations across a wide range of cultures, body stillness most often occurred in singers when a light mechanism (Mechanism 2) voice was employed (see (1.1.2.2 for details). Koufman (Koufman, Radomski, Joharji & Russell, 1996) compared different singing styles and found that contemporary popular styles involve greater laryngeal tension compared with classical singing. Koufman also reported variations in laryngeal muscle tension between contemporary popular styles. He grouped styles with similar laryngeal biomechanics together and then rated them from highest to lowest in terms of laryngeal muscle tension. Rock/gospel showed the greatest level of tension, followed by bluegrass/country & western, music theatre and popular/jazz. It was observed earlier, that body movement follows a similar grading – it is most frequent and more dynamic in Blues/Rock/Gospel styles and less frequent in pop and jazz. Similarly, Thalen and Sundberg (Thalen & Sundberg, 2001) used the phonation mode categories pressed, normal, flow and breathy to classify singing styles at the voice source. They found that Blues was close to pressed, Jazz and Pop were in the mid-range for 'pressedness', that is with a high level of glottal adduction, and that classical operatic was near flow phonation.

The accusation is often levelled at western contemporary popular (WCP) singing styles that they are intrinsically abusive, although there is no evidence that this is the case amongst professional singers (Phyland, Oates & Greenwood, 1999) except for those working under substandard or exploitative conditions (Gilman, Merati, Klein, Hapner & Johns, 2009; Wilson, 2003). Much of the controversy over vocal health in WCP singing arises because of disagreements over the correct use of the laryngeal mechanism. Vocal dysfunction, in its most extreme form as nodules or polyps on the vocal folds, has often been associated with damage created by a permanent state of laryngeal effort (Grini-Grandval, Ouaknine & Giovanni, 2000) or excessive vocal fold adduction possibly resulting in vocal fold impact stress (Grillo & Verdolini, 2006). Impact stress creates micro-traumas that lead to nodule formation (Grillo & Verdolini, 2006; Grini-Grandval et al., 2000). This is sometimes referred to as pressed voice (Grillo & Verdolini, 2006). It is a concern therefore that Blues singing has been described as pressed (Thalen & Sundberg, 2001), implying that its practice is contra-indicated for those wishing to maintain vocal health. This has certainly been the perspective of some voice professionals. However, the dysfunctional state of constant hyperfunction of the voice is different to the varying effort levels that correspond to the requirements of singing (Koufman et al., 1996). WCP styles do require more laryngeal tension than classical styles with rock and gospel demonstrating the highest levels of laryngeal work (Koufman et al., 1996) but this does not of itself mean that they are vocally abusive (Hollien, 1983; Koufman et al., 1996) unless other aspects of healthy singing technique such as good breath support are not present (Koufman et al., 1996).

If glottal adduction is stronger in blues-related styles, then respiratory drive must be proportionately stronger (Finnegan, Luschei & Hoffman, 2000) so as not to damage the voice (Koufman et al., 1996). In the previous chapters, it was shown that two of the singers who identified themselves as primarily R&B/gospel singers and who had the highest SPL levels, showed a very large drop in SPL when they could not move in the second condition. This raises the question, of whether they use movement to generate muscle contraction to increase respiratory drive to proportionally match a higher effort level at the larynx and whether singers who favour R&B/gospel over other WCP styles might be more inclined to adopt this strategy. As a preliminary to answering this question it was necessary to ascertain which laryngeal mechanism the singers from the previous studies were using. In the absence of direct measurement, this could only be judged perceptually by experts. A perceptual study was therefore designed that used the common song recordings analysed in Chapters 2 to 4.

5.1 Vocal mechanisms used by six western contemporary popular singers as perceived by vocal experts from three different musical backgrounds

5.1.1 Introduction

Johan Sundberg stated that "Generally, it is easy to determine the register from the voice timbre"(Sundberg, 1987b). Grillo & Verdolini (2006) also commented that varying patterns of vocal fold adduction are "often quite readily distinguished by listeners" (p. 1). Henrich and colleagues (Henrich, d'Allessandro, Doval & Castellengo, 2005) stated that an audible reduction in perceived loudness as the singer moved upwards in pitch indicates that a singer has made a transition into Mechanism 2. If this be the case, singing experts should be able to agree on the vocal mechanism used by the singers in this study. However, most empirical singing studies are predicated on the assumption that professional or trained singers will be using western classical technique. Classical training causes the timbral differences between registers or mechanisms to be minimized (Svec, Sundberg & Hertegard, 2008) whereas many western contemporary popular singers use these differences as a musical device to create contrast (Hollien, 1983). It is likely that expert listeners would make judgments on the basis of their own taste, listening and singing experience and training (Honing & Ladinig, 2006). If so, perceptual judgments by expert judges from different singing backgrounds may differ.

This study assessed what the singers' usual vocal mechanisms were at the point of high SPL and F0 analysed in Chapter 2, through the perceptual judgments of expert listeners. To ensure that the results were not biased toward one stylistic grouping's perception of the voice technique used, I sought expert listeners who were singers, teachers and voice researchers from different stylistic backgrounds. Being scientist-practitioners would ensure that their judgments were both practically based and well informed as to vocal physiology. As teachers they were used to listening critically to singers and quickly forming an opinion on the techniques used.

My hypotheses were that:

1. Experts would not always agree on the mechanism used.

2. Singers 3 and 6 would be judged to be in Mechanism 1.

5.1.2 Method

5.1.2.1 Participants

Three voice experts, each a performer, singing teacher and post-graduate empirical voice researcher were invited to listen to a set of vocal recordings. Each expert listener specialised in a different style of singing encountered in western music: Expert A – classical, Expert B – world music/contemporary and Expert C – music theatre.

5.1.2.2 The recordings

Six WCP singers sang the same song excerpt of the R & B/soul song *I Never Loved a Man (Like I Love You)* sung by Aretha Franklin (Franklin, 1998) three times. Each singer sang the word "never" twice on the same F0 in each excerpt. These can be seen as sub-phrases 1 and 3 in each excerpt as shown in Figure 1 of Paper 1 in Chapter 2. These were extracted making a series of six samples per singer. Because the sound samples were short, they were grouped by singer rather than randomized so the expert listeners could get to know the singers voices and form an opinion in conditions closer to their experience as teachers. These samples can be heard on the CD in Appendix D-i.

5.1.2.3 Response sheet

Mechanism equates to various names such as heavy mechanism or chest voice and Mechanism 2 equates to light mechanism, falsetto or head voice, amongst others (Castellengo & Henrich, 2004). Because of the multiplicity of terms, the terms that are commonly used as the equivalents of Mechanisms 1 and 2 were grouped on the response sheet using the more general term "voice quality" (Svec et al., 2008) 1 and 2. This was to avoid favouring the terminology of one pedagogical or stylistic system over another and to minimise confusion.

Judges were asked to rate from 1 to 4 the voice quality on the syllable "ne" of the word "never" from each sound sample on the recording using the following categories:

- 1 = heavy mechanism, modal register, chest register, mechanism 1, thick fold
- 2 = light mechanism, loft register, head register, mechanism 2, thin fold
- 3 = other
- 4 = cannot identify the voice quality used

Because the experts involved were from different musical genres, it was highly likely that they would use different terminology to describe the same phenomena. To allow for the existence of a mixed voice or middle register (Castellengo & Henrich, 2004; Svec et al., 2008) or for the possibility that the listeners might not approve of the terminology options provided, the third option "other" was allowed, with encouragement to write their own descriptive words of the voice quality heard in a "comments" column that followed. A copy of the response sheet can be seen in Appendix C.

Singer	Voice Samples						Intra-judge reliability	Judges
	S1	S2	S3	S4	S5	S6		
Singer 1								
	2	2	2	2	2	2	100%	A
	1	1	1	1	1	1	100%	B
	3	3	3	3	3	3	100%	C
Inter-judge reliability	0	0	0	0	0	0		
Singer 2								
	2	2	2	2	2	2	100%	A
	1	1	1	1	1	1	100%	B
	2	2	3	2	3	3	50%	C
Inter-judge reliability	66%	66%	0	66%	0	0		
Singer 3	1	1	1	1	1	1	100%	A
	1	1	1	1	1	1	100%	B
	1	3	3	1	3	3	66%	C
Inter-judge reliability	100%	66%	66%	100%	66%	66%		
Singer 4	2	1	2	2	2	2	83%	A
	3	3	3	3	3	3	100%	B
	2	2	2	2	2	2	100%	C
Inter-judge reliability	66%	0%	66%	66%	66%	66%		
Singer 5	1	1	1	1	1	1	100%	A
	3	3	3	1	1	1	50%	B
	3	3	1	1	3	1	50%	C
Inter-judge reliability	66%	66%	66%	100%	66%	100%		
Singer 6	1	1	1	1	1	1	100%	A
	1	1	1	1	1	1	100%	B
	1	1	1	1	1	1	100%	C
Inter-judge reliability	100%	100%	100%	100%	100%	100%		

Table 5.1: Inter-judge and intra-judge reliability in rating laryngeal mechanisms of six song samples per singer

5.1.3 Results

5.1.3.1 Intra- and inter-rater consistency

Judgments were highly variable for some singers and more consistent for others. Table 1 shows that judges tended to be internally consistent but inter-judge reliability was much lower. Judges were only in complete agreement in the case of Singer 6 who was judged to be in Mechanism 1 and were evenly divided between qualities 1, 2 and 3 (heavy mix) in the case of Singer 1. The terminology used by all three experts for the third "other" voice quality was very similar. Judge A used the term "blend" and Judges B and C used "mix". For this third voice quality judges also liked to add extra qualifiers in the comments column that implied gradations such as "heavy mix", "light mix".

5.1.3.2 Judgments of mechanism

Figure 5.1 shows the mechanism judgments for each singer using the assessments across all three judges. The singers who were judged most often to be in Mechanism 1 were the R & B/gospel singers. Only the three R & B/gospel singers were judged never to be in Mechanism 2. However, of the three, the judges expressed the most uncertainty in classifying Singer 5, making comments such as "heavy with some lightness," "first note hard to categorize," "possible mix with nasal resonance".

5.1.3.3 Reaction to Protocol

Some interesting unprovoked comments were made by the judges. Judge A commented "of course they did not use only one mechanism since they were good singers." Judge B said that she thought all the participants were all 'trying to sing in Mechanism 1 but with varying degrees of success."

The judges had no problem being offered multiple terms on the response sheet. Judge A volunteered that she thought that being offered many alternative expressions for the same mechanism was a good idea. The only terms questioned were the use of "modal" for 1 and "loft" for 2 although they have been used elsewhere (Henrich et al., 2005; Shipp, 1975). The issue raised by Judge A was that she regarded "modal" as meaning "speech" voice and that people do not all speak in the same mechanism.

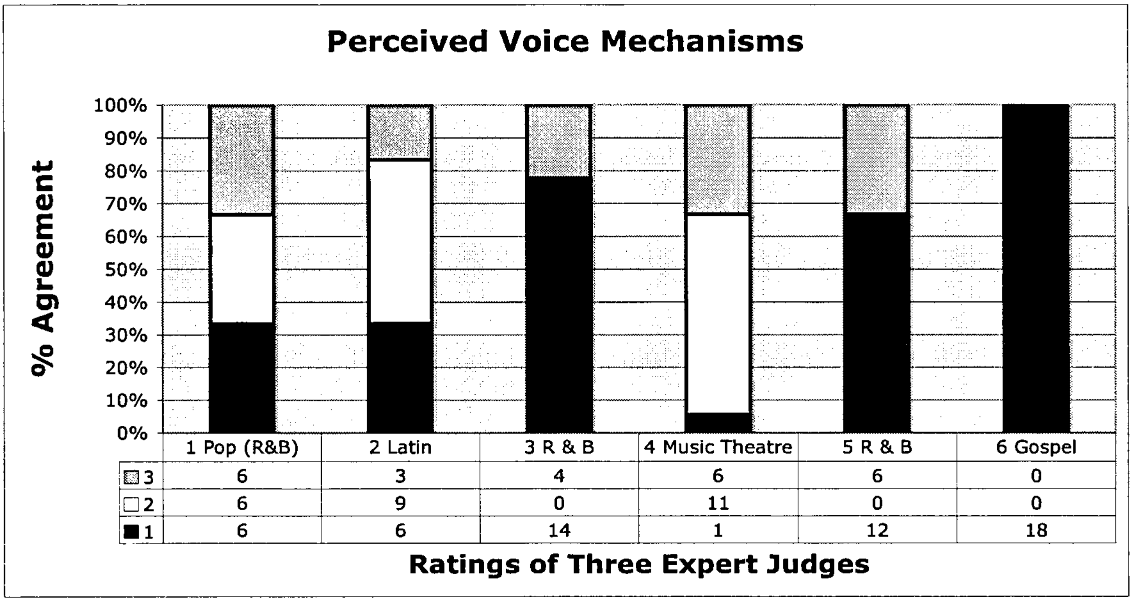

Figure 5.1: Ratings by three expert judges of laryngeal mechanism used in each of the singers six song samples

5.1.4 Discussion

As hypothesized, Singers 3 and 6 were judged to be using Mechanism 1 most of the time. Unexpectedly, Singer 5 was also judged to be in Mechanism 1 most of the time although her SPL levels were not shown to be as high in the Chapter 2 study. This means that the mechanism used was along similar stylistic lines to those outlined by Koufman, with all the R&B/Gospel singers being judged never to be using Mechanism 2, though occasionally using a 'mixed' voice and the pop, Latin and music theatre favouring Mechanism 2 and 'mixed' voice.

The lack of consistency across judges indicates that there may be differences in the perception or terminology used to describe the voice mechanisms used. This is not surprising in light of the controversy that has surrounded the definition of register and mechanism (Sundberg & Kullberg, 1999). Although register is sometimes defined as being synonymous with mechanism, it is also defined as including perceptual elements introduced by the vocal tract that impact on perceived timbre. This shows that even for experts, judging vocal mechanism perceptually is difficult, at least for some types of voice production. This may be the case within a genre where the target timbre is agreed upon, as suggested in the earlier quotations, but not between genres where spectral balance that indicates a register may be modified in the vocal tract in a different way. It would be hard to find a set of expert listeners who were more qualified than the three who participated here. It is unlikely then that the disparity between some of their judgments is due to lack of professional skill. Rather, it seems that a large factor in the disparity of judgments relates to their own perception of the music as informed by their own experience. Familiarity with musical genre by a subject is more important than musical training in perceiving anomalies in timing (Honing & Ladinig, 2006). This means that an expert listener who is not familiar with the musical genre is not necessarily going to be a better judge than, for example, an untrained WCP practitioner who is highly familiar with the genre.

The even division between judges regarding Singer 1 is of note. It is most likely that she was in Mechanism 1 as evidenced by the fact that she lowered the pitch of the song and altered the melody slightly to avoid the highest notes (Chapter 3, Figure 3.1) of the excerpt (not included in sample used here). Singer 1's voice was distinguished by her continuous use of vibrato, an unusual characteristic in a WCP singer, which would have altered the perceived timbre by reducing the high frequency partials (Hibi & Hirano, 1995). It seems that judgments of her voice were confounded by her unusual use of vibrato throughout the tone in combination with a strong R&B technique that this led to the divergence of opinion.

After the recording was made of Singer 1, she commented that she had had a classical singing teacher for a time who had changed her technique. This also could have caused confusion in listening since the vibrato is an element more common in classical singing than in WCP. Vibrato is an essential part of the voice quality of western classical singing (Hirano, Hibi & Hagino, 1995). It is produced by oscillation of the internal and some of the external musculature of the larynx and sometimes also parts of the vocal tract (Hirano et al., 1995). The respiratory muscles do not oscillate in activity during vibrato in classical singing although the airflow does (Hirano et al., 1995). These actions cause oscillations in the amplitude of the F0 and sometimes also of intensity and spectral balance of the voice creating pulsations in the sound that may be pleasing to the ear (Hirano et al., 1995). There are different standards of what is good vibrato in different styles of music in terms of rate, F0, intensity and timbre (Li-de, 1995). Tones with vibrato display a higher airflow rate than straight tones, which indicates lower glottal resistance than in straight tones (Hirano et al., 1995). This means that the muscular effort at the glottis is higher when the tone is straight than when sung with vibrato. This could be due in part to the participation of the cricothyroid muscle in voice with vibrato. The activity of the cricothyroid thins the edges of the vocal folds causing a drop in the high spectral range. The reduction in high harmonics caused by this could have modified a belt sound, softening (Hirano et al., 1995) some of its characteristic brightness. This would make the vocal mechanism harder to pinpoint perceptually.

Vibrato occurs spontaneously when the supraglottic area is neither constricted nor widened (Hirano et al., 1995). The higher range of Mechanism 1 requires the widening of the supraglottal area (MacCurtain & Welch, 1983). This may account for Singer 1's avoidance of the high notes in the song passage and lowering of the pitch overall. It is possible that remaining in Mechanism 1 at the higher pitches in the song sample would have precluded the vibrato that is part of this singer's vocal signature. The other singers in the study sang the high notes of the sample with a straight tone. As is common in this style, vibrato is often delayed on long high belted notes (Edwin, 2000) meaning that on short notes, such as on the samples used here, there is often no vibrato.

Not all sang singers were in the same fundamental frequency (F0) range because they had lowered the key of the song (Chapter 3, Figure 3.1). Fundamental frequency is known to change the perception of SPL. The most inter-judge reliability occurred with regard to the two subjects who sang at the lowest pitch. The lowest note of Singer 6 was only a semitone higher than Singer 3 who was male and she was the only singer to receive a unanimous judgment of Mechanism 1. It seems, however, that F0 was not the only factor because Singer 5 received the next highest level of inter-judge agreement that she was in Mechanism 1 even though she sang in exactly the same pitch range as Singer 4 who was judged to be most often in Mechanism 2.

There is a F0 range of at least one octave in which either Mechanism 1 or 2 can be used (Castellengo & Henrich, 2004). This part of the vocal range is often referred to as 'mixed' voice. Within this range a singer has the option to either reduce SPL Mechanism 1 by ~10dB or increase SPL in Mechanism 2 by ~5dB if they want to disguise a shift of mechanism so as to move smoothly across the pitch range (Castellengo & Henrich, 2004). In addition, by altering the shape of the vocal tract, the vocal timbre can be altered to simulate the alternative mechanism (Miller & Schutte, 2005). The sound samples here fell at a point where the singers could either belt the note (Mechanism 1) at the top of their pitch range, the most taxing option for the laryngeal mechanism, or move into a 'mixed' or Mechanism 2 voice. This explains why the judges often used the word "mix" or "blend" when describing what they hear since it also explains the grading of "heavy mix" and "light mix" by Judge C: Heavy mix could feasibly be a softened Mechanism 1 and Light mix a strengthened Mechanism 2.

Singing teachers have been using this terminology for a long time (Miller & Schutte, 2005) but it was surprising that the experts from disparate musical fields used similar terminology to describe the third voice mode. Would the results have been more reliable if the judges had not been singers? Knowledge of mirror neurons indicates that hearing a sound related to a listener's own experience of action triggers motor pathways in the brain (Fadiga, Craighero & D'Ausilio, 2009). This indicates that the listener actually experiences the action with the person enacting the sound. In other words, the expert listeners would have been experiencing singing with the singers on the recording and reacting to the sound as if to their own voice. This would also explain why each listener was consistent within in their judgments and would explain the comments of experts A and B and why they reacted to the samples so differently. Judge A's comment implied that she saw variation in mechanism as a sign of expertise. This is consistent with the training of classical singing which makes more use of Mechanism 2. On the other hand, Judge B's comment that the singers were attempting Mechanism 1 but not always succeeding implies that shifts to Mechanism 2 were a sign of failure. Perhaps in Judge B's case, she interpreted the shifts to lighter voice negatively because she perceived it as not appropriate to the R & B style of the song or possibly she was more attuned to the sound because their style of singing was closer to her own. Much of the perceptual judgment of the laryngeal mechanism would be unavoidably based on the spectral balance of the voice as mediated by the vocal tract. As a singer increases F0 within Mechanism 1, higher partials increase in amplitude. Higher partials above 1.5kHz increase the perception of vocal effort (Sundberg, 1987a) as well as loudness. A contemporary singer is likely to appreciate the increase of the high partials and the perception of effort so that their lack would be seen as a failure whereas to a classical singer the timbre might appear too harsh or the sense of effort may be interpreted as strain.

5.1.5 Limitations and future research

Though the method of using a collection of terms for Mechanism 1 and 2 was generally successful, it would be advisable to remove the terms "modal" and "loft" in a follow-up to this study. These terms, which are used less commonly than the others, caused some confusion amongst the judges. In future, it would be good to make provision for judges to designate the terms of their choice, as a way of fine-tuning the response sheet and making it possible to draw more substantive conclusions from the choices made. For example, did the judges interpret the voice quality as meaning laryngeal mechanism only or did they include vocal tract contributions to the sound. I would also add a new voice quality category that would include the terms 'mix', 'blend' and 'middle register' since this term seems to be widely accepted, with the possibility of still adding qualifying descriptive terms in the last column.

It is possible that listening to the same singer in succession in the current study altered the judges' perceptions of the samples following, but the lack of uniformity of judgments of some singers by the same listeners implied that this was not the case. Lack of uniformity may have simply implied that the judges concerned were applying a more nuanced judging system.

A randomized trial using singers of the same voice type, singing excerpts from a larger number of songs in the same F0 range across singers would be useful and should provide more substantive results. In a case where samples were randomized, samples longer than one word would be desirable, for the listeners to be confident of their judgments.

These results highlight how important it is that the listener likes and is experienced in the musical style that is being perceived. It appears that a larger study with experts only within the focus singing style would possibly be more consistent or with several groups of expert listeners; R & B, classical, non-musical voice experts with different stated musical tastes, R&B singers with no training or teaching experience, etc. A study such as this with a control group of voice experts, such as speech therapists who are not singers, could also be illuminating. The question remains, if the listeners had been experts but not practitioners, would there have been more agreement between judges? Non-practitioners are also music listeners with musical tastes. Because of the impact of experience rather than training on music perception, perceptual studies using non-singing expert listener-judges should also include their musical and vocal style preferences as well as their academic or professional knowledge.

5.2 Conclusion

There is no universally accepted terminology for describing the laryngeal mechanisms used by singers. As expected, there was a variety of opinions and descriptors used by three judges coming from divergent schools of singing, in relation to which laryngeal mechanism they thought the six western contemporary popular singers were using. Therefore, any point of agreement could be considered strong. This study showed that the R & B singers used Mechanism 1 more than the other singers and never used Mechanism 2. All three judges acknowledged the existence of a middle voice quality, which they called 'mixed' or 'blended' voice.

The judges were in 100% percent agreement in only one case, Singer 6, although intra-judge reliability was much higher. The internal consistency of judgments in combination with the lack of inter-judge reliability in judging the vocal mechanisms of these singing samples indicates that expert judges from different musical backgrounds may either perceive vocal mechanisms differently or that they label the same mechanisms differently. Perceptual judgments of one style of voice by experts of another style should therefore be considered to be of limited validity. Cross-referencing between multiple single-genre panels of judges including singers and pedagogues in addition to impartial medical/ scientific experts is likely to produce more nuanced and accurate assessments. This would seem to be the most appropriate design for perceptual studies in any style of singing.

Vocal mechanism use in various WCP singing sub-genres and its relationship to body movement type and frequency is worthy of further research. This is of interest in light of expanding knowledge of vocal function and the contribution of particular techniques to the sustained vocal health of singers. Singers who try to achieve high sound levels in Mechanism 1 without the attendant body movement to assist and support the voice may be at risk of stressing and possibly damaging their voices.

CHAPTER 6: CONCLUSION

6.1 Further discussion of findings

It was argued in the introduction that movement is integral to the performance of western contemporary popular (WCP) singers. High vocal sound pressure level (SPL) is also an important part of WCP styles and is a good indicator of vocal strength and efficiency as well as being important for musical and emotional expression. The main question asked in this thesis was whether movement affected singer SPL. Drawing on evidence from a wide range of disciplines, possible explanations were proposed for how the three parts of the vocal system - respiration, phonation and articulation, might be interacting with body movement during WCP singing performance.

The first paper (Chapter 2) explored whether there were particular body movements associated with sound pressure level (SPL) variations that might indicate that movement amplitude was associated with SPL amplitude. Such associations were found to exist. Through the analysis of video footage and simultaneously recorded sound recordings, observations were made of several different types of movement. The most common movement noted across singers was also the most closely associated with intensity variation, that is, a torso movement in a posterior direction that reached its maximum displacement at the same time as the point of highest SPL. In this first paper the physiological tasks associated with SPL were outlined in order to understand further whether there might be a causal relationship between increased movement and an attendant increase in SPL, in particular by means of increasing subglottal pressure (Ps), which is the main physiological driver of SPL. The intention was to use SPL as a surrogate measure for testing Ps variation because there is a linear relationship between the two pressures if laryngeal and articulatory factors remain the same.

With the connection between antero-posterior movement and SPL identified, the second paper in Chapter 3 aimed to confirm the link by comparing peak SPL between a condition in which singers were allowed to move freely with one in which singers were directed to stand still. The difference was confirmed, both acoustically and statistically. Paper 3 presented in Chapter 4 also established the effect of movement on overall SPL. This occurred in spite of efforts made in the protocol to be as ecologically valid as possible, using performance-like terminology and imagery to direct the singers and imposing minimal restraints on their behaviour in other respects in the protocol that fell well within the capability of the experienced professionals who participated.

Papers 1 and 2 established an association between movement and SPL under performance-like conditions. In Paper 3 (Chapter 4) an unexpected result was found in which singers were able to maintain their SPL range in the non-movement condition even though the maximum was reduced. This highlighted the importance of involuntary behaviours and automatic processes in the process of singing. In addition, a preliminary perceptual study in Chapter 5 pinpointed some possible stylistic differences in the use of laryngeal mechanism and its possible links to movement behaviours in WCP singing, as well as the impact of stylistic background in perceptual research involving singing experts.

More direct experimentation will be needed under more narrowly focused conditions to identify a causal connection between movement and SPL. Suggestions will be made in the discussion below on how that might be accomplished as well as how interesting new questions arising from other findings from this research might produce more wide-ranging future research on singing practice and music practice in general.

6.1.1 Limitations

6.1.1.1 Limits of SPL as surrogate measure

As this was novel research in a new field, a decision was made to privilege ecological validity and observation over highly controlled quantitative work. In this regard, SPL as a surrogate measure of Ps was useful but not without its limitations. While there is a linear/quadratic relationship between Ps and SPL output (Van den Berg, 1956), it is not valid to draw conclusions about Ps in a comparison of two sung notes that are not at the same F0 because it may be possible to reach the same SPL through changes in timbre (MacCurtain & Welch, 1983). SPL difference between movement conditions could be compared across subjects but only to compare absolute intra-subject SPL because the surrogate measure only maps onto Ps if laryngeal and articulatory variables are the same. As seen in Chapter 5, perceptual judgments of the vocal mechanisms used by each subject varied.

6.1.1.2 Problems of improvisation

To maintain ecological validity, singers were given considerable discretion in their performances, in order to closely approximate their singing behaviour during an actual performance. There was a risk, however, that singers would vary the songs so much that acoustic comparison with other singers would not be possible. Additional singers were recruited to protect against this risk that some would need to be eliminated.

The data from three of the original nine singers could not be included in the sound analysis that follows. As presaged in the Methodological Considerations, one singer, predominantly a jazz singer, had a highly variable way of interpreting the song's melody. The melodic and dynamic variations were so far from the original song that they could not be compared to either the other singers' or his own interpretations. Although it was a shame to lose the data, especially of another high quality male subject, it did make the point that highly improvisatory singing is difficult to study empirically and this difficulty is no reflection on the standard of the performance.

Another male singer's recordings were unusable because of technical problems with the recording. Finally, the elimination of the third subject was due to an unexpected consequence. One female subject who was primarily a music theatre singer was unable to reach her usual performance standard on the common song, as demonstrated by its comparison to the higher standard of the two songs from her own repertoire. She related that she had been trained to always learn songs in the first instance from a score. As a result, she did not feel confident performing a song learnt by ear alone, which meant the standard of singing was much lower than on the other recordings.

6.1.1.3 Comparison of similar voice types

The number of high quality singers who were available to participate in this study was limited due to the small population of professional R & B singers in Sydney. More R & B singers are scattered across the continent of Australia but budget, time and travel constraints prevented them from being flown to Sydney. Research conducted in higher population centres in the world could allow for much larger studies in which WCP singers could be grouped and compared according to voice type. In future replications of the method used in this study, it would be useful to perform a voice range profile (VRP) on all the singers participating. The VRP, also known as phonetogram, is a profile of a singer's physical limits with regard to fundamental frequency and sound pressure level and is used to assess potential vocal performance (LeBorgne & B.D., 2002). This could act as an objective measure in order to compare similar voice types. This would also be useful as it is not a convention among WCP singers to classify their voices in the manner of the classical world (e.g. contralto, soprano). This would allow song key to be set for each voice type without fear of damaging the participants' voices or causing them to produce uncharacteristic acoustic results due to strain. More conclusions could then be drawn from movement and acoustic results across singers rather just between conditions in individual singers because the pitches would be the same.

6.1.1.4 Inexperience

Singer 1, the youngest in the study and the only self-described 'pop' singer, showed a tendency to move her head up and down with the pitch line, a phenomenon noted elsewhere in a study of young, non-professional singers (Thompson & Russo, 2007).

The fact that she was the only singer in this study to do this, that this action accompanied the head forward position and that she was the least experienced of the six singers (Chapter 2, Table 1) indicated that this tendency is not an optimal technique. She also the performed one action that could be described as an *emblem*, that is, an action that has a specific meaning (Ekman, 1977). This comprised the shaking of the head on the word "never" which occurred on both loud and soft sub-phrases. Emblematic gestures are commonly seen amongst pop singers on commercial music videos. This behaviour conveyed verbal or emotional meaning rather than serving a functional role in vocal production.

6.1.1.5 Differences in training: Singer 4

Training and experience in different vocal styles may account for individual variation between the singers in this study. For example, Singer 4, who had the smallest difference in SPL between the two conditions, had a different background from the other singers. She described herself as a music theatre singer, which necessarily places her role as an actor on an equal plane with her role as a singer. In her case, because the term *director* was used in the imagery of the instructions for the NM condition, it is possible that she favoured the visual direction over that of the sound that she produced. It is also probable that her acting training and work as a singer/actor had prepared her with strategies for singing in a body posture she has not spontaneously chosen.

In addition, due to extra time spent on setting levels for Singer 4's voice (Chapter 2, Paper 1), it may be that by the time she reached the common song, she was tired. Her result for the common song produced different results in SPL than her other two songs. Fatigue may have been a factor in the loss of SPL in the common song in the both conditions. However, she appeared to compensate in other ways. Reaching maximum SPL, though important, is only one factor in determining the quality of a singing performance. Singers may choose to alter other more subtle, interpretive behaviours when the SPL amplitudes cannot be reached, such as phrasing, vibrato, micro-intonation and note durations to create other means of emphasis (Sundberg, 1987; Wolfe, 2002).

6.1.1.6 Singing too close to physiological limit on first take: Singer 6

The respiratory pressures normally used in phonation are low compared with the maximum possible physical limits (Leanderson & Sundberg, 1988), sometimes known colloquially as "oversinging". However, a good singer's dynamic range on high notes is likely to sit close to the maximum obtainable (Schutte, 1983). This is not efficient by the criteria usually used in judging vocal efficiency in speech because there is too much muscular work required for a given output (Schutte, 1983). Singing, by its nature, is inefficient because the goals of singers are not to minimize work but to maximise communication with an audience (Schutte, 1983) by whatever means are available to them. Therefore, it makes sense that there should be a large amount of variability in the pressures generated by singers depending on their intent (Huber, 2007).

When a subject repeats a vocal measure, the first take reflects the usual voice (Sihvo, Laippala & Sala, 2000) but with Singer 6 this was not the case. She sang most strongly on the first take (M), at a much higher SPL than that reached by all the other female singers. She then dropped dramatically with every take thereafter including the other M takes. The large drop was probably due to fatigue due to over-singing on the first M take. She had sung too close to her physical limit on the first take and was unable to maintain that level. As has been noted previously (Schutte, Stark & Miller, 2003), musically usable dynamic range is not necessarily as large as the physiological range and there is a risk to voice in pushing too close to the physiological limit. There also was some vocal distortion detectable on this note, which also could have caused fatigue (Borch, Sundberg, Lindestad & Thalen, 2004). This would explain the big SPL level drop on the third take which is the lowest M line in Figure 4.3 (Chapter 4). We concluded that the middle M line (Take 2) is more characteristic placing her levels with Singers 1 and 2 (Chapter 4, Figure 4.3).

6.1.1.7 Physical differences

The sprinter-distance runner dichotomy may be applied to singers (Titze, 1991) with respect to pitch production. Singing notes with high pitch require constant contraction of the laryngeal muscles. Titze (1991) suggests that some singers, like sprinters, may be able to produce brief episodes of extreme muscle contraction in the laryngeal muscles but are not able to maintain the high pitch comfortably. Other singers may be likened to long-distance runners in that they are able to remain for long periods in the high part of their range without being able to produce the 'thrilling high note' (p.210). Such individual differences could also apply to the ability to maintain glottal adduction for SPL control as well as to differences in respiratory drive, as outlined earlier (1.3.4.4). It has been suggested that singers should be classified by body type (Cowgill, 2004), or more importantly in terms of thorax proportions (Hoit & Hixon, 1987), for accurate comparisons between singers. Future studies of movement in WCP singing could include such torso type groupings.

6.1.1.8 Levels of preparation and memorization

Although it is rarely mentioned in the singing literature, it is impossible to know if all the singers' voices were equally warmed up and this would be the case even if a warm up was included in the protocol as we would not know the baseline condition of the voice before the warm up. Variation in the degree of warm up may have significant affected the results. However, in order to reduce the variability in quality of warm-up, participants performed two familiar song excerpts prior to the commencement of data collection of the song analysed. Further, recording times were scheduled late in the day in a further effort to ensure that the singers were warmed up. The participants in these studies had varying knowledge of this song before the protocol and presumably had also practised it before the recording. Whether a phonational task is spontaneous or memorized, spoken or sung has an impact on cerebral hemispheric dominance (Formby, Thomas & Halsey, 1989) and this has an impact on the neurological organisation for the task of singing the song (Formby et al., 1989) and thereby on the acoustic outcome. These limitations occur in all voice studies.

6.1.1.9 Training period

In order to establish a causal link between movement and SPL change a more thorough training period than that provided here may be required. As professional singing involves high level skills, the 6 month supervised training period used by Sengupta in a study on Indian classical singing (Sengupta, 1990) would be the most appropriate to determine whether WCP singers can learn to sing a small repertoire of WCP songs without movement without it altering the acoustic effect. This could be tested using a voice range profile on several occasions both before and after training. Such an involved and long-term study was beyond the resources and scope of this thesis.

6.1.1.10 Limitations of laboratory and field work

It is difficult to evoke under laboratory conditions the spontaneity and emotional arousal that is important for real stage performance (Pettersen & Bjørkøy, 2007). Intensities achieved by actors have been shown to be higher on stage than when recorded in a laboratory (Emerich, Titze, Svec, Popolo & Logan, 2004). Emotional arousal created by a real performance with interaction with fellow performers and audience would have further impact on results in singing. Other than for the reasons of visual analysis, having of two video cameras in the laboratory was an advantage. Being performers, the singers constantly talked and played to the cameras and they became more energetic when they knew that they were being recorded. However, a study with WCP singers in a live performance would be useful, especially in light of the comments about emotion from Singer 5.

However, there are also major technical challenges in getting an accurate recording in live conditions (Fielder, 1995). Unlike the recording of a single actor, live performance with a WCP band is very loud and always involves "spill" into the singer's microphone from other instruments and amplified sound coming from monitors both on the stage (fold-back) and in the venue (front of house speakers). On a large stage it may be possible to get enough separation of the vocal signal from the other instruments, by using a greater distance (which on a large stage would feel natural) or by creating some kind of sound barrier between the singers and other instrumentalists especially those in the same frequency range as the voice. Sound spill could be reduced further by the singer using in-ear fold-back. A head-mounted microphone would need to be used and it would have to be very close to the mouth to get a good signal-to-noise ratio (Fielder, 1995). High and low pass filters could be used to remove sounds above and below the range of the voice during analysis. Another performance alternative that would get a cleaner and more accurate sound recording for analysis would be to use a recording studio with a live audience, similar to the sort of live performances done for radio or television programs. The singer could then be in a separate glassed-in recording booth and could use headphones or in-ear phones to hear the band and audience. The singer would then be able to physically interact with the audience and band. A high level professional WCP singer would be accustomed to recording studios as well as radio and television appearances and should not find this too difficult or unnatural a performance scenario, especially if stage lighting and other effects were used to evoke a performance atmosphere.

6.1.2 Implications of characteristic movements noted in P1

Due to the idiosyncratic nature of WCP singing, movement behaviour differences between subjects were expected. As has been shown in classical singers, intra-subject variability in respiratory strategies occur due, amongst others, to training effects (Lassalle, Grini, Amy de la Breteque, Ouaknine & Giovanni, 2002) or to differences in body or torso type (Cowgill, 2004; Hoit & Hixon, 1987). Although the association between SPL and antero-posterior torso movement was the main finding of this research, there were other variations in movement patterns that could be significant that have only been briefly mentioned in Chapter 2. In this section, additional movement phenomena that might have impacted the main findings will be discussed as well as the implications these further movement patterns will be explored.

6.1.2.1 Additional points about respiration and antero-posterior torso movement

I would like at this point to return to the definition of "support" supplied in the introduction as respiratory patterning, inspiratory or expiratory, which facilitates Ps control without interfering with vocal fold vibration. This section explores how either interference or optimisation of the voice might occur by altering respiratory patterning through changes in body movement.

Isometric versus isotonic contraction

It would be expected in light of research on the effects of cueing on respiratory strategies in singing that the NM condition would have an effect on respiratory kinematics (Dromey & Ramig, 1998; Stathopoulos & Sapienza, 1993; Winkworth & Davis, 1997). However, it would also be expected in normal vocalization that the relative respiratory to laryngeal contributions to SPL change would still be effective in producing the same SPL (Stathopoulos & Sapienza, 1993). However, it is possible, in this case, that the laryngeal load in the song examples used was already at its maximum because of the use of Mechanism 1, such that glottal adduction was already at its maximum, leaving stronger respiratory drive the only option for boosting Ps further. It has been noted that classical singers' musically usable dynamic range is not necessarily as large as the physiological range (Schutte et al., 2003), that is, classical singers are not pushing their voices to their dynamic limits. WCP singers, to the contrary do seem using their voices at a level closer to their physiological limit, as shown by the high decibel peak levels that they reached and the wide dynamic range that they used. Koufman's research on laryngeal work, cited earlier (Koufman, Radomski, Joharji & Russell, 1996) supports this view, at least in the sub-genres of rock and gospel. Perhaps the sense that these singers were taking their voices closer to the edge of their physiological range gives singing pedagogues the sense that it is dangerous to vocal health. However, as noted earlier, although taxing, this is only dangerous to the voice if they are pushed to this limit without proportional levels of respiratory drive; if, for example, an increase in Ps could not be managed to match an increase in glottal closure.

There are limits to expiratory muscle contraction for generating increases in Ps. Muscle contraction in which muscle length remains the same (isometric contraction) may produce more negative effects on singing than muscle contraction in which the muscle lengthens (isotonic) since they involve different muscle recruitment patterns (Green, 1986). Intense isometric contraction interrupts respiration until task completion (Dejours, 1985-7). This effect is related to reflexes induced by defaecation which cause respiration to be locked down, an effect that is reproduced in any strong exertion in the torso (Gould, 1971). When the maximum point of isometric contraction is reached, any increase would interrupt respiration all together (Dejours, 1985-7) interrupting vocalization as well. Therefore, maximal expiratory muscle contraction that is executed without movement may be more limited than that performed with movement. Further to this, the laryngeal closure reflexes discussed in Chapter 1, with their potential for vocal damage could be activated by strong isometric muscle contraction because they can be triggered by strong respiratory drive (Finnegan, Luschei & Hoffman, 2000).

Thus, standing still could induce isometric muscle contraction in the torso. If this muscle action was too strong it could potentially interrupt voice production at both the laryngeal and respiratory levels. Moving during singing may be a way of avoiding triggering these reflexes that are detrimental to singing while allowing the creation of high Ps needed to produce high notes in Mechanism 1. Otherwise, if moving is not an option then the only way to avoid damage is to reduce glottal adduction, thereby reducing the SPL.

Rectus abdominis use

In Chapter 2, various functions of the posterior torso movement were discussed, including it being a stretch of the abdominal muscles. One possibility that was not covered in that chapter was that it may be being used to activate a particular abdominal muscle. Normally, the abdominal muscles act in concert but certain postural manoeuvres can trigger the contraction of specific muscles (de Troyer, Estenne, Ninane, Gansbeke & Gorini, 1990). One such movement is head flexion (de Troyer et al., 1990; Strohl, Mead, Banzett, Loring & Kosch, 1981), which activates the *rectus abdominis*, the most superficial of the abdominal muscles. Head flexion occurred when the singers in this research performed the posterior torso movement (Chapter 2). The rectus abdominis is not generally considered to be as important in singing as the obliques (Leanderson, Sundberg & von Euler, 1987). However it has been shown to be used, along with other expiratory muscles, to a higher degree by professional opera singers than student singers (Pettersen & Westgaard, 2004). Another similar action was observed in the idiosyncratic movements of Singer 5 in which she tilted the pelvis, thus shortening the xiphopubic distance. This indicates the activation of the rectus abdominis muscle (Mier et al., 1985). This may indicate that posterior torso movement or pelvic tilting are used by WCP singers to help them achieve a temporarily higher level of Ps that avoids the negative effects on respiration of isometric contraction. This could be an interesting subject of future research, especially since the *rectus abdominis* could be tested more easily and reliably with electromyography (EMG) than the deeper muscles that have often been studied in other singing research.

Respiration higher priority than posture

A common pattern among the singers in the movement condition was a temporary cessation of rhythmic movement during the Peak notes. It is no surprise that this should happen because it has already been explained at length that singing a high SPL and F0 note represents a high level of physical difficulty in terms of respiratory muscle contraction, lung volume management and stress on the vocal folds. However, there are several further reasons that could be put forward for this phenomenon of movement decreasing when difficulty increases.

Uncoupling of entrainment: In the introduction, the potential advantages and disadvantages of coupling locomotion to respiration for singing were discussed (1.4.3.4). It was noted that that the uncoupling of respiration to movement may not be worth the many advantages of entrainment which include the reduction of energy expenditure. One interpretation of the cessation of rhythmic movement on peak notes was that it was such an uncoupling. The only singer who appeared to be quite comfortable moving rhythmically at all times, regardless of F0 or SPL, was Singer 5. This may have been due to Singer 5's different movement patterns, some of which were noted in Paper 1 in Chapter 2. Another action by Singer 5 not previously mentioned is rotation of the torso during locomotion, which can maintain intercostal muscle support thereby stabilising that thorax (Rimmer, Ford & Whitelaw, 1995). This could have been advantageous in recruiting the Ps required for the more demanding notes of the song without stopping other actions.

Prioritisation of respiratory over postural tasks: Because the same muscles perform postural, movement and respiratory tasks, the central nervous system must coordinate and prioritise these muscle functions. The central nervous system reflexively prioritises the function of respiratory drive over postural or movement functions (Hodges, Heijnen & Gandevia, 2001) because of respiration's importance in maintaining normal oxygen-CO2 exchange for survival. There are different levels of reflexes in terms of volitional control and responsiveness to training (Prochazka, Clarac, Loeb, Rothwell & Wolpaw, 2000) which seem here to have allowed some of the singers to perform rhythmic movements while singing. However,it seems that the added respiratory muscle demand required during a surge in Ps for a loud note could have created a conflict with the postural function causing a temporary hiatus in the rhythmic movement. Some rhythmic movements of the lower, such as those of Singers 2, 3 and 6 were intermittent and limited to the limbs, indicating that they were more related to timekeeping than the entrainment of movement to respiration. In these cases, if their movements were for that purpose, it would be more likely that they would go out time during the Peak note. This was not measured here but there is a body of research that suggests a relationship between locomotion, rhythm and gesture (London, 2006) and its role in classical music (Friberg & Sundberg, 1999; Sundberg, 2000). Such research would be of interest in furthering the understanding role of body movement in rhythm perception and timekeeping and its special role in WCP music.

The challenge of not moving

The NM condition presented a different set of challenges. It is not only movement that can create interference with singing (Sterr, 2005). Not moving also presents difficulties because great deal of the high level of muscular interaction that occurs in order to maintain a fixed posture while breathing (Rimmer et al., 1995). A postural action superimposed on respiration can inhibit respiratory muscles (Rimmer et al., 1995), causing delays in action. Whether these muscles are primarily being used for postural or respiratory purposes, when these functions conflict, for example when respiratory demand increases, the CNS which will to recruit the muscles for respiratory purposes over postural functions (Hodges et al., 2001). Although the respiratory action (singing being the respiratory action, in this case) wins out in the end of this conflict of functions, muscle inhibitions such as this could well be causing the delays in timing seen in Figure 3.3 in Chapter 3, as well as the reduction in SPL already noted.

Lengthened inspiration time

The calculations for dB without edits in order to observe inspiration gaps and timing are shown in Figure 3.3. This figure reveals differences between N and NM conditions with respect to duration of the phrases and inter-phrase inspiration. This is clearly demonstrated in singers 3, 4 and 5 who each lengthen the inspiration time in the NM condition. One singer shortened the phrases in the NM condition with no major changes in inspiration length (Singer 6). Singer 2 displayed a combination of lengthened inspiration time and shortened phrase length. Singer 1 shortened inspiration time while keeping phrase length consistent in both conditions.

The inspiratory muscles behave differently to other muscles: if the shortening of the inspiratory muscles is interrupted for as little as 250ms, they are reflexively inhibited whereas in a limb muscle this would lead to excitation (Gandevia, Allen, Butler, Gorman & McKenzie, 1998). It is feasible that this could lead to an alteration of the attainable lung volume or the weakening of other muscle responses leading to reduce Ps.

Head forward posture as postural compensation

The two singers (Singers 1 and 6) who showed the head forward movement (Chapter 2, Figure 3) with accompanying distorted sound may have been compensating for muscle weakness. A chin poked forward may not directly originate from or be causing the voice dysfunction observed but may be due to poor muscle tone (St. George, 1989), remembering that the muscles of respiration are also postural muscles. For example, the lack of abdominal muscle strength may be causing the problem of which both vocal dysfunction and the forward head posture are a symptom. Certainly Singer 6's strategy of using the mechanical approach of bending forward to compress the abdomen could be a replacement for expiratory muscle contraction. A head-forward posture in singers is likely to be part of a suite of postural problems that may emanate from issues with core strength or muscle imbalance and so cannot be analysed in isolation (St. George, 1989; Wilson Arboleda & Frederick, 2006). A systems approach to analysing postural alignment for singers such as that used by physical therapists is therefore most desirable though rarely seen in speech pathology and voice pedagogy (Wilson Arboleda & Frederick, 2006).

6.1.2.2 Movements associated with lower body movement – various points on rhythm

In the analysis in Chapter 2, it was noted that it was characteristic for the singers to mark the musical beat with their lower limbs. However, the direction and amplitude of the antero-posterior (AP) movement of the torso related to the dynamics. As a result, this meant that the onset and duration characteristics of the AP torso movement were different to the timing of the lower limb movement. It is likely that the complexity of this relationship, at least in part, accounted for difficulties with timing in the non movement condition. There is potential for conflict between these patterns. This effect is also likely to be noticeable in WCP music with its strict tempo and metrical structure.

Differences in rhythmic movement

During the movement study (Chapter 2), there was some variability between singers in their rhythmic movement patterns. Four singers marked every beat in the bar so that the rhythmic movements were more frequent and therefore involved faster body position change (Singers 1,2,3,5) while Singer 6 only moved on the first beat of every bar making body movement slower. Singer 4 was exceptional in that her feet did not move at all and no regular rhythmic body movements were apparent. This indicates that movement that manifests as physical timekeeping is not essential to voice production for maintaining SPL, for example, via sensorimotor stimulation (Todd & Cody, 2000). However, it may be important for timing accuracy for WCP sub-genres that feature high levels of syncopation such as R & B and Latin styles. It is notable that Singer 4, who did not perform physical timekeeping, was a music theatre singer. Music theatre singing, is not noted for its rhythmic complexity, focusing instead on lyrical and melodic components. In addition, music theatre singers are trained to be able to sing in many different postures and to sing and dance to pre-choreographed patterns. Thus, music theatre singers are less likely to respond unconsciously to rhythms in the music in the way that, for example, an R & B or rock singer might.

Interference with rhythm and timing

It is possible that the singers were using rhythmic movement may be used by singers for time-keeping accuracy. It was common for rhythmic lower limb movements to stop when there was a moment of high difficulty such as on high SPL notes. This may have been due to the difficulty of uncoupling of respiratory entrainment (1.4.5.4) (Lee & Banzett, 1997). Synchronizing movement to music (e.g. leg movement) is a task that on its own normally requires low effort (Large, 2000). However, the sudden increase in action requirements for the vocal production of the peak note (e.g. AP torso movement) might have created a conflict that led to inaccurate timing or difficulty with the movement (Pfordresher, 2003).

Where movement and music are closely interlinked, as in music emanating from African traditions, of which WCP is one, the non-sonic elements of the motional pattern are important determinants of the accuracy of the production of the sonic pattern. It has been asserted that a change in a physical motion pattern can lead to deterioration in rhythmic quality as well as influencing the sound spectrum because of changes in impact force in instrumental playing (Baily, 1985). As with loudness targets, interference with sensory feedback can also interfere with timing (Gentilucci, Benuzzi, Bertoloani, Daprati & Gangitano, 2000; Pfordresher, 2006). Timing changes caused by the restriction of movement in the non-movement condition could have resulted of changes in how the singers' perceive their own voice timbre as high frequency levels reduce with lowered SPL. The singers in this study were unhappy with the results they were getting in the non-movement mode and negative self-perception affects production because alterations in timing of expected feedback can register as an error (Baily, 1985). Timing and rhythm does not just concern the beat but also the pattern of the melody. As such melody and rhythm are jointly determined (Pfordresher, 2006). Such negative reactions could result in a downward spiral in performance quality on either a voice production or rhythmic level. Vocal timing and sound spectrum have been linked in a study on the effect of a bandpass filter on an auditory sidetone of the speakers' own voice, which found that the main effect on vocal response was phonation time (Fulton & Spuehler, 1962).

Speed, duration, timing and targeting are all interconnected. Interference with the timing of auditory feedback has been shown to disrupt sound production in music performance. In studies using sound manipulation methods such as delays and prelays, asynchronies in the timing of feedback to instrumentalists caused more changes in production than alterations in pitch feedback (Pfordresher, 2006). One theory suggests that changes in the timing of output interferes with planning (Pfordresher, 2006). Another puts forward the theory that it is the asynchrony of physical movements with the sound amplitude contour that creates production problems due to the creation of an interfering signal (Pfordresher, 2006). The timing change created by the change of inspiration time and the alteration of note lengths could be one factor in SPL but the inability to mark time with the lower limbs in the non-moving condition could have compounded this problem. SPL interference and timing changes may be controlled separately as the consistency in the SPL reduction shown in the percentile graphs suggests (Chapter 4, Figure 4.3). However, not all singers showed the slowing effect. Changes in the mechanisms used to regulate SPL triggered by the use of different cues for loudness change are the result of neural control being affected by an internal loudness target (Huber, Chandrasekaran & Wolstencroft, 2005). Movement patterns may be linked to those targets since limb movements may relate to internal targeting (Gentilucci et al., 2000).

Tempo and expression

The lengthening of inspiration time has already been mentioned. As outlined earlier, expiratory action is increased by acceleration, spinal flexion or movement in a cranial direction and inspiratory action is enhanced by deceleration, spinal extension or movement in a caudal direction (Lee & Banzett, 1997). Thus, movement restriction may affect tempo by altering respiration speeds. Higher speed dynamic variation conveys stronger emotions and cues the perception of particular emotions such as sadness (Kotlyar & Morozov, 1976; Sundberg, Iwarsson & Hagegård, 1995) so a slowing of dynamic variation could interfere with the expressiveness of the singing that could be perceptible by both audience and singer.

Locomotion

Locomotive movements were noted in the characteristic behaviour of the singers. The shoulder extension, the down and backward movement toward anatomical position is a powerful muscle action important in rhythmic activities such as locomotion or any other activity involving opposite arm movmements (Jensen, Schultz & Bangerter, 1983). This action was particularly noted in Singer 5. Particularly important in this action is the *lattisimus dorsi* (Jensen et al., 1983) which is also an important inspiratory and expiratory muscle (Grabiner, 1989) and is its contraction is suggested as a pedagogical technique for facilitating high intensity singing (Estill, 1995).

Interference with expressive timing and movement

Human rhythmic performance is by its nature expressive (Clarke, 1999). There are several theories that suggest that the imitation physical movement in music is the main source of musical expression (Timmers & Honing, 2002). The generative theory of expression assumes expression is a performer's mental response to the musical structure but also assumes that other aspects of performance are not memorized (Timmers & Honing, 2002). It has been suggested that WCP singers repeat certain expressive body actions at particular points in the music in relation to meaning (Davidson, 2001) (as opposed to the choreographed movement of, for example, backing singers, which is planned specifically to be decorative and not to detract from the focus on the lead singer). There was little evidence of this kind of planning in this research. Such behaviour would imply that there are certain body actions that are consciously or unconsciously "scored" as part of the performance of the music and that some body movements always occur at certain points in the music and others are improvised and varied. This may indicate that the gestures noticed by other writers who analysed footage of performances in front of audiences (Davidson, 2006) may relate either to performers singing on large stages and therefore feeling the need to amplify communicative gestures or to other performance aspects that could be planned or choreographed by an outside person such as a stage director. Future research of live performances in front of audiences is therefore needed to further clarify the role of display from the functional role of movement for voice production.

Special relationship of rhythm with voice

Oliver Sach's story related at the beginning in Chapter 1, indicated that there was something special about the combination of rhythm with vocalizing that we do not yet fully understand and that goes beyond muscle and respiratory function alone. The traditional worksong discussed in Chapter 1 may be a manifestation of the usefulness of this special relationship. For example, in Mali, agricultural workers sing rhythmic worksongs that allow them to get more work done using less strength (Smith, 1999). The findings in Papers 1 to 3 indicate that this may be based on physical principles. Many have been explored so far. The last to be discussed in this section is the possibility of the neural effects of movement on speech.

A focus on rhythm affects phonation. Masuda found, working with intellectually disabled subjects who had from mild to severe difficulty with speech, that focusing on rhythm and pitch was more successful than the standard preoccupation with the articulation of vowels and consonants for rehabilitation of speech (Masuda, 1996). He found that rhythmic body movement in combination with ultra-low frequency vibrotactile stimulation during the speaking of a target sentence improved disabled participants' speed and durations that were close to those of a non-disabled control group. He asserts that articulatory movement (micro-motorics) is more closely related to rhythmic body movement (macro-motorics). Macromotorics are easier to influence and therefore may be a way to influence the (micro-motorics). The use of low frequency vibration is designed to increase vestibular and somatosensory stimulation. Masuda also noted that rhythmic body movement increased vocal F0 in a severely disabled subject who was almost non-verbal. He concluded that the use of body movement while speaking had taught the subject how to manipulate Ps at both the respiratory and vocal fold levels.

Masuda's work brings together several phenomena that have been noted in the studies in this thesis, namely, body movement, vestibular stimulation by high levels of low frequency sound (similar to the effect of loud rock music on the vestibular system described in Chapter 3) and phonation. He observed improvements in articulatory function as well as respiratory and laryngeal function with the addition of movement and vibration. This indicates that the negative effects of the non-moving condition noted in this thesis may also have affected articulation. Future research on the effect of not moving on articulatory variables would bring clarification. Masuda's work indicates that there is much more research needed to understand the links between optimal phonational function and rhythm and that such research could have useful applications beyond singing.

6.1.2.3 Hand and lower arm movement – significance of gesticulation

In the movement study in Chapter 2 it was noted that hand and lower arm movements were used by most of the singers when their movement was unrestricted and that these movements related to the language of the song lyric rather than the musical features of the song. These movements are in keeping with the fairly narrow definition of the term gesture, meaning a limb or body movement used with intent to express an idea, emotion or attitude (Feyereisen & de Lannoy, 1991; Goldin-Meadow & McNeill, 1999). However, there are many valid definitions of the term used in different contexts (Cadoz & Wanderley, 2000): The term "musical gesture" can refer to an abstract musical element unrelated to the physical movement (Gritten & King, 2006; Wanderley, 2002). It has also been used to describe changes in the vocal tract during singing (MacCurtain

& Welch, 1983). Gesture is also used as a broad term that can refer to a change in position of any part of the body (Feyereisen & de Lannoy, 1991).

A better term to describe the actions observed in the singers in Chapter 2 may be "gesticulations", which have been defined as distinct from codified hand signals such as emblems, which are learned and consistent in meaning and form (McNeill, 2002). Gesticulations, by contrast, are idiosyncratic, created spontaneously during the course of speech (McNeill, 2002) or singing. They magnify the main linguistic message and are expressive of manner, degree and intensity rather than having a specific meaning (Corballis, 1999; Goldin-Meadow & McNeill, 1999). In the movements observed in Chapter 2, Singer 3 did not move his arms at all while other singers gesticulated in different ways on each take of the song, sometimes dramatically so, as in the case of Singer 5. This indicated that hand gesture allows for a high degree of individual expression on the part of the singers. Hand gesture is also an advantageous means of physical expression because it is possible to move the hands and not affect respiration or posture if the upper arms are uninvolved or anchored, since they not linked directly to the respiratory/postural muscles (Jensen et al., 1983).

The results in Chapter 2 indicated that hand and head movement was most closely associated with language patterns. Evolutionary factors may have created strong neural links between movement of the face, hands and lower arms with language (Corballis, 1999). Babies synchronize arm movements with crying (non-verbal vocalizing) from the time of birth and that this is considered to be an indicator of healthy neural development (Jurgens, 2002; Watanabe, Mizukami & Kobayashi, 1991). At an earlier stage of human development, both sign language and spoken sounds were used to communicate and that over time spoken language overtook gesture as the predominant means of communication (Donald, 1999). Ancillary hand gestures remain as part of the human expressive canon (Goldin-Meadow & McNeill, 1999). That hand gesture is 'hardwired' in human behaviour is indicated further by the existence of hand gesture in the congenitally blind (Goldin-Meadow & McNeill, 1999). Gesture can be as effective as oral language as indicated by the sophisticated sign language of the deaf (Goldin-Meadow & McNeill, 1999).

Archaeologist Steven Mithen has now taken theories of evolution a step further by theorizing that music and dance evolved with language and gesture (Mithen, 2006). He proposed that this coincided with the advent of bipedalism, which simultaneously changed the vocal tract, allowing for language and singing to develop, and the freeing of body for sign language and other communicative body movement (Mithen, Morley, Wray, Tallerman & Gamble, 2005). He bases his theory on fossil and archaeological records and evidence from current human biology and behaviour. Central to his theory is the evolutionary importance of communication for the survival of humans. It is for this reason that music, for example in the form non-verbal vocalization, is a means of communication that is still neurologically on the same hierarchical level as language (Mithen et al., 2005). Mithen's theory could explain the complex and seemingly involuntary interactions seen between voice, body movement, rhythm and emotion in the behaviour of the singers who were part of this research. The perception by the listener of the performance is also important. Evolutionary theory may also explain the phenomenon in which audiences incorporate musicians' physical gestures with the sonic aspects of music in their perception of the emotional content of music performance (Dahl & Friberg, 2007; Davidson, 1995).

6.2 Other relevant factors

In this section a range of questions are raised and discussed in light of the results presented in Chapters 2 to 5. It is wide-ranging in scope and highlights the preliminary nature of this body of work. It raises many possible avenues for future research.

6.2.1 Reflexive, involuntary and unconscious mechanisms

The original hypothesis was that movement restraint would restrict expiratory muscle contraction. As a result, it was expected that movement restraint would affect the peak

SPL that required very high Ps levels. Instead, the reduction appeared throughout the song even where Ps levels were low. There was also an unexpected appearance of what appeared to be an automatic SPL range setting mechanism that kept SPL levels within a range of around ~30dB. This highlighted the importance of involuntary behaviours and automatic processes in singing. This is important for the formulation of future research questions but also for the design of ecologically valid research protocols that do not interfere with these characteristic but unconscious phenomena that regulate SPL and F0.

6.2.2 Processing without awareness

Automatic behaviours may be genetic or acquired through training, as in athletic or musical skill development. One definition of automaticity is the mental processing of an event without the monitoring of it (Tzelgov, 1999). The event occurs so quickly that there is not a sense of attention. Thus the speed of execution can have an impact on attentional focus in contrast to a non-automatic event in which monitoring occurs, with the performer aware of their attentional focus on the event (Tzelgov, 1999). That antero-posterior torso movement was being used to increase Ps for higher pitches or intensities was suggested by the results of the movement study in Chapter 1. In the study in Chapter 3 when a non-movement condition was introduced, the surprise of the singers at the difficulty they had singing in this condition pointed to their lack of awareness of the importance of their movement to the sound produced. This further suggests that this technique – if the term technique can be applied to an unconscious process – is only obliquely volitional, that is, the singers may be aware of some voluntary activity and the end sound but may not be aware of associated actions. This may occur when a conscious and highly trained activity (singing) enslaves a more primitive reflexive behaviour (postural muscle action) (Prochazka et al., 2000).

The issue of voluntary versus involuntary behaviour in relation to respiration for singing is not new. There is divided opinion in western classical singing pedagogy between those who think that respiration should be "natural", that is, unconscious and those who believe that breathing has to be voluntarily "controlled" (Burgin, 1973; Monahan, 1978). Breathing is not normally controlled by conscious effort but by other involuntary routes. It may be possible that singers are unconsciously triggering these mechanisms by oblique methods which they understand to be spontaneous expressive gestures or dance movements without being conscious of the physical functions that they serve. If a singer from experience knows that they can easily produce a particular desired sound by moving a certain way then they may spontaneously move that way without knowing why. Successful singers have no reason to question this process unless it stops working for them or if they want to teach it to someone else.

6.2.2.1 Anticipatory postural adjustments and singing

As discussed earlier (1.4.3.3.), high speed motor skills involve preflexes whereas reflexes are not as fast because they must occur after the fact. In other words, high speed skills involve anticipation of an event and operate differently on a neurological level. The overtraining of musicians and athletes involves such anticipation. When a motor skill is being learned, sensory feedback of some kind is required to learn the consequences of an action. When a motor skill has already been learned to a high level, sensory feedback is not required any more because the result of the action is known and postural adjustments can be made in advance (Massion, Alexandrov & Vernazza, 1988). This could lead over time to a perception that the action is "natural", implicit or obvious whereas a great deal of unconscious training has happened over time. It is possible that this is the case with WCP singers who learn on the job. Certainly their surprise at how difficult it was for them not to move indicates a low level of attentional focus on what is happening in their bodies. It appeared that instead that they were focused on their sensations which manifested in enjoyment or expressiveness or outward on communication.

Postural preparation for a motor task requires a pre-movement adjustment as well as response after the task completion (Lee, 1980). This is known as an anticipatory postural adjustment and it automatically occurs prior to an intentional movement

(Bouisset & Zattara, 1986). Pre-phonatory posturing is a kind of anticipatory postural adjustment that occurs during inspiration and is also not consciously planned. One may be conscious of the intentional movement, e.g. moving to the rhythm of the music, while not being aware of these before and after task adjustments. Thus, a singer may not be aware of them in relation to vocal technique or movement. Alternatively they might think the connection is so obvious and commonsensical that it does not merit analysis.

6.2.2.2 Slowing of inspiration and pre-phonatory posturing

Although the differences in acoustic output analysed here occurred during the expiratory phase of the respiratory cycle, it is possible that the challenge to the singers created by the NM condition was to the inhalatory phase where pre-phonatory posturing occurs. It has already been noted that some singers had longer inspiration times in the NM condition (Figure 3.3, Chapter 3). This is easily observable because the singers were performing *a cappella*. Because there was no external timekeeping, which would come from accompaniment, the singers could alter their speed of execution. This allowed observation of the changes in inspiration and phrase length that occurred in the NM condition. The longer gaps between lines in the NM condition, in particular in Singers 4,5 and 6 may indicate that not being able to move may have inhibited inspiration speed (since extra length could also indicate breath holding or extra exhalation at the end of the previous phrase). Movement may create faster inspiration times by facilitating the creation of a lower end expiratory lung volume, which improves the following inspiration. As well as being a defining factor in expertise, as discussed already, inspiration speed has also been shown to be faster in projected voice (Thorpe, Cala, Chapman & Davis, 2001). Any challenge to posture can indirectly challenge ventilation, in particular the activation of the diaphragm in postural control which is activated involuntarily (Gandevia, Butler, Hodges & Taylor, 2002). As the main muscle of inspiration, inhibition of the diaphragm could be a factor in reducing Ps through the reduction of lung volume at the phonatory onset. If movement was used as a mechanism to trigger expiratory muscle contraction on the sung phrase in the M condition, the absence of this mechanism may cause the singer to resort to increased lung volume as a compensatory strategy. This could lead to more time being spent getting air into the lungs. Increasing lung volume is not usually favoured as a means of increasing loudness in trained voice users because of the extra tension it can induce due to the difficulties of controlling the strong passive recoil pressures of the ribcage that increase the greater the lung volume (Leanderson & Sundberg, 1988). The measurement of inspiration time and its relationship to phrase-length and to movement patterns was not a part of this study but it would be a useful area of future research.

6.2.2.3 Implicit body movement

In the introduction to this thesis, it was suggested that WCP singers might be unconsciously adopting and memorizing body movement behaviours that optimized their vocal technique without awareness of that technique. I also suggested that this approach may occur because song learning for most WCP singers is part of an orally transmitted rather than written tradition.

That the singers were surprised that it was so difficult to perform the same songs without movement could be a sign of the movement's automaticity. Since one of the aims of the methodological approach was to not interfere with such unconscious behaviour in the first condition, this could be seen as an indication of the methodology's success in achieving that aim. Singer 5 objected to the NM condition because she felt it would interfere with her singing but even she expressed surprise after the completion of the protocol at how physically difficult it was for her. The music theatre singer whose data was unfortunately not used in the analysis, commented that she was surprised to find the part of the protocol that involved standing still "exhausting" and was intrigued as to why that might be. Motor behaviours can be learned implicitly and do not require conscious thought to be executed well (Baddeley, 2004). It appears that the body behaviour associated with singing by this group of WCP singers may have acquired implicitly (Mackey, 2008) with the learning of the song. That this may have been advantageous to their singing was indicated by the reduction of SPL in all cases when they were not allowed to move, even when they thought they would have no problem with it.

6.2.2.4 Advantages of involuntary muscle activity

Why might involuntary or unconscious muscle activity in singing be preferable to conscious activity? Voluntary expiration causes the abdominal muscles to work in concert, but involuntarily induced respiratory muscle activity features a different recruitment pattern, with the *transversus abdominis* always being activated first (de Troyer et al., 1990) an action that may be pre-programmed within the central nervous system (Hodges & Richardson, 1999). The *transversus* is the most efficient of the abdominal muscles to be using because of its circumferential structure around the entire abdomen (de Troyer et al., 1990). A pattern of all the abdominal muscles (*transversus*, obliques and *rectus abdominis*) working in concert has been associated with novice actors, whereas idiosyncratic respiratory muscle patterning has been found to be associated with a high level of skill in actors (Hixon, Watson & Maher, 1987). Pettersen and Westgaard (2004) found the muscular patterns for the generation of Ps in professional classical singers to be idiosyncratic . It is possible the NM condition required the singers to move into a volitional mode of respiratory behaviour that was less advantageous to singing because it caused the abdominal muscles act in concert.

6.2.2.5 Automaticity links postural function with internal laryngeal muscles

In Chapter 5, the issue of laryngeal mechanism was discussed at length. The crico-thyroid muscle, as the name implies, attaches to the cricoid and thyroid cartilages of the larynx. When it contracts, it makes the space between the two cartilages smaller and is associated with a tilting action at the larynx (Shipp, 1975), changes of neck posture and the reduction of tension at the vocal folds (Honda, Hirai, Masaki & Shimada, 1999). It is associated with the singing of high F0 tones and with vibrato. The use of crico-thyroid muscle is something that distinguishes trained from untrained singers

(Laukkanen, Takalo, Arvonen & Vilkman, 2002) but also the classical from the more speech-like voice qualities such as those used in the blues.

It is likely that the levels of activity of the crico-thyroid that distinguished between the R & B/Gospel singers and the other singers in Chapter 5 as it is active during vibrato (Hibi & Hirano, 1995; Niimi, Horiguchi, Kobayashi & Yamada, 1988) where it is associated with a reduction of vocal stress. Unlike other laryngeal muscles, the crico-thyroid is not involved in automatic vocal behaviours because it does not contain neuro-muscular spindles and does not receive any efferent innervation from the recurrent laryngeal nerve, making its activation "semi-voluntary" (Gould, 1971). The internal laryngeal muscles on the other hand behave more reflexively and are linked to postural and respiratory function via proprioceptive reflexes. Due to this postural change affects both respiration and vocal fold position.

There is more variability in crico-thyroid use amongst WCP singers. The more speech-like the timbre, the more likely that the crico-thyroid is not being used. Lack of use by WCP singers of the crico-thyroid muscle may indicate that they are using more automatic links between posture and voice. Singer 6 was unanimously perceived to be using Mechanism 1 at all times by the expert judges in Chapter 5. It would have been interesting to know if the difference in her voice use was due to a difference in crico-thyroid activation. This may be indicated by the use of Mechanism 1, and that she was using very little or no vibrato on her peak notes might indicate that she was not using the crico-thyroid. If so, she might have required higher respiratory drive to protect the voice. Although this was not tested here specifically, it would be a useful area for future research to discover whether there is a connection between crico-thyroid activation and automatic movement behaviours in WCP singers. As the crico-thyroid is an external laryngeal muscle, its activity can be more easily be directly measured than internal laryngeal muscle using electromyography (Sundberg, Leanderson & Von Euler, 1989) or ultrasound (de Troyer et al., 1990).

6.2.2.6 Singer experience and training

One would expect that more experienced singers would be more likely to be able to cope with the unexpected performance condition of being asked to stand still while singing. Previous evidence from a study of opera singers suggested that altered body posture from upright to supine does not create difficulty in maintaining Ps control (Sundberg, Leanderson, von Euler & Knutsson, 1991). In this study, to the contrary, the most experienced singers, Singer 5 and 6, showed bigger reductions in the NM condition than Singer 1, the least experienced who had a smaller mean SPL difference (Chapter 3, Table 3.1). This would suggest that the degree of connection between movement and SPL is part of an entrained behaviour that under normal performance conditions would maximise performance quality but when disrupted interferes not only with the kinaesthetic feedback but also with vocal production. This explanation is supported by two studies comparing respiratory behaviour in experienced vocal performers. In the first Hixon (Hixon et al., 1987) studied the respiratory behaviour of Shakespearian actors and found that novice actors used less abdominal displacement and much less variation in respiratory patterning than the novice actors and inspired more slowly than expert actors. Another study into the respiratory behaviour of classical singers found that there was a more targeted and efficient selection of abdominal muscles employed by experienced professional classical singers compared to student singers (Lassalle et al., 2002).

Skilled performance is underpinned by integrated, partially automatic, sensory motor processes. It is possible that SPL reduction in the NM condition occurred as result of the interruption of these processes. It is part of the automatic execution model of skilled performance (Baumeister, 1984) that making a person conscious of what they are doing during an activity that they normally accomplish automatically can impair performance. This occurs through the inhibition of feedback loops. If inhibition of feedback loops were a factor, one would expect there to be a learning effect as the singers became accustomed to the conditions. Although singing in a laboratory under experimental conditions is not like a public performance, it is not unlike a recording studio in that movement is restricted so as not to interfere with equipment or make noise. Singers 5 and 6 who had large differences between the two conditions had extensive recording studio experience. Singer 2's Peak Note levels (Chapter 3, Figure 3.2) and SPL tracings (Chapter 3, Figure 3.3) initially appeared to demonstrate a learning effect since the Peak Note SPL increased with each take in the NM condition, although she never matched her maximum peak in the M condition. However, it was discovered on cross-referencing with the video material that the increases in peak note levels in the NM condition coincided with brief but strong body movements during execution. She had been cautioned after the second take that she was starting to move and should endeavour to remain still. However, she was unable to comply and moved more on the third take. This movement may have caused the increase in SPL. Other participants demonstrated similar difficulties in complying with the instruction to remain still during the NM condition and some were able to achieve this better than others. Similar behaviour was also found in a study of recording for operatic voice, in which a singer continued to move the head and body while singing despite instructions to the contrary and her best efforts to comply (Cabrera, Davis, Barnes, Jacobs & Bell, 2002).

6.2.3 Learning by imitation – mirror neurons

In the introduction, reference was made to the historical association between rhythmic movement and singing in the musical form of the worksong and how worksongs contributed to the origin of the blues and thereby to R & B (1.2.3) . The worksong may have been one way of accessing the advantages of this involuntary *transversus abdominis* activation, which helps protect the back by supporting the spine (Grillner, Nilsson & Thorstensson, 1978; Hodges, Butler, McKenzie & Gandevia, 1997) but there may be neural phenomena that link voice with movement. WCP singing is generally learned by imitation, which is likely to include body movement, even if unconsciously, rather than being limited to laryngeal or articulatory behaviour alone. The study of mirror neurons is significant in relation to the way the WCP singers learned the song in this research and may be responsible for significant differences in technique between WCP singers and western classical singers. Mirror neurons may be a unifying principle between many of the factors discussed so far.

Mirror neurons allow the seemingly automatic human ability to observe and imitate the physical actions and language of another with a high level of accuracy (Fadiga, Craighero & D'Ausilio, 2009), as well as both the perception and production of music (Molnar-Szakacs & Overy, 2006). Originally noted in primates and birds (Welberg, 2008), awareness of mirror neurons has been extended to human activity where they may be instrumental in forming and maintaining internal auditory models (Aamodt, 1999). There are motor, visual and auditory neurons and it appears that imitative action can be mapped on sensory information (Fadiga et al., 2009). Musicians are a case in point, since they map motor to auditory information onto actions. Mirror neurons are also implicated in language acquisition and comprehension via Broca's area (Fadiga et al., 2009). Mirror neurons also allow the continuing acquisition and, over time, modification of new skills throughout life (Aamodt, 1999).

Most importantly for this research, mirror neurons may potentially be the functional link between voice and movement and emotion since it appears that their are implicated in all these areas (Molnar-Szakacs & Overy, 2006) and could explain the tight bond between these three phenomena as it appeared in theses findings. Further, this is an exciting new area of research with regard to singers since it incorporates all the elements of singing action, that is motor coordination, hearing, language and musical awareness (Fadiga et al., 2009). The function of mirror neurons may explain the ease with which singers can simultaneously imitate a sung sound with regard to emotion, pitch, loudness, timbre, words, timing and body behaviour (Fadiga et al., 2009). It may also explain why body movement in the WCP singers observed in this research had been incorporated with the singing performance so as to be implicit. It also implies that the verbal instruction used in the non-movement condition may not have given enough information for them to perform the action properly. Actually performing the action of singing the example without moving, or demonstrating it on a film to the participants, might have produced better and more ecologically sound results in the non-movement condition. This would be more in keeping with the first condition with the way they had learnt the common song from an auditory model. Another factor of interest is that the auditory-vocal connection created by mirror neurons, in keeping with the autophonic response discussed in Chapters 3 and 4, is that it is less troubled by auditory disruption than by other sensory interference, indicating that it is based on motor activity (Prather, Peters, Nowicki & Mooney, 2008).

The existence of mirror neurons also offers a possible explanation of the ubiquity of the worksong outlined in Chapter 1. The call-response format is very common in the worksong, that is, where a lead singer "calls" a line of a song that the group repeats or elaborates on it while simultaneously rhythmically performing manual labour of some kind that involves a repetitive action. It is likely then that an oral tradition of this kind incorporates physical actions that are mapped onto to the voice and that the voice would incorporate the characteristics of respiratory and laryngeal muscle strength of someone used to manual labour. This could help to explain the robustness of the R & B voice described by Lovetri (2002) and seen in the Mechanism 1 singing of Singers 3, 5 and 6 (Chapter 5, Figure 5.1,). The existence of mirror neurons would add new meaning to the concept of oral tradition because it would explain how physical technique has been passed on with little conscious awareness or verbal instruction over centuries. This mechanism for learning may also explain why so many WCP singers have been successfully self-taught and have felt no need to have formal instruction beyond the observation of others performers. It also has implications for the change in singing voice use now found in singers as they have no choice but to imitate sound recordings alone without the visual and motor physical cues that go with them. This may account for some of the vocal difficulties that I have encountered in singing students who have grown up in non-singing environments without the financial advantages to be able to attend live performances by good singers. This is also sometimes made worse by the high degree of studio manipulation on commercial recordings that alters natural sound cues and rock videos in which singers perform actions on camera that they would never do in a live performance thus depriving novices of realistic auditory/visual models. As such the study of the function of mirror neurons in singing practice could have implications for many areas from singing teaching methods, to the validation of traditional oral methods of music transmission to funding for singing programs in schools.

6.2.4 Slowed singing speed and reduced SPL due to postural sway interference

The antero-posterior (AP) torso movement seen in Chapter 2 originally appeared to be either an exaggerated respiratory movement or postural sway. Because the direction of the movement was found to relate to SPL change rather than normal respiratory phasing, there remained the issue of postural sway. Postural sway is the AP postural response provided by automatic postural control mechanisms. Because body stance changes are based on information from multiple senses, including the vestibular, visual and somatosensory systems (Van der Kooij, Jacobs, Koopman & Grootenboer, 1999) and is inherently unstable, postural sway is very sensitive to a wide range of perturbations including competing attentional demands, emotional interference (Dault, Yardley & Frank 2003) and movement speed (Gurfinkel, Levik, Popov, Smetanin & Shlikov, 1986). Standing still, although unconsciously achieved through postural controls, is quite difficult for the body to maintain and may explain why some of the participants in the study reported difficulty or fatigue in the non-movement condition. Postural control is based on all sensory inputs and perturbation in any of these increases postural sway. Stillness perturbs the vestibular system leading to an increase in body movement. That is, trying to stand still creates movement, which would have created conflict.

As the human body moves through the many unknown environments it encounters, the nervous system is constantly processing inputs from all the senses in order to inform stance control. The nervous system integrates this in order to create an estimate of the body's position in space and then controls the muscles either to maintain that position or move from it depending on the person's intent (Van der Kooij et al., 1999). The downside of this is that the transmission and integration of the information causes a neural delay estimated to be 100 ms (Van der Kooij et al., 1999). The nervous system compensates for the delay using projections based on this estimate. However this compensation cannot be completely reliable since it is dependent on sensory information which may be inaccurate due to the unfamiliarity of the situation or to sensory deficits (Van der Kooij et al., 1999). Interference with the function of stance control may therefore account for the slowing of tempos that occurred in the non-movement condition (Chapter 3, Figure 3.3). As deceleration has inspiratory effects, this could have lowered Ps thereby causing the reduction of the overall SPL (Lee & Banzett, 1997).

6.2.5 Sensorimotor interactions

It has been suggested that a possible reason for WCP vocalists singing loudly is that they can't hear themselves because of a high degree of instrumental noise masking their own voices (Borch & Sundberg, 2002). As a working singer, I would suggest that this is unlikely, unless the singer is inexperienced or there are difficulties with the singer hearing themselves through fold-back monitors. As seen in Chapters 3 and 4, the singers still sang loudly even without accompaniment as there is a stylistic preference for higher levels of low frequency sound in WCP music (Dibble, 1995). This means that devices used in acoustic music to "project", that is, to boost the higher frequency to match the singer's formant (Borch & Sundberg, 2002; Thorpe et al., 2001) may not an aesthetically viable option. This may account for WCP singers choosing to boost overall SPL rather than just the higher partials. The higher frequency component of belting voice quality can then be used if brighter sound is required. Alternatively, a singer can just move closer to the microphone to increase intensity, one of the possibilities of microphone technique (Edwin, 2001).

However, the masking of the high level of noise at WCP concerts does lead to a different type of behaviour due to common occurrences such as human error or equipment failure. Even more unfortunately, this often happens early in a singer's career when fold-back monitors may not be used and sound engineers may be sub-standard (Wilson, 2003). It has also been suggested that WCP singers may be deprived of auditory and proprioceptive feedback (Borch & Sundberg, 2002). It is possible that WCP singers learn to rely more on the physical sensations associated with their voices than their peers who have quieter accompaniment. In this case their reliance may be more on proprioceptive and vestibular information than auditory inputs.

Although it is little known, the autophonic effect is a recognized effect by which a person is able to make an accurate (1.1x power of the measured SPL) in speech subjective judgment of their SPL using muscle effort as a feedback mechanism (Lane, Catania & Stevens, 1961). The speaker's own judgment was found to be more accurate than that of a listener (0.7x power of the measured SPL). This is a possible mechanism for the overall reduction of SPL in Chapter 4 because of the identified accuracy of the effect and because the change from movement to non-movement would have had a direct relationship to the muscle effort involved.

Singers of WCP music may have even more cause to be able to monitor SPL via muscle effort that via sound since they usually sing in situations where amplified bands provide the backing in noisy venues. This means that they have to learn to override the Lombard effect in order to sing effectively. This also applies to the sidetone effect created by foldback monitors that either over- or under-amplify the singer's voice (Borch & Sundberg, 2002). It is possible that WCP singers learn to rely more on sensorimotor feedback when performing than singers who work in less noisy acoustic settings.

6.2.6 Emotion: "but it's all about emotion"

One of the most thought provoking results of this research, touched upon in Chapter 2, was when Singer 5, on being asked to stand still and sing, exclaimed "but it's all about emotion!" My interpretation of her tone when she said it was that she was shocked and exasperated that I thought anyone could sing under those conditions. The implications of the nature and strength of her reaction are significant, revealing the primacy of the connection between emotion and movement in her preferred singing style and that this may also be the case with other singers of R & B. For her, it seemed to be a given that body movement, emotion and singing were inextricably intertwined and should have no need of explanation. For this reason, there follows a further exploration of how emotion, movement and singing might be connected and if so, whether the connection was conscious or automatic.

6.2.6.1 Difficulty suppressing movement

In Singer 2's Peak Note levels (Chapter 3, Figure 3.2) and SPL tracings (Chapter 3, Figure 3.3) it initially appeared that she was adjusting to the non-movement condition and was demonstrating a learning effect since the Peak Note SPL increased with each take in the that condition, although she never matched her maximum peak in the M condition. However, it was discovered on cross-referencing with the video material that the increases in peak note levels in the NM condition coincided with brief but strong body movements during execution. She had been cautioned after the second take that she was starting to move and should endeavour to remain still. However, she was unable to comply and moved more on the third take. This movement may have caused the increase in SPL. Other participants demonstrated similar difficulties in complying with the instruction to remain still during the NM condition and some were able to achieve this better than others. Similar behaviour was also found in a study of recording for operatic voice, in which a singer continued to move the head and body while singing despite instructions to the contrary and her best efforts to comply (Cabrera et al., 2002).

6.2.6.2 Affect programs

In the introduction, it was shown that there are body movements associated with the basic emotions, such as anger and happiness. A central mechanism for controlling emotional behaviour is referred to as an affect program. Affect programs are open to change and can be associated with particular body movements, facial expressions or vocal habits (Ekman, 2003). If the singers are truly experiencing emotion while singing and that emotion has become implicated with body movement behaviour as part of an affect program, it would be harder for them to alter their behaviour. Emotional responses linked to body movement alone are easier to unlearn that those associated with facial movement or the voice (Ekman, 2003). This could be indicated by the difficulty the singers had in dissociating their vocal from body behaviour and without it having detrimental effects on voice production. Exercise just prior to music listening has also been shown to increase the strength of the emotional reaction to the music (Dibben, 2004). This suggests that there may be a movement and emotion loop in which movement stimulates emotion and emotion triggers movement.

Reference was made earlier to the model of the emotional motor system for voice production (1.4.3.3). If singing and movement are linked via these pathways, the emotional motivation of the singer would affect the organization of respiratory behaviour. The intention and purpose of the subject has an effect on the muscle recruitment patterns of expiratory muscle behaviour. Strohl (Strohl et al., 1981) found that in speech, recitation, coughing and laughter the relative activity of the upper and lower abdomen equalized, in contrast with normal respiration, in which tonic activity occurs mainly in the lower abdomen with phasic activity in the upper abdomen. Significantly, when the intended result of the subject's behaviour changed so did the type of abdominal activity.

Talking about an emotional event can cause a person to re-experience the physical responses associated with it (Ekman, 2003). Singing with emotional connection seems to evoke similar responses affecting respiration (Foulds-Elliott, Thorpe, Cala & Davis, 2000) and singing after emotional an emotional stimulus results in increased lower lateral abdominal muscle activity (Pettersen & Bjørkøy, 2007). It should be pointed out that emotional connection does not necessarily make voice production easier although it may facilitate the communication of that emotion to an audience. It can be more effortful to perform in an emotional way. This is due, at least in part, to the expression of emotion involving muscular effort which changes depending on the emotions expressed (Averill, 1969). Emotive speech involves more variation in Ps than nonsense words (Leanderson et al., 1987). This means that the emotional intent (or lack of it) will alter Ps levels. There is a difference again between emotive speech and singing with differences in recruitment patterns of the muscles that drive the Ps change with more engagement of the oblique abdominal muscles for singing while emotive speech involves more intercostal muscle recruitment, although both feature rapid and precise changes in pressure (Leanderson et al., 1987). Being as WCP singing can involve changes of voice quality, including more speech-like sounds, either of these patterns may exist in WCP singing. In the Foulds-Elliot study discussed earlier (3.5.5), the classical singers' sound changed when "emotionally connected". To date, I am not aware of any similar study undertaken on "emotional connection' using WCP singers as subjects although this would be of great interest.

Lower fundamental frequency sounds and timbres with enhanced lower partials convey stronger emotional cues to the listeners in speaking voice (Scherer, 1995). This is is interesting in that WCP singing favours the use of the lower range Mechanism 1 configuration. The movement itself perpetuates the emotional response by stimulating the symphathetic nervous system and muscular effort (Dibben, 2004). This, in combination with the pleasurable and rhythmic movement stimulating effects of the high amplitude low frequency sound of the instrumental backing (Dibble, 1995; Todd & Cody, 2000) provides possible psychological and physiological reasons for the widespread success of WCP music.

6.2.6.3 Spontaneous and emotional vs planned and technical

The issue of emotional involvement during singing under research conditions could be important in light of theories that contend that emotion may control body and vocal activity by involuntary pathway (Holstege & Ehling, 1996). The primacy of emotional individual expression over technique and spontaneity over planning within WCP styles (1.2.4 - 1.2.5) means that the potential for interference from external factors under experimental conditions is much greater than for classical singing. In most cases, the brain brings about the behaviours that are the goal of intent without the individual being aware of them (LeDoux, 1998). Emotional goals reduce self-awareness and self-attention further. For example, if attention is directed during spontaneous, emotional laughter, the laughter is reduced or ceases (Ruch & Ekman, 2001). If we project this onto other emotional voice-body states, it appears it would easier to disrupt genuine emotional expression than when it is contrived. The West African influence on WCP music has created "a rhythmic, emotion-charged, enveloping music that often focuses on primal and spiritual desires."(Mosher, 2008, p.109) It is possible that this focus on singing as an intense individual emotional and transcendent experience within WCP music means that it is especially sensitive to interference from attentional focus. The first part of the protocol used in these studies which drew attention away from the movement behaviour seems to have been successful in eliciting a natural performance response. However, it is hard to verify whether the diminution of singing output in the non-moving condition was simply due to attention causing them to disengage emotionally or to the physical inaction or to the lack of the link between the two. If this were to be tested further, it would be necessary to enter upon a significantly longer training period with WCP singers to see if they could incorporate non-movement within the affect programs involved in the singing of these songs. Even if this is possible, the evidence here and the broader evidence of the literature suggests that the SPL output would be still altered due to different muscle recruitment and respiratory patterns, although the singers would probably be able to compensate to some extent for this by producing higher partials via the articulators. It is interesting to recall that Singer 1 had a significantly different voice and movement profile from the other singers and this was indicated by the disagreement between the voice experts as to what voice mechanism she was using. Her background was that she had been a self-taught pop singer who had been to a classical teacher who had told her not to move around when she was singing. She also had a high degree of vibrato in her singing. It is unclear whether she was taught this or whether is arose spontaneously out of the different body behaviours that she was encouraged to adopt. One way of researching this issue would be to perform a longitudinal case study following a WCP singer who wanted to move into classical singing, recording their body behaviour and acoustic changes over time. A similar case study for a singer moving from classical to WCP would also be of interest.

6.2.6.4 Emotion, intent and body movement in singing

Attempting to understand why one sings and the effects that has on behaviour brings the role of intent and emotion into focus. Intention to behave affects actual behaviour because neural organisation translates goal orientation into specific sequences of action in the execution of music (Palmer, 1989). In the context of singing in performance, intent involves the desire to express and communicate to others, emotion or a musical or lyrical idea or image. Singing with the intention to communicate to an audience has been defined as performance with emotional connection (Foulds-Elliott et al., 2000) and is essential to high quality performance (Davidson, 2010). It is intent that brings about the initiation of voice production and the nature of that intent changes respiratory function in speech (Huber, 2007; Winkworth, Davis, Adams & Ellis, 1995) and singing (Foulds-Elliott et al., 2000). It is through intent and goal orientation that the central nervous system entwines sung performance with a range of non-verbal behaviours that communicate emotional and other information to an audience as well as functional behaviours related to the production of sound. Studies in which variation in vocal intensity is an experimental condition may further knowledge about how phonation is neurologically controlled (Huber, 2007).

6.3 Two types of future research

6.3.1 Inside out: researching the singer's subjective experience and self-perception

6.3.1.1 Movement effects on other musical characteristics

In the beginning of this thesis I quoted Hudson's criticism of the "noble posture" for classical singing. A critique or comparison of the relative merits of two styles of singing is not the intention here but rather the use of pedagogical methods which may be advantageous for one style of singing for another for which it is not appropriate. This is particularly important because whether the singers were moving or not changed the sound significantly. This research has shown that movement during singing is not just an adjunct to performance that is enjoyable for the singer and entertaining for the audience, but has a quantifiable impact on sound intensity. Further research needs to be done to test this relationship on other musical aspects such as rhythmic accuracy, tempo and pitch. Some guidelines on further research has been suggested throughout this chapter.

6.3.1.2 More research on kinaesthetic awareness

Hudson (2002) has also commented that actors and dancers have much more kinaesthetic awareness than classically trained singers. The findings here also validate some of the methods used in modern acting training. In the last century, western style acting training changed dramatically under the influence of the Asian physical and theatrical arts and knowledge of scientific developments which led to greater spontaneity and involvement and awareness of body in acting (Hodge, 2000). Although there were and are still many methods of acting training, the acknowledgement of the importance and intertwining of body, emotion, dynamic posture and voice for acting was established. WCP singing as represented by R & B emphasises the spontaneous multi-sensory pleasure (Cooper, 1996; Heilbut, 1985) of singing and conveys that to its audience (Heilbut, 1985).As such WCP singing philosophically may have more in common with acting than with classical singing practice. Because of this and the use of speech-related voice qualities in WCP singing, it may be fruitful to conduct research on the efficacy of acting voice methods for the improvement of WCP singing.

6.3.1.3 Vocal self-perception and subjective responses

In a study of the descriptive language of timbre used by jazz singing teachers it was found that a large proportion of the descriptors related to subjective bodily sensations (Prem & Parncutt, 2008). Though the study did not record how this intersected with the singers' concurrent experience of loudness or pitch, it indicated that their own singing experience was largely perceived in terms of subjective corporeal sensation. Much of the perceptual research regarding singing has dealt with the perception of sung sound from the audience's perspective. Although this is of interest to singers, it is also necessary to cross-reference this information with how it sounds and feels to the person singing. What is a significant to the singer/listener themselves in terms of the audio feedback loop and how that alters their behaviour may be different to what may be acoustically significant to the audience/listener. Singer Lisa Popeil remarked at her surprise on the difference between her own experience of the sensation of singing and her own vocal function as revealed by MRI (magnetic resonance imaging) and video-fluoroscopy in a study comparing belt and classical vocal techniques (Popeil, 1999).

It is necessary to relate the subjective experience of singers with empirical data. This then could incorporate knowledge regarding vestibular and autophonic responses discussed in Chapters 3 and 4 as well as emotional effects. Psychology research has been criticized for its neglect of the sensations of emotional experience (Ekman, 1977). Similarly, research into the self-perception of singing voice, not just in terms of auditory perception but also physical and emotional sensations, would be highly valuable to singing practitioners.

Unfortunately, in some of the literature, there is a tendency to devalue the subjective experience of singers and the imagery they use, describing it as unscientific. For example one study begins with a description of what most classical singers think they know helps them reach their maximum intensity and then proceeds to show how their perception is wrong (Kmucha, Yanagisawa & Estill, 1990). In future research, it would be useful if the perceptions of expert WCP singers about what they experience on a multi-sensory level were more closely analysed and correlated with empirical data.

6.3.1.4 Observation of the unsaid

Sound, vision and physical sensations are all involved in music execution and its perception by both the player performer and the audience (Dahl & Friberg, 2007). This includes the non-sonic aspects of performance which can be equally worthy of study and can provide insights to practitioners on how movement involved in musical execution can alter nature of the sound (Baily, 1985), thereby affecting both the player and the listener. For example, Dibble found that there is a general sense expressed by rock music listeners that below a certain sound level rock music "does not work" (Dibble, 1995, p.251). This would seem too vague a comment to be useful, but this opinion was so widespread that he investigated it. He was later able to pinpoint empirically that at or above 96dB rock music "felt right". This feeling has since been attributed to vestibular sensation and has been dubbed the "rock threshold" (Todd & Cody, 2000). This information is now very useful for sound engineers working with musicians but also in understanding the acoustic intensity levels targeted by the singers here. Because such subjective sensory effects cannot always be verbalized by singers, it is important that researchers observe and question closely these performers' instinctive responses as guides to future research.

6.3.2 Outside in: Cross-cultural studies

6.3.2.1 Philosophical underpinnings

It is particularly European-based art music culture with its social proscription of body movement by audiences and its focus on music as a notated, intellectual activity that has cut the physical experience out of the musical experience (Repp, 1993). It is likely that in the modern, industrialized world, with its attention on music as a digitally manipulated, recorded auditory event, as opposed to something that is experienced with all the senses, has taken this a further step away from the reality of live performance. However, music lovers and musicians themselves, of all music types, prefer to attend a live performance over a recorded one (Wolfe, 2002) because they are more aware of sensory elements that are not present in recording. The attitude that music is primarily an intellectual rather than physical event has carried over into scientific research into singing. This is partly a side-effect of the western tendency to regard the mind and body as separate, an inheritance of the Cartesian perspective of the mind being the "ghost" in the "machine" that was the body (Sacks, 1991; LeDoux, 1998, p.39). Studies of music cognition have often not acknowledged the spatiomotor aspects of music (Baily, 1985). As a result much of the research into singing voice has been focused on laryngeal function and spectral analysis of recordings to the neglect of other areas such as observational analysis. Ethnomusicologists, on the other hand, who have tried to define what is universal in music, have found that they are unavoidably presented with issues related with psycho-physiological factors (Baily, 1985). Because empirical singing research is in its early stages, it makes sense to step back and observe large global trends in singing behaviour before narrowing the focus and producing large amounts of data concerning aspects of voice that may not be of great significance to singers and the practice of their art. The advantage of an observational approach is that singers and singing teachers already have the skills to pinpoint trends and points of interest that a may elude a non-practitioner. This then allows empirical researchers to focus on the questions raised within their area of expertise, whether it be biomechanics, neurology, laryngology, respiratory physiology, phonology, psychology or any of the other relevant sciences.

6.3.2.2 Cross-cultural research

In the science of singing journal literature, it is highly prevalent for the style of singing being studied not to be mentioned at all even though the scientific detail was meticulous. This is because the primary focus has been and remains on western classical singing. The music theatre term "legit" (shortened from "legitimate") refers to voice quality that has many of the same features as classical singing (Schutte & Miller, 1993). Higher level music in this tradition is associated with written notation, formal training and an intellectual approach to music even though only a small proportion of the world's musicians read music (Baily, 1985). Music from musical traditions that use imitation and modelling rather that notation as a means to learning is generally not empirically researched even when the music demands high levels of technique (Bowles, 1999).

Ethnomusicology is a discipline that has already accumulated large amounts of cross-cultural observational evidence (Rogers & Symons, 2005) about all kinds of music practice. A collaboration of the observational approach of ethnomusicology, with its sensitivity to the pitfalls of racial and cultural preconceptions, with empirical singing research could yield exciting revelations about voice. It was a source of great disappointment to me in my reading that I could find almost no empirical singing research on styles outside the western, and particularly the western classical form.

Rhythmic complexity seems little valued. Bowles (Bowles, 1999) commented that during the 1920s "black musicians made arduous, painstaking efforts to master technique at ever more demanding levels of virtuosity ... Nevertheless imagery of blacks as simple, carefree folk possessing natural gifts of rhythm prevailed" (p.11). This point of view with regard to African or African-American musicianship is still held by some in the 21st Century, and one which I have heard put forward by many individuals in my capacity as a teacher, performer and researcher in Australia and Europe. I have also encountered similar attitudes towards the Rom in Eastern Europe, who are often personally reviled while being lauded and envied for their "natural" musical abilities. This prejudice is perhaps one of the reasons for the dearth of empirical studies of popular singing because if one believes, for example, that rhythmic sense or a particular voice timbre comes "naturally" to some because of their race, it cannot be acquired by others, making the results of research limited in application. Both empirical and cross-cultural musicological research should help dispel such myths.

Rhythmic and melodic patterns in WCP music, as in many other traditions (Baily, 1985), are learned via imitating movement as well as sonic patterns. In such traditions, the non-sonic moments, such as rests, are important since movement continues when there is no sound occurring. It is possible this is what has lead analysts so far to not be aware of the movements that are not connected to sound production, even though musical patterns are partly defined by those rests. In addition, preparation for the sounded parts of the music must occur during those rests, as in the raising of the percussionists arm or the inspiratory breath of the singer. Research into how mirror neurons affect music acquisition (Fadiga et al., 2009) will hopefully illuminate and validate these learning processes in the future. This research has shown that whether practitioners are conscious of it or not, body movement is occurring and has significant effects on the sound.

6.3.2.3 Potential for singing in cross-genre and cross-cultural research

It is a conventional wisdom that classical vocal training prepares a singing student for any kind of singing. The results of this study indicate that the western classical singing method, with its emphasis on physical restraint may not be appropriate for singers in popular styles, at least with respect to physical behaviour. All the singers had reduced SPL in the non-movement condition of this study but the degree to which it affected them varied, with R & B and gospel singers showing the greatest reduction in output. The division of behavioural and acoustic output along stylistic lines indicates that there may be different patterns of body behaviour linked to voice use within WCP music as well as between WCP and classical singing. There is not likely to be one universal behaviour that can be called good or healthy for all singing styles because musical goals may differ (Dayme, 2009). Future studies of body movement patterns during singing within specific WCP sub-genres such as R & B, jazz, music theatre and rock styles observing larger numbers of expert singers are indicated but such study could be taken to a wider range of musical styles of singing from many parts of the world. Singing is ideal for cross-cultural study because the vocal instrument is the same everywhere in the world. It is how the that instrument is played that varies. Singing is truly at once a personal, biological and cultural phenomenon.

6.4 Conclusion

6.4.1 Personal pedagogy

I began this thesis by discussing how I came to this research through questions raised in my own practice of singing, singing performance and singing teaching. I continue to use worksong, call response and Accent method exercises which help boost vocal intensity for all singers. This research has confirmed that these exercises boost intensity because of the association between body movement, breathing, rhythm, sensory awareness and emotional connection. I began this research with the intention of finding the nexus between these factors but, it seems, no one factor can be left out. The reason that this system functions so well may be that the unifying factor is a neural linking system, such as the emotional motor system and mirror neurons. Multi-sensory inputs have also been shown to be important in which case the integration of these inputs by the nervous system is a key factor.

The many involuntary functions discussed earlier relate closely to multi-sensory inputs including vision, proprioception, and vestibular inputs as well as the more obvious auditory feedback. The reduction in intensity when the singers were asked not to move may be the result of self-awareness or the change of attentional focus interrupting these normally involuntary functions. This has important implications in teaching practice. The issue of attentional focus for performers and the dichotomy between unconscious and conscious attention is well-known to performers and has been discussed including terms such as the "inner" and "outer critic". This research has shown that interference with automatic processes can have measurable acoustic effects on voice via outwardly visible mediating behaviours such as respiration and movement. These results show that it may be more useful for musicians to focus on sensory awareness rather than struggling with issues of consciousness. This indicates approaches such as the "inner game" methods and mindfulness techniques that focus on sensory awareness may be useful and I have already started using such methods with my students to good effect.

To deal with the issue of self-awareness, I have come to explain to students that there are two modes: practise mode which includes self-awareness and technical work which is a necessary physical training process for developing new skills. The second mode is performance mode in which conscious thought should be replaced by the feeling of physical sensations, emotions and the use of mental imagery to fully experience the song. In other words, performance state is one in which attention is on the senses rather than the intellectual analysis of them.

Emotional disconnection may also have been a central reason for the reductions of SPL in the non-movement condition possibly due to the interruption of the emotional motor system. Since the issue of emotion was mentioned in connection with movement by Singer 5 during data collection, I have changed my teaching practice with regard to how to engage support for the voice. Although the worksong and other methods mentioned above were useful in the initial stages and when able to move, it still presented a problem when a singer could not make these movements. I had for a time taught the technique of "anchoring" which involved conscious muscle contraction but found it did not work for all people and sometimes led to excess tension. I now know that this may be due to its creation of excessive self-awareness in certain individuals and also because it involved standing still. I now teach emotional engagement as the primary trigger for support with its attendant factors such as understanding of the meaning of lyrics in order to draw on one's own emotional experience and the focusing on the will to communicate to the listener. I have found this the most effective method yet for eliciting a supported voice without vocal strain. This is a significant change in focus in my teaching method that is purely due to my research. I had, of course, seen emotion, respiration and support as important facets of singing without seeing the *sensation* of emotion as the link between them. This awareness of sensation and emotion approach has also proven to be a useful technique for helping students with performance anxiety.

6.4.2 Validity of perception

This research has led me to an appreciation of the difference between empirical evidence and perception in singing. Singers' perceptions of how they achieve their best sound should not be dismissed. It is not possible for one's experience and taste not to come into play when listening to a singer's voice. Singing teachers who use imagery have been dismissed as purveyors of mythology when all language used in teaching must incorporate metaphor and simile to be effectively understood – because emotion and imagery and intent affect physiology. Singing teachers need to recognize the difference between the imagery used to elicit a physiological response and the physiological responses themselves and voice scientists need to realize that understanding vocal physiology alone does not make a good singer. In addition to the embodied instrument that we all possess, we also need imagination, a love of music, emotional rapport with the lyric of a song, life experiences, artistry, pleasure in singing for its own sake and a wish to communicate to a listener. Much remains that is mysterious about this complex form of human expression.

BIBLIOGRAPHY

Aamodt, S. (1999). Singing in the brain: song learning in adult zebra finches. *Nature Neuroscience, 2*(7), 590.

Agostini, E. & Mead, J. (1985-7). Statics of the respiratory system. In *The Respiratory System* (Vol. 1, pp. 387-409). Bethesda, Md: American Physiological Society.

Alison, J. A., Regnis, J. A., Donnelly, P. M., Adams, R. D., Sullivan, C. E. & Bye, P. T. P. (1998). End-expiratory lung volume during arm and leg exercise in normal subjects and patients with cystic fibrosis. *American Journal of Respiratory and Critical Care Medicine, 158,* 1450-1458.

Appel, M., Childs, A., Healey, E., Markowitz, S., Wong, S. & Mead, J. (1986). Effect of posture on vital capacity. *Journal of Applied Physiology, 61*(5), 1882-1884.

Averill, J. R. (1969). Autonomic response patterns during sadness and mirth. *Psychophysiology, 5*(4), 399-413.

Baddeley, A. (2004). *Your memory: a user's guide* (Fourth ed.). Buffalo, N.Y.: Firefly Books.

Bagnall, A. D. & McCulloch, K. (2005). The impact of specific exertion on the efficiency and ease of the voice: A pilot study. *Journal of Voice, 19*(3), 384-390.

Baily, J. (1985). Music structure and human movement. In P. Howell, I. Cross & R. West (Eds.), *Musical structure and cognition* (pp. 237-258). London: Academic Press.

Bandler, R., Keay, K. A., Vaughan, C. W. & Shipley, M. T. (1996). Columnar organization of PAG neurons regulating emotional and vocal expression. In P. Davis & Fletcher (Eds.), *Vocal Fold Physiology: controlling complexity and chaos* (pp. 137-151). San Diego,London: Singular Publishing

Banfield, W.C. (1999). Some aesthetic suggestions for a working theory of the "undeniable groove": how do we speak about black rhythm, setting text and composition? In A. M. S. Nelson (Ed.), *"This is how we flow": Rhythm in Black Cultures* (pp. 32-41). Columbia, South Carolina: University of South Carolina Press.

Banfield, S. (2000). Stage and screen entertainers in the twentieth century. In J. Potter (Ed.), *Cambridge Companion to Singing*. Cambridge: Cambridge University Press.

Bassiouny, S. (1998). Efficacy of the Accent Method of voice therapy. *Folia Phoniatrica et Logopaedica, 50*, 146-164.

Baumeister, R. F. (1984). Choking under pressure: self-consciousness and paradoxical effects of incentives on skillfull performance. *Journal of Personality and Social Psychology, 46*(3), 610-620.

Bestebreurtje, M. E. & Schutte, H. K. (2000). Resonance strategies for the belting style: results of a single female subject study. *Journal of Voice, 14*(2), 194-204.

Björkner, E., Sundberg, J., Cleveland, T. & Stone, E. (2005). Voice source differences between registers in female musical theater singers. *Journal of Voice, In press.*

Blindman's Holiday, (1989) [CD]. *Traditional Vocal Music*. Pan.

Blindman's Holiday, (1992) [CD]. *Archipelago*. BMG.

Blindman's Holiday, (1997) [CD]. *Airport Lounge.*

Bouisset, S., & Zattara, M. (1986). Anticipatory postural adjustments and dynamic asymmetry of voluntary movements. In V. S. Gurfinkel (Ed.), *Stance and Motion: facts and concepts* (pp. 177-183).

Borch, D. Z. & Sundberg, J. (2002). Spectral distribution of solo voice and accompaniment in pop music. *Logopedics Phoniatrics Vocology, 27*(1), 37-41.

Borch, D. Z., Sundberg, J., Lindestad, P. A. & Thalen, M. (2004). Vocal fold vibration and voice source aperiodicity in 'dist' tones: a study of a timbral ornament in rock singing. *Logopedics Phoniatrics Vocology, 29*(4), 147-153.

Borden, G. J. (1979). An interpretation of research on feedback interruption in speech. *Brain and Language, 7*(May), 307-319.

Bouhuys, A., Mead, J., Proctor, D. F. & Stevens, K. N. (1968). Pressure-flow events during singing. *Annals of the New York Academy of Sciences, 155*(1), 379-381.

Bouhuys, A., Proctor, D. F. & Mead, J. (1966). Kinetic aspects of singing. *Journal of Applied Physiology, 21*, 483-496.

Bourne, T., Garnier, M. & Kenny, D. T. (2010). Music theatre voice: production, physiology and pedagogy. In S. Harrison (Ed.), *Perspectives on Teaching Singing*: Australian Academic Press.

Bowles, J. (1999). A rap on rhythm. In A. M. S. Nelson (Ed.), *"This is how we flow": Rhythm in Black Cultures* (pp. 5-14). Columbia, South Carolina: University of South Carolina Press.

Brackett, N. & Hoard, C. (Eds.). (2004) The New Rolling Stone Album Guide (4th ed.). New York: Fireside.

Bruno, E., De Padova, A., Napolitano, B., Marroni, P., Batelli, R., Ottaviani, F., et al. (2007). Voice disorders and posturography: variables to define the success of rehabilitative treatment. *Journal of Voice, In Press.*

Bunch, M. & Chapman, J. (2000). Taxonomy of singers used as subjects in scientific research. *Journal of Voice, 14*(3), 363-369.

Burgin, J. (1973). *Teaching Singing*. Metuchen, N.J.: The Scarecrow Press Inc.

Cabrera, D., Davis, P. J., Barnes, J., Jacobs, M. & Bell, D. (2002). Recording the operatic voice for acoustic analysis. *Acoustics Australia, 30*(3), 103-108.

Cadoz, C., & Wanderley, M. (2000). Gesture - Music. In M. Wanderley & M. Battier (Eds.), *Trends in Gestural Control of Music*. Paris: Ircam Centre Pompidou.

Carlsson, G. & Sundberg, J. (1992). Formant frequency tuning in singing. *Journal of Voice, 6*(3), 256-260.

Castellengo, M. & Henrich, N. (2004). *Is voix mixte, the vocal technique used to smoothe the transition across the two main laryngeal mechanisms, an independent mechanism?* Paper presented at the International Symposium on Musical Acoustics, Nara, Japan.

Cavagna, G. A., Dusman, B. & Margaria, R. (1968). Positive work done by a previously stretched muscle. *Journal of Applied Physiology, 24*(1), 21-32.

Chalmers, K. & Latham, A. (2002). Work Song. In A. Latham (Ed.), *The Oxford Companion to Music.*

Chapman, J. (1986). *Making connections – primal singing.* Paper presented at the Voice Conservation Symposium, London.

Chaytor, N. & Schmitter-Edgecombe, M. (2003). The Ecological validity of neuropsychological tests: a review of the literature on everyday cognitive skills. *Neuropsychology Review, 13* (4), 181-197.

Clarke, E. F. (1999). Rhythm and timing in music. In D. Deutsch (Ed.), *The Psychology of Music* (2nd ed., pp. 227-235). New York: Academic Press.

Cleveland, T. F., Stone, R. E., Jr., Sundberg, J. & Iwarsson, J. (1997). Estimated subglottal pressure in six professional country singers. *Journal of Voice., 11*(4), 403-409.

Collyer, S. (1997). The classical teacher and belting. *Australian Voice*, 37-40.

Collyer, S. & Davis, P. (2006). Effect of facemask use on respiratory patterns of women in speech and singing. *Journal of Speech, Language, and Hearing Research, 49*(2), 412-423.

Cooper, B. L. (1996). Revisiting rhythm and blues royalty. *Popular Music and Society, 20*(3), 119-122.

Corballis, M. C. (1999). Phylogeny from apes to humans. In M. C. Corballis & S. E. G. Lea (Eds.), *The Descent of Mind: psychological perspectives on hominid evolution* (pp. 40-70). Oxford: Oxford University Press.

Cordo, P. J. & Nashner, L. M. (1982). Properties of postural adjustments associated with rapid arm movements. *Journal of Neurophysiology, 47*(2), 287-302.

Corthals, P. (2004). Sound pressure level of running speech: percentile level statistics and equivalent continuous sound level. *Folia phoniatrica et logopaedica, 56*(3), 170-181.

Couser, J. I., Martinez, F. J. & Celli, B. R. (1992). Respiratory response and ventilatory muscle recruitment during arm elevation in normal subjects. *Chest, 101*, 336-340.

Cowgill, J. G. (2004). *Breathing for singers: a comparative analysis of body types and breathing tendencies.* Florida State University.

Crenna, P., Frigo, C., Massion, J., Pedotti, A. & Deat, A. (1988). Forward and backward axial movements: two modes of central control. In V. S. Gurfinkel (Ed.), *Stance and motion: facts and concepts* New York: Plenum Press.

Cross, I. (2003). Music as biocultural phenomenon. *Annals of the New York Academy of Sciences, 999*, 106-111.

Dahl, S. (2000). The playing of an accent -preliminary observations from temporal and kinematic analysis of percussionists. *Journal of New Music Research, 29*(3), 225-233.

Dahl, S. & Friberg, A. (2007). Visual perception of expressiveness in musicians' body movements. *Music Perception, 24*(5), 433-454.

Dault, M. C., Yardley, L., & Frank, J. S. (2003). Does articulation contribute to modifications of postural control during dual-task paradigms?. *Cognitive Brain Research, 16*, 434-440.

David, A. (1991). Autogenic drainage – the German approach. In J. A. Pryor (Ed.), *Respiratory Care* (pp. 65-78). London: Churchill Livingstone.

Davidson, J. W. (1995). What does the visual information contained in music performances offer the observer? Some preliminary thoughts. In R. Steinberg

(Ed.), *Music and the Mind Machine: The psycholophysiology and psychopathology of the sense of music*: Springer-Verlag.

Davidson, J. W. (2001). The role of the body in the production and perception of solo vocal performance: a case study of Annie Lennox. *Musicae Scientiae, 5*(2), 235-256.

Davidson, J. W. (2006). She's the one: multiple functions of body movement in a stage performance by Robbie Williams. In A. Gritten & E. King (Eds.), *Music and Gesture*: Ashgate Publishing.

Davidson, J. W. (2010). *The psychology of performance.* Paper presented at the HCSnet Winterfest, Bowral, NSW, Australia.

Davis, P., Zhang, S. P. & Bandler, R. (1996a). Midbrain and medullary regulation of respiration and vocalization. In G. Holstege, R. Bandler & C. B. Saper (Eds.), *Progress in Brain Research* (Vol. 107, pp. 315-325): Elsevier Science B.V.

Davis, P., Zhang, S. P. & Bandler, R. (1996b). Midbrain and medullary regulation of vocalization. In P. Davis & Fletcher (Eds.), *Vocal Fold Physiology: controlling complexity and chaos*. San Diego,London: Singular Publishing.

Davis, P., Zhang, S. P., Winkworth, A. L. & Bandler, R. (1996). Neural control of vocalization: respiratory and emotional influences. *Journal of Voice, 10*(1), 23-38.

Dayme, M. B. (2009). *Dynamics of the singing voice* (5th ed.). Wien, New York: Springer.

Dejours, P. (1985-7). Control of respiration in muscular exercise. In *The Respiratory System* (pp. 631-648). Bethesda, Md.

de Troyer, A. (1983). Mechanical role of the abdominal muscles in relation to posture. *Respiration Physiology, 53*, 341-353.

de Troyer, A., Estenne, M., Ninane, V., Gansbeke, D. v. & Gorini, M. (1990). Transversus abdominis muscle function in humans. *Journal of Applied Physiology*, 1010-1016.

Dibben, N. (2004). The role of peripheral feedback in emotional experience with music. *Music Perception, 22*(1), 79-115.

Dibben, N. (2009). *Consuming musical bodies: star image and song personality in vocal performance*. Paper presented at The musical body: gesture, representation and ergonomics in performance. Retrieved Aug 5, 2009.

Dibble, K. (1995). Hearing loss and music. *Journal of the Audio Engineering Society, 43*(4), 251–266.

Donald, M. (1999). Preconditions for the evolution of protolanguages. In M. C. Corballis & S. E. G. Lea (Eds.), *The Descent of Mind: psychological perspectives on hominid evolution* (pp. 138-154). Oxford: Oxford University Press.

Dromey, C. & Ramig, L. O. (1998). The Effect of lung volume on selected phonatory and articulatory variables. *Journal of Speech, Language, and Hearing Research, 41*, 491-502.

Druz, W. S. & Sharp, J. T. (1981). Activity of respiratory muscles in upright and recumbant humans. *Journal of Applied Physiology, 51*, 1552-1561.

Edman, K. A. P., Elzinga, G. & Noble, M. I. (1978). Enhancement of mechanical performance by stretch during tetanic contractions of vertebrate skeletal muscle fibres. *Journal of Physiology, 281*, 139-155.

Edwin, R. (2000). From classical to pop: a case study. *Journal of Singing, 56*(3), 21-72.

Edwin, R. (2001). Working with "Mike". *Journal of Singing, 58*(2), 171-172.

Ekman, P. (1977). Biological and cultural contributions to body and facial movement. In J. Blacking (Ed.), *The Anthropology of the Body* (pp. 39-84). London: Academic Press.

Ekman, P. (2003). *Emotions Revealed: understanding faces and feelings*. London: Weidenfeld & Nicholson.

Elkins, M., Alison, J. A. & Bye, P. T. P. (2005). Effect of body position on maximal expiratory pressure and flow in adults with cystic fibrosis. *Pediatric Pulmonology, 40*, 385-391.

Elliot, N., Sundberg, J. & Gramming, P. (1995). What happens during vocal warm-up? *Journal of Voice, 9*(1), 37-44.

Emerich, K. A., Titze, I. R., Svec, J. G., Popolo, P. S., & Logan, G. (2004). Vocal range and intensity in actors: a studio versus stage comparison. *Journal of Voice, 19*(1), 78-83.

Estenne, M., Zocchi, L., Ward, M. & Macklem, P. T. (1990). Chest wall motion and expiratory muscle use during phonation in normal humans. *Journal of Applied Physiology, 68*(5), 2075-2082.

Estill, J. (1995). *Voice Craft: A user's guide to voice quality* (Vol. 2). Santa Rosa: Estill Voice Training Systems.

Estill, J. (1996). Primer of compulsory figures: level one. In *Voice-craft: A user's guide to voice quality* (pp. 31-34). Santa Rosa, CA: Estill Voice Training Systems.

Estill, J., Baer, T., Honda, K. & Harris, K. S. (1984, 1985). *Control of pitch and quality, Part II: an EMG study of infrahyoid muscles.* Paper presented at the 13th Symposium: Care of the Professional Voice, Julliard School, New York City.

Fadiga, L., Craighero, L. & D'Ausilio, A. (2009). Broca's area in language, action and music. *Annals of the New York Academy of Sciences*(1169), 448-.

Fant, G. (1982). Preliminaries to Analysis of the human voice source. *KTH Speech, Music and Hearing Quarterly Progress and Status Report*, 1-27.

Fant, G., Hertegird, S. & Kruckenberg, A. (1996). Focal accent and subglottal pressure. *TMH-QPSR, 37*(2), 29-32.

Fant, G., Kruckenberg, A. & Liljencrants, J. (2000). The source-filter frame of prominence. *Phonetica, 57*(2-4), 113-127.

Feyereisen, P., & de Lannoy, J. D. (1991). *Gestures and Speech: psychological investigations*. Cambridge/Paris: Cambridge University Press/Editions de la Maison des Sciences de l'Homme.

Fielder, L. D. (1995). Dynamic-range issues in the modern digital audio environment. *Journal of the Audio Engineering Society, 43*(5), 322-339.

Finnegan, E. M., Luschei, E. S. & Hoffman, H. T. (2000). Modulations in respiratory and laryngeal activity associated with changes in vocal intensity during speech. *Journal of Speech, Language & Hearing Research, 43*(4), 934-950.

Fitt, S. S. (1988). Body type. In D. kinesiology (Ed.). London: Collier Macmillan.

Formby, C., Thomas, R. G., & Halsey, J. H. (1989). Regional cerebral blood flow for singers and nonsingers while speaking, singing, and humming a rote passage. *Brain and Language, 36*(4), 690-698.

Foulds-Elliott, S. D., Thorpe, C. W., Cala, S. J. & Davis, P. J. (2000). Respiratory function in operatic singing: effects of emotional connection. *Logopedics Phoniatrics Vocology, 25*(4), 151-168.

Franklin, A. Aretha: Queen of Soul. The very best of Aretha Franklin (1998) [CD]. WEA Internaitonal Inc.

Friberg, A., & Sundberg, J. (1999). Does music performance allude to locomotion? A model of final *ritardandi* derived from measurements of stopping runners. *Journal of the Acoustical Society of America, 105*(3), 1469-1484.

Fulton, R. T., & Spuehler, H. E. (1962). Effects of frequency filtering on delayed sidetone on vocal responses. *Journal of Speech and Hearing Research, 5*, 382-386.

Gandevia, S., Butler, J. E., Hodges, P. & Taylor, J. L. (2002). Balancing acts: Respiratory sensations, motor control and human posture. *Clinical and Experimental Pharmacology and Physiology, 29*(1-2), 118-121.

Gandevia, S. C., Allen, G., Butler, J., Gorman, R. B. & McKenzie, D. K. (1998). Human respiratory muscles: sensations, reflexes and fatiguability. *Clinical and Experimental Pharmacology and Physiology, 25*(10), 757-763.

Gastinger, S., Sefati, H., Nicolas, G., Sorel, A., & Gratas-Delamarche, A. (2010). Estimates of ventilation from measurements of rib cage and abdominal distances: a portable device. *European Journal of Applied Physiology, 109*(6), 1179-1189.

Gentilucci, M., Benuzzi, F., Bertoloani, L., Daprati, E., & Gangitano, M. (2000). Language and motor control. *Experimental Brain Research, 133*, 468-490.

Gilman, M., Merati, A. L., Klein, A. M., Hapner, E. R. & Johns, M. M. (2009). Performer's attitudes toward seeking health care for voice issues: understanding the barriers. *Journal of Voice 23*(2), 225-228.

Godley, K. (Writer) (1993). One World, One Voice. UK: BMG.

Goldman, M. D., Grassino, A., Mead, J. & Sears, T. A. (1978). Mechanics of the human diaphragm during voluntary contraction: dynamics. *Journal of Applied Physiology: Respiratory, Environmental & Exercise Physiology, 44*(6), 840-848.

Goldin-Meadow, S., & McNeill, D. (1999). The role of gesture and mimetic representation in making language the province of speech. In M. C. Corballs & L. S.E.G. (Eds.), *The Descent of Mind: psychological perspectives on hominid evolution* (pp. 155-172). Oxford: Oxford University Press.

Gonçalves, M. & Leonard, R. (1998). A hardware-software system for analysis of video images. *Journal of Voice, 12*(2), 143-150.

Gould, W. J. (1971). Effect of respiratory and postural mechanisms upon action of the vocal cords. *Folia Phoniatrica, 23*, 211-224.

Grabiner, M. D. (1989). The Shoulder Complex. In P. J. Rasch (Ed.), *Kinesiology & Applied Anatomy* (pp. 117-135).

Green, H. J. (1986). Muscle power: fibre type, recruitment, matabolism and fatigue. In N. L. Jones, N. McCartney & A. J. McComas (Eds.), *Human Muscle Power* (pp. 67-79). Champaign, Ill: Human Kinetics Publishers.

Griffin, B., Peak, W., Colton, R., Casper, J. & Brewer, D. (1995). Physiological characteristics of the supported singing voice. A preliminary study. *Journal of Voice, 9*(1), 45-56.

Grillner, S., Nilsson, J. & Thorstensson, A. (1978). Intra-abdominal pressure changes during natural movements in man. *Acta Physiologica Scandinavica, 103*, 275-283.

Grillo, E. U., & Verdolini, K. (2008). Evidence for distinguishing pressed, normal, resonant and breathy voice qualities by laryngeal resistance and vocal efficiency in vocally, trained subjects. *Journal of Voice, 22*(5), 564-552.

Grimby, L. (1986). Single motor unit discharge during voluntary contraction and locomotion. In N. L. Jones, N. McCartney, A. J. J. McComas, N.L., N. McCartney & A. J. McComas (Eds.), *Human Muscle Power* (pp. 111-130). Champaign, Ill: Human Kinetics Publishers.

Grini, M. N., Ouaknine, M. & Giovanni, A. (1998). Modifications posturales et ségmentaires contemporaines du forçage vocal (Contemporary postural and segmental modification of forced voice). *Revue de Laryngologie Otologie Rhinologie, 119*(4), 253-257.

Grini-Grandval, M. N., Ouaknine, M. & Giovanni, A. (2000). Forçage vocal et variance de la vitesse: corrélation entre la vitesse de déplacement du centre de gravité et le travail des muscles posturaux (Forcing the voice: the correlation between the speed of displacement of the centre of gravity and the work of the postural muscles). *Revue de Laryngologie Otologie Rhinologie, 121*(5), 319-323.

Gritten, A., & King, E. (Eds.). (2006). *Music and Gesture*. Aldershot: Ashgate Publishing Ltd.

Gurfinkel, V. S., Levik, Y. S., Popov, B. N., Smetanin, B. N. & Shlikov, V. Y. (1986). Body scheme in the control of postural activity. In V. S. Gurfinkel (Ed.), *Stance and Motion: facts and concepts*.

Hall of Fame, Rock and Roll (2007). Inductees: Aretha Franklin. from http://www.rockhall.com/hof/inductee.asp?Id=106

Harvey, M. S. (1999). Jazz time and our time: a view from the outside in. In A. M. S. Nelson (Ed.), *"This is how we flow": Rhythm in Black Cultures* (pp. 15-31). Columbia, South Carolina: University of South Carolina Press.

Headlam, D. (2002). Appropriation of blues and gospel in popular music. In A. Moore (Ed.), *The Cambridge companion to blues and gospel music* (pp. 158-187). Cambridge, UK Cambridge University Press.

Heilbut, A. (1985). *The Gospel Sound: Good News and Bad Times*. New York: Anchor Press/Doubleday.

Henrich, N., d'Allessandro, C., Doval, B. & Castellengo, M. (2005). Glottal open quotient in singing: measurements and correlation with laryngeal mechanism, vocal intensity, and fundamental frequency. *Journal of the Acoustical Society of America, 117*(3), 1417-1430.

Henriquez, V., Schulz, G., Bielamowicz, S. & Ludlow, C. (2007). Laryngeal reflex responses are not modulated during human voice and respiratory tasks.

Hibi, S. & Hirano, M. (1995). Voice quality variations associated with vibrato. In O. Fujimura & H. Hirai (Eds.), *Vocal Fold Physiology: Voice Quality Control*. San Diego, CA: Singular.

Hill, A. R., Kaiser, D. L., J-Y, L. & Rochester, D. F. (1985). Steady-state response of conscious man to small expiratory resistive loads. *Respiration Physiology, 61*, 369-381.

Hirano, M., Hibi, S. & Hagino, S. (1995). Physiological aspects of vibrato. In P. Dejonckere, M. Hirano & J. Sundberg (Eds.), *Vibrato* (pp. 9-33). San Diego: Singular Publishing.

Hixon, T. (1987). Respiratory function in speech. In T. J. Hixon (Ed.), *Respiratory Function in Speech and Song*. Boston: College Hill Press.

Hixon, T., Mead, J. & Goldman, M. D. (1976). Dynamics of the chest wall during speech production: function of the the thorax, rib cage, diaphragm, and abdomen. *Journal of Speech and Hearing Research, 19*, 297-356.

Hixon, T., Watson, P. j., & Maher, M. Z. (1987). Respiratory kinematics in classical (Shakespearean) actors. In T. J. Hixon (Ed.), *Respiratory Function in Speech and Song* (pp. 375-400). Boston: College Hill Press.

Hodge, A. (Ed.). (2000). *Twentieth century actor training* (2003 ed.). London: Routledge.

Hodges, P., Cresswell, A. G. & Thorstensson, A. (2004). Intra-abdominal pressure response to multidirectional support-surface translation. *Gait and Posture, 20*, 163-170.

Hodges, P. & Gandevia, S. C. (2000). Activation of the human diaphragm during a repetitive postural task. *Journal of Physiology, 522 Pt 1*, 165-175.

Hodges, P. & Gandevia, S. C. (2000). Changes in intra-abdominal pressure during postural and respiratory activation of the human diaphragm. *Journal of Applied Physiology, 89*, 967-976.

Hodges, P., Gandevia, S. C. & Richardson, C. A. (1997). Contractions of specific abdominal muscles in postural tasks are affected by respiratory maneuvers. *Journal of Applied Physiology, 83*(3), 753-760.

Hodges, P., Gurfinkel, V. S., Brumagne, S., Smith, T. C. & Cordo, P. C. (2002). Coexistence of stability and mobility in postural control: evidence from postural compensation for respiration. *Exp Brain Res, 144*(3), 293-302.

Hodges, P., Heijnen, I., & Gandevia, S. (2001). Postural activity of the diaphragm is reduced in humans when respiratory demand increases. *Journal of Physiology, 537*(3), 999-1008

Hodges, P. & Richardson, C. A. (1999). Transversus abdominis and the superficial abdominal muscles are controlled independently in a postural task. *Neuroscience Letters, 265*(2), 91-94.

Hoit, J. (1995). Influence of body position on breathing and its implications for the evaluation and treatment of speech and voice disorders. *Journal of Voice, 9*(4), 341-347.

Hoit, J. & Hixon, T. (1987). Body type and speech breathing. In T. J. Hixon (Ed.), *Respiratory Function in Speech and Song* (pp. 401-424). Boston: College-Hill Press.

Hollien, H. (1983). *Report on vocal registers.* Paper presented at the Stockholm Music Acoustics Conference, Stockholm.

Holmberg, E. B., Hillman, R. E. & Perkell, J. S. (1988). Glottal airflow and transglottal air pressure measurements for male and female speakers in soft, normal, and loud voice. *Journal of the Acoustical Society of America, 4*(2), 511-529.

Holstege, G. & Ehling, T. (1996). Two motor systems involved in the production of speech. In P. Davis & Fletcher (Eds.), *Vocal Fold Physiology: controlling complexity and chaos* (pp. 153-169). San Diego,London: Singular Publishing

Honda, K., Hirai, H., Estill, J. & Tohkura, Y. (1995). Contributions of vocal tract shape to voice quality: MRI data and articulatory modeling. In O. Fujimura & M. HIrano (Eds.), *Vocal Fold Physiology: voice quality control* (pp. 23-38). San Diego, CA: Singular Publishing Group.

Honing, H. (2006). On the growing role of observation, formalization and experimental method in musicology. *Empirical Musicology Review, 1*(1), 2-6.

Honing, H., & Ladinig, O. (2006). *The effect of exposure and expertise on timing judgements in music: preliminary results.* Paper presented at the 9th International Conference on Music Perception and Cognition, Bologna.

Huber, D. & Runstein, R. (2005). *Modern Recording Techniques* (Sixth Edition ed.): Focal Press/Elsevier.

Huber, J. (2007). Effects of cues to increase sound pressure level on respiratory kinematic patterns during connected speech. *Journal of Speech, Language, and Hearing Research, 50*(3), 621-634.

Huber, J. & Chandrasekaran, B. (2006). Effects of increasing sound pressure level on lip and jaw movement parameters and consistency in young adults. *Journal of Speech, Language, and Hearing Research, 49*, 1368-1379.

Huber, J., Chandrasekaran, B. & Wolstencroft, J. (2005). Changes to respiratory mechanisms during speech as a result of different cues to increase loudness. *Journal of Applied Physiology, 98*(6), 2177-2184.

Hudson, B. (2002). The effects of the Alexander technique on the respiratory system of the sing/actor Part II: implications for training respiration in singer/actors based on concepts of Alexander technique. *Journal of Singing, 59*(2), 105-110.

Isshiki, N. (1964). Regulating mechanisms of vocal intensity variations. *Journal of Speech and Hearing Research, 7*, 17-29.

Iwarsson, J. (2001). Effects of inhalatory abdominal wall movement on vertical laryngeal position during phonation. *Journal of Voice, 15*(3), 384-394.

Iwarsson, J. & Sundberg, J. (1998). Effects of lung volume on vertical larynx position during phonation. *Journal of Voice, 12*(2), 159-165.

Jensen, C. R., Schultz, G. W. & Bangerter, B. L. (1983). *Applied Kinesiology and Biomechanics* (3rd ed.): McGraw Hill

Johnson, J. H., Turner, C. W., Zwislocki, J. J. & Margolis, R. H. (1993). Just noticeable differences for intensity and their relation to loudness. *Journal of the Acoustical Society of America, 93*(2), 983-991.

Jónsdottir, V., Laukkanen, A.-M., Illomäki, I., Roininen, H., Merja, A.-B. & Vilkman, E. (2001). Effects of amplified and damped auditory feedback on vocal characteristics. *Logopedics Phoniatrics Vocology, 26*, 76-81.

Jurgens, U. (2002). Neural pathways underlying vocal control. *Neuroscience and Biobehavioral Reviews, 26*(2), 235-258.

Kim, Y., Kang, J. & Kim, K. (2009). Characteristics of glottic closure reflex in a canine model. *Yonsei Medical Journal, 50*(3), 380-384.

King, E. (2006). Supporting gestures: breathing in piano performance. In A. Gritten & E. King (Eds.), *Music and Gesture*. Aldershot: Ashgate.

Kirchner, J. & Suzuki, M. (1968). Laryngeal reflexes and voice production. *Annals of the New York Academy of Sciences, 155*, 93-109.

Kmucha, S., Yanagisawa, E. & Estill, J. (1990). Endolaryngeal changes during high-intensity phonation videolaryngoscopic observations. *Journal of Voice, 4*(4), 346-354.

Konno, K. & Mead, J. (1967). Measurement of the separate volume changes in rib cage and abdomen during breathing. *Journal of Applied Physiology, 22*(3), 407-422.

Kooijman, P. G., de Jong, F. I., Oudes, M. J., Huinck, W., van Acht, H. & Graamans, K. (2005). Muscular tension and body posture in relation to voice handicap and voice quality in teachers with persistent voice complaints. *Folia phoniatrica et logopaedica, 57*(3), 134-147.

Kotby, N. & Fex, B. (1998). The Accent Method: behavior readjustment voice therapy. *Logopedics Phoniatrics Vocology, 23*, 39-43.

Kotlyar, G. M. & Morozov, V. P. (1976). Acoustical correlates of the emotional content of vocalized speech. *Soviet Physics Acoustics, 22*(January-December), 208-211.

Koufman, J. A., Radomski, T. A., Joharji, G. M. & Russell, G. B. (1996). Laryngeal biomechanics of the singing voice. *Otolarygology – Head and Neck Surgery, 115*, 527-537.

Kozlovskaya, I., Dmitrieva, I., Grigorieva, L., Kirenskaya, A. & Kreidich, Y. (1986). Gravitational mechanisms in the motor system. Studies in real and simulated weightlessness. In V. S. Gurfinkel (Ed.), *Stance and Motion: facts and concepts* (pp. 37). ?: ?

Kurosawa, K. & Davidson, J. W. (2005). Non-verbal interaction in popular performance: The Corrs. *Musicae Scientiae, 9*(1), 111-133.

Ladefoged, P. & McKinney, N. P. (1963). Loudness, sound pressure, and subglottal pressure in speech. *Journal of the Acoustical Society of America, 35*(4), 454-460.

Lane, H. L., Catania, A. C., & Stevens, S. S. (1961). Voice level: autophonic scale, perceived loudness and effects of sidetone. *Journal of the Acoustical Society of America, 31*(2), 160-167.

Lane, H. L. & Tranel, B. (1971). The Lombard sign and the role of hearing in speech. *J. Speech Hear. Res., 14*, 677-709.

Large, E. W. (2000). On synchronizing movements to music. *Human Movement Science, 19*, 527-566.

Lassalle, A., Grini, M. N., Amy de la Breteque, B., Ouaknine, M., & Giovanni, A. (2002). Étude comparative des stratégies respiratoires entre les chanteurs lyriques professionnels et débutants [Comparative study of respiratory mechanisms between professional classical singers and beginners]. *Revue de Laryngologie Otologie Rhinologie, 123*(5), 279-289.

Laukkanen, A. M., Takalo, R., Arvonen, M. & Vilkman, E. (2002). Pitch-synchronous changes in the anterior cricothyroid space during singing. *Journal of Voice., 16*(2), 182-194.

Leanderson, R. & Sundberg, J. (1988). Breathing for singing. *Journal of Voice, 2*(1), 2-12.

Leanderson, R., Sundberg, J. & von Euler, C. (1987). Breathing muscle activity and subglottal pressure dynamics in singing and speech. *Journal of Voice, 1*(3), 258-261.

Leanderson, R., Sundberg, J., Von Euler, C. & Lagercrantz, H. (1984, 1985). *Diaphragmatic control of the subglottic pressure during singing.* Paper presented at the 13th Symposium: Care of the Professional Voice, Julliard School, New York City.

LeBorgne, W., & B.D., W. (2002). Phonetogram changes for trained singers over a nine-month period of vocal training *Journal of Voice 16*(1), 37–43.

LeDoux, J. (1998). *The Emotional Brain.* London: Weidenfeld & Nicolson.

Lee, D., Craig, C. M. & Grealy, M. A. (1999, Oct 7). *Sensory and intrinsic coordination of movement.* Paper presented at the Proceedings Biological Sciences/Royal Society.

Lee, D., Georgopoulos, A. P., Clark, M. J., Craig, C. M. & Port, N. L. (2001). Guiding contact by coupling the taus of gaps. *Experimental Brain Research, 139*(2), 151-159.

Lee, H. & Banzett, R. (1997). Mechanical links between locomotion and breathing: can you breathe with your legs? *News in Physiological Sciences, 12*(December), 273-278.

Lee, W. (1980). Anticipatory control of postural and task muscles during rapid arm flexion. *Journal of Motor Behavior, 12*(3), 185-196.

Li-de, G. (1995). Including factors and treatments for vibrato problems. In P. Dejonckere, M. Hirano & J. Sundberg (Eds.), *Vibrato* (pp. 145-149). San Diego: Singular Publishing.

Lim, V., Oates, J., Phyland, D. & Campbell, M. (1998). Effects of laryngeal endoscopy on the vocal performance of young adult females with normal voices. *Journal of Voice, 12*(1), 68-77.

London, J. (2006). Musical rhythm: motion, pace and gesture. In A. Gritten & E. King (Eds.), *Music and Gesture*: Ashgate Publishing.

Loring, S. H. & Mead, J. (1982). Abdominal muscle use during quiet breathing and hyperpnea in uninformed subjects. *Journal of Applied Physiology, 52*, 700-704.

Lovetri, J. (2002). Contemporary commercial music: more than one way to use the vocal tract. *Journal of Singing, 58*(3), 249-252.

Lovetri, J. (2009). Going a new way.

MacCurtain, F. & Welch, G. (1983). *Vocal tract gestures in soprano and bass: a xeroradiographic-electro-laryngographic study.* Paper presented at the SMAC (Stockholm Music Acoustics Conference) 83.

Macefield, V. G., Gandevia, S. C., McKenzie, D. K. & Butler, J. E. (1996). Cortical and reflex control of human respiratory muscles. In P. Davis & Fletcher (Eds.), *Vocal Fold Physiology: Controlling Complexity and Chaos*. San Diego,London: Singular Publishing

Mackey, J. (2008). Musical Improvisation, Creativity and Uncertainty. In G. Bamme (Ed.), *Risk and Uncertainty* (pp. 105-112).

Massion, J., Alexandrov, A., & Vernazza, S. (1988). Coordinated control of posture and movement: respective role of motor memory and external constraints. In M. L. Latash (Ed.), *Progress in Motor Control* (Vol. 1, pp. 127-150).

Masuda, Y. (1996). An analysis of spoken language development among three intellectually disabled adults. *AI & Society, 10*, 259-272.

McNeill, D. (2002). Gesture and language dialectic. *Acta Linguistica Hafniensia.*

McFarland, D. H. & Smith, A. (1992). Effects of vocal task and respiratory phase on prephonatory chest wall movements. *Journal of Speech and Hearing Research, 35*(5), 971-982.

Mead, J. & Agostini, E. (1985-7). Dynamics of breathing. In *The Respiratory System.*

Meizel, K. (2009). Making the dream a reality (show): The celebration of failure in *American Idol. Popular Music and Society, 32*(4), 475 – 488.

Messum, P. (1998). The Accent Method. *Speak Out! Newsletter of the IATEFL Pronunciation SIG, 22*(July).

Middleton, R. (2000). Rock Singing. In J. Potter (Ed.), *Cambridge Companion to Singing* (pp. 28-41). Cambridge: Cambridge University Press.

Mier, A., Brophy, C., Estenne, M., Moxham, J., Green, M., & de Troyer, A. (1985). Action of the abdominal muscles on rib cage in humans. *Journal of Applied Physiology*, 1438-1443.

Miles, B. & Hollien, H. (1990). Whither belting? *Journal of Voice, 4*(1), 64-70.

Miller, D. G. & Schutte, H. (1990). Formant tuning in a professional baritone. *Journal of Voice, 4*(3), 231-237.

Miller, D. G. & Schutte, H. (2005). 'Mixing' the registers: glottal source or vocal tract? *Folia phoniatrica et logopaedica, 57*, 278-291.

Milstein, C. F. & Watson, P. J. (2004). The effects of lung volume initiation on speech: a perceptual study. *Journal of Voice, 18*(1), 38-45.

Mithen, S., Morley, I., Wray, A., Tallerman, M., & Gamble, C. (2005). Review feature: The singing Neanderthals: the origins of music, language, mind and body. *Cambridge ArchaeologicalJournal, 16*(1), 97-112.

Mithen, S. (2006). *The Singing Neanderthals: the origins of music, language,mind and body*. Cambridge, Massachusetts: Harvard University Press.

Molnar-Szakacs, I., & Overy, K. (2006). Music and mirror neurons: from motion to 'e'motion. *SCAN 1*, 235-224.

Monahan, B. (1978). *The art of singing: a compendium of thoughts on singing published between 1977 and 1927*. Metuchen, N.J.: The Scarecow Press.

Moore, A. (2002). Authenticity as authentication. *Popular Music, 21*(2), 209–223.

Moseley, G. L., Hodges, P. & Gandevia, S. (2002). Deep and superficial fibers of the lumbar multifidus muscle are differentially active during voluntary arm movements. *Spine, 27*(2), 29-36.

Mosher, C. (2008). Ecstatic sounds: the influence of pentecostalism on rock and roll. *Popular Music and Society, 31*(1), 95 – 112.

Naito, A. & Niimi, S. (2000). The larynx during exercise. *Laryngoscope, 110*(7), 1147-1150.

Nelson, A. M. S. (1999a). Rhythm and rhyme in rap. In A. M. S. Nelson (Ed.), *"This is how we flow": Rhythm in Black Cultures* (pp. 47-49). Columbia, South Carolina: University of South Carolina Press.

Nelson, A. M. S. (Ed.). (1999b). *"This is how we flow": Rhythm in Black Cultures.* Columbia, South Carolina: University of South Carolina Press.

Newsom Davis, J. & Sears, T. A. (1970). Proprioceptive reflex control of the intercostal muscles during their voluntary activation. *Journal of Physiology*(209), 711-738.

Niimi, S., Horiguchi, S., Kobayashi, N., & Yamada, M. (1988). Electromyographic study of vibrato and tremolo in singing. In *Vocal Physiology: voice production, mechanisms and functions* (pp. 404-413). New York: Raven Press Ltd.

Norris, C. M. (1997). *Abdominal Training*. London: A & C Black London.

Orgill, R. (2002). *Mahalia: a life in gospel music.* Cambridge, Massachusetts: Candlewick Press.

Palmer, C. (1989). Mapping musical thought to musical performance. *Journal of Experimental Psychology: Human Perception and Performance, 15*, 331 – 346.

Palmer, C. (1997). Music performance. *Annual Review of Psychology, 48*, 115-138.

Paymer, M. E. (Ed.). (1993). *Facts Behind the Songs: a handbook of American popular music from the Nineties to the '90s*. New York: Garland Publishing.

Pettersen, V. (2005). Muscular patterns and activation levels of auxiliary breathing muscles and thorax movement in classical singing. *Folia phoniatrica et logopaedica, 57*(5-6), 255-277.

Pettersen, V., Bjørkøy, K., Torp, H. & Westgaard, R. H. (2005). Neck and shoulder muscle activity and thorax movement in singing and speaking tasks with variation in vocal loudness and pitch. *Journal of Voice, 19*(4), 623-634.

Pettersen, V., & Bjørkøy, K. (2009). Consequences from emotional stimulus on breathing for singing. *Journal of Voice, 23*(3), 295-303.

Pettersen, V. & Westgaard, R. H. (2002). Muscle activity in the classical singer's shoulder and neck region. *Logoped Phoniatr Vocol, 27*(4), 169-178.

Pettersen, V. & Westgaard, R. H. (2004). Muscle activity in professional classical singing: a study on muscles in the shoulder, neck and trunk. *Logopedics, Phoniatrics, Vocology, 29*(2), 56-65.

Pettersen, V. & Westgaard, R. H. (2004). The association between upper trapezius activity and thorax movement in classical singing. *Journal of Voice, 18*(4), 500-512.

Pettersen, V. & Westgaard, R. H. (2005). The activity patterns of neck muscles in professional classical singing. *Journal of Voice, 19*(2), 238-251.

Pfordresher, P. Q. (2003). Auditory feedback in music performance: evidence for a dissociation of sequencing and timing. *Human Perception and Performance, 29*(5), 949-964.

Pfordresher, P. Q. (2006). Effects of hearing the past, present or future during music performance. *Perception and Psychophysics, 68*(3), 362-376.

Phyland, D. J., Oates, J. & Greenwood, K. M. (1999). Self-reported voice problems among three groups of professional singers. *Journal of Voice, 13*(4), 602-611.

Plant, R. L., Freed, G. L. & Plant, R. E. (2004). Direct measurement of onset and offset phonation threshold pressure in normal subjects. *Journal of the Acoustical Society of America, 116*(6), 3640-3646.

Plant, R. L. & Hillel, A. D. (1998). Direct measurement of subglottic pressure and laryngeal resistance in normal subjects and in spasmodic dysphonia. *Journal of Voice, 12*(3), 300-314.

Popeil, L. (1999). Comparing belt and classical techniques using MRI and video-fluoroscopy. *Journal of Singing, 56*(2), 27-29.

Potter, J. (2000a). Elvis Presley to rap: moments of change since the forties. In J. Potter (Ed.), *Cambridge Companion to Singing* (pp. 133-157). Cambridge: Cambridge University Press.

Potter, J. (2000b). Jazz singing: the first hundred years. In J. Potter (Ed.), *Cambridge Companion to Singing*. Cambridge: Cambridge University Press.

Prather, J., Peters, S., Nowicki, S., & Mooney, R. (2008). Precise auditory-vocal mirroring in neurons for learned vocal communication. *Nature, 451*, 305-310.

Prem, D., & Parncutt, R. (2008). *Corporality in the timbre vocabulary of professional female jazz vocalists.* Paper presented at the First International Conference of Students of Systematic Musicology (SysMus08), Graz, Austria.

Prentice, R. L. (1989). Surrogate endpoints in clinical trials: definition and operational criteria. *Statistics in Medicine, 8*, 431-440.

Prochazka, A., Clarac, F., Loeb, G. E., Rothwell, J. C. & Wolpaw, J. R. (2000). What do *reflex* and *voluntary* mean? Modern views on an ancient debate. *Experimental Brain Research, 130*, 417-432.

Purves, D., Fitzpatrick, D., Augustine, G. J., Katz, L. C., Williams, S. M., McNamara, J. O., et al. (2001). *Neuroscience* (2nd ed.). Sunderland, Mass: Sinauer Assoc.

Rasch, R. & Plomp, R. (1999). The Perception of Musical Tones. In D. Deutsch (Ed.), *The Psychology of Music* (pp. 99-101). San Diego: Academic Press.

Reed, E. (1989). Changing theories of postural development. In M. H. Woollacott & A. Shumway-Cook (Eds.), *Development of Posture and Gait across the Life Span* (pp. 2-20): University of South Carolina Press.

Repp, B. (1993). *Musical motion: some historical and contemporary perspectives.* Paper presented at the SMAC (Stockholm Music Acoustics Conference) 93.

Richards, M. (1992). Mangarayi Lesson Plans and Descriptions (Publication no. 660). Retrieved 20/8/10: http://www1.aiatsis.gov.au/aseda/T_6.htm

Rimmer, K. P., Ford, G. T. & Whitelaw, W. A. (1995). Interaction between postural and respiratory control of human intercostal muscles. *Journal of Applied Physiology, 79*, 1556-1561.

Rogers, V. & Symons, D. (Eds.). (2005). *The Legacy of John Blacking*. Crawley: University of Western Australia Press.

Rostolland, D. (1982). Phonetic structure of shouted voice. *Acustica, 51*, 80-89.

Rothenberg, M. (1988). Acoustic reinforcement of vocal fold vibratory behavior in singing. In O. Fujimura (Ed.), *Vocal Physiology: Voice Production Mechanisms and Functions* (pp. 379-389). New York: Raven Press.

Roubeau, B. (2009). Laryngeal vibratory mechanisms: the notion of vocal register revisited. *Journal of Voice, 23*(4), 425-438.

Roubeau, B., Castellengo, M., Bodin, P. & Ragot, M. (2004). Phonétogramme par registre laryngé [Laryngeal registers as shown in the voice range profile]. *Folia phoniatrica et logopaedica, 56*(5), 321-333.

Rubin, J. S., Blake, E. & Mathieson, L. (2007). Musculoskeletal patterns in patients with voice disorders. *Journal of Voice, 21*(4), 477-484.

Ruch, W. & Ekman, P. (2001). The expressive patterns of laughter. In A. Kazniak (Ed.), *Emotion, qualia and consciousness* (pp. 426-443). Tokyo: Word Scientific Publisher.

Ryker, K. S., Roy, N. & Bless, D. M. (1998). Vocal violence in actors: an investigation into its acoustic consequences and the effects of hygienic laryngeal release training. *NCVS Status and Progress Report, June*, 163-173.

Sackheim, E. (1969). *The Blues Line: a collection of blues lyrics*. New York: Grossman.

Sacks, O. (1991). *A Leg to Stand On*. London: Picador.

Sacks, O. (2007). *Musicophilia: tales of music and the brain*. London: Picador.

Sand, S. & Sundberg, J. (2005). Reliability of the term 'support' in singing. *Logopedics Phoniatrics Vocology, 30*, 51-54.

Sataloff, R. T., Spiegel, J. R. & Hawkshaw, M. J. (2003). History and physical examination of patients voice disorders. In *Diagnosis and Treatment of Voice Disorders* (pp. 137-170). Australia;UK: Delmar Learning.

Sauter, D., Eisner, F., Ekman, P. & Scott, S. (2010). Cross-cultural recognition of basic emotions through nonverbal emotional vocalizations. ***PNAS.***

Sawashima, M., Niimi, S., Horiguchi, S. & Yamaguchi, H. (1988). Expiratory lung pressure, airflow rate, and vocal intensity: data on normal subjects. In O. Fujimura (Ed.), *Vocal Physiology: voice production, mechanisms and functions* (pp. 416-422). New York: Raven Press Ltd.

Scherer, K. R. (1995). Expression of emotion in voice and music. *Journal of Voice, 9*(3), 235-248.

Scherer, K. R. & Oshinsky, J. S. (1977). Cue utilization in emotion attribution from auditory stimuli. *Motivation and Emotion, 1*(4), 331-346.

Schneider, C. M., Dennehy, C. A. & Saxon, K. G. (1997). Exercise physiology principles applied to vocal performance: the improvement of postural alignment. *Journal of Voice, 11*(3), 332-337.

Schutte, H. (1983). *The efficiency of voice production.* Groningen: Kemper.

Schutte, H., Stark, J. A., & Miller, D. G. (2003). Change in singing voice production, objectively measured. *Journal of Voice, 17*(4), 495-501.

Schutte, H. K. & Miller, D. G. (1993). Belting and pop, nonclassical approaches to the female middle voice: some preliminary considerations. *Journal of Voice, 7*(2), 142-150.

Scotto, C. N. D. (1998). Cervical spine abnormalities in professional singers. *Folia Phoniatria et logopaedica, 50*(4), 212-218.

Sengupta, R. (1990). Study on some aspects of the "singer's formant" in North Indian classical singing. *Journal of Voice, 4*(2), 129-134.

Shaffer, L. H. (1982). Rhythm and timing in skill. *Psychological Review, 89*(2), 109-122.

Shipp, T. (1975). Vertical laryngeal position during continuous and discrete vocal frequency change. *Journal of Speech and Hearing Research, 18*, 688-706.

Sihvo, M., Laippala, P., & Sala, E. (2000). A study of repeated measures of softest and loudest phonations. *Journal of Voice, 14*(2), 161-169.

Siegel, G. M. & Herbert, L. P. (1974). Auditory feedback in the regulation of the voice. *Journal of the Acoustical Society of America, 56*(5), 1618-1624.

Sluijter, A. M. C., vanHeuven, V. J. & Pacilly, J. J. A. (1997). Spectral balance as a cue in the perception of linguistic stress. *Journal of the Acoustical Society of America, 101*(1), 503-513.

Smith, S. & Thyme, K. (1976). Statistical research on changes in speech due to pedagogic treatment (the Accent Method). *Folia Phoniatrica, 28*, 98-103.

Smith, Z. K. (1999). The rhythm of everyday politics. In A. M. S. Nelson (Ed.), *"This is how we flow": Rhythm in Black Cultures* (pp. 127). Columbia, South Carolina: University of South Carolina Press.

St. George, F. (1989). *The Muscle Fitness Book.* Sydney: Simon and Schuster Australia.

Stathopoulos, E. & Sapienza, C. (1993). Respiratory and laryngeal function of women and men during vocal intensity variation. *Journal of Speech and Hearing Research, 36*(February), 64-75.

Sterr, A. (2005). Preparing not to move: does no-response priming affect advance movement preparation processes in a response priming task? *Biological Psychology, 72*, 154-159.

Stevens, S. S. (1955). The Measurement of Loudness. *Journal of the Acoustical Society of America, 27*(5), 815-829.

Stevens, S. S. (1972). Perceived Level of Noise by Mark VII and Decibels (E) *Journal of the Acoustical Society of America*, 575-601.

Stone, E., Cleveland, T. F., Sundberg, J. & Prokop, J. (2003). Aerodynamic and acoustical measures of speech, operatic, and broadway vocal styles in a professional female singer. *Journal of Voice, 17*(3), 283-297.

Strohl, K. P., Mead, J., Banzett, R. B., Loring, S. H. & Kosch, P. C. (1981). Regional differences in abdominal muscle activity during various maneuvers in humans. *Journal of Applied Physiology, 51*(6), 1471-1476.

Suess, W. M., Alexander, A. B., Smith, D. D., Sweeney, H. W. & Marion, R. J. (1980). The effects of psychological stress on respiration: a preliminary study of anxiety and hyperventilation. *Psychophysiology, 17*(6), 535-540.

Sundberg, J. (1987a). Articulation. In *Science of Singing* (pp. 93-133). DeKalb, Illinois: Northern Illinois University Press.

Sundberg, J. (1987b). Breathing. In *The Science of the Singing Voice* (pp. 25-48). DeKalb, Illinois: Northern Illinois University Press.

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

Sundberg, J. (1987c). The Perception of Singing. In *Science of Singing* (pp. 25-48). DeKalb, Illinois: Northern Illinois University Press.

Sundberg, J. (1987d). The Voice Source. In *Science of Singing* (pp. 49-92). DeKalb, Illinois: Northern Illinois University Press.

Sundberg, J. (1995). Vocal fold vibration patterns and modes of phonation. *Folia Phoniatr Logop, 47*, 218-228.

Sundberg, J. (2000). Emotive transforms. *Phonetica, 57*, 95-112.

Sundberg, J. (2000). Four years of research on music and motion. *Journal of New Music Research, 29*(3), 183-185.

Sundberg, J., Elliot, N., Gramming, P. & Nord, L. (1993). Short-term variation of subglottal pressure for expressive purposes in singing and stage speech: a preliminary investigation. *Journal of Voice, 7*(3), 227-234.

Sundberg, J., Gramming, P. & Lovetri, J. (1993). Comparisons of pharynx, source, formant, and pressure characteristics in operatic and musical theatre singing. *Journal of Voice, 7*(4), 301-310.

Sundberg, J., Iwarsson, J. & Hagegård, H. (1995). A singer's expression of emotions in sung performance. In O. Fujimura & M. Hirano (Eds.), *Vocal Fold Physiology: Voice Quality Control* (pp. 217-231). San Diego, CA: Singular Publishing Group.

Sundberg, J. & Kullberg, A. (1999). Voice source studies of register differences in untrained female singing. *Logopedics Phoniatrics Vocology, 24*, 76-83.

Sundberg, J., Leanderson, R., & Von Euler, C. (1989). Activity relationship between diaphragm and cricothyroid muscles. *Journal of Voice, 3*(3), 225-232.

Sundberg, J., Leanderson, R., von Euler, C. & Knutsson, E. (1991). Influence of body posture and lung volume on subglottal pressure control during singing. *Journal of Voice, 5*(4), 283-291.

Sundberg, J. & Skoog, J. (1997). Dependence of jaw opening on pitch and vowel in singers. *Journal of Voice, 11*(3), 301-306.

Sundberg, J., Titze, I. R. & Scherer, R. (1993). Phonatory control in male singing: a study of the effects of subglottal pressure, fundamental frequency, and mode of phonation on the voice source. *Journal of Voice, 7*(1), 15-29.

Sutton, R. A. (1980). Drumming in Okinawan classical music: a catalogue of gestures. *Dance Research Journal, 13*(1), 17-28.

Suzuki, M., Mellert, V., Richter, U., Moller, H., Nielsen, L., Hellman, R., et al. (2003). Precise and full-range determination of two-dimensional equal loudness contours [Electronic Version]. *NEDO (New Energy and Industrial Technology Development Organisation)*.

Suzuki, Y. & Takeshima, H. (2004). Equal-loudness-level contours for pure tones. *Journal of the Acoustical Society of America, 116*(2), 919-933.

Svec, J., Sundberg, J. & Hertegard, S. (2008). Three registers in an untrained female singer analysed by videokymography, strobolaryngoscopy and sound spectrography. *Journal of the Acoustical Society of America, 123*(1), 347-353.

Svec, J. G., Schutte, H. K. & Miller, D. G. (1999). On pitch jumps between chest and falsetto registers in voice: data from living and excised human larynges. *Journal of the Acoustical Society of America, 106*(3/1), 1523-1531.

Tanaka, S. & Gould, W. J. (1983). Relationships between vocal intensity and noninvasively obtained aerodynamic parameters in normal subjects. *Journal of the Acoustical Society of America, 73*(4), 1316-1321.

Tang, J. & Statholopoulos, E. T. (1995). Vocal efficiency as a function of vocal intensity: a study of children, women and men. *Journal of the Acoustical Society of America, 97*(3), 1885-1891.

Thalen, M. & Sundberg, J. (2001). Describing different styles of singing: a comparison of a female singer's voice source in "Classical", "Pop", "Jazz" and "Blues". *Logopedics Phoniatrics Vocology, 26*(2), 82-93.

Thompson, W. F., & Russo, F. A. (2007). Facing the music. *Psychological Science, 18*(9), 756-757.

Thorpe, W. C., Cala, S. J., Chapman, J. & Davis, P. J. (2001). Patterns of breath support in projection of the singing voice. *Journal of Voice, 15*(1), 86-104.

Timmers, R., & Honing, H. (2002). On music performance, theories, measurement and diversity. *Cognitive Processing, 1*(2), 1-19.

Titze, I. R. (1988). Regulation of vocal power and efficiency by subglottal pressure and glottal width. In O. Fujimura (Ed.), *Vocal Physiology: voice production, mechanism and function* (pp. 227-238). New York.

Titze, I. R. (1991). Fundamental frequency scaling and voice classification. In R. T. Sataloff & I. R. Titze (Eds.), *Vocal health and science : a compilation of articles from the NATS bulletin and the NATS journal* (pp. 204-212). Jacksonville, FL: National Association of Teachers of Singing.

Titze, I. R. & Sundberg, J. (1992). Vocal intensity in speakers and singers. *Journal of the Acoustical Society of America, 91*(5), 2936-2946.

Todd, N. P. M., & Cody, F. W. (2000). Vestibular responses to loud dance music: A physiological basis of the ''rock and roll threshold''? . *Journal of the Acoustical Society of America, 107*(1), 496-500.

Tracy, J. & Robins, R. (2008). The nonverbal expression of pride: evidence for cross-cultural recognition. *Journal of Personality and Social Psychology 94*(3), 516–530.

Transylvaniacs, The. *On our way* [Haza is kéne már menni]. (1994). [CD]. Tall Poppies.

Tzelgov, J. (1999). Automaticity and processing without awareness. *Psyche, 5*(3).

Van den Berg, J. (1956). Direct and indirect determination of the mean subglottic pressure. *Folia Phoniatrica, 8*, 1-24.

Van der Kooij, H., Jacobs, R., Koopman, B. & Grootenboer, H. (1999). A multisensory integration model of human stance control. *Biological Cybernetics, 80*, 299-308.

Van Fleck, P. (2001). Rahat Nusrat Fateh Ali Khan. *Billboard, 113,* 28.

van Soest, A. J. & van Ingen Schenau, G. J. (1998). How are explosive movements controlled? In M. L. Latash (Ed.), *Progress in Motor Control* (Vol. 1, pp. 361-387): Human Kinetics.

Wanderley, M. (2002). Quantitative analysis of non-obvious performer gestures. In I. Wachsmuth & T. Sowa (Eds.), *Gesture and sign language in human-computer interaction* (pp. 241-253). Berlin: Springer Verlag.

Wanderley, M., Vines, B., Middleton, N., McKay, C. & Hatch, W. (2005). The musical significance of clarinetists' ancillary gestures: an exploration of the field. *Journal of New Music Research, 34*(1), 97-113.

Watanabe, T., Mizukami, K., & Kobayashi, N. (1991). Quantitive Analysis of neonatal intrapersonal synchrony between crying vocalisation and arm movement. *Biology of the Neonate, 60 (suppl)*, 86-93.

Watson, A. D. H. (2010). *The Biology of Musical Performance and Performance-related Injury*. Landham, MD: The Scarecrow Press Inc.

Watson, P. J. & Hixon, T. (1996). Respiratory behavior during the learning of a novel aria by a highly trained classical singer. In P. Davis & Fletcher (Eds.), *Vocal Fold Physiology: Controlling Complexity and Chaos* (pp. 325-343). San Diego,London: Singular Publishing

Welberg, L. (2008). Singing in the brain. *Nature Reviews: Neuroscience.*

West, J. B. (2000). *Respiratory Physiology: The Essentiels* (6th ed.): Lippincott, Williams & Wilkins.

Whitelaw, W. A., Ford, G. T., Rimmer, K. P. & De Troyer, A. (1992). Intercostal muscles are used during rotation of the thorax in humans. *Journal of Applied Physiology*, 1940-1944.

Wilder, C. N. (1983). Chest wall preparation for phonation in female speakers. In D. M. Bless & J. H. Abbs (Eds.), *Vocal Fold Physiology: contemporary research and clinical issues* (pp. 109-123): College-Hill Press.

Wilson Arboleda, B. M., & Frederick, A. L. (2008). Considerations for maintenance of postural alignment for voice production. *Journal of Voice, 22*(1), 90-99.

Wilson, G. J. (1991). Stretch-shorten cycle: nature and implications for human muscle performance. *Journal of Human Muscle Performance, 1*(3), 11-31.

Wilson, P. (2003). Sinful modern music: science and the contemporary commercial singer. *Australian Voice, 9*, 12-16.

Winkworth, A. L. & Davis, P. J. (1997). Speech breathing and the Lombard effect. *Journal of Speech, Language, and Hearing Research, 40*(February), 1-11.

Winkworth, A. L., Davis, P. J., Adams, R. D. & Ellis, E. (1995). Breathing patterns during spontaneous speech. *Journal of Speech and Hearing Research, 38*(February), 124-144.

Winkworth, A. L., Davis, P. J., Ellis, E. & Adams, R. D. (1994). Variability and consistency in speech breathing during reading:lung volumes, speech intensity and linguistic factors. *Journal of Speech and Hearing Research, 37*, 535-555.

Wolfe, J. (2002). *Speech and music, acoustics and coding, and what music might be 'for'.* Paper presented at the 7th International Conference on Music Perception and Cognition, Adelaide.

Yamaguchi, H., Yotsukura, Y., Sata, H., Watanabe, Y., Hirose, H., Kobayashi, N., et al. (1993). Pushing Exercise program to correct glottal incompetence. *Journal of Voice, 7*(3`), 250-256.

Yasuda, T., Nakagawa, T., Inoue, H., Iwamoto, M. & Inokuchi, A. (1999). The role of the labyrinth, proprioception and plantar mechanosensors in the maintenance of an upright posture. *European Archives of Oto-Rhino-Laryngology, 256*, S27-S32.

Yates, B. J. & Miller, A. D. (1998). Physiological evidence that the vestibular system participates in autonomic and respiratory control. *Journal of Vestibular Research, 8*(1), 17-25.

Yates, B. J. & Stocker, S. D. (1998). Integration of somatic and visceral inputs by the brainstem. *Experimental Brain Research*(119), 269-275.

Zemlin, W. R. (1998). *Speech and Hearing Science: anatomy and physiology* (4th ed.). Boston: Allyn and Bacon.

Zwicker, E. & Fastl, H. (1999a). Just-Noticeable Sound Changes. In E. Zwicker & H. Fastl (Eds.), *Psycho-acoustics: facts and models* (pp. 176): Springer.

Zwicker, E. & Fastl, H. (1999b). Loudness. In *Psychoacoustics: facts and models* (pp. 203-238): Springer.

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Appendix A-i: The acoustic consequences of movement restraint on six professional western contemporary popular singers (Paper 4)

Please refer to the following four pages.

The acoustic consequences of movement restraint on six professional western contemporary popular singers

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ABSTRACT

In western contemporary popular (WCP) styles of singing, high sound levels must be achieved, usually in the presence of a high level of body movement in performance. However, in recording studios, under stage direction or in the process of participation in empirical voice research, singers are often required to stand still. There is an assumption that singers will be able to achieve the same sound output under these conditions. This study assessed whether the restraint of body movements of six professional WCP singers would alter their acoustic output, in this case, their sound pressure level (SPL). 3-D video footage of the body movements were collected simultaneously with sound recorded through a head-mounted microphone while all sang the same R & B song in two conditions, with and without movement. The recordings were analysed for SPL and the results of the two conditions were compared. There was a significant reduction in the SPL at peak points in the 'no movement' condition but also throughout the phrase. This indicates that WCP singers need to be cautious about excessive restraint of their body movements if they wish to achieve optimal singing outcomes.

Keywords

Contemporary popular singing, body movement, SPL

1. INTRODUCTION

It is commonly assumed that WCP singers should be able to reproduce their usual stage standard in terms of vocal performance while standing still. This is exemplified by the concept taught by many classical pedagogues of the "noble posture", a stance that is maintained throughout the entire breath cycle [13] even though it has been observed empirically that posture differs during inspiration and expiration [9] and in particular just prior to a sudden increase in sound output, a phenomenon referred to as prephonatory posturing [19, 27]. In some prior singing studies, static postures have been studied, largely with regard to the issue of body alignment, particularly of the head and neck [31]. Although adjustments from one posture to the next would of necessity require body movement, this phase of behaviour has been rarely noted or discussed, possibly because the classical singers observed in most studies do not move as much as WCP singers but also because of technological limitations. New technologies for observing body movement may change this in the future but still present technical problems such as altering subject behaviour and presenting synchronisation problems with sound recording [7].

However, significant anterior-posterior (AP) movements by a highly disciplined professional classical soloist were noted in a methodological study on microphone use for voice research [1] indicating that even classical singers may be moving more than previously thought. To our knowledge, prior to our research, the effects of movement restraint on sound output have not been tested.

Sound pressure levels (SPL - measured in decibels) is a common measure of voice function [2]. High SPLs are required within WCP music [3]. WCP singers achieve high levels within these styles using higher levels of muscle effort at the larynx [16] and higher internal pressures [22]. This combination creates a higher vocal load for WCP singers than for classical singers at equivalent sound levels [23], which can cause voice damage if not approached correctly [10]. This makes knowledge gained from the study of the physiological production of SPL of direct practical use to singers wanting to avoid vocal injury.

This study challenges the assumption that a static physical posture can be used in all singing situations on the basis of knowledge of the interactions of upper body behaviour with respiratory [6, 27], laryngeal [15] and vocal tract function [11 & Shimada, 1999, 18]. It is well-established that subglottal pressure (Ps) is the main factor in SPL regulation [25] and that this is controlled by interactions between the respiratory and laryngeal systems [21]. There is a linear relationship between subglottal pressures generated beneath the vocal folds in the respiratory system and SPL variation, which means that higher Ps is required with increases in SPL [26]. SPL can be voluntarily altered on three levels - in the vocal tract, at the larynx and in the respiratory system [28], elements which, unfortunately, are impossible to separate fully without multiple, simultaneous and invasive procedures which would impede movement and create discomfort in the singer [4]. An example of this would be direct measurement of Ps by tracheal puncture [5] . Other indirect methods of calculating Ps have been of questionable accuracy [20] and have only been conducted when subjects were standing still. In view of the preliminary nature of this study it was considered that observation of SPL levels in different conditions would give us an indirect indication of the effect of movement on Ps production if all other factors at the

App. 2

point of comparison (pitch, vowel, vocal register) remained the same [24] . Information gained could then be applied to more highly controlled studies in the future. We conducted a preliminary study in which we examined the singers' movement behaviours and the relationships between these and SPL variation [29]. We analysed the antero-posterior (AP) torso movement direction frequency and characteristics at the point of maximum sustained SPL and found that the most common movement of the torso was in a posterior direction. It was also found that this was more likely to occur at high SPL points than low SPL points to a statistically significant degree. Results showed that there was an association between the AP torso movement of WCP singers and dynamic variation indicating a possible function of the movement in the voice production of SPL variation. One function of movement may be that it facilitates abdominal muscle contraction to raise Ps [29].

In light of this knowledge, we then hypothesized that if the posterior torso movement on the high SPL note was being used to create the high SPL, restraining the singers from moving would reduce SPL at those points. We also decided we would need to measure longer samples for SPL to assess whether movement restraint would have an effect on dynamics at other points in a sung phrase with points of both high and low vocal loading.

2. METHOD

Participants were six singers of contemporary popular music, 1 male and 5 female, ranging in age from 21 to 46 years with between 5 and 28 years of professional experience of both stage and recording studio performance.

To avoid using cues that might trigger atypical SPL output strategies [12] or body postures [31], verbal instructions were minimized by providing a vocal model of an R & B song on a recording to all participants to learn. Singers were permitted to alter the key of the song to suit their habitual range and style of delivery. However, they were requested to maintain a similar dynamic range to the original recorded version provided to them. Singers were encouraged to sing and behave as if in performance. No other verbal cues were given. A head-mounted microphone was used to keep the singers' distance from the microphone constant.

After singing in the first condition, the singers were then requested to sing again, behaving as if they had been given the instruction to remain still in a spotlight by a director. This imagery was chosen to provide a realistic musical rationale for a stationary performance.

3. RESULTS

One line of the song excerpt contained notes of both high pitch and highest SPL, therefore representing the most demanding section of the song in terms of maximal voice production. This was referred to as the Peak Phrase (PP). SPL was calculated on this line. A note of the highest SPL within the PP was referred to as Peak Notes (PN) in the subsequent analysis.

For all singers, the maximum SPL attained on a PN occurred in the M condition. Individually, singer mean differences on the PN ranged from at 0.96 dB which is at just noticeable difference (JND) [32] to 4.6 dB making the output reductions in the NM condition acoustically significant. SPL values and difference scores (N-NM) were consistently lower in the NM condition for each singer. The mean difference was 2.37dB (SD=1.3); t=4.46 (df=5), p (two-tailed) =.007. The paired t-test assessing the averaged differences for all six singers between the M and NM conditions, averaged over the three takes in each condition showed that the mean difference of 2.87dB (SD=1.3) was statistically significant [t=4.42 (df=5), p (one-tailed) =.039].

SPL calculations of the entire Peak Phrase in both conditions can be seen in Figure 1.

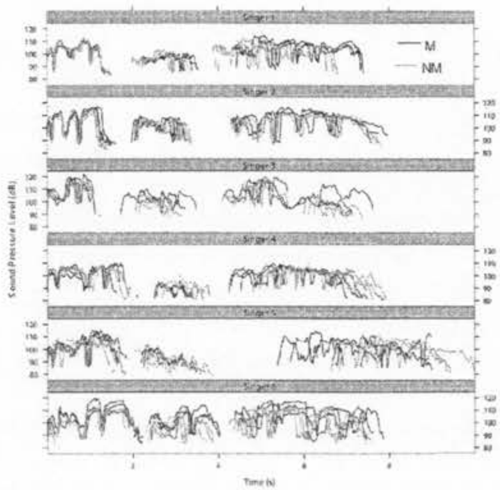

Figure 1. SPL of Peak Phrase in Movement (M) and No Movement (NM) conditions

SPL output was reduced at many points in the phrase in the NM condition and not just at points of high SPL.

4. DISCUSSION

The results indicated that vocal SPL is reduced when movement is reduced. This occurred even though the singers were not restricted in the way they could sing the song, and were permitted to lower the key in accordance with their habitual pitch range. Even though the singers sometimes reduced the two-octave pitch range of the song, thereby minimizing the vocal load and making the song easier to sing, the relationship between movement and SPL remained significant. The singers varied widely in age and length of experience and yet all experienced an audible reduction in SPL indicating that this effect was robust.

These results indicate that there may be either a direct physical function in the movement of these singers that assists with the production of the high SPL required for these styles of singing or that the manner of singing is entrained with movement in such a way that it cannot be easily separated without a reduction in SPL. The fact that SPL was reduced at lower pitches and at quieter points in the dynamics where Ps demands are lower indicates that the effects of movement restraint are not solely related to interference with Ps generation.

There are several possible explanations for this effect, which we have discussed in more detail elsewhere [30]. One possibility is that the NM condition interfered with the autophonic response, whereby the SPL of one's own voice is regulated on a multisensory level by factors such as the sensation of muscle effort [8, 14, 17]. The restraint of active body behaviour may have interfered with that response by altering the sensory feedback required for the mechanism to work. This would also explain the alterations at all SPL levels.

5. CONCLUSION

The results of this study indicate that restraint of body movement leads to reduced SPL levels in WCP singing. These results have significant practical implications for those working with singers during the conduct of voice research, in professional recording studios and on stage in that the placement of physical constraints on singers may have detrimental effects on SPL control that may be insurmountable even in very experienced singers. Those working with WCP singers need to be cautious in restraining their body movements if they wish optimal singing results to be achieved with regard to sound level.

6. REFERENCES

[1] Cabrera, D., Davis, P.J., Barnes, J., Jacobs, M. and Bell, D. Recording the operatic voice for acoustic analysis. *Acoustics Australia, 30* (3). 103-108.

[2] Corthals, P. Sound pressure level of running speech: percentile level statistics and equivalent continuous sound level. *Folia phoniatrica et logopaedica, 56* (3). 170-181.

[3] Dibben, N. The role of peripheral feedback in emotional experience with music. *Music Perception, 22* (1). 79-115.

[4] Finnegan, E.M., Luschei, E.S. and Hoffman, H.T. Estimation of alveolar pressure from direct measures of tracheal pressure during speech. *NCVS Status and Progress Report* (June). 1-10.

[5] Finnegan, E.M., Luschei, E.S. and Hoffman, H.T. Modulations in respiratory and laryngeal activity associated with changes in vocal intensity during speech. *Journal of Speech, Language, & Hearing Research, 43* (4). 934-950.

[6] Gandevia, S.C., Butler, J.E., Hodges, P.W. and Taylor, J.L. Balancing acts: Respiratory sensations, motor control and human posture. *Clinical and Experimental Pharmacology and Physiology, 29* (1-2). 118-121.

[7] Giovanni, A., Assaiante, C., Galmiche, A., Vaugoyeau, M., Ouaknine, M. and Le Huche, F. Forçage vocal et posture: études expérimentales chez le sujet sain [Vocal forcing and posture: experimental studies on normal subject] [French]. *Revue de Laryngologie Otologie Rhinologie, 127* (5). 285-291.

[8] Ho, A.K. Volume perception in Parkinsonian speech. *Movement Disorders, 15* (6). 1125-1131.

[9] Hodges, P.W., Gurfinkel, V.S., Brumagne, S., Smith, T.C. and Cordo, P.C. Coexistence of stability and mobility in postural control: evidence from postural compensation for respiration. *Exp Brain Res, 144* (3). 293-302.

[10] Hollien, H., Report on vocal registers. in *Stockholm Music Acoustics Conference*, (Stockholm, 1983), Royal Swedish Academy of Music

[11] Honda, K., Hirai, H., Masaki, S. and Shimada, Y. Role of vertical larynx movement and cervical lordosis in F0 control. *Language and Speech, 42* (4). 401-411.

[12] Huber, J.E., Chandrasekaran, B. and Wolstencroft, J.J. Changes to respiratory mechanisms during speech as a result of different cues to increase loudness. *Journal of Applied Physiology, 98* (6). 2177-2184.

[13] Hudson, B. The effects of the Alexander technique on the respiratory system of the sing/actor Part II: implications for training respiration in singer/actors based on concepts of Alexander technique. *Journal of Singing, 59* (2). 105-110.

[14] Ingham, R.J., Warner, A., Byrd, A. and Cotton, J. Speech effort measurement and stuttering: investigating the chorus reading effect. *Journal of Speech, Language, and Hearing Research, 49* (3). 660-670.

[15] Kooijman, P.G., de Jong, F.I., Oudes, M.J., Huinck, W., van Acht, H. and Graamans, K. Muscular tension and body posture in relation to voice handicap and voice quality in teachers with persistent voice complaints. *Folia phoniatrica et logopaedica, 57* (3). 134-147.

[16] Koufman, J.A., Radomski, T.A., Joharji, G.M. and Russell, G.B. Laryngeal biomechanics of the singing voice. *Otolarygology - Head and Neck Surgery, 115*. 527-537.

[17] Lane, H.L., Catania, A.C. and Stevens, S.S. Voice level: autophonic scale, perceived loudness and effects of sidetone. *Journal of the Acoustical Society of America, 31* (2). 160-167.

[18] MacCurtain, F. and Welch, G., Vocal tract gestures in soprano and bass: a xeroradiographic-electro-laryngographic study. in *SMAC (Stockholm Music Acoustics Conference) 83*, (1983), Royal Swedish Academy of Music, 219-238.

[19] McFarland, D.H. and Smith, A. Effects of vocal task and respiratory phase on prephonatory chest wall movements. *Journal of Speech and Hearing Research, 35* (5). 971-982.

[20] Plant, R.L. and Hillel, A.D. Direct measurement of subglottic pressure and laryngeal resistance in normal subjects and in spasmodic dysphonia. *Journal of Voice, 12* (3). 300-314.

[21] Sawashima, M., Niimi, S., Horiguchi, S. and Yamaguchi, H. Expiratory lung pressure, airflow rate, and vocal intensity: data on normal subjects. in Fujimura, O. ed. *Vocal Physiology: voice production, mechanisms and functions*, Raven Press Ltd, New York, 1988, 416-422.

[22] Schutte, H.K. and Miller, D.G. Belting and pop, nonclassical approaches to the female middle voice: some preliminary considerations. *Journal of Voice, 7* (2). 142-150.

[23] Sundberg, J., Gramming, P. and Lovetri, J. Comparisons of pharynx, source, formant, and pressure characteristics in operatic and musical theatre singing. *Journal of Voice, 7* (4). 301-310.

[24] Sundberg, J., Leanderson, R., von Euler, C. and Knutsson, E. Influence of body posture and lung volume on subglottal pressure control during singing. *Journal of Voice, 5* (4). 283-291.

[25] Sundberg, J., Titze, I.R. and Scherer, R. Phonatory control in male singing: a study of the effects of subglottal pressure, fundamental frequency, and mode of phonation on the voice source. *Journal of Voice, 7* (1). 15-29.

[26] Tanaka, S. and Gould, W.J. Relationships between vocal intensity and noninvasively obtained aerodynamic parameters in normal subjects. *Journal of the Acoustical Society of America, 73* (4). 1316-1321.

[27] Thorpe, W.C., Cala, S.J., Chapman, J. and Davis, P.J. Patterns of breath support in projection of the singing voice. *Journal of Voice, 15* (1). 86-104.

[28] Titze, I.R., Shirley, G.I., Long, R., Stathopoulos, E., Ramig, L.O., Carroll, L.M. and Riley, W.D. Messa di voce: an investigation of the symmetry of crescendo and decrescendo in a singing exercise. *NCVS Status and Progress Report* (June). 145-152.

[29] Turner, G. and Kenny, D.T. A preliminary investigation into the association between body movement patterns and dynamic variation in Western contemporary popular singing. *Musicae Scientiae, In press.*

[30] Turner, G. and Kenny, D.T. Restraint of body movement potentially reduces peak SPL in western contemporary popular singing. *Musicae Scientiae, In press.*

[31] Wilson Arboleda, B.M. and Frederick, A.L. Considerations for maintenance of postural alignment for voice production. *Journal of Voice, In press.*

[32] Zwicker, E. and Fastl, H. Just-Noticeable Sound Changes. in Zwicker, E. and Fastl, H. eds. *Psycho-acoustics: facts and models*, Springer, 1999, 176.

App. 5

Appendix A-ii: The relationship between sound pressure level and spontaneous body behaviour in western contemporary popular singing (Paper 5)

Please refer to the following four pages.

THE RELATIONSHIP BETWEEN SOUND PRESSURE LEVEL AND SPONTANEOUS BODY BEHAVIOUR IN WESTERN CONTEMPORARY POPULAR SINGING

Gemma Turner and Dianna T. Kenny

Australian Centre for Applied Research in Music Performance, Sydney Conservatorium of Music, University of Sydney

ABSTRACT

Singers of Western contemporary popular (WCP) music are known for their dynamic stage behaviour, both physically and vocally. This paper tests the hypothesis that body movement in WCP singing may be associated, not only with idiosyncratic expression but with the generation of the high sound amplitudes achieved by singers in this vocal style. Six professional and semi-professional singers performed a section of an R&B/soul song, first with their usual stage behaviour and then while standing still. This was recorded using a headset-mounted microphone to avoid the singers changing their mouth distance from the microphone during performance. The recordings were analysed for sound pressure level and the results of the two conditions were compared. There was a significant reduction in the sound pressure level recorded by the singers both statistically and acoustically in the 'no movement' condition. Movement during WCP singing may therefore facilitate SPL control, though by what means is yet to be determined.

1. BACKGROUND

The Western contemporary popular (WCP) music world values the excitement generated in an audience by a singer who can produce a powerful sound. High sound pressure levels (SPL)] are an important part of the perception of the acoustic expression of emotion in speech and singing, particularly for strong emotions such as anger and happiness [1, 2]. However, high sound levels are physically taxing for the voice especially when delivered at high pitch [3,4]. This combination of vocal stressors may lead to functional problems with the voice in the long-term if not executed with the appropriate technique [5]. As a result, singers want to know how to master control of high vocal sound levels. In this paper, we observed the interaction of body movement and SPL in professional contemporary popular singing in order to discover whether some aspects of body movement during singing serve a functional as well as expressive role in vocal production in WCP styles.

WCP singing has a different acoustic profile to that of a western classical singer [6,7] which means that techniques suitable for Western classical singing may not appropriate for a singer in the WCP style: WCP vocal production is more "speech-like" in timbre, although a large range of techniques are employed and considered acceptable [8]. WCP singers also differ markedly from Western classical singers in body behaviour. Classical training leads to the minimisation of body movement [9] in contrast to WCP singing. WCP singers use a variety of body behaviours when singing, some idiosyncratic, some observable across a wide range of singers. These movements often appear to parallel dynamic variations in the vocal line.

The aim of this study was to determine whether the body behaviour of WCP singers is associated with SPL levels. Given that some postural and movement characteristics have been associated with dysfunctional voice [10, 11] it is possible that there are similarly characteristic patterns of optimal voice use. Singers learn by various means to optimize their posture and respiratory drive [12]. The dependent variable in this study is acoustic output and SPL represents the physical correlate of that output as well as providing a good measure of subjective loudness [13].

This study compared singers' spontaneous singing performance behaviour against a performance condition that required them to sing while standing still. It was hypothesised that if movement is being used to optimize SPL production then the removal of movement should lead to a reduction in SPL, especially at moments of high vocal

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loading such as at high pitch. We hypothesized that it would be less likely to have an effect at points where loading is lower such as at low pitch or at quieter parts of the songs.

2. METHOD

Participants were 6 singers, 1 male and 5 female, ranging in age from 21 to 46 years. They were all professional or semi-professional singers of WCP music. with strong voices with an ability to produce a powerful sound.

The study design permitted observation of singers in a manner consistent with their performance style while maintaining sufficient rigor such that valid data could be collected in as authentic a performance setting as possible, thereby making the results more meaningful to practitioners. The common song (CS) spanned a 2-octave range, originally F3 (175 Hz) - F5 (698Hz), without a transition to loft register. This large range ensured that even if the singers lowered the key they would not be able to avoid the transition point. To avoid problems which could be created by singers using microphone technique , the microphone was mounted on a headset to keep the singers' distance from the microphone constant.

All the singers prepared three short song excerpts, two of their own choice from their own repertoire including a verse plus chorus in addition to the song excerpt provided by the researchers. These self-chosen songs were used as a vocal warm-up and also as a means of helping the singers feel at ease by singing familiar songs.. The own repertoire songs were also used to assess whether the samples taken of the CS represented the singers' usual vocal performance standard. Singers were advised that they could sing the song in the key of their choice and could personalise the song as they would any other song in their repertoire. However, they were requested to maintain a similar dynamic range to the original recorded version provided to them. It was requested that the other two song excerpts they were to bring to the session have a similarly large dynamic range as the song provided to them. No limitations were placed on pitch range or musical style.

All the singers sang unaccompanied in a large untreated room at the Faculty of Health Sciences, The University of Sydney. The singers sang each of their three song excerpts three times. The starting pitch of each song was nominated by the singer and was played on a pitch-pipe before each recording. Songs were recorded digitally and videoed simultaneously with two video cameras from front and side-on. Singers were encouraged to sing and behave as if in performance. A taped rectangle on the floor represented the range of the cameras and singers were advised that they could move as they wished within this space. The video was intended for later analysis but also had the effect of making the singers more performance aware and more likely to behave as if on stage.

When this first part of the protocol in which the singers performed in their usual manner [i.e. called the Movement (M) condition] was concluded, singers were requested to sing the songs again, but this time behaving as if they had been given the instruction by a stage director to remain still. All three songs were then repeated under this second Non-Movement (NM) condition. The protocol took no more than 40 minutes for all participants.

Line 11 of the song excerpt contained notes of both high pitch and highest SPL, therefore representing the most demanding section of the song in terms of maximal voice production. This was referred to as the Peak Phrase (PP). The notes of highest SPL within the PP were referred to as Peak Notes (PN) in the subsequent analysis. The PP was a note on the first syllable of the word "never," the vowel /ɛ/, was measured for mean dB in PRAAT from the offset of the sound /n/ to the onset of the /v/.

A one sample t-test was conducted to assess the null hypothesis that there would be no difference between the movement and non-movement conditions; that is, the difference in Peak Note SPL between the two conditions would not be significantly different from zero. A paired t-test assessed the averaged differences over the three takes in each condition for all six singers between the M and NM conditions.

The SPL of the entire song excerpts were calculated at a sampling rate of 100 Hz using PRAAT. SPL percentile values where calculated from the dB listings generated in order to show the entire dynamic range of the whole song samples. The percentile levels indicate which SPL levels had been exceeded between 1 and 99% of measurement time.

3. RESULTS

For all singers, the maximum SPL attained on the PN occurred in the M condition (Figure 1). SPL values and difference scores (N-NM) were consistently lower in the NM condition for each singer. The hypothesis tested by the one-sample test was not confirmed. The mean difference was 2.37dB (SD=1.3); t=4.46 (df=5), p(two-tailed)=.007. The paired t-test assessing the averaged differences for all six singers between the M and NM conditions, averaged over the three takes in each condition (see Table 1) showed that the mean difference of 2.87dB (SD=1.3) was statistically significant [t=4.42 (df=5), p (one-tailed) =.039].

All singers showed an absolute dynamic range of ~30dB in both conditions at the dynamic extremes. Figure 2 shows graphs representing percentile levels 1-99 for all singers in both conditions. It illustrates that highest and lowest SPL occurred in parallel; that is, when peak SPL was reduced, there was a concomitant reduction in lowest SPL, and when highest SPL increased, lowest SPL increased. This allowed singers to maintain a consistent dynamic difference in SPL throughout the song. For mid range SPL, singers showed more variation. The percentile levels across all singers show SPL of greater than ~80dB for 99% of the duration of the song.

The graphs show higher SPL levels in the M condition at the extremes of the dynamic range in most cases. In all singers the maximum L99 attained was in the M condition. Singers 3, 5 and 6 showed larger differences between conditions at all percentiles. Singer 5 showed the phenomenon of parallelism of SPL most clearly, with a ~3dB gap between the lowest M percentile line and the highest NM percentile line up to the 40th percentile area, with some crossing over at ~L80-90.

4. DISCUSSION

The results indicated that vocal SPL is reduced when movement is reduced or eliminated in WCP singing. Our first hypothesis was confirmed. Individually, singer mean differences on the PN ranged from at 0.96 dB (Singer 4) which is at JND to 4.6 dB (Singer 6). This occurred even though the singers were not restricted in the way they could sing the song, and were permitted to lower the key in accordance with their habitual pitch range. Even though the singers sometimes reduced the two-octave pitch range of the song thus minimizing the vocal load and making the song easier to sing, the relationship between movement and SPL remained significant.

The SPL percentile graphs in Figure 2 present an overview of the SPL range used within the entire CS excerpt. Figure 2 shows that, as hypothesised, the mid-range SPL was more variable than the higher range. Contrary to expectation, SPL percentiles at the low end of the dynamic range reduced to a similar degree to the reductions shown at maximum SPL. The singers in this study were asked to sing with a large dynamic range but remained consistently within ~30dB. The precision of the maintenance in SPL range in the NM condition is noteworthy and to our knowledge has not been previously reported.

5. CONCLUSION

The results of this study indicate that body movement may facilitate SPL production in WCP singing. The links between voice and body movement are complex: we will aim, in a future study, to provide a detailed description of the kind of movements singers use at different levels of SPL. It is a conventional wisdom that classical vocal training prepares a singing student for any kind of singing. The results of this study indicate that the Western classical singing method, with its emphasis on physical restraint may not be appropriate for singers wanting to sing in popular styles, at least with respect to physical behaviour.

6. REFERENCES

1. Kotlyar, G.M. and V.P. Morozov, "Acoustical correlates of the emotional content of vocalized speech", Soviet Physics Acoustics, 1976. 22(January-December):208-11.

2. Scherer, K.R. "Expression of emotion in voice and music", Journal of Voice, 1995. 9(3):235-48.

3. Jónsdottir, V., et al., "Effects of amplified and damped auditory feedback on vocal characteristics", Logopedics Phoniatrics Vocology, 2000. 26:76-81.

4. Schutte, H.K. "The efficiency of voice production", 1983, Groningen: Kemper.

5. Hollien, H. "Report on vocal registers", In Stockholm music Acoustics Conference, 1985. Stockholm: Royal Swedish Academy of Music.

6. Bestebreurtje, M.E. and H.K. Schutte, "Resonance strategies for the belting style: Results of a single female subject study", Journal of Voice, 2000. 14(2):194-204.

7. Schutte, H.K. and D.G. Miller, "Belting and pop, nonclassical approaches to the female middle voice: some preliminary considerations", Journal of Voice, 1993. 7(2):142-50.

8. Middleton, R. "Rock Singing". In: J. Potter, editor, "Cambridge Companion to Singing", 2000, Cambridge: Cambridge University Press.

9. Pettersen, V., "Muscular patterns and activation levels of auxiliary breathing muscles and thorax movement in classical singing", Folia Phoniatr Logop, 2005. 57(5-6):255-77.

10. Grini, M.N., et al., "Modifications posturales et segmentaires contemporaines du forcage vocal" [Contemporary postural and segmental modification of forced voice], Revue de Laryngologie Otologie Rhinologie, 1998. 119(4):253-7.

11. Grini-Grandval, M.N., et al., "Forcage vocal et variance de la vitesse: correlation entre la vitesse de deplacement du centre de gravite et le travail des muscles posturaux" [Forcing the voice: the correlation between the speed of displacement of the centre of gravity and the work of the postural muscles], Revue de Laryngologie Otologie Rhinologie, 2000. 121(5):319-23.

12. Pettersen, V. and R.H. Westgaard, "The association between upper trapezius activity and thorax movement in classical singing", Journal of Voice, 2004. 18(4):500-12.

13. Rasch, R. and R. Plomp, "The Perception of Musical Tones", In: D. Deutsch, editor "The Psychology of Music" ,1999, San Diego: Academic Press: 99-101.

Appendix A-iii: Conference abstract: The relationship between spontaneous physical movements and vocal intensity in western contemporary popular singing styles

Gemma Turner and Dianna T. Kenny

Australian Centre for Applied Research in Music Performance
The University of Sydney

Jenny Alison

The University of Sydney

Singers of different cultures singing in different genres use the same physical gestures at similar dynamic points in musical phrases. In addition to their creative and cultural determinants, could there be a physical basis for some of these gestures? Eight professional or semi-professional singers of contemporary music were recorded with a headset microphone and videoed from front and side on a) behaving as they would in performance and b) standing still as if they had been given the direction to do so as part of a show. Each singer was given the same excerpt of a song with a recorded example to prepare for the session and was asked to bring two other song excerpts of their own choosing that had a similar dynamic range. Each singer performed each song excerpt 3 times in each condition. Subjects were not aware that they were going to be asked to repeat the samples in the standing still condition until the first condition had been recorded. The recordings of singing in each condition are now being analysed for intensity using PRAAT software. Preliminary results indicate reductions of intensity peaks and averages in the non-moving condition for most subjects and dramatic reductions for some subjects. Pedagogically, teachers need to be cautious when limiting the range of movements used by students when singing in contemporary popular styles.

Appendix B-i: Ethics proposal

Full project title

The effect of body movement on vocal intensity in contemporary singing

Description of project

Although there are many theories amongst singers regarding the most effective ways to sing there is limited scientific research in this area. In addition, most studies of singing have concentrated on Western classical singing styles. Contemporary singing styles, for example, rock, jazz, rhythm and blues and soul have not been studied in detail. In contemporary singing, dance movements and expressive body gestures are tied very closely to vocal performance. This occurs particularly in singing styles that have grown out of the African-American tradition.

In previous studies (1,2) the measurement equipment required the singer to remain relatively still. Although information from these studies has been valuable in understanding the respiratory patterns, chest wall movement and sub-glottal pressures required for some types of singing, it has meant that there have been constraints on the movements that singers might normally use when performing. Considering that some of the muscles of respiration are also involved in posture and movement, it would be reasonable to consider that posture and movement could have an effect on vocal intensity.

Therefore this study aims to provide some basic information on the way singers of contemporary music perform. In particular, the study aims to show whether there is a relationship between body movement and vocal intensity. The hypothesis of the proposed study is that by moving the body in certain ways singers are able to increase vocal intensity.

To avoid movement constraints an observational methodology will be adopted for this study. In Experiment 1 the movement behaviours and voice intensity of singers of contemporary styles will be recorded. In Experiment 2 more detailed analysis of the effects of particular movements on voice intensity will be studied.

Methods

Subjects

For Experiment 1, six contemporary singers, male and female and of professional standard will be recruited. In Experiment 2, 15 amateur or professional-standard male and female singers of contemporary styles will be recruited.

Equipment: Experiments 1 & 2

All recordings will take place at National Voice Centre laboratory at the Cumberland Campus of the University of Sydney.

A sound recording will be made with a microphone head-set and recorded to digital audio tape (DAT). Simultaneously with the sound recording, the singers will be videoed with 3D Video (that is from front and side-on), so that gestures and torso movements can be viewed and analysed more effectively.

All mains powered electrical equipment (computer, video and DAT recorder) will be powered through a laboratory grade mains isolation transformer. The sound recording will be analysed for sound intensity and spectrographically using Cool-Edit or similar software. Variations in vocal intensity will be correlated with physical events that coincided with or immediately preceded them as observed on video.

Experiment 1: Observing the habitual movements of singers of contemporary music and how these movements relate to vocal intensity.

For this study, subjects will be asked to sing in contemporary styles in the range where they can produce their most powerful sound and to behave as if they were in a live performance. Movements will be analysed for their possible connection with the generation of higher sound intensities. The recording equipment used will place no movement constraints on the subjects.

Protocol

1. The singer will sing excerpts e.g. one verse & chorus, of two songs of their own choice, which demonstrates a great dynamic range, ie from soft to loud.

2. The singer will then be asked to sing part of a well-known song with a large dynamic range. Prior to the session a tape recording of this song will have been provided for the subject to prepare for the session. The singer will be instructed to sing it in his/her own way but with similar dynamics to the tape provided.

3. The subject will then be asked to repeat the song excerpts from 1 and 2 above while standing still.

Experiment 2: The effect of isolated body movements on vocal intensity

Movements which correlate with higher sound intensities in Experiment 1 will be used as the basis for Experiment 2. In addition, movements which should not have an effect on vocal intensity will be used as control movements, for example, small movements from the wrist.

Protocol

A series of musical phrases with varied pitch and set dynamics will be played to the subjects. These will be placed within a comfortable part of lower register of the subject's voice.

1. Each time a particular phrase is to be sung, a movement will performed at one point. The movement will have been demonstrated to the subject by the researcher and the subject will be instructed at which point in the phrase to perform the movement. Each phrase will be sung with different movements performed at the same point.

2. The subject will be instructed to sing all the phrases without movement.

References

1. Sundberg, J et al Influence of Body Posture and Lung Volume on Subglottal Pressure Control During Singing J Voice 1991 5: 283-291

2. Bouhuys A, Proctor DF, Mead J Kinetic aspects of singing J Appl Physiol 21: 483-496

Appendix B-ii: Ethics acceptance letter

COPY

HUMAN ETHICS COMMITTEE
The University of Sydney
Room K4.01 Main Quad A14
Sydney 2006
Tel: (02) 9351.4474 Fax: (02) 9351.4812 E-mail:human.ethics@reschols.usyd.edu.au

Mrs J Alison
School of Physiotherapy
C42

26 May 2000

Dear Mrs Alison

Title: ***The effect of body movement on vocal intensity in contemporary singing***

Ref No: ***00/03/03***

Thank you for your correspondence dated 26 May 2000 addressing comments made to you by the Committee. After considering the additional information, the Committee approved your protocol on the above study.

The additional information will be filed with your application.

In order to comply with the National Health and Medical Research Council guidelines, and in line with the Human Ethics Committee requirements the Chief Investigator's responsibility is to ensure that:

(1) The individual researcher's protocol complies with the final and Committee approved protocol.
(2) Modifications to the protocol cannot proceed until such approval is obtained in writing.
(3) The confidentiality and anonymity of all research subjects is maintained at all times, except as required by law.
(4) All research subjects are provided with a Subject Information Sheet and Consent Form.
(5) The Subject Information Sheet and Consent Form be on University of Sydney letterhead and include the full title of the research project and telephone contacts for the researchers.
(6) The following statement appears on the Subject Information Sheet:
Any person with concerns or complaints about the conduct of a research study can contact the Manager of Ethics and Biosafety Administration, University of Sydney, on (02) 9351 4811.
(7) The standard University policy concerning storage of data should be followed. While temporary storage of audio-tapes at the researcher's home or an off-campus site is acceptable during the active transcription phase of the project, permanent storage should be at a secure, University controlled site for a minimum of five years.
(8) A progress report is provided by the end of each year. Failure to do so will lead to withdrawal of the approval of the research protocol and re-application to the Committee must occur before recommencing.
(9) A report and a copy of the published material is provided at the end of the project.

Yours sincerely

for ***Professor Barry Baker***
Chairman
Human Ethics Committee
cc. Ms G Turner, 17 Maddock St, Dulwich Hill 2203
D:\Ethics\HEC CORRESPONDENCE\Protocols\Add Info\2650500app.doc

Appendix B-ii: Subject information sheet 1

The University of Sydney National Voice Centre

Faculty of Health Sciences
College of Health Sciences

Cumberland Campus
East Street (PO Box 170)
Lidcombe NSW 2141
Telephone: +61 2 9351 5352

SUBJECT INFORMATION SHEET

Research Title: Observing Contemporary Singers
Investigators: Jenny Alison, Gemma Turner, A/Prof Jack Crosbie

Project Contact person: Gemma Turner, telephone (02) 9716 4538

1. Background to study

There are many theories amongst singers and singing teachers about how the voice is produced and the best and healthiest ways to sing but there has been very little scientific research into this area. The few studies of singing have been mainly of Western classical singing. Contemporary singing has not been studied in any depth. This study aims to observe contemporary singers who practise their art at a high level. It is hoped that this will contribute to the improvement in the teaching of contemporary vocal technique and add to the legitimacy and understanding of non-classical vocal styles in the fields of voice teaching and voice science. It is also hoped that by opening more discussion on contemporary voice that other voice scientists will see fit to study non-classical styles of singing in the future.

2. Description of Study - methods and demands

For this study, you will be asked to bring two songs from your repertoire that you know well and that normally would be sung by you with a wide dynamic range, that is, with extremes from soft to loud. We will ask you to sing an excerpt from each of these two songs . We would like you to sing and be as animated and expressive as you would be in a live performance in front of an audience. You will also be asked to sing a section of a song provided by us in advance on tape which will be no longer than a verse plus chorus. You may sing this song in your own way and in a key in which feels comfortable for you but we would like you to aim to sing as dynamically as the singer on the tape.

We will ask you to sing each of these three song excerpts at least 3 times.

Research Title: Observing Contemporary Singers

Your singing will be recorded with a microphone on a head-set (like a radio-mic) which means that you will be able to move around without affecting the recording. You will be given time to get used to this set-up. At the same time you will be videoed from the front and side on.

We would like you to wear (or bring to wear) comfortable, close-fitting clothing such as singlets, t-shirts, dance or gym-wear to make you easier to observe on video. There will be time for you to warm up your voice at the beginning of the session. Let us know in advance if you have any particular requirements for this, such as a keyboard or if
you want privacy to warm up. You may stop to rest, do more warm-ups or to eat or drink at any time during the study.

Up to 2 hours of your time will be needed for briefing you, setting up equipment and recording your singing.

All aspects of the study, including results, will be strictly confidential and only the investigators named above will have access to information on participants. The recordings of your voice will be kept confidential by coding them with a subject number rather than your name. The results of the analyses will be submitted as part of a thesis and may be published in scientific publications, but your name will not be identified. With your consent, short sound samples of your voice may be included on a CD with the thesis. Your name would be kept confidential and the samples would be no longer than a few seconds. Voice recordings would only be used for the purposes of this research study and further specific consent would be sought prior to any further use.

While we intend that this research will further knowledge in voice production, it may not be of direct benefit to you.

Participation in this study is entirely voluntary. You are not obliged to participate and, if you do participate, you can withdraw at any time. Whatever your decision it will not affect your relationship with the researchers.

When you have read this information Gemma Turner will discuss it with you further and answer any question you may have.

Any person with concerns or complaints about the conduct of a research study can contact the Manager of Ethics and Biosafety Administration, University of Sydney, on (02) 9351 4811.

Gemma Turner
Tel: (02) 9716 4538
Email: gtur8984@mail.usyd.edu.au

Appendix B-iii: Subject information sheet 2

The University of Sydney **National Voice Centre**

Faculty of Health Sciences
College of Health Sciences

Cumberland Campus
East Street (PO Box 170)
Lidcombe NSW 2141
Telephone: +61 2 9351 5352

SUBJECT INFORMATION SHEET

Research Title: The effect of gesture on contemporary voice
Investigators: Jenny Alison, Gemma Turner, A/Prof Jack Crosbie

Project Contact person: Gemma Turner, telephone (02) 9569 3410

You are invited to participate in a study on "The effect of gesture on contemporary voice"

1. Background to study

There are many theories amongst singers and singing teachers about how the voice is produced and the best and healthiest ways to sing but there has been very little scientific research into this area. The few studies of singing have been mainly of Western classical singing. Contemporary singing has not been studied in any depth. This study aims to observe contemporary singers who practise their art at a high level. It is hoped that this will contribute to the improvement in the teaching of contemporary vocal technique and add to the legitimacy and understanding of non-classical vocal styles in the fields of voice teaching and voice science. It is also hoped that by opening more discussion on contemporary voice that other voice scientists will see fit to study non-classical styles of singing in the future.

2. Description of Study – methods and demands

For this study, you will be asked to sing a series of musical phrases. These will be short, easy-to-learn phrases which will be played to you on the day. A series of body gestures will be added to the singing of these phrases. The gestures will be shown to you by the researcher and you will be instructed as to when in the phrase to perform them.

You will be asked to sing each phrase plus gesture combination at least 3 times.

Research Title: The effect of gesture on contemporary voice

You will be recorded with a microphone on a head-set (like a radio-mic) which means that you will be able to gesture without adversely affecting the recording. You will be given time to get used to this set-up. At the same time you will be videoed from the front and side on.

We would like you to wear (or bring to wear) comfortable, close-fitting clothing such as singlets, t-shirts, dance or gym-wear to make you easier to be seen clearly on the video.
There will be time for you to warm up your voice at the beginning of the session. Let us know in advance if you have any particular requirements for this, such as a keyboard. You may stop to rest, do more warmups or to eat or drink at any time during the study.

Up to 2 hours of your time will be needed for briefing you, setting up equipment and recording your singing.

All aspects of the study, including results, will be strictly confidential and only the investigators named above will have access to information on participants. The recordings of your voice will be kept confidential by coding them with a subject number rather than your name. The results of the analyses will be submitted as part of a thesis and may be published in scientific publications, but your name will not be identified. With your consent, short sound samples of your voice may be included on a CD with the thesis. Your name would be kept confidential and the samples would be no longer than a few seconds. Voice recordings would only be used for the purposes of this research study and further specific consent would be sought prior to any further use.

While we intend that this research will further knowledge in voice production, it may not be of direct benefit to you.

Participation in this study is entirely voluntary. You are not obliged to participate and, if you do participate, you can withdraw at any time. Whatever your decision it will not affect your relationship with the researchers.

When you have read this information Gemma Turner will discuss it with you further and answer any questions you may have.

Any person with concerns or complaints about the conduct of a research study can contact the Manager of Ethics and Biosafety Administration, University of Sydney, on (02) 9351 4811.

Gemma Turner

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Appendix B-iv: Subject consent form 1

The University of Sydney — National Voice Centre

Faculty of Health Sciences
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East Street (PO Box 170)
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INFORMED CONSENT

I, ____ hereby voluntarily
print name

consent to participate in the research entitled:

Observing Contemporary Singers

Conducted by: **Gemma Turner, Jenny Alison and Jack Crosbie**

I understand that the information obtained from this research may by used in future research, and may be published. However, my right to privacy will be retained, that is, personal details will not be revealed.

The procedure as set out in the attached information sheet has been explained to me and I understand what is expected of me and the benefits and risks involved. My participation in the project is voluntary.

I acknowledge I have the right to question any part of the procedure and can withdraw at any time without this being held against me.

I have been familiarised with the procedure.

Subject: ______________________________
signature

Date: ______________________________

Witness: ______________________________
print name

____
signature

Date: ______________________________

Ref: Informed Consent/1999/as

Appendix B-v: Subject consent form 2

The University of Sydney **National Voice Centre**

Faculty of Health Sciences
College of Health Sciences

Cumberland Campus
East Street (PO Box 170)
Lidcombe NSW 2141 (1825)
Telephone: +61 2 9351 5352

Informed Consent Form

INFORMED CONSENT

I, ____ hereby voluntarily
print name

consent to participate in the research entitled:

The effect of gesture on contemporary voice

Conducted by: **Gemma Turner, Jenny Alison and Jack Crosbie**

I understand that the information obtained from this research may by used in future research, and may be published. However, my right to privacy will be retained, that is, personal details will not be revealed.

The procedure as set out in the attached information sheet has been explained to me and I understand what is expected of me and the benefits and risks involved. My participation in the project is voluntary.

I acknowledge I have the right to question any part of the procedure and can withdraw at any time without this being held against me.

I have been familiarised with the procedure.

Subject: ______________________________________
signature

Date: ______________________________________

Witness: ______________________________________
print name

____
signature

Date: ______________________________________

Ref: Informed Consent/1999/as

Appendix C-i: Studies 1-3 common song lyric sheet

Excerpt from

I Never Loved A Man (The Way I Love You) (1967)
Artist: Aretha Franklin
Composer: Ronnie Shannon

You're a no good heartbreaker
You're a liar and you're a cheat
And I don't know why
I let you do these things to me

My friends keep tellin' me
That you ain't no good
Whoa, but they don't know
That I'd leave you if I could

I guess I'm all uptight
And I'm stuck like glue
'Cause I ain't never, I ain't never, never, no, no
Loved a man the way that I - I love a you

Appendix C-ii: Study 4 judge response sheet laryngeal mechanism

Please rate the voice quality on the syllable "ne" of "never" for each sound sample you will hear on this recording. The rating is as follows:

1 = heavy mechanism, modal register, chest register, mechanism 1, thick fold

2 = light mechanism, loft register, upper register, mechanism 2, thin fold

3 = other

4 = cannot identify the voice quality used

Comments: Add your own descriptive terms for the voice quality heard

Singer	Sample	Voice Quality Rating	Comments
1	1		
	2		
	3		
	4		
	5		
	6		
2	1		
	2		
	3		
	4		
	5		
	6		
3	1		
	2		
	3		
	4		
	5		
	6		

Singer	Sample	Voice Quality Rating	Comments
4	1		
	2		
	3		
	4		
	5		
	6		
5	1		
	2		
	3		
	4		
	5		
	6		
6	1		
	2		
	3		
	4		
	5		
	6		

Appendix D-i: Multimedia listings – CD

Song excerpts sung by singer participants for expert judgement in Study 4 (Chapter 5): 1-3 (Movement condition) 4-6 (Non-movement condition) for each singer.

Singer 1

1. M
2. M
3. M
4. M
5. M
6. M

Singer 2

7. M
8. M
9. M
10. M
11. M
12. M

Singer 3

13. M
14. M
15. M
16. M
17. M
18. M

Singer 4

19. M
20. M
21. M
22. M
23. M
24. M

Singer 5

25. M
26. M
27. M
28. M
29. M
30. M

Singer 6

31. M
32. M
33. M
34. M
35. M
36. M

37. Studies 1-3 (Chapters 2-4) Song excerpt provided to singer participants of I never loved a man (like I love you) sung by Aretha Franklin.

Appendix D-ii: Multimedia listings – DVD

Each track contains video footage of each singer singing the Peak Phrase of the Common Song. Samples are of Peak Phrase takes 1-3 (Movement condition) positioned side by side.

1. Singer 1
2. Singer 2
3. Singer 3
4. Singer 4
5. Singer 5
6. Singer 6