Respiration in operatic singing: Intention to communicate

Susannah Foulds-Elliott

A thesis submitted in fulfilment
of the requirements for the degree of Doctor of Philosophy

School of Communication Science and Disorders
Faculty of Health Sciences
University of Sydney

2004

Abstract

Professional operatic singing can be performed technically for practice and rehearsal, or with heightened emotion through intention to communicate with an audience. Previous studies of respiration in operatic singing have not taken into account the professional performer's ability to differentiate at will between rehearsal and performance modes of singing. The aim of this thesis is to investigate the differences between singing 'with intention to communicate' (as if performing) and singing 'technically' (as if in rehearsal). The hypothesis is that this specified change of condition would change the respiratory patterns employed by the singers. Estimation of respiratory patterns was obtained using magnetometers. Performance singing was labelled 'IC' (intention to communicate). Rehearsal singing was labelled 'T' (technical) and also included 'TL' (technical loud) and 'TS' (technical soft). Each of the five singers performed two tasks (a free choice aria in Italian, and a set song). Only intra-subject analysis was used. One thousand and one breaths were analysed. These were then matched, so that only complete musical phrases (sung six times by the same singer) were compared with each other. Seven hundred and sixty-two matched phrases were analysed in this way. Measured variables were initiation lung volume (ILV), termination lung volume (TLV), the amount of lung volume expired (LVE), %VC released per second (Flow), the expiratory time (Te), and inspiratory time (Ti). Sound pressure level (SPL) was measured. This study also examined the ability of experienced listeners to distinguish between the T and IC performances from DAT recordings. Findings show that in comparison with T singing, IC singing used more air, with a greater percentage of vital capacity expired per second, but without a simple association with sound pressure level or expiratory time. Listeners were able to distinguish IC from T performances, demonstrating a perceived difference in the quality of the vocal output. These results demonstrate that performance intention to communicate, compared to rehearsal, results in a measurable difference in respiratory parameters, and therefore needs to be specified in future research.

Acknowledgements

With deep gratitude I thank:

- Dr. William Thorpe, supervisor, 2000-2004,
  (associate supervisor, 1996-1999),
  who has supported this study through from start to finish, and with whom I brought this study to its conclusion.
- Assoc. Prof. Pamela Davis, supervisor, 1996-1998,
  who enabled and challenged me to set up this study.
- Assoc. Prof. Jean Callaghan, associate supervisor, 2000-2004,
  who challenged and inspired my struggle with the musical and pedagogical concepts involved in this study.
- Prof. Jan van Doorn, associate supervisor, 2000-2004,
  for invaluable advice on thesis structure.
- Dr. Meg Rohan, for invaluable advice and help with statistical analysis.
- Ms. Patricia Price, artistic adviser,
  who advised in the conceptual setting up, and selected singers for the data collection of this study.
- Dr. Stephen Cala, medical adviser,
  who assisted during data collection.
- Prof. Emeritus David Galliver, singer, teacher and researcher,
  for the original inspiration for this work.
- Ms. Gwenyth Annear, singer and teacher,
  for the inspirational teaching out of which this work came.
- Prof. Catherine Ellis, ethnomusicologist,
  who initially challenged and supported me in putting together the research, performance and teaching aspects of this work.
- The Rev'd Robin Elliott, my husband,
  who kept me going in every way.

This project was approved by the University of Sydney Ethics Committee.

Publications and presentations arising out of this work:

Publications

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.

Foulds-Elliott, S.D. (2000b). Emotional connection in operatic singing: Traditional and scientific insights. *Australian Voice 6*: 9-15.

Lecture presentations

Foulds-Elliott, S.D. (1996). *The singer's formant.* Paper presented to the National Voice Centre, Sydney, July.

Foulds-Elliott, S.D., Davis, P.J., Thorpe, C.W., Cala, S., & Price, P. (1998). *Respiratory function in professional operatic singing during variation in emotional connection and loudness.* Paper presented at the Fourth Voice Symposium of Australia, Melbourne, October.

Book reviews

Foulds-Elliott, S.D. (1999). Review of the book *Singing and Imagination*. In *Australian Voice 5*:77.

Foulds-Elliott, S.D. (2000a). Review of the book *Singing and Voice Science*. In *Postwest 17*:60.

TABLE OF CONTENTS

PART 2
Respiration in operatic singing: Intention to communicate

4. Literature review – experimental studies of breathing in speech and song.

5. Method

6. Results

List of Figures and Tables

PHOTOGRAPHS

APPENDIX

Preface

Technique is of no value except as it makes communication possible.
Miller 1986, p.204.

As a performer and teacher I have always been fascinated at the way in which performance makes the technical side of singing both easier for the singer and more convincing for the audience than a purely technical effort. I believe that both aspects are necessary. This thesis takes as a starting point that the reason for developing technique (the functionality aspect of singing) is to be able to communicate to an audience. This work sets out to consider the moment in performance at the inception of the phrase. This is the moment before the singer takes the breath for each phrase.

As defined by Richard Miller in his book *The structure of singing. System and art in vocal technique* (1986), this moment is a point of fusion between the technical and the communicative aspects of singing. Miller talks about the discipline with which singers use the memory of previous experience to bring together the many technical aspects of singing into one concept, which becomes a psychological attitude.

…the singer fuses into one whole the many technical facets of singing: a single mental concept at the inception of the phrase combines them into one musical act. At the same time, in the musical realm, an equally important happening takes place: conception of the entire contour of the musical phrase in that instant in which the phrase commences. Collected into one split second of insight, by the same psychological process by which any conceptual thought can be born in an instant, the singer should sense the contour, the shape of the entire musical phrase and its literary idea, prior to the initiation of the phrase in word and tone.
Miller 1986, p.203.

Miller goes on to say that this procedure has already been well established in daily thought and speech, but that due to the real-time aspect of the performance of singing, singers face the temptation of thinking of individual components of their art instead of fusing them into one experience through "simultaneous anticipation of them at the inception of the phrase". Miller then discusses the discipline required to practise making this technical and artistic unity, which must be developed and mastered as in the use of any other technique.

At the moment before the professional singer takes the breath for each phrase, the various technical aspects of singing fuse into one whole with emotional connection as the singer focuses on communicating the meaning of the music. Professional singers can also increase technical thinking in rehearsal mode, for example, if various technical aspects need to be individually addressed. Then, in performance mode, once again the technical aspects are fused as the singer's intention becomes focused primarily on communicating to an audience.

The aim of this thesis is to compare lung volume behaviour in operatic singers during rehearsal mode (technical singing, where the singer increases awareness of individual technical components) with lung volume behaviour during performance mode (fusing the technical components and increasing intention to communicate). Professional singers are expected to be able to make this differentiation between rehearsing and performing. The main question of this thesis is whether these changes in intention result in a measurable difference.

The basic hypothesis of this thesis is that such changes in intention will be reflected in physiological differences, showing changes in breathing patterns. The secondary hypothesis is that listeners can perceive these changes of intention.

This thesis is divided into two parts. Part 1 (Chapters 1, 2 and 3) gives an introduction to operatic singing, while Part 2 (Chapters 4 to 9) presents the original research.

In Part 1, Chapter 1 traces the history and origins of operatic singing, particularly with respect to its emphasis on communicating to an audience. Chapter 2 summarises performance aspects of operatic singing, including technical and stylistic components, and reviews the literature related to how performers communicate emotionally with an audience. Chapter 3 discusses and defines the intention to communicate.

Part 2 begins with Chapter 4, which gives a voice science literature review, with critical assessment of previous research in the areas of singing, respiration and emotion. The main focus here is on the singing respiration studies based on the two-compartment method of Konno and Mead (1967) from which the methodology of my original contribution is taken. This methodology is described in Chapter 5, along with the description of data collection (respiratory, sound pressure level and perceptual). Chapter 6 comprises the results section, and Chapter 7 provides a discussion of the main findings of these investigations in the light of previous research. Pedagogical speculation and implications for singing pedagogy are discussed in Chapter 8, and Chapter 9 presents the final conclusions.

PART 1

Operatic singing

1. History

Opera can be narrowly defined as a dramatic work in which the text is sung throughout (Sadie 1980). Using this definition, one of the first known operas was Peri's *Dafne*, (now lost), originally performed in 1597. This was closely followed in 1600 by Peri's *Euridice,* with part of the music written by Caccini. The composition of these operas heralded a musical renaissance which had been gradually developing throughout the 16th century, with the evolution of a completely new aim in the composition and performance of music, particularly vocal music. The dominance of polyphony, or many lines of melody played or sung simultaneously by a group of musicians, had resulted in the texture of music becoming increasingly complex. The Council of Trent, which met from 1545 to 1563, heard complaints about the complicated polyphony of church music which made the words and meaning inaccessible to congregations (Grout 1960). Musical composition had become musician-oriented rather than audience-oriented. As the 16th century continued, there was a swing back to taking audience reaction into account, and the meetings, discussions and arguments within groups such as the Florentine Camerata provided the means by which the new ideas and experiments gradually developed and finally succeeded in the creation of a new genre (Pirrotta 1954).

1.1. The new music

In 1602 Caccini published a treatise entitled *Le nuove musiche, ("the new music"),* providing the basis for training singers to perform the new operatic style. This publication and the musical renaissance it heralded, came out of meetings such as those of the Florentine Camerata in which the musicians, composers, artists and researchers were inspired by the new humanism of the times to make a re-connection with ancient Greek drama in music. One of the main musical aims was to reinstate Greek precepts, including the Aristotelian view that music purges passion by arousing that passion. Musicians of the time were increasingly dissatisfied with the dominant madrigal form, which had developed to a point where the many simultaneous sung melodies obscured the words and meaning of the music for a listener. In fact, the form had developed as a participatory art and was not intended primarily for listeners. The new vocal music reacted against polyphony, using solo voice and minimal accompaniment with the aim of communicating the emotion and meaning of the words to a listening audience in a way that would allow the audience to experience it for themselves. The development of ways and means of training the solo voice to communicate effectively developed along with the new music.

1.2. The Florentine Camerata

1.2.1. Bardi

Count Giovanni Bardi of Florence hosted the meetings of the informal group of musicians, scientists, philosophers, poets and historians which later came to be known as the Florentine Camerata. The earliest mention of the meeting of this group is in 1573, in the *Diario* of the Accademia degli Alterati (Palisca 1989). Giovanni Bardi was a man dedicated to the advancement of knowledge in many areas of science and the arts, and he also masterminded spectacles and entertainments for the court. His interest in ancient Greek music produced correspondence from 1572 to 1578 with the scientist Girolamo Mei, whose research produced insights into ancient Greek music and condemnation of the modern counterpoint. These ideas were communicated to Caccini by Bardi in letters probably dating from 1578 (Palisca 1989). Early musical experiments were made by performers and composers such as Vincenzo Galilei, a musician sponsored by Bardi from the early 1560's. Galilei wrote his *Dialogo della musica antiqua et della moderna* (published at around the beginning of 1582) indicating that he wanted to make a practical application of his theories about rediscovering the precepts of ancient music in order to improve the music of his own times (Sadie 1980). Pietro Bardi, son of Giovanni, wrote to Duke Guglielmo Gonzaga of Mantua in 1582, describing the music of Galilei as he sang a setting of the lament of Count Ugolino from Dante's *Inferno* "in dramatic style" with an ensemble of viols (Sadie 1980). This apparently caused a musical sensation, and led to further composition by Galilei of lamentations and responses for Easter services. Galilei's letter to Gonzaga in 1582 says that Galilei composed these lamentations and responses according to the methods of the ancient Greeks, using a single voice reciting (Palisca 1989).

1.2.2. Bardi's influence

Bardi's influence at court began to decline with the appointment of the new Duke Ferdinand from 1587. In 1592 Bardi left Florence and went to Rome to become the *maestro di camera* and lieutenant general of the pontifical guard for Pope Clement VIII. Bardi took Caccini with him as secretary. Palisca (1989) estimates that Bardi's Camerata was active from approximately 1573 to 1592, reaching prominence between 1577 and 1582, and declining by the mid 1580's.

1.2.3. Rival cameratas

Pirrota (1954) shows that there were at least two rival cameratas: those associated with Cavalieri, and another group associated with Corsi. Cavalieri was appointed as superintendent of court artists by the new Grand Duke in 1588, and took over from Bardi in influence at court. Cavalieri encouraged Corsi, who was a younger leader of another camerata (Palisca 1989). Corsi's group experimented with music drama in the 1590's, leading to one of the first known operas, Peri's *Dafne* with text by Rinuccini (probably first performed in 1597, and now lost) and Peri's *Euridice* (also with text by Rinuccini, and partly composed by Caccini) in 1600 (Pirrota 1954). Caccini dedicated the score of *Euridice* to Bardi, and it was in this dedication that we have the earliest use of the term 'camerata' applied to Bardi's group.

1.2.4. Musical revolution

It was through Bardi's correspondence with Mei and sponsorship of Galilei and Caccini that the existing principles and philosophy of musical composition received radical revision in the light of ancient Greek precepts. This led to the development of the new musical form in which a single voice expressed the text in a way that was musically appropriate for that 'affection' or emotion to be aroused in the listener. Counterpoint was used only in the accompaniment. The natural rhythms and melodies found in the speech patterns for particular emotions were used in the new music. Mei's (mistaken) theory that the music of the ancient Greeks was sung continuously, without spoken sections, influenced the theoretical and experimental development of musicians such as Galilei and Caccini, and eventually led to the composition and production of the first operas (Palisca 1989).

1.2.5. Popular music

Popular music during the 16th century also provided an influence towards the creation of the new musical forms of the 17th century. The frottola of the late 15th and early 16th centuries was the fore-runner of the madrigal, but also led to the 16th century popular music forms of the vilanella, the canzonet, and the new villottas. These forms were part songs, but the melody (in the highest part) began to show more dominance, with the other parts becoming less obvious (or indeed being played on instruments) (Pirrotta 1954). Singers began to develop the technique of improvisatory embellishment of the main melody, and often performed with lute or stringed instrument. Sixteenth century music exhibiting these characteristics was called 'pseudo-monody' (as opposed to the accompanied monody of the 17th century) and was often found in stage music and masques (intermedi). (Pirrotta 1954).

1.3. Bel canto

The term 'bel canto' (beautiful singing) has been open to many interpretations and is associated with a variety of historical time periods and conflicting ideas of vocal technique. The term itself was first used only in the late 19th century as a way of referring back to the beginning of monody and the development of the solo voice in the 17th century, which led to the rise of a professional class of virtuoso solo singers with the ability both to move and to astound an audience (Stark 1999). 20th century scholars show a conflicting use of the term 'bel canto', which for some such as Silva (1922) meant florid vocal ornamentation, while for others such as Bukofzer (1947) it meant a smooth and emotionally communicative lyricism. Bel canto has been associated with 18th century opera (Duey 1951), particularly the works of Mozart (Apel 1969; Stark 1999), and yet the modern understanding of bel canto is associated with the works of Rossini, Donizetti, Bellini and the earlier works of Verdi (Stark 1999). The 'golden age' of bel canto is often considered to extend from the middle of the 17th century to the beginning of the nineteenth century (Randel 1986). The term 'bel canto' has been used for a variety of styles and historical periods, but in its broadest sense (in which it is used in this thesis) it refers to the establishment of the old Italian school of singing of the late 16th and early 17th century, and its subsequent development in the virtuoso singing which flowered in the following centuries.

The seeds of the controversy regarding the term 'bel canto' have been identified by Galliver (1972), who pointed out that the musical theorising and experimentation that went on in late 16th century Florence resulted in the creation of a new vocal sound, not just a new way of composing music. Creating this new vocal sound was analogous to creating a new instrument with which to play the new music. It can be supposed that the new instrument was created by adding the component of projection, according to ideas of dramatic intoning, but in order to communicate effectively to an audience it was based on the exclaiming of emotion with dramatic projection (Caccini 1602, Galliver 1969). Singing using this technique was referred to as *cantare con affetto* (singing with emotion) (Galliver 1974). *Cantare con la gorga* (singing with the throat) referred to singing which had developed as instrumental imitation and demanded virtuosity and flexibility, without the projection of emotional exclamation on which the operatic sound was later built (Galliver 1973; 1987). Over time, as the operatic style developed, these two aspects were united in the bel canto ideal which incorporated both beauty of sound and vocal flexibility (Stark 1999).

2. Performance

The singer's instrument is made up of the personal anatomy of the singer. The way in which the anatomy is accessed to produce the operatic sound was first developed in the 17th century, and this has provided the foundation out of which the various strands of today's pedagogy have arisen. A concise and detailed summary of the history of the development of these strands can be found in Miller's "Historical Overview of Vocal Pedagogy" (in Sataloff, 1998; Ch. 26, pp. 301-313). In pedagogical terms, the technical aspects of singing are the individual, physical components of the singer's anatomy which are used in order to create the sound. These physical components are only partially able to be voluntarily accessed individually, so knowledge of the way they function (physiology) is very important. Understanding of anatomy and physiology from the 17th century to the present time has undergone progressive development, and vocal pedagogy by and large has incorporated this development as it has occurred (Miller, in Sataloff 1998). Understanding of the neurophysiology involved in the control used by operatic singers is a highly complex area and current understanding is still developing.

From this brief overview it is clear that in considering operatic singing we are looking at a specific phenomenon which developed at a historical point in time, has been handed on from teacher to student for four hundred years, and which we are gradually coming to understand in a physical sense. Modern understanding of the physical aspects of operatic singing is summarised in section 2.1. For musicians the term 'technical' is used to imply some sort of breaking down of the work in hand into its individual components. Musicians agree that technical excellence alone is not enough to make performance worthwhile, and that 'technique' (or the way the technical aspects are used) is the tool or vehicle through which the effective musician does something more – the effective musician communicates through the technique. The technical components for the singer (physical, musical, literary) are fused into one by the conceptual intention to communicate at the inception of the phrase, which results in the taking of the breath, and then the phonated release of that breath in the form of sound.

The following sections give an overview of the relevant anatomy and physiology for singing.

2.1.Technical aspects

2.1.1. Anatomy (structure)

Overviews of the anatomy of voice production are found in texts such as Sataloff (1998), Sundberg (1987) and Titze (1994). In summary, the three systems responsible for voice production are the respiratory system, the vocal folds, and the vocal tract. In the respiratory system, the spongy structures of the lungs are contained within a sac inside the rib cage, and are connected to tubes (bronchi) which join the trachea and culminate in the vocal folds. The vocal folds themselves are housed within the larynx, which comprises four main anatomic units composed of the skeleton, mucosa, intrinsic and extrinsic muscles.

The laryngeal skeleton consists mainly of the thyroid cartilage, cricoid cartilage and two arytenoid cartilages (see Figure 1 below).The thyroarytenoid muscle extends from the arytenoids to the inside of the thyroid cartilage (behind the area commonly known as the Adam's apple). The medial part of the thyroarytenoid muscle (also known as the vocalis muscle) forms the body of the vocal fold on each side.

Although the vocal folds can be described as muscle with a covering of mucous membrane (Sundberg 1987), the work of Hirano shows that they consist of five layers with different mechanical properties constituting the mucosa (epithelium and superficial layer of lamina propria), ligament (intermediate and deep layers of lamina propria), and muscle (thyroarytenoid muscle) (Hirano 1974, 1975, 1977; Hirano & Sato 1993). Two-fifths of the length of the vocal folds are cartilagenous, and the other three-fifths are membranous and are critical for vibratory function relating to sound quality (Sataloff 1998). These tissues are elastic and may be either passive or active, allowing flexibility in pitch control (Miller 1986).

The vocal folds originate on the thyroid cartilage and run posteriorly, each fold inserting into an arytenoid cartilage (Sundberg 1987). The glottis is the slit between the vocal folds (see Figure 2). The glottis is opened and closed by the rotating movements of the arytenoid cartilages. The thyroid and cricothyroid cartilages are related to each other rather like the visor on a helmet, so that when the cricothyroid muscle between these two cartilages contracts, in effect the thyroid cartilage is tilted further down in relation to the cricoid cartilage, and the vocal folds are stretched and therefore lengthened (see Figure 3). Adduction brings the folds together, and abduction separates them. The vocal folds are adducted in voiced sound, and abducted in unvoiced sound (Sundberg 1987).

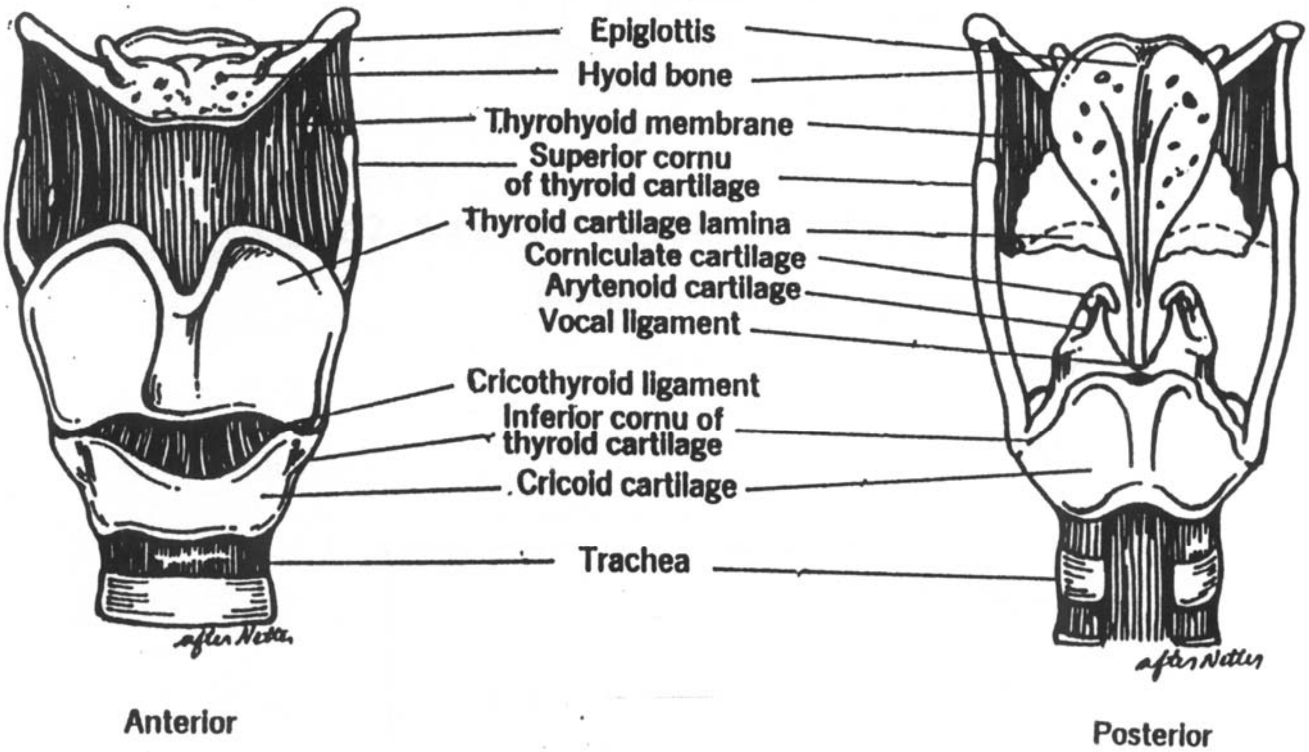


Figure 1 - cartilages of the larynx (from Sataloff 1998).

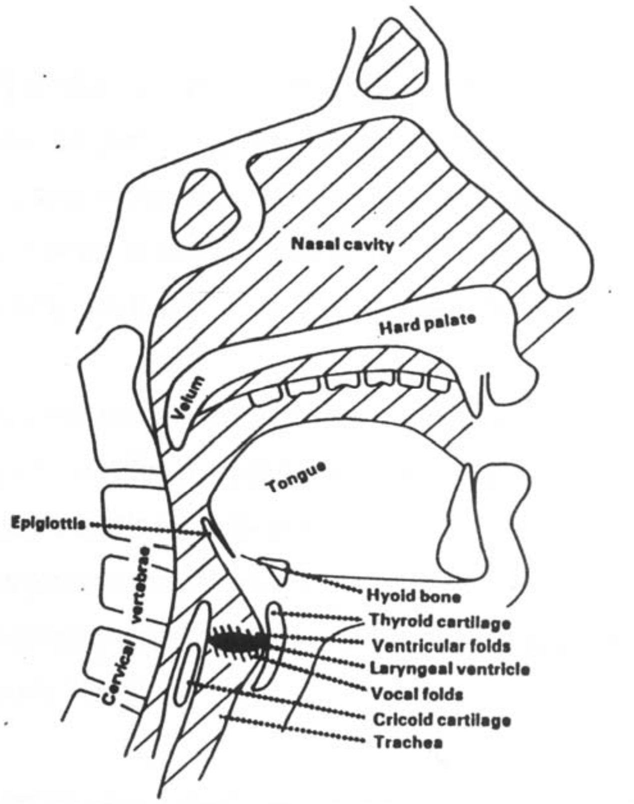


Figure 2 - Schematic representation of voice organ, mid-saggital profile (from Sundberg 1987)

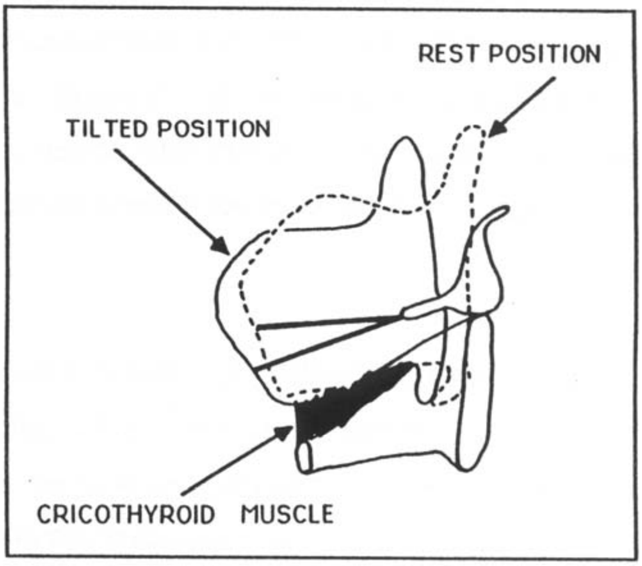


Figure 3 - Vocal fold lengthening (from Sataloff 1998)

Sataloff (1998) divides the vocal fold into two zones, consisting of the muscular region built on the supporting mass of the thyroarytenoid muscle and forming the body of the vocal fold, wrapped in a loosely-attached covering layer of epithelial tissues similar to rubber bands. This elastic cover is particularly well-formed at the vocal ligament (Sataloff 1998).

The vocal tract is the combination of the pharynx, mouth and nose cavities. The shape of the vocal tract is extremely adaptable, with the tongue, lips and jaw (the articulators) all able to move over a wide range and thereby produce a variety of shapes. The cervical vertebrae constitute the back wall of the pharynx, with constrictor muscles forming the side walls. The velum, or soft palate, forms a ceiling for the pharynx and can either block or open the nasal cavities, which, in addition to the passage out through the nares, contain narrow channels leading up to the maxillary and frontal sinus cavities. Opening the velum therefore has a significant influence on the sound quality, as in nasalised vowels (Sundberg 1987).

The lungs power the voice through a supply of pressurised air which is able to excite vibrations in the vocal folds and thus generate sound. The diaphragm is generally described by singers as the support system, but in anatomical terms the abdominal muscles provide the breath support (Sataloff 1998). The complex anatomy for support in singing is not yet understood (Sataloff 1998). It is known that the diaphragm and the external intercostal muscles are the primary muscles used in inspiration. The primary active expiratory muscles are the external oblique, internal oblique, rectus abdominis, and transversus abdominis. Sataloff (1998) gives a thorough discussion of the anatomy involved, and also discusses the lack of pedagogical agreement in the use of abdominal muscle activity for singing.

2.1.2. Physiology (function)

In order to sing, the breathing apparatus (power source), the vocal folds (vibrator) and the vocal tract (resonator) need to work together. Air is compressed by the power source and forced towards the larynx. The Bernoulli force acts to draw vocal folds together when there is a flow of air through them. Underpressure is created, while the middle layer of the airstream flows undisturbed through the glottis. Velocity is greater in those layers which have to travel further. The underpressure has its effect along the vocal folds which in effect strive to close the glottis (described in detail by Sundberg 1987; and Titze 1994) The Bernoulli force plays an important role in adduction for voiced sound, as well as the adducting muscles which adjust glottal width to allow vocal fold vibration. The elasticity of the vocal folds makes a contribution in the same direction as the Bernoulli force. As the airstream passes through a sufficiently narrowed glottis, the non-linear properties of the vocal folds allow them to rapidly open and close with the rate of vibration ranging from less than 100 times per second up to about 1000 times per second (Sundberg 1987). For example, soprano top C (C6) is 1046 cycles per second, while bass low C (C2) is 65 cycles per second. Subglottal pressure, velocity of airflow at the glottis, and supraglottal pressure all affect the quality of the sound produced at the sound source.

2.1.2.1. Physiological effects: acoustics and SPL

Pitch is related to the frequency of the glottal opening and closing during vocal fold vibration. Sound pressure level (SPL) is related to the amplitude of the pressure pulses emitted, and is determined by such factors as subglottal pressure and glottal resistance. Finally, timbre, which is largely related to the relative magnitudes of all the harmonic components in the sound, is mainly determined by the shape of the supraglottic vocal tract, interacting with the harmonics generated by the glottal vibration. The sound at vocal fold level contains a complete set of harmonics which can be accentuated or attenuated by complex interactions in the supraglottic vocal tract (Sataloff 1998). The shape of the larynx tube itself in relation to the shape of the pharynx is important in obtaining the carrying power of the operatic voice known as the singer’s formant (Sundberg 1987). This phenomenon is a spectrum envelope peak in the vicinity of 3 kHz, found in male operatic voices and lower female operatic voices.

2.2. Stylistic aspects

Opera singers must not only create the raw material of the operatic sound but must also respond appropriately to the stylistic parameters of the music being sung. Professional singing involves the communication of emotion within the boundaries of the style of music being performed. Increasing intention to communicate will increase the telling elements of that particular style. In the operatic style, the singer must use the operatic vocal sound in various ways (see section 2.2.1.), according to the style of the composer (see section 2.2.2.).

2.2.1. Voice quality

A specific requirement of operatic vocal sound is that the singer must be able to project the voice over a full symphony orchestra without a microphone, relying on the acoustic abilities of the voice itself. This ability gives the traditional ringing sound to the operatic voice (Sundberg 1987).

Vibrato is another characteristic of the operatic sound, and can be described by the three parameters of amount of pitch undulation (amplitude), temporal measures of undulation (frequency), and intensity variation (Miller 1986).

2.2.2. Musical style

As well as producing the raw material of the operatic sound, the operatic singer must use the stylistic guidelines of the music being sung, in collaboration with the expectations of the particular conductor with which they are working at the time. Conductors will have a variety of positions in relation to trends in interpretation, but professional singers need to be able to make a stylistic shift in the use of technique between music of the classical era (Mozart, for example) and nineteenth century composers such as Puccini. Professional singers must explore stylistic expectations to varying degrees depending on their individual techniques (Sadie & Brown 1989).

The music of earlier and later composers is performed in different ways, and each composer will also display national characteristics (to a greater or lesser extent) which must also be taken into account in performance. The rhythm of early music is generally related to dance style and displays a more even progression than the rhythm of much 19th century music, which progresses with excitement towards climactic statements (Sadie & Tyrell 2001). For example, to be stylistically acceptable, the music of Mozart (1756-1791) must be sung in general without rubato or change of speed within sections, and without pitch sliding either towards or away from each note. This would be considered unacceptable in singing the music of Puccini (1858-1924), which generally requires change of speed within phrases so that the approach to louder, higher notes may slow the speed, while the significant high notes where a dramatic point is made may be expected to be held for longer than the written notation specifies. Musically significant notes are sometimes required to be joined by portamento, or a supported sliding change of pitch. Portamento in music by Mozart would be stylistically unacceptable. Vibrato may show greater variation in the Puccini style compared to the Mozart style. It is expected that in professional performance, emotional effect must be communicated within the parameters of the style of music being performed, so that increasing communication in the Puccini style will increase the telling elements of that style such as vibrato and portamento. Increasing communication in the Mozart style will not in general give such variation in vibrato.

When performing a whole opera, the operatic singer must remain within the stylistic parameters set by the composer. Successful communication will depend on how far the performer can push the stylistic boundaries while still remaining within them. Concert performances, on the other hand, will usually involve selected arias and songs from various sources, not always from the operatic repertoire. Concert repertoire may include Lieder (German song), art song (English song), French song, and songs by the great composers of any country. Each one will have its own stylistic parameters according to its nationality and composer. Folksongs are also sung by operatic singers in concert performances. Depending on the arranger, folksongs when sung by operatic singers take on more operatic elements (projected voice, vibrato, rubato) than when sung by folksingers. A folksinger may keep a more regular tempo (often working with drum or percussion using repeated rhythmic motifs) and use less vibrato variation than an operatic singer singing an arranged folksong from the established concert repertoire.

2.3. Communication aspects

Music, in both its notated structure and also in the way in which it is performed, is considered to be “an effective means of emotional communication” (Juslin & Laukka 2000). In considering the communication aspects of singing, we return to Miller’s ‘point of fusion’ as described in the Preface (p.10). Miller (1986) points out that the emotive meaning of the words has an effect on the musical shape of the phrase. The composer has initially shaped the musical phrase according to the composer’s own interpretation of the meaning of the words. The singer must make an emotional connection with the composer’s emotive meaning from the musical clues, and it is the singer’s task to communicate this meaning to an audience. The many individual technical components which a singer must take into account, must be gathered up into a single concept with emotional connection when the singer in performance intends to communicate. The intention to communicate, which musicians understand as fusing the separate technical aspects of singing into a single unifying concept, implies a change in brain function. In terms of current neurophysiology, we can only speculate on what is involved in this process. The following section gives some indication of what is currently known in the area of the neurophysiology of singing.

2.3.1. Neurophysiology (control)

Sataloff (1998) describes volitional voice as originating in the cerebral cortex. The command for vocalisation is established in the centres for speech and expression, and then after being processed by the precentral gyrus (motor cortex), motor nuclei in the brainstem and spinal cord are alerted to activate the larynx, thoracic and abdominal muscles, and articulators. Motor activity refinement is provided by the cerebral cortex, cerebellum and basal ganglia, and by autonomic nervous systems. The singer makes adjustments through auditory feedback from the ear, through to the brainstem, and then to the cerebral cortex, from where adjustments can be made to match the intended rather than the actual sound. Tactile feedback from phonatory muscles may also help but this is not currently fully understood (Sataloff 1998).

Separate innervation of the vocalis muscle and the cricothyroid muscle may be contributing to singers’ ability to use the differential control necessary for rapid changes in pitch, dynamics and intensity as well as dramatic coloration (Miller 1986).

LeDoux (1987) summarises the neurophysiology of emotion, describing it as a complex and incompletely understood process involving evaluation (both conscious and unconscious), experience and expression of emotion, through limited links between affective and cognitive processing systems.

Further development of neurological understanding of emotional expression has been made by Davis, Zhang, Winkworth and Bandler (1996) who have explored the concept that the ‘unconscious’ emotional pathways may be important in providing integrated responses which co-ordinate the various mechanisms involved in voice production. Davis, Zhang & Bandler (1993) showed that the motor pattern for vocalisation in decerebrate cats is directly affected by activity in the periaqueductal grey area in the midbrain, and that this motor pattern is regulated by afferent information from the lungs and upper airways. Zhang, Davis, Bandler and Carrive (1994) found that the PAG has a role in integrating the activity and timing of laryngeal, respiratory and oral muscle activity. Davis, Zhang and Bandler (1996) postulate a model of interaction between PAG and cortical structures in which separate neural pathways for sound production and articulation are proposed. PAG areas are part of the emotional motor system (Holstege 1991) and are involved in the expression of emotion (Bandler, Carrive & Zhang 1991; Holstege 1991). Davis, Zhang, Winkworth and Bandler (1996) propose a new hypothesis on the neural control of vocalisation, which is that the PAG generates respiratory and laryngeal motor patterns essential for emotional or involuntary vocalisation including singing.

2.3.2. Singing studies

Although respiration has been measured in studies of operatic singing (reviewed in section 4.3.), the intention to communicate (as a variable) has not been identified or measured. However, there has been research on the acoustic effects of emotional expression, perceptual differentiation and identification of emotions, and the relationships between respiration, emotion and loudness.

2.3.2.1. Acoustic effects of emotional expression

Scherer (1995) summarises research on the expressive aspects of speech and singing, concluding that for speech, pitch variability is associated with anger and joy, while sadness is associated with quieter speech and slower articulation. Sundberg, Iwarsson and Hagegard (1995) concluded from previous research that pitch aspects play a major role in communicating emotion in speech. They set up a study to explore emotional expression in operatic singing with an international opera singer, comparing musical examples sung both expressively and in a deliberately neutral way. Six expert listeners evaluated tapes of the performances for expressivity. Results indicated that tempo and overtone content were the best cues for expressivity. Loudness and rate of loudness variation showed variance, with agitated pieces displaying increased rates of loudness variations and faster tempos, and non-agitated pieces showing decreased rates of loudness variations and slower tempos. These results were in agreement with Kotlyar and Morosov (1976) who studied 11 singers performing the same music excerpts with different expressive input (joy, sorrow, anger, fear and neutrality). Their results showed that sadness was characterised by slower tempo reflected in longer syllable durations, while anger and happiness were louder. Anger also showed faster syllable onsets and decays.

2.3.2.2. Perceptual differentiation of emotion

Several studies have shown that listeners can mostly differentiate between different emotions expressed in singing (Sundberg 1994; 1997, and Scherer 1995). Sundberg (1998) also reviews expression in singing, concluding that listeners can mostly correctly interpret the emotional intention of singers. Sundberg relates these results to voice function, and is in agreement with the findings of Laukkanen, Vilkman, Alku and Oksanen (1997) for speech in suggesting that tenderness and sadness are communicated through low subglottal pressure and reduced glottal adduction, while more agitated moods are associated with high subglottal pressures.

Sundberg (1994) identified voice quality assessment criteria for classical solo singing, concluding that vocal expression has been an area neglected in research, and that it depends mainly on recognition of the sound patterns influenced by the general body language of emotional communication. Wapnick and Ekholm (1997) used 12 solo voice assessment criteria in a study on expert evaluation. The criteria were: (1) appropriate vibrato, (2) resonance/ring, (3) color/warmth, (4) intensity, (5) dynamic range, (6) efficient breath management, (7) evenness of registration, (8) flexibility, (9) freedom throughout vocal range, (10) intonation accuracy, (11) legato line, and (12) diction. Ekholm, Papagiannis and Chagnon (1998) extended this study using the first four criteria, which were able to be judged from a single sustained tone. They found that voice experts considered vibrato onset delay (even in onsets as small as 0.5 seconds) to be detrimental, contributing to lower ratings in other criteria. An unexpected finding was that perception of vibrato onset delay was not influenced by rate and extent of vibrato, which are generally thought to be critical factors in voice assessment (Sundberg 1987). In general, lower rate and larger extent for vibrato would lead to lower assessment levels. Although Ekholm et al. (1998) also found that vibrato amplitude was a critical parameter, their study points to the importance of the timing of vibrato onset. ‘Colour/warmth’ ratings were low in the absence of vibrato. ‘Resonance/ring’ ratings seemed to depend on higher mean vowel formant frequency.

Intensity was described by Ekholm et al. (1998) as 'clarity/focus', and showed particularly high correlation with 'resonance/ring' perception. Low within-subject correlations were found between ratings of entire excerpts and ratings of individual vowel segments of an excerpt.

2.3.2.3. Respiration and emotion

Emotional expression is commonly associated with particular respiratory activity (eg. sighs, laughter) and there has been extensive research on the variation in respiratory effect caused by different emotional states (Heim, Knapp, Vachon, Globus & Nemetz, 1968). Averill (1969) found that physiological reactions to stimulus films included sympathetic activation to both sadness and mirth, but that respiratory changes were predominant in mirth while cardiovascular changes were more characteristic of sadness.

Heim, Knapp, Vachon, Globus and Nemetz (1968) related emotional states in speaking subjects (asthmatic patients in therapy sessions) to variations in breathing. They found that respiratory amplitude more than respiratory rate (as found in previous studies) was a better indicator of emotion. Winkworth, Davis, Adams and Ellis (1995) found that some of the lung volume variation in the spontaneous speech of young women was associated with changes in mood state.

2.3.3. Acting studies

Performance disciplines understand that there is a relationship between respiration, emotion and vocalisation. It is argued that either changing the physical patterns including breathing, posture and facial expression will connect the performer to the emotion (Stanislavski 1963) or that invoking the emotion itself will give rise to the respiratory, postural and facial changes which will communicate that emotion. One acting method which seeks to incorporate both of these approaches is Grotowski's (1968), in which a two-way relationship between the emotional and the physical is established. What evidence is there for such a relationship?

Bloch, Lemeignan and Aguilera-T (1991) used facial, postural and respiratory actions from subjects reliving intense emotional experiences, to generate patterns for evoking specific emotional states in actors. The six emotional states studied by Bloch et al. (1991) show well-differentiated changes in breathing patterns. This gives some support to Ley's (1994) notion that there is a reciprocal relationship between emotion and breathing, because the findings of Bloch et al. (1991) suggest that either the emotion may give rise to the breathing pattern, or the breathing pattern may give rise to the emotion. It has also been found in the study of Bloch et al. (1991), that breathing and expression in actors learning the emotional state exercises progressed from an initial ‘robotic’ stage, with few changes in respiratory parameters, to a more ‘natural’ stage showing greater variability. Watson and Hixon (1996) show some support for the findings of Bloch et al. (1991) in their study of respiratory behaviour during the learning of a new aria by a highly trained classical singer, demonstrating increases in lung volume initiation and excursion as learning and memorisation progress towards convincing performance. These findings would suggest that not only is there a reciprocal relationship between breathing and emotion in vocalisation, but that it is a relationship which can be developed.

3. Intention to communicate

In performance, the professional singer fuses the technical, musical and literary aspects of singing by using a single, unifying concept at the inception of each phrase (as described by Miller 1986, and quoted in the preface of this thesis). This concept can be thought of as the singer's intention to communicate the emotional meaning of the music and words to the listener. For the professional singer, everything from the taking of the breath through to the phonated release of that breath in the form of sound, occurs as a response to this single unifying concept formed in order to communicate the meaning of what they are performing, rather than as a voluntary taking of the breath and making of the sound.

All effective performers, singers, and actors, in story-telling in all its forms, use intention to communicate to put across their story. The intention to communicate can be used whether or not the performer has developed a 'technique' (learned ability to use specific muscle combinations) with which to put across the story. The specific technique of operatic singing is unusual in that the muscle patterns which create it were discovered as a result of communicating emotion through exclamation (see section 1). Operatic technique itself can nevertheless, like any other technique, be used in real time with or without the intention to communicate to listeners.

The way the breath is taken has traditionally been the starting point for teaching operatic singing, and current international vocal pedagogy still holds to this (Miller, Ch. 26, in Sataloff 1998). Miller (1986) points out that errors in vocal technique are usually due to techniques of breath management, and also that technical singing skills are usually due to techniques of breath management. Acting studies have explored the use of specific breathing patterns to invoke specific emotions in actors, with a view to using these breathing patterns to induce emotion in an audience (Bloch et al.1991). Breathing patterns are associated with convincing and unconvincing singing, and with convincing performance. Does this mean that performance breathing may have a unique pattern discernible from rehearsal breathing? If this is the case, respiratory research with professional singers (who can differentiate between rehearsal and performance singing due to the particular demands of their profession) may contain variability which could be accounted for by specifying the condition.

The following original research sets out to compare breathing patterns in operatic singing for performance mode (using intention to communicate), with breathing patterns for rehearsal mode (using technical singing).

PART 2

Respiration in operatic singing: Intention to communicate

4. Literature review –

Experimental studies of breathing in speech and song.

4.1. Introduction

The purpose of this study was to measure respiratory parameters in operatic singing, comparing intention to communicate (performance mode) with technical singing (rehearsal mode). The main question was whether intention to communicate would result in a change in respiratory measures. The literature review provides the scientific background to this study, with reference to studies measuring respiration in speech and song.

Section 4.2. reviews the literature relating to the variables of vocal loudness mechanisms in speech and singing, as well as gender effects, while section 4.3. gives a critical summary of respiratory studies of operatic singing based on Konno and Mead's two-compartment model of respiratory measurement, which provides the theoretical basis for this investigation into respiratory patterns during singing. Section 4.4. summarises the aim of this study.

4.2. Variables in voice production measurement

4.2.1. Vocal loudness mechanisms (laryngeal and respiratory)

Decisive factors in vocal loudness (sound pressure level - SPL) are identified by Gauffin and Sundberg (1989) as primarily sub-glottal pressure, and indirectly, mode of phonation (from the extremes of breathy to pressed phonation, with the optimal flow phonation found between the two). Flow phonation results in maximum sound production for minimum subglottal pressure. The laryngeal mechanism increases vocal loudness by altering the glottal vibration such that the vocal folds close faster (increased adduction) and stay closed longer (increased adduction period), resulting in changes of the rate of flow through the glottis (Timcke, Leden & Moore 1958). This observation has been supported through studies using inverse filtering waveforms, showing vocal intensity increases accompanied by longer closed phase and sharper closing slope in the vocal fold vibrations (Holmberg, Hillman & Perkell 1988). These laryngeal changes are accompanied by increased loudness, with increased high frequency emphasis in the acoustic spectra (Monsen & Engebretson 1977). This supports the early finding of Muller (1837; in Bouhys, Proctor & Mead 1966) that increase of loudness is associated with increase of pitch in singing. Muller showed that to sing a tone louder, subglottic pressure must be increased, but this will also increase pitch unless vocal fold tension is simultaneously decreased. It has been shown by Gauffin and Sundberg (1989) using sung syllables at different degrees of loudness, that non-singers, compared with singers, increase pitch with an increase in loudness, and that this loudness is typically associated with a change of phonation towards a 'screaming sound' (Gauffin & Sundberg 1989). Singers, compared with non-singers, have learnt to manipulate pitch and loudness independently, and increases in loudness are not generally associated with changes of phonation towards the pressed extreme.

Respiratory mechanisms have been studied through measurements of both lung volume and sub-glottal pressure. In general, it seems that increased initiation lung volume (ILV) is used to achieve the higher subglottal pressures required for louder speech (Hixon, Goldman & Mead 1973; Hixon, Mead & Goldman 1976). It has been shown that subglottal pressure increases in conjunction with increases in loudness (Holmberg, Hillman & Perkell 1988; Isshiki 1964; 1965; and Tanaka & Gould 1983). However, in the early studies of Isshiki (1964; 1965) who showed that oral airflow, subglottic pressure and glottal resistance were important factors for regulating vocal loudness, the point was made that various combinations of laryngeal and respiratory factors can be used to produce vocal sounds of the same loudness. Stathopoulos and Sapienza (1993) also found different interactive patterns of the laryngeal and respiratory systems. Three of 20 subjects used primarily the expiratory mechanism for increasing vocal intensity, whereas two of 20 subjects used primarily the laryngeal mechanism for increasing vocal intensity. Another 15 subjects used a combination of both. Previous vocal training was not considered as a variable.

Only a few studies have addressed the relationship between acoustic output and respiratory function in singers. Bouhys, Proctor and Mead (1966) showed increases of subglottic pressure with increasing sound intensity in singers, but with variability in flow rates. However, these subjects were at varying levels of training. In a study on trained (male) classical singers, Leanderson, Sundberg and von Euler (1987) showed that diaphragm coactivation during phonation may have an effect on voice quality, tending to stabilize the vocal tract. Watson and Hixon (1996) found that increases in lung volume initiation levels were accompanied by increases in inspiratory flow, when a male classical singer developed from the initial learning of an aria through to performing it from memory as if for a paying audience.

4.2.2. Gender differences

Stathopoulos and Sapienza (1993) found that women initiated speech at a higher lung volume than men. Gibson, Pride, O'Cain and Quagliato (1976) found that 6 young men (24-29 yrs of age) showed higher lung recoil pressures at full inflation than 10 young women (21-31 yrs of age) or 6 elderly women (60-69 yrs of age). Maximum flow did not show gender differences. Cotes (1974) found a gender difference in speech between young men and young women after standardising for height, the difference being that young women have a smaller total lung capacity than young men. Ringqvist (1966) showed that respiratory pressures during speech in men are greater than in women. He looked at 94 women and 106 men, each divided into seven different age groups ranging from 18-83 yrs old.

Given that Cotes (1974) shows that even after standardising for height, young women have a smaller total lung capacity than young men; and that it has been shown by Ringqvist (1966) that men can generate higher respiratory pressures than women: Gibson et al. (1976) question whether a greater degree of lung distension in males was the sole reason for these gender differences. They found that the overall elastic properties of the lungs of young men and women were identical, and so respiratory muscle strength alone was not enough to account for gender differences in lung volumes.

Holmberg, Hillman and Perkell (1988) and Monsen and Engebretson (1977) both show glottal waveform differences between male and female voices, but Holmberg et al. (1988) show no difference in air pressure between male and female voices over three different loudness conditions.

Another group of studies found similar function of the respiratory systems of men and women (although without varying vocal intensity). Hoit, Hixon, Altman and Morgan (1989) found that gender had no effect on speech breathing when measures were normalised across comparable ages. Hodge and Rochet (1989) compared findings for young women with the findings of Hoit and Hixon (1986) for young men, and found that that there were no appreciable gender differences. However they did find an effect for height.

Women need to initiate at a higher ILV than men to achieve the same static recoil pressure, because lung volume is smaller in females (Stathopoulos & Sapienza 1993; Bode, Dosman, Martin, Ghezzo & Macklem 1976). Stathopoulos and Sapienza (1993) showed that higher lung and rib cage volumes achieve increases in tracheal pressure associated with increased loudness. Subjects were 10 men and 10 women between the ages of 20 and 30 years of age. Findings were in agreement with Holmberg et al. (1988), showing respiratory function differences between women and men, with ILV and rib cage volumes higher for women than for men.

Thomasson and Sundberg (1997) found that air expenditure per sung phrase was in the 40% vital capacity (VC) decade for females (2 sopranos, one mezzo), and in the 20% VC decade for males (4 baritones). Consequently the females showed a slightly higher flow rate (mode 6-8% VC/s) compared to the males (mode 4-6% VC/s). However, they did not find higher ILV in women than in men, as found by Stathopoulos and Sapienza (1993) for speaking. Watson and Hixon (1985) studied respiratory kinematics in 6 male classical singers, and Watson, Hixon, Stathopoulos and Sullivan (1990) studied respiratory kinematics in 4 female classical singers, finding no difference between their respiratory kinematics and those of the males in the Watson and Hixon (1985) study.

4.3. Respiration in singing

4.3.1. Measurement technology

Because of the need to measure respiratory function in speech and singing without obstructing the mouth, a variety of indirect measures of respiratory behaviour have been used. This section describes the important features of several techniques, with comments on their merits and shortcomings.

The body plethysmograph was used in an early, seminal study by Bouhys, Proctor and Mead (1966). In this impracticable form of measurement, the entire torso of the subject from the neck down is encased in a sealed enclosure. Lung volume measurements are obtained by the displacement of known volumes of air into and out of the sealed box, in which the subject sits.

Konno and Mead (1967) showed that adequate estimates of respiratory patterns could be obtained by measuring movement of the torso at only two points - on the rib cage and abdomen. Furthermore, by this method one can examine the relative contributions of rib cage and abdominal motion to the total volume of air breathed, and thus gain an insight into how different respiratory muscles behave. In this two-compartment model, measurements of the relative motion of chest wall at the two levels of rib cage and abdomen are summed to account for lung volume change. Displaced air volume results from the action of both levels. The diameter of both the rib cage and the abdomen have a linear relation to their volume displacements (Gould 1984). This two-compartment kinematic model (measuring respiration through movement of rib cage and abdomen) has been used in singing studies because of its noninvasive nature, allowing the singer to perform naturally without physical encumbrance.

Several technologies are commonly used to obtain rib cage and abdomen measurements. In the magnetometer method, the diameter measurements are obtained through the relationship between tuned pairs of electromagnetic coils, one of which transmits while the other receives a high-frequency AC electromagnetic field. In order to measure the anteroposterior diameter of the rib cage, one magnetometer is taped to the skin of the subject at the level of the sternum, and the other at the same level on the spine. To measure the diameter of the abdomen, another pair of magnetometers is usually placed at the umbilicus and at the same level on the spine. If the magnetometers remain parallel to each other, the output voltage is linearly related to the distance between the magnetometers of each pair. Limitations in the use of magnetometers are related to movement artifacts, and to the presence of large metal structures or electric motors in the environment which could affect voltage output. Magnetometer measures have been used in singing studies by Watson and Hixon (1985); Watson, Hoit, Lansing and Hixon (1989); Watson, Hixon, Stathopoulos and Sullivan (1990); Watson and Hixon (1996); and Hoit, Jenks, Watson and Cleveland (1996).

In the respiratory inductance plethysmography method, elasticised bands containing inductance wires are placed around the chest and abdomen of the subject. The bands sense changes in cross-sectional areas of the rib cage and abdomen, and reflect changes in lung volume by providing a sum of the two signals. Respiratory inductance plethysmography in the form of Respitrace has been used by Leanderson, Sundberg & von Euler (1987); and Thomasson & Sundberg (1997; 1999).

Respiratory activity can also be assessed by measuring the sub-glottal pressure by means of esophageal balloon (Bouhys, Proctor & Mead, 1966; Leanderson, Sundberg & von Euler 1987), and EMG activity in the respiratory muscles themselves (Watson, Hoit, Lansing & Hixon 1989). These measures, in combination with kinematic measures of movement and volume, provide a more complete picture of respiratory behaviour but are more invasive and hence make natural vocalisation more difficult.

4.3.2. Studies based on the two-compartment model

Since 1980, six main studies of respiration during operatic singing have used the theoretical basis of Konno and Mead's two-compartment model (1967) in which chest wall movement is used to measure rib cage and abdomen dimensions, the sum of which provide tidal volume. Four studies used magnetometers (Watson & Hixon 1985; Watson, Hoit, Lansing & Hixon 1989; Watson, Hixon, Stathopoulos & Sullivan 1990; Watson & Hixon 1996), and three used Respitrace (Leanderson, Sundberg & von Euler 1987; Thomasson & Sundberg 1997; 1999). Table 1 below summarises the voice types used in each of these studies, and Table 2 shows how many of each voice type were studied. Subjects numbered seven women and nineteen men, of which sixteen were baritones.

Watson and Hixon (1985) studied 6 male singers (all baritones), and found predominant abdominal lung volume displacement in most inspirations, followed by predominant rib cage lung volume displacement. Watson, Hoit, Lansing and Hixon (1989) studied 4 male singers (2 baritones, 1 bass baritone and 1 bass) also utilising EMG recordings of abdominal muscle activation, and found that the lateral abdominal region was more active than the middle, with abdominal EMG decrements with or just prior to inspiration and associated with kinematic recording of outward displacement of the abdomen.

Table 1. Gender differences in classical singing studies.

	CLASSICAL PROFESSIONAL SINGING		
	Males:	Thomasson & Sundberg (1997)	4 baritones
		Watson & Hixon (1996)	1 baritone
		Watson & Hixon (1985)	6 baritones
		Watson, Hoit, Lansing & Hixon (1989)	2 baritones 1 bass-baritone
		Leanderson, Sundberg & von Euler (1987)	3 baritones 1 tenor
	Females:	Thomasson & Sundberg (1997)	2 sopranos (1 pregnant) 1 mezzo
		Watson, Hixon, Stathopoulos & Sullivan (1990)	2 sopranos 2 mezzos
	CLASSICAL NON-PROFESSIONAL SINGING		
		Bouhys, Proctor & Mead (1966)	8 singers (type unidentified) rated: trained, untrained, experienced

Table 2. Voice types used in classical singing studies.

Baritones	16
Bass-baritones	1
Basses	1
Tenors	1
Sopranos	4
Mezzos	3

Watson and Hixon (1996) also used magnetometers, but this study was unique in that it looked at four sequential performances of a specially composed aria for one baritone, from sight reading in the first session to performing from memory as if for a paying audience in the fourth session. Sessions 3 and 4 showed 10% fewer breaths; a noticeable increase in variations of loudness; larger lung volume initiation, terminations and excursions; and in session 4, a higher average flow. This would seem to indicate a move towards flow phonation (highest ratio of output sound pressure to input tracheal pressure - Gauffin & Sundberg 1989). There was also a change in expiratory-inspiratory transitions in session 4, in those inspirations which had to be quick for musical reasons. These were characterised by use of the abdomen at the start of inspiration, followed by the rib cage. It was thought that this maximised the function of the diaphragm, so that it could adjust quickly to the expanded state.

Leanderson, Sundberg and von Euler (1987) used a combination of acoustic, kinematic and glottal flow measures. The pressure difference across the diaphragm was measured by means of a swallowed esophageal catheter with two pressure transducers; the lower one in the gastric ventricle and the upper one in the esophagus. This was combined with kinematic measurements made using Respitrace, and oral pressure measurements taken from a mouth catheter. The results suggested that increases in transdiaphragmatic activity caused phonation to move towards flow phonation and therefore away from pressed phonation. It was concluded that transdiaphragmatic activity stabilised vocal tract parameters, leading to a reduction in formant frequency variability.

Thomasson and Sundberg (1997; 1999) measured professional classical singers, both male and female, using Respitrace. The aim of this study was to increase understanding of breath control in classical singing in comparison to speech, using the Agostini and Mead (1964) concept that the magnitude of recoil forces in the lung depends on the lung volume. Pitch and loudness variables were not taken into account.

Thomasson and Sundberg (1997) concluded that for singing compared to speech, initiation lung volume (ILV) is substantially higher, termination lung volume (TLV) is similar, breath group volume (BGV - the difference between ILV and TLV) was three times larger, and normalised mean flow rate (NMFR - the ratio between BGV and phrase duration) was about twice as high. This suggests that greater static recoil forces have to be taken into account when singing, compared to speaking. Female singers showed lower TLV, larger BGV and higher NMFR than male singers, indicating that the female singers used slightly more of their vital capacity than the male singers, and may be using more air (see Tables 3 and 4 below for comparison of lung volumes from previous studies).

Table 3 – Initiation lung volume (ILV), termination lung volume (TLV) and lung volume expired (LV) for speaking and country singing.

			ILV (SD) (%VC)	TLV (SD) (%VC)	Lung Vol (%VC)
Country and Western professional singing:					
Males	Hoit, Jenks, Watson & Cleveland (1996)				
	6 males	singing	34-80	9-46	
Speaking:					
Males	Hixon, Goldman & Mead (1973)				
	Hixon, Mead & Goldman (1976)				
	6 males	non-singers:			
		conversation and normal reading	50-60	30-50	
		loud reading	60-80	40-70	
		louder speech	60-80	40-70	
Females	Winkworth, Davis, Ellis & Adams (1994)				
	6 young females:				
		reading	49(7)	36(6)	13
	Winkworth, Davis, Adams & Ellis (1995)				
	6 young females:				
		spontaneous speech	47(7)	35(7)	13

Table 4. Initiation lung volume (ILV), termination lung volume (TLV) and lung volume (LV) results from classical singing studies.

				ILV (SD) (%VC)	TLV(SD) (%VC)	Lung Vol (%VC)
Classical professional singing:						
Males	Thomasson & Sundberg (1997)					
		4 baritones:		66(15)	38(13)	28(13)
	Watson & Hixon (1996)					
		1 baritone:				
			sight reading	60(10)	21(14)	39(14)
			after practice	62(10)	20(15)	42(16)
			as if to p. aud. + music	75(7)	27(17)	48(18)
			as if to p. aud. - music	81(15)	25(23)	56(24)
	Watson & Hixon (1985)					
		6 baritones:		60-90	15-35	30-65
Females	Thomasson & Sundberg (1997)					
		3 females:		73(11)	30(13)	43(17)
	Watson, Hixon, Stathopoulos & Sullivan (1990)					
		4 females:		43-93	28-52	15-43
Classical non-professional singing:						
	Bouhys, Proctor & Mead (1966)					
		8 singers:				
			singing softly (p)	1.8 litres per phrase		
			singing loudly (ff)	2.3 litres per phrase		

4.4. Conclusion

As the Chapter 4 literature review has shown, there is a complex relationship between emotional expression, respiration and vocalisation in both singing and speech. However, it seems that emotional activation can alter vocal loudness in speech, both directly and via changes in respiration. The question arises as to whether the highly consistent lung volume behaviour shown by professional operatic singers can reflect specified changes in acted mood state, or intention. Previous research would suggest that performing with intention to communicate compared to rehearsing technically would increase respiratory parameters in the operatic singer.

Although intention to communicate in studies of operatic singing has not been specifically measured, the acoustic effects of emotional expression (section 2.3.2.1.) and the perceptual identification and differentiation of emotional expression in singing (section 2.3.2.2.) have been studied. There have also been studies of the relationship between respiration and emotion in speech (section 2.3.2.3.), and respiration and increased loudness in both speech and singing (section 4.2.1.). The variable of gender difference (section 4.2.2.) was shown to have a possible effect in studies using larger numbers of subjects, whereas loudness (section 4.2.1.) was shown to be an important variable to take into account in any study of emotion and vocalisation.

Previous respiration studies in singing have shown a wide range of results, as summarised in Tables 3 and 4. However, there are a few generalisations that can be made. Firstly, more air is used in operatic singing than in speaking, with higher ILV, lower TLV, and much longer breath groups. The static recoil forces are therefore greater at phrase initiation for operatic singing compared to speaking, but cover a wider range, with smaller forces at the end of phrases. Secondly, the amount of air used in singing depends heavily on the style of singing, with country and western singers showing little lung volume difference when comparing singing with speaking. Non-professional singing has been shown to use more air for louder singing compared to quieter singing.

Respiration studies have not previously used intention to communicate as a measured variable, although as discussed in section 2.3.2., different emotional states have been found to cause variation in respiratory effect (Heim et al. 1968). Changes of mood state have also been associated with lung volume variation in breathing patterns during spontaneous speech (Winkworth, Davis, Adams & Ellis 1995). Bloch, Lemeignan and Aguilera-T (1991) have used respiratory patterns from recalled emotional experience to evoke specific emotional states in actors, giving support to Ley's (1994) notion that there is a reciprocal relationship between emotion and breathing. Watson and Hixon (1996) show some support for the findings of Bloch et al. (1991) in the study of respiratory behaviour during stages of learning a new aria by a highly trained classical singer, showing an increase in lung volume initiation and excursion through rehearsal stages to final performance.

Previous research in the areas of speech breathing, and of quiet breathing (un-associated with speech), shows both substantial differences between subjects and surprising consistency within subjects even over time. Substantial inter-subject variability has been reported both for quiet breathing (Shea, Walter, Murphy & Guz 1987; Tobin, Mador, Guenther, Lodato and Sackner 1988), and for speech breathing (Wilder 1983; Hodge & Rochet 1989; Winkworth, Davis, Ellis & Adams 1994). *Intra*-subject consistency for lung volumes during speech has also been reported (Watson, Hixon, Stathopoulos & Sullivan 1990; Hixon et al 1973). As discussed in section 2.3.2.3., some of the variation in lung volume has been associated with mood state (Winkworth, Davis, Adams & Ellis 1995). It would seem from these results that there is a lot of variation in speech breathing between individuals, but also that individuals themselves can show consistency with their own speech breathing patterns.

Thomasson and Sundberg (1999) found highly consistent lung volume behaviour in professional operatic singers singing arias and art songs. Thomasson and Sundberg (1997) found greatly increased lung volume levels for performance mode operatic singing in comparison with speech breathing. The following study sets out to use the highly consistent lung volume behaviour of professional operatic singers to explore the issue of communication intention, and its possible effect on lung volume behaviour.

5. Method

This study examined whether comparison between singing technically and singing with intention to communicate in the performance of operatic singers showed changes in the respiratory variables of lung volume expired (LVE), and the initiation and termination points of lung volume expired, namely initiation lung volume (ILV) and termination lung volume (TLV). Other variables measured were the amount of air released per second (Flow) and the duration of inspiration (Ti) and expiration (Te). Sound pressure level (dB) was also measured so that possible influence on any effects could be taken into account.

This study also examined the ability of experienced listeners to distinguish between these intentions from recordings of the performances.

5.1. Singers

Singers were five opera singers: three baritones and two sopranos, all employed with Opera Australia. Three singers were professionally active operatic soloists and two were professionally employed opera choristers/soloists. Details of age, height, weight and professional experience are given in Table 5 (below). Mean performing experience was 18 years (range, 6-30 years). The singers were chosen (through recommendation by an internationally recognised adjudicator) for their ability to communicate to an audience.

Table 5. Singer information. Description of singer number, voice type, age, height, weight, vital capacity (VC), number of years performing, description of singing experience, choice of aria (and composer).

Singer	Voice type	Age	Height (cm)	Weight (kg)	VC (litres)	No. of yrs performing	General description	Aria	Composer
1	baritone (dramatic)	48	170	78	5.04	25	operatic soloist	*Pieta, rispetta amore*	Verdi
2	baritone (light)	49	168	70	3.74	21	operatic chorister and soloist	*Vedro mentr'io sospiro*	Mozart
3	baritone (lyric)	59	178	81	4.27	30	operatic soloist	*Mondo reo*	Verdi
4	soprano (coloratura)	27	165	55	3.41	7	operatic soloist	*O mio babbino caro*	Puccini
5	soprano (lyric)	24	170	79	3.61	6	operatic chorister and soloist	*Quando me'n vo'*	Puccini

5.2. Data recording

All data recording took place in a large acoustically treated television recording studio (80 square meters). Singers arrived at their allotted time and did not see or converse with each other. Singers 1 and 2 took part in the study on consecutive days, while singers 3, 4 and 5 took part in the study on the same day with 2 hours allotted to each singer. Singers brought their own written music, putting one copy on the stand in front of them and giving another copy to the accompanist to play from. Although singers knew their song and aria very well, the written music was used as a reference if necessary.

5.2.1. Equipment

- adjustable frame to position singers
  (custom made, as shown in photos 1, 3 and 4)
- electric piano (Yamaha Clavinova 811)
- free-field head-phones (Beyer Dynamic DT331)
- magnetometer system (GMG Scientific)
- computer acquisition/display system (MacLab S, AD Instruments)
- Chart 3.5 software (AD Instruments)
- syringe (3 litre Hans Rudolph)
- microphone (Rode NT2)
- DAT recorder (Tascam DA-P1)
- spirometer (PK Morgan 130A)
- noseclip
- CoolEdit software (Syntrillium)
- Lynx audio digital sound card
- Audiomedia II audio digital sound card (Digidesign)
- music stand

5.2.2. Magnetometers

Estimation of respiratory patterns was obtained according to the two-compartment non-invasive kinematic model using magnetometers (Konno & Mead 1967), as used in singing studies by Watson and Hixon (1985); Watson, Hoit, Lansing and Hixon (1989); Watson, Hixon, Stathopoulos and Sullivan (1990); Watson and Hixon (1996); and Hoit, Jenks, Watson and Cleveland (1996). The two-compartment model using magnetometers is described in detail in section 4.3. To calculate respiratory information during singing, measurement of torso movement was made at the rib cage and at the abdomen. To make this measurement, pairs of magnetometers were taped to the skin of the singers. The rib cage had one of a magnetometer pair taped to the singer's skin at the level of the sternum between the nipples, and the other of the magnetometer pair taped to the back of the singer, on the spine at the same level as the first magnetometer (rib cage anterior/posterior: RC AP). The rib cage also had a pair of magnetometers taped one on each side of the singer, at the level of the nipples (rib cage laterals: RC LATS) as shown in Photos 3, 4 and 5. The abdomen had one of a magnetometer pair taped to the singer's skin just above the umbilicus, and the other of the magnetometer pair taped to the singer's skin on the spine at the same level as the umbilicus (abdomen anterior\posterior: Abd. AP). The abdomen also had a pair of magnetometers taped one on each side of the singer at the level of the umbilicus (abdomen laterals: Abd. LATS). Care was taken to tape the magnetometers parallel to each other, as the output voltage is linearly related to the distance between the magnetometers of each pair.

5.2.3. Signal acquisition

The signals from the magnetometers (rib cage and abdominal motion; anterior/posterior, and lateral), spirometer and microphone, were monitored in real time and stored via the MacLab computer acquisition/display system and Chart software (Photo 7). The singing sound was sensed with a high-quality microphone positioned 40 cm from the singer's lips (see Photo 1) and recorded digitally on a DAT recorder.

Photo 1 - Singer positioned with frame; microphone distance

Photo 2 - Singer, head-phones, piano

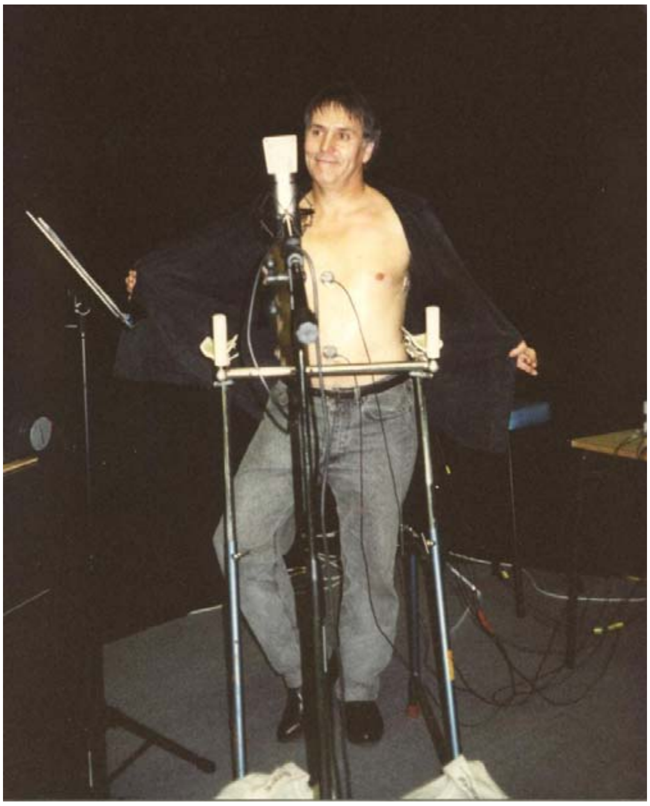


Photo 3 - Magnetometer attachment, anterior

Photo 4 - Magnetometer attachment – posterior

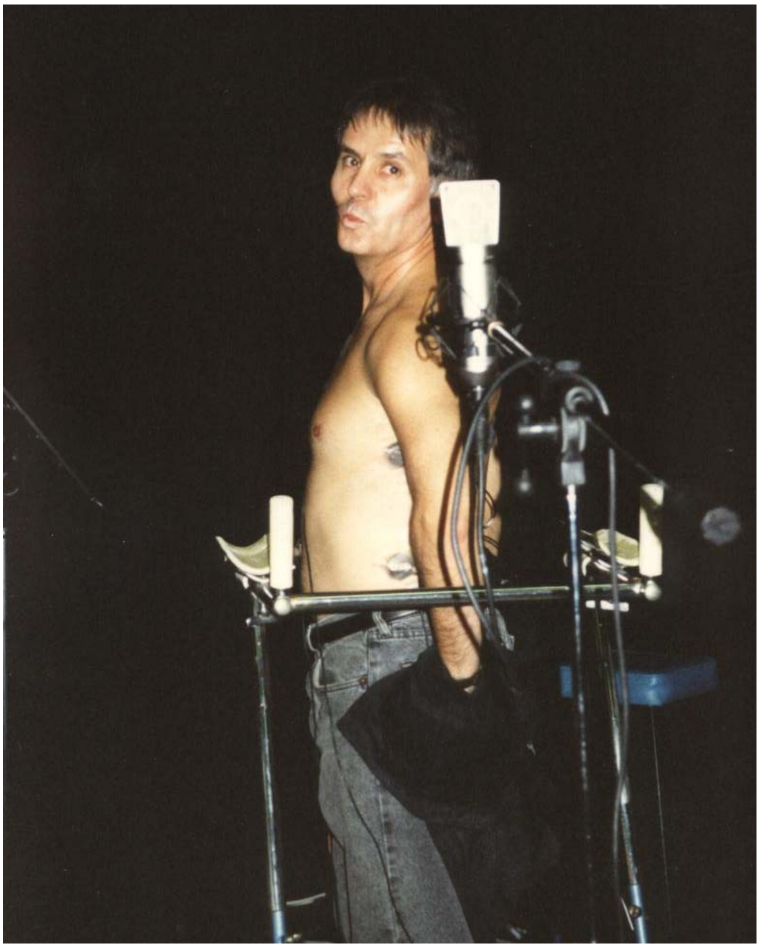


Photo 5 - Magnetometer attachment, laterals

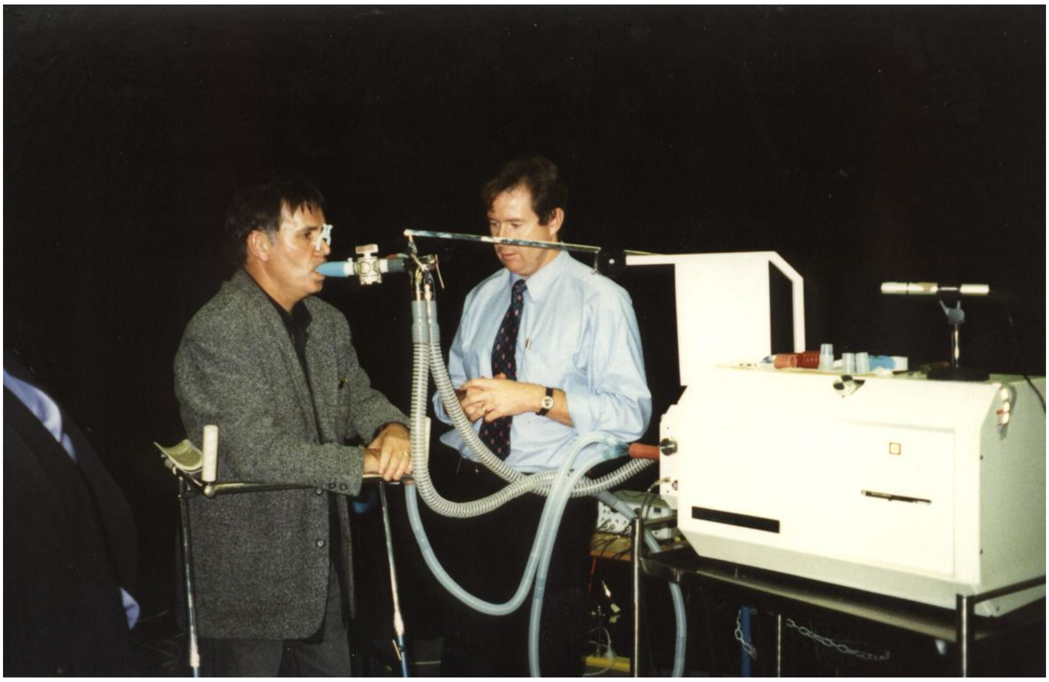


Photo 6 - Spirometer measurement

Photo 7 - Computer acquisition/display system

5.2.4. Calibration

For the purpose of calibrating the system for lung volume estimation, the singer was connected by a mouthpiece and wide-bore tubing to a volumetric spirometer (Photo 6). A noseclip was attached. The singer then performed the following respiratory and vocal tasks (Hixon, Goldman & Mead 1973; Hixon, Mead & Goldman 1976): a period of 3 to 5 minutes of quiet tidal breathing; relaxation against a resistance (for which the singer inspired to total lung capacity and then, as completely as possible, relaxed the respiratory apparatus with a closed glottis); vital capacity manoeuvres (in which the singer inspired to total lung capacity and then expired completely to residual volume); isovolume manoeuvres (in which the singer moved volume back and forth from rib cage to abdomen while the tubing to the spirometer was closed off, keeping the spine in the same position, with each manoeuvre taking from 5-10 seconds); and several long sustained notes into the mouthpiece.

Vital capacity was calibrated using a PK Morgan 130A spirometer calibrated with a 3L Hans Rudolph syringe. Vital capacity measurements were made in order to normalise the breathing ranges to allow for comparison between singers. The weighted rib cage and abdominal magnetometer signals were summed, and the signal was calibrated against the vital capacity manoeuvre to provide a measure of lung volume in %VC. The highest and lowest peaks were selected from the best of 3 similar VC manoeuvres. Isovolume manoeuvres were used to calculate the relative proportions of RC and ABD contributions to the sum signal, hereafter called LV. The sum signal was calculated as Sum = (RC + K1 x Abd - K2) x 100/K3. K1 was obtained from the relative movement of rib cage to abdomen during isovolume manoeuvres. K2 and K3 were then obtained from the weighted sum RC + Abd x K1 during the VC manoeuvres – K2 as the value at residual volume and K3 as the value at total lung capacity.

Following calibration, the singer was unencumbered and free of any connection to the mouth for all subsequent performances.

5.2.5. Positioning of singers

For singing the singers were standing, stabilised by resting their arms at a comfortable level on an adjustable frame placed around them (Photo 1). A professional accompanist was provided and the piano sound was conveyed to the singer via free-field head-phones capable of permitting the singer to hear their own voice unimpeded (Photo 2). This meant that singers could hear the accompanist and their own voice, but that the voice recording was not contaminated by the piano sound. Singers were asked to remain in the same position in relation to the frame while singing, and were also asked not to move their head while singing. A researcher was positioned next to the singer at all times during singing to remind them not to move, and to check that they did not do so. If the singer moved, the researcher was to indicate the fact to the computer operator, who was to note it at that point in the MacLab comment box, and then to ask the singer to start the take again.

5.2.6. Protocol

Information provided to the singers about the aim of the experiment was purposely vague, so as not to affect their behaviour. In particular, the participant information sheet stated: “We are interested in recording some aspects of your voice and body movements in operatic singing”. The magnetometers were described simply as “magnetic sensors on your upper body”, and the respiratory measurements made prior to singing were introduced as: “First, we would like to assess your lung function”. Singers were instructed to perform to their usual professional standard, but asked to sing in two different ways. In the technical (T) condition, singers were asked to sing ‘technically’ as if they were rehearsing; in the intention to communicate (IC) condition, singers were asked to sing as if they were communicating emotionally to an audience. In each condition, in one task (Aria task) singers sang a free-choice Italian aria from their repertoire (see Table 5), and in the other task (Song task) sang the song *Drink to me only with thine eyes.* This song was selected because it contains louder and softer sections, can be sung by singers of different voice types, and was well known by the singers. Each singer therefore had four singing takes (IC Aria, T Aria; IC Song, T Song). These takes were repeated. This resulted in eight different takes. These T and IC takes were repeated so that these takes could be combined, in order to enhance reliability of measurement in these conditions of primary concern. To the extent that there is consistency between takes, the measure can be considered reliable (Nunnally 1978).

Singers also performed four additional takes. The style of singing required for these takes was not familiar to participants and is not an acceptable way of singing within the operatic style, but was collected because of the need to consider Sound Pressure Level as a variable. Singers therefore were not asked to repeat these takes. In the technical loud (TL) condition, singers sang their chosen aria and the set song in a technically loud way; and in the technical soft (TS) condition they sang their chosen aria and the set song in a technically soft way. This resulted in an additional four takes for each singer. In total, therefore, singers performed 12 takes each.

Singers chose their own order of takes. Table 6 below shows their choices. Singers 1 and 2 both chose to sing the Aria first, while singers 3, 4 and 5 sang the Song first and the Aria second. Singers 3 and 4 chose the same order: Song followed by Aria, with two T takes followed by two IC takes, and lastly TL and TS. Singer 5, though also starting with Song; T, saved the IC takes until last because she said she 'wanted to save the easiest takes till last'. All singers chose to sing Aria IC takes as a pair, one after the other. For Song, this was also the case except for singer 1. The technical takes were performed one after the other for Aria (except for singer 5) and mostly one after the other for Song (with the exception of singers 5 and 1).

Singer	Take 1	Take 2	Take 3	Take 4	Take 5	Take 6	Take 7	Take 8	Take 9	Take 10	Take 11	Take 12
1	T1 Aria	T2 Aria	IC1 Aria	IC2 Aria	TL Aria	TS Aria	T1 Song	T2 Song	IC1 Song	IC2 Song	TL Song	TS Song
2	IC1 Aria	IC2 Aria	T1 Aria	T2 Aria	TL Aria	TS Aria	T1 Song	T2 Song	IC1 Song	IC2 Song	TL Song	TS Song
3	T1 Song	T2 Song	IC1 Song	IC2 Song	TL Song	TS Song	T1 Aria	T2 Aria	IC1 Aria	IC2 Aria	TL Aria	TS Aria
4	T1 Song	T2 Song	IC1 Song	IC2 Song	TL Song	TS Song	T1 Aria	T2 Aria	IC1 Aria	IC2 Aria	TL Aria	TS Aria
5	T1 Song	TL Song	TS Song	T2 Song	IC1 Song	IC2 Song	T1 Aria	TS Aria	TL Aria	T2 Aria	IC1 Aria	IC2 Aria

The singers' choices were not revealed to the accompanist (so that the accompanist did not influence the level of performance). Rather, after each take, the singer indicated which condition they had just completed by whispering to the experimenter (who was standing next to them). After each take, singers also marked how emotional they had felt (during that take) on an emotion gauge. The emotion gauge was a 5-point response scale where 1 indicated 'non-emotional', 3 indicated 'some emotion' and 5 indicated 'emotional but in control'. This allowed comparison between the amount of 'intention to communicate' that a singer intended, and what (s)he thought had actually been achieved. The emotion gauge was used as a personal indicator for these professional singers because for intention to communicate, the technical aspects of singing are fused with emotional connection (see section 3). If a singer had reported an inappropriate level of emotion for any take, (perhaps 'non-emotional' in an intention to communicate take), the take would have been repeated. Also, if the experimental procedure had distracted the singer from performing at the level they intended, the singer had a means of indication immediately after that take. The highest level on the emotion gauge was 'emotional but in control', indicating to singers that emotional connection was required, but not the full-blown emotion of bad performance described by Miller (1986, p. 202) as ‘publicly wallowing in private emotion’.

The singers consented to sing all 12 takes without any long breaks, as they were attached to the magnetometers. A glass of water was provided and the singers occasionally had a few seconds break and a sip of water. However, once they had finished the calibration procedures and started the protocol, there were no long pauses. The procedure lasted approximately three hours for Singer 1, and two hours each for the other singers.

5.3. Respiratory measurements

For each take, individual breaths (referred to from the musical point of view as phrases) were manually identified and marked on the lung volume sum trace within the Chart software. For each of the identified phrases, focus was on two variables: initiation lung volume (ILV) to identify how high the phrase breath was initiated in the Vital Capacity, and termination lung volume (TLV) to identify how low the phrase breath was terminated in the Vital Capacity. Two other variables also were calculated: lung volume expired (LVE = ILV-TLV), and Flow (% vital capacity expired per second). In addition, expiratory duration (Te) and inspiratory duration (Ti) were recorded (see Figure 4 below). Sound pressure level (SPL) was also recorded.

Information about 1,001 breaths was collected. Of these 1,001 breaths, 483 were breaths taken in the Song task, and 518 were breaths taken in the Aria task. In the IC (intention to communicate) condition, the two takes resulted in 345 breaths; and in the T condition (technical), the two takes resulted in 338 breaths. The TL (technical loud) condition resulted in 158 breaths, and the TS (technical soft) condition resulted in 160 breaths. For data analysis see section 6.1.

5.3.1. Matched respiratory data

Breaths were also examined for whether the singer started and finished phrases in the Song and Aria tasks at the same point for each condition. If a singer either breathed in the middle of a phrase, or joined two phrases together without breathing between them, at any point in any of the takes for that condition, that phrase (breath) was excluded from all of the takes for that particular singer. This resulted in a collection of musically matched data allowing phrase-by-phrase analysis. 762 of the 1,001 breaths satisfied this specification (239 were excluded). Of the 762 matched breaths, there were 306 for song and 456 for aria. The matched breaths consisted of

254 breaths for IC, 254 breaths for T, 127 breaths for TL, and 127 breaths for TS. Matched breaths for individual singers are shown in the Results section, Chapter 6.4.

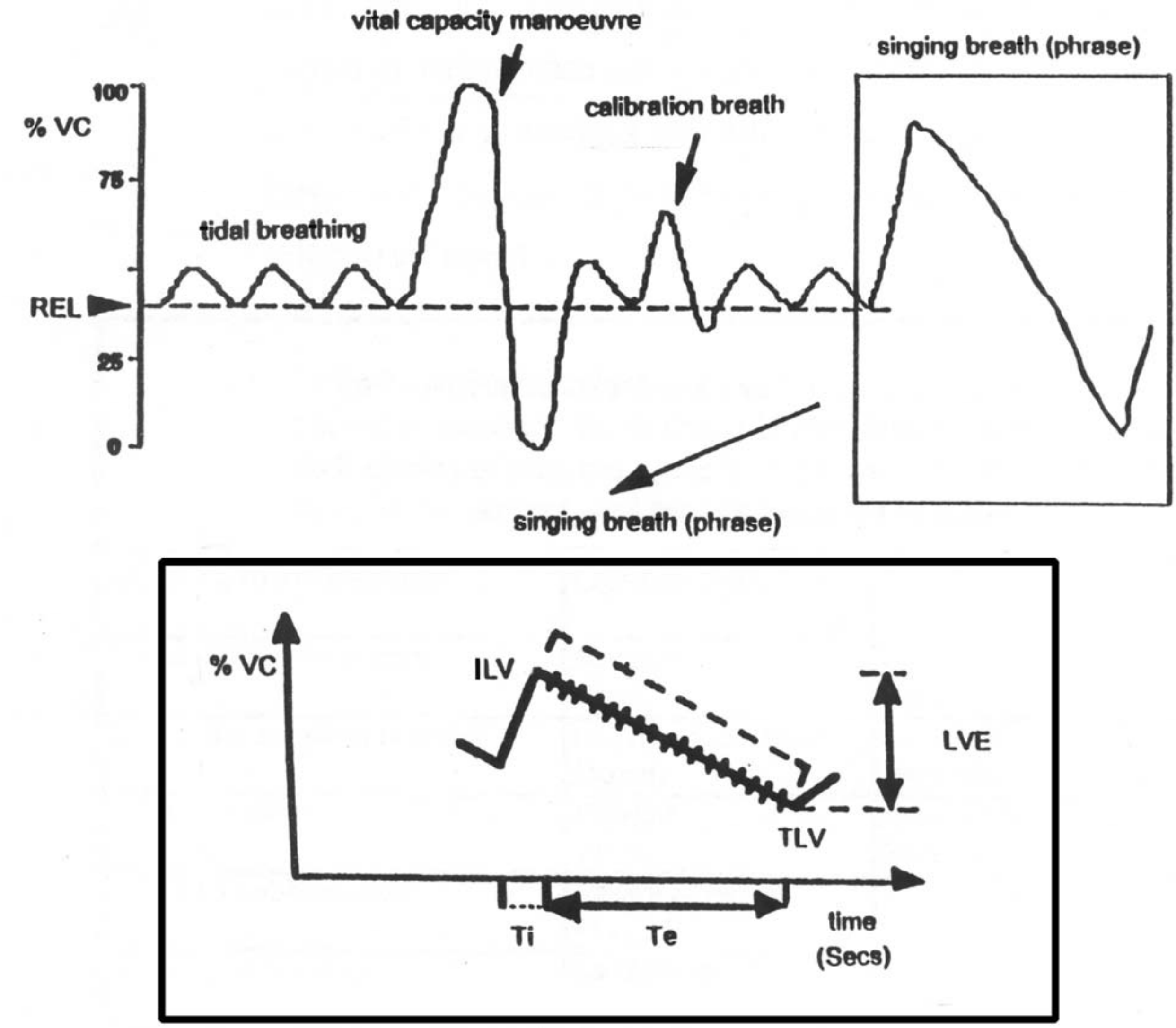


Figure 4. Schematic illustration of breathing variables (adapted from Winkworth 1995). REL = resting expiratory level, approximately 40% VC. VC = vital capacity. Inset indicates a singing breath (phrase), and shows how the variables were measured. ILV = initiation lung volume, TLV = termination lung volume, LVE = lung volume expired, Ti = inspiratory time, and Te = expiratory time.

5.4. Sound pressure level data collection

An index of loudness was also computed, giving a maximum score for sound pressure level for each phonated breath. Sound pressure level was normalised for each singer such that their maximum output across the 12 takes was called 0 dB. Even though a calibration tone was collected, technical difficulties resulted in the necessity of using normalised dB instead. DAT recordings were transferred to computer storage via a digital sound card (Audiomedia II, Digidesign) after which the extent of each phrase was identified and labelled with the aid of a sound editing program (Cool Edit, Syntrillium). Sampling rates were 40Hz. The maximum power within each phrase was then calculated, and raw values were converted to normalised SPL by adding the highest dB produced by a singer to each of that singer's scores, which made 0 the loudest score for each singer (with increased negativity showing decreased SPL).

5.5. Perceptual data collection

DAT recordings of the performances were played to four experienced listeners, whose professions involve assessment of operatic singers. The recordings used one phrase per singer (the phrase chosen for each singer is shown in Table 7 below), with the singer singing that same phrase with intention to communicate (IC), technically (T), and technically loud (TL). Every excerpt pair was sung by the same singer – choices were only intra-subject. The recordings were played with the male singers' recordings first, followed by the female singers. Within this gender separation, the recordings were presented in random order, as a paired comparison forced choice task. Gender separation was made on the recommendation of the artistic advisor to this study in order to prevent aural confusion in the listeners, as the male and female voice types are an octave apart. Also, context effects have been found to cause drift in listeners' voice ratings (Gerratt, Kreiman, Antonanzas-Barroso & Berke 1993).

The order of the recordings is shown in Appendix 7. For the study there was a written direction only, which was: 'Please circle the most emotionally convincing example in each pair, regardless of dynamic'. Any questions by the listeners were referred back to this statement. The excerpts were prepared firstly by making a selection of short musically complete statements of between 15 to 30 seconds from each take. The selections were made by an experienced opera singer (not one of the listeners) who was also a singing teacher at the University of Adelaide, a music graduate (B.Mus.Hons.), and a vocal examiner for the Australian Music Examinations Board. In making the selections, phrases in which the main point of each aria was musically summarised were chosen. This meant that each selection gave the singer the musical means with which to portray a strong message. The selections are specified in Table 7 below.

Table 7. Acoustic selections used in the perceptual test recordings played to listeners. Each singer is identified by number, followed by their choice of aria, the opera it came from, the composer, the words sung in the excerpt, and the bar numbers of the excerpt.

singer number & aria choice	opera & composer	words & bar numbers
1. Pieta, rispetto amore	*Macbeth* Verdi	"Ah! Sol la bestemmia" Bars 15 - 16
2. Vendro, mentr'io sospiro	*Le Nozze di Figaro* Mozart	"Ei posseder dovra?" Bars 14 - 15
3. Mondo reo	*Falstaff* Verdi	"Allor scomparira la vera virilita dal mondo" Bars 12 - 16
4. O mio babbino caro	*Gianni Schicchi* Puccini	"E se l'amassi indarno" Bars 15 - 16
5. Quando me'n vo	*La Boheme* Puccini	"Ma ti senti morir" Bars 49 - 50

Twelve pairs of excerpts were taken from the recordings of each of the five singers, consisting of the following 6 combinations for both song and aria: IC 1st take / Tech 1st take; IC 2nd take / Tech 1st take; IC 1st take / Tech 2nd take; IC 2nd take / Tech 2nd take; IC 1st take / TL; IC 2nd take / TL. Three of the 12 pairs from each singer were chosen at random to be repeated for reliability assessment, so that fifteen pairs in all came from each of the 5 singers. This resulted in 75 pairs in total. The order was then randomised for each gender and adjusted so that half of each pair presented the IC condition first in the pair, and half presented it second in the pair. The order of the pairings was then randomised as well. Master tapes for each gender were made from the excerpts using CoolEdit software, playing through a Lynx audio digital card in a PC. These tapes were played to individual listeners on DAT equipment using high quality headphones in a partially sound-proofed audio room. Excerpt 72 was found to be faulty and listeners were instructed to ignore it. This left 74 excerpt pairs, of which the first 45 compared male excerpts and the next 29 compared female excerpts. There were 37 Aria excerpts and 37 Song excerpts. A list of the order in which the excerpts were played, together with the repeated excerpts indicated, as well as the listeners' results, can be found in Appendix 7. Intra-rater reliability of the four listeners was assessed from the consistency of ratings for repeated excerpts.

6. Results

6.1. Introduction

Results are shown for both grouped data and then individual subjects separately to show inter-subject differences and to illustrate individual patterns.

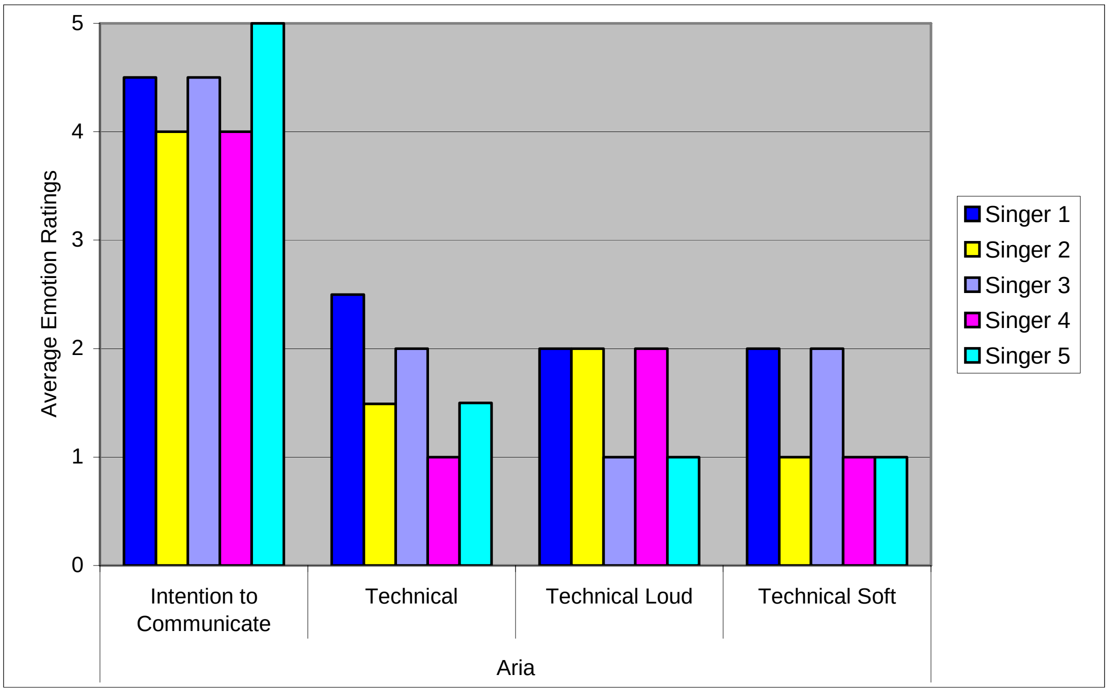
This results section begins with the emotion gauge results (section 6.2.) which indicate the level of emotion singers themselves believed that they had put into each take (immediately after singing that take) to differentiate between intention to communicate and technical takes (as described in section 5.2.6.). Repeated measures analysis of variance was used to analyse the results of the emotion gauge. Section 6.3. summarises the overall results (using Statview 4.5) in a table of means for all variables (Table 8) and identifies direction of change in respiratory parameters comparing across conditions (Figure 6a and 6b). To test the strength of the identified pattern, and to explore individual variability, data was then matched for phrasing across takes (using Statview 4.5), so that the only phrases examined were those in which the singer started and finished the breath at the same musical point in each of the six takes containing that phrase. After matching, the data was assessed for consistency within T and IC conditions using an intra-class correlation coefficient with Excel and SPSS soft-wear packages (section 6.4.1.). The matched data was then used to examine the relationship between T and IC conditions for all variables using t-tests (section 6.4.2.) and scattergrams (Figure 7). Significant patterns of difference were found when comparing lung volumes for the two conditions of primary interest (IC and T), so to explore the strength of these patterns, the data was ranked using the Friedman test (on Excel and SPSS soft-wear) (section 6.4.3. to 6.4.5, with a summary of ranking results in section 6.4.6.) The kinematic results are presented in section 6.5 to illustrate the strong individual differences found. Perceptual results are shown in section 6.6.

6.2. Emotion gauge.

As described in section 5.2.6., singers indicated after each take how emotional they had felt during that take, using a 5-point response scale where 1 indicated 'non-emotional', 3 indicated 'some emotion', and 5 indicated 'emotional but in control'. Figure 5 below shows singers' average self-ratings for Aria, and for Song conditions, for each type of take. This gauge was used to make an immediate check straight after each take as to whether the singer was satisfied that they had performed as they intended.

The pattern of ratings is clear: when singers performed the Song or Aria with the intention to communicate to an audience, they reported feeling greater emotion than when they were performing in a technical way, in a technically loud way, or in a technically soft way. Statistical testing provided evidence for this pattern. Looking first at the Song data, a repeated measures analysis of variance (ANOVA) showed that the effect of condition (IC, T, TL, TS) was strong and significant ($F(1,4) = 41.93$, $p = .003$). Post hoc tests showed that as expected, singers reported greater emotion in the Intention to Communicate condition than in the Technical condition ($t(4) = 6.08$, $p = .004$), than in the Technical Loud condition ($t(4) = 23.47$, $p < .001$), and than in the Technical Soft condition ($t(4) = 4.83$, $p = .008$).

Similarly, a repeated measures ANOVA showed similar results for the Aria data: the effect of condition (IC, T, TL, TS) was strong and significant ($F(1,4) = 112.53$, $p < .001$). Post hoc tests also showed that singers reported greater emotion in the Intention to Communicate condition than in the Technical condition ($t(4) = 10.61$, $p < .001$), than in the Technical Loud condition ($t(4) = 6.89$, $p = .002$), and than in the Technical Soft condition ($t(4) = 10.95$, $p < .001$).



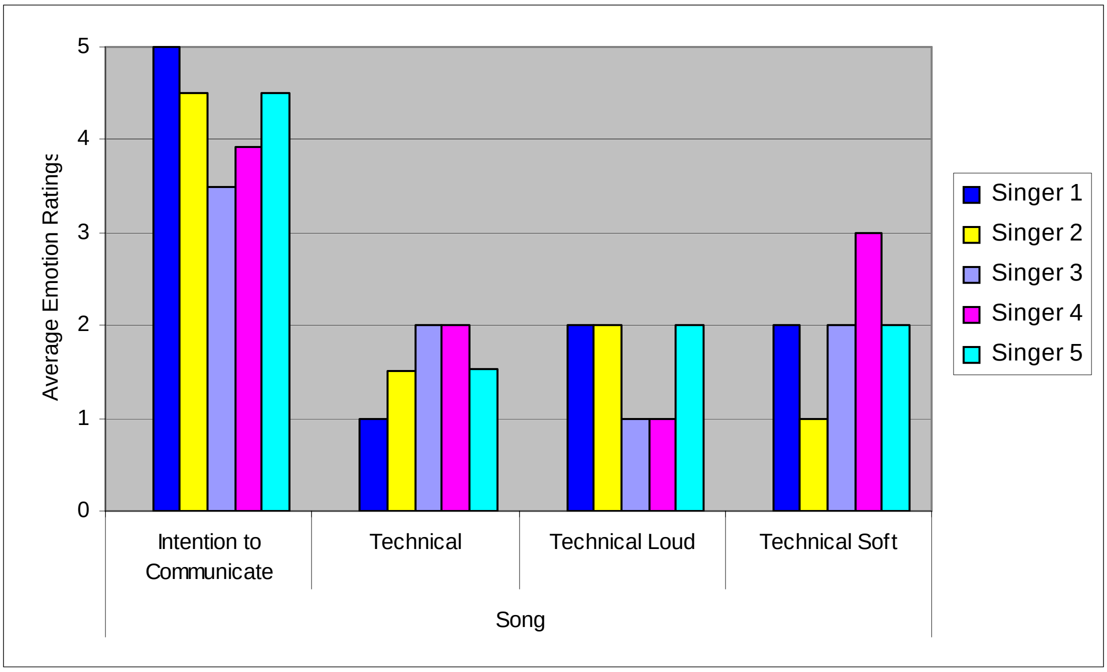


Figure 5. Emotion gauge. Singers average self-rating of emotion level after performing the Aria and Song tasks for each condition. 1 indicates 'non-emotional', 3 indicates 'some emotion', and 5 indicates 'emotional but in control'.

6.3. Complete respiratory data

Table 8 below shows the mean and standard deviation for each measure for female (*N* = 2) and male (*N* = 3) singers individually in each condition, as well as these descriptive statistics when data for all singers is combined. This presentation is consistent with the presentation of data in previous studies (see Tables 3 and 4). From this data set, Figure 6a below compares conditions, showing means for each variable, with combined task results (Aria and Song) as well as a comparison between the two different tasks.

As shown in Figure 6a, the main difference between IC and the technical conditions is a large increase in Flow, particularly for the Aria task. Overall, IC (shown in black), compared to the Technical conditions, shows higher ILV, lower TLV, higher LVE, and a greater amount of Flow. Expiratory and inspiratory duration did not show much difference between conditions (as indicated by the amount of standard deviation), and SPL for IC was lower than TL, and higher than TS.

Table 8. Complete data. Mean and standard deviation for each measure for female ($N = 2$) and male ($N = 3$) singers, as well as descriptive statistics across all singers in each condition.

			Intention to Communicate	Technical	Technical Loud	Technical Soft
ILV (Initiation Lung Volume) % VC	Aria	All	77 (12)	72 (11)	74(12)	70(12)
		Females	79 (12)	76 (14)	82(10)	71(15)
		Males	76 (11)	69 (9)	67(10)	69(10)
	Song	All	73(11)	68(11)	72(11)	68(11)
		Females	72(11)	66(13)	81(10)	66(13)
		Males	74(10)	70(10)	68(9)	68(10)
TLV (Termination Lung Volume) % VC	Aria	All	31(15)	38(11)	36(14)	40(12)
		Females	33(13)	41(10)	39(13)	44(13)
		Males	30(16)	36(12)	33(13)	38(11)
	Song	All	25(16)	28(15)	25(13)	25(17)
		Females	30(11)	35(12)	34(12)	33(14)
		Males	22(18)	24(15)	21(12)	21(17)
LVE (Lung Volume Expired) % VC	Aria	All	46(16)	34(13)	38(15)	29(12)
		Females	46(13)	35(10)	43(12)	27(9)
		Males	46(18)	33(15)	34(17)	31(14)
	Song	All	48(13)	40(13)	47(11)	42(15)
		Females	42(10)	31(8)	46(10)	34(9)
		Males	52(14)	45(13)	47(12)	47(16)
Flow (% VC expired per second)	Aria	All	8.9(3.9)	6.6(2.1)	7.3(2.1)	5.6(2.5)
		Females	7.2(2.4)	5.4(1.4)	6.5(1.3)	3.8(1.5)
		Males	10.2(4.3)	7.4(2.1)	7.8(2.4)	6.9(2.4)
	Song	All	6.6(1.8)	5.5(1.8)	6.4(1.3)	5.7(2.5)
		Females	6.2(1.8)	4.4(1.3)	5.8(1.0)	4.0(0.8)
		Males	6.8(1.7)	6.2(1.5)	6.7(1.3)	6.7(2.6)
Ti (inspiratory duration in secs)	Aria	All	.57(.35)	.68(.33)	.60(.32)	.61(.36)
		Females	.52(.34)	.67(.36)	.58(.32)	.63(.39)
		Males	.61(.35)	.69(.30)	.60(.32)	.59(.34)
	Song	All	.62(.26)	.64(.26)	.62(.22)	.63(.28)
		Females	.60(.28)	.64(.29)	.59(.24)	.71(.32)
		Males	.63(.25)	.65(.25)	.59(.24)	.59(.25)
Te (expiratory duration in secs)	Aria	All	5.4(2.6)	5.2(2.3)	5.1(2.3)	5.4(2.8)
		Females	5.8(1.9)	5.9(1.7)	5.8(1.6)	6.1(2.3)
		Males	5.1(2.9)	4.7(2.5)	4.6(2.7)	4.9(3.0)
	Song	All	6.9(1.5)	6.7(1.6)	6.9(1.1)	7.4(2.1)
		Females	6.2(1.5)	6.5(1.9)	7.5(2.8)	7.8(2.6)
		Males	7.3(1.4)	6.8(1.3)	6.6(1.4)	7.1(1.8)
SPL (Sound Pressure Level, in dB. Normalized: 0 = loudest)	Aria	All	-8 (5)	- 11 (5)	- 8 (5)	- 17 (5)
		Females	-8(6)	-9(6)	-7(5)	-15(5)
		Males	-10(5)	-12(5)	-9(4)	-18(5)
	Song	All	-17(6)	-17(6)	-13(3)	-22(5)
		Females	-18(4)	-19(4)	-15(3)	-22(3)
		Males	-17(7)	-16(7)	-12(3)	-23(5)

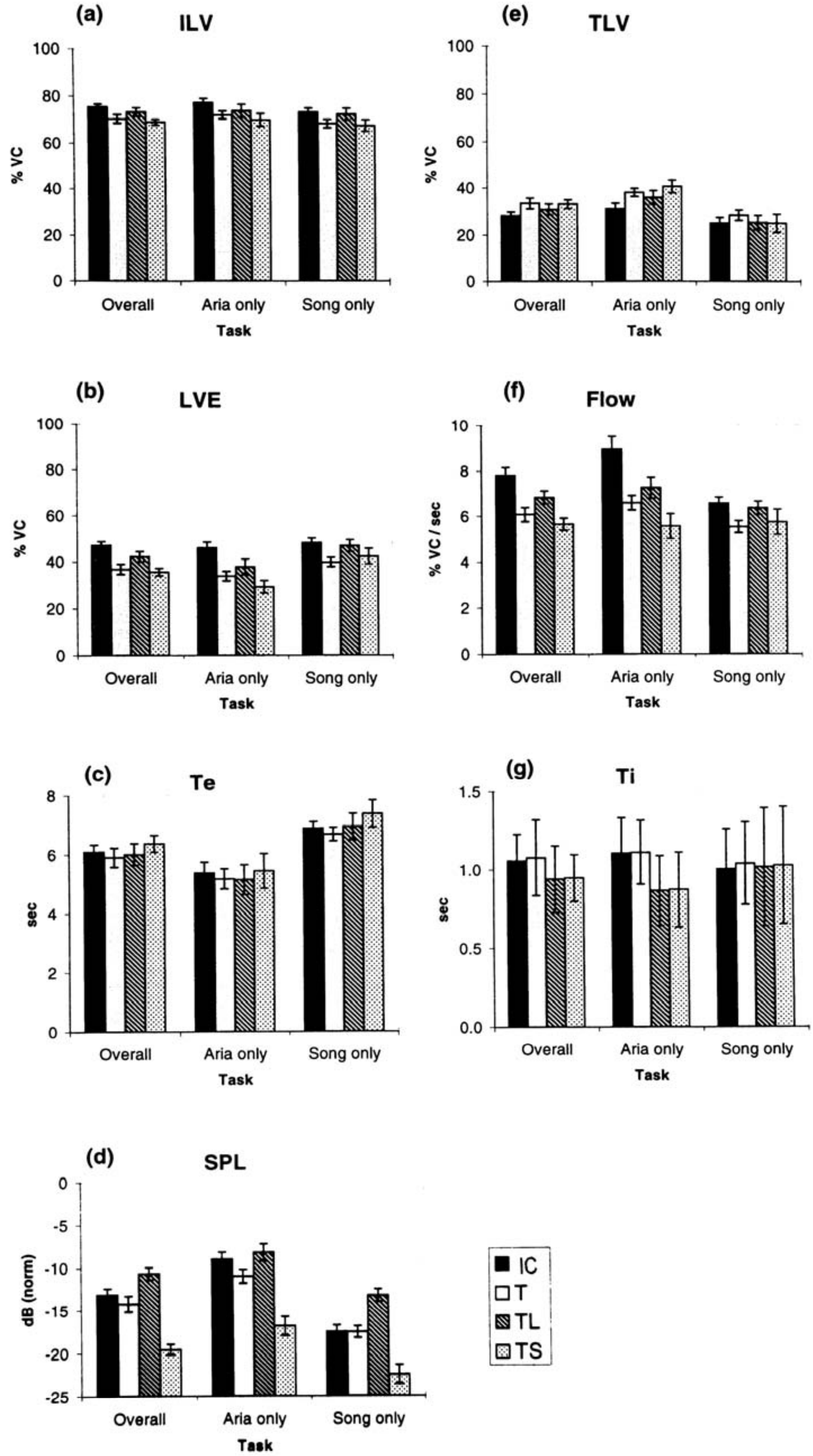
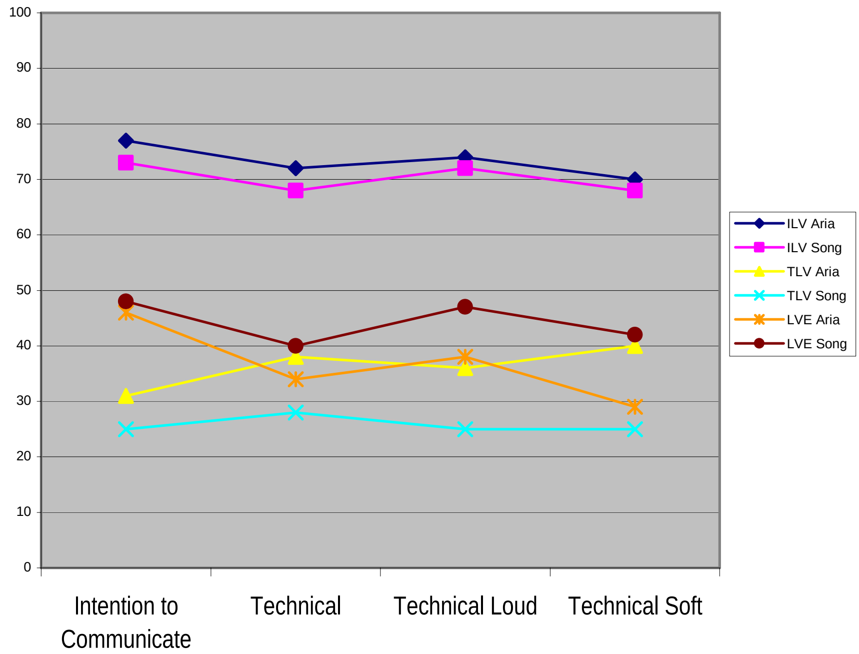


Figure 6a. Complete respiratory data (ILV, TLV, LVE, Flow, Te and Ti) and SPL (normalised dB). Bar charts showing all conditions (IC,T,TL and TS) and all singers (5). Mean (and standard deviation) taken from each breath for all data, and for Song and Aria tasks separately.

Figure 6b below compares means for Initiation Lung Volume (ILV), Termination Lung Volume (TLV), and Lung Volume Expired (LVE) for all five singers in each condition, for both Song and Aria tasks. This figure demonstrates the direction of change and relationship between respiratory parameters in the complete data, comparing across conditions. For IC compared to the other conditions, there is a rise in LVE and ILV and a fall in TLV, in both Aria and Song tasks.



In summary then, for the complete respiratory data before matching of phrases, the average ILV was higher for IC than for the other three conditions, with 75% VC for IC, 70% for T, 73% for TL, and 69% for TS. The average TLV was lower for IC than for the other three conditions, with 28% VC for IC, 31% for TL, and 33% for both T and TS. SPL was lower for IC singing than for TL, and was higher for IC singing than for T. Flow (%VC per second) was greater for IC than for the Technical conditions. There was little difference for Te and Ti shown between conditions.
To test the significance and strength of the patterns found in the complete data, and to explore individual variability, the next step was to compare only matched phrases of the data.

6.4. Matched respiratory data

(Data matched for phrasing across takes)

To match the phrases, the data presented in Table 8 were examined for whether the singer started and finished phrases of the song and aria at the same point in each of the 6 takes. Of the 1001 breaths, 762 satisfied this specification (239 breaths were excluded).

For these 762 breaths, Table 9 below shows the number of musical phrases for Song and for Aria that were analysed for each singer. Each phrase of music was sung six times by each singer (IC, IC, T, T, TL, TS).

Singers	Song Phrases	Aria Phrases	Total number of matched breaths
1	14 X 6 = 84	19 x 6 = 114	84 + 114 = 198
2	12 X 6 = 72	20 x 6 = 120	72 + 120 = 192
3	11 x 6 = 66	8 x 6 = 48	66 + 48 = 114
4	2 x 6 = 12	12 x 6 = 72	12 + 72 = 84
5	12 x 6 = 72	17 x 6 = 102	72 + 102 = 174

6.4.1. Consistency of performance in IC and T conditions

As described in section 5.2.6., in the IC and T conditions, each singer sang the aria and song twice in the IC and twice in the T conditions. Consistency of performance in these two takes was examined using an intra-class correlation coefficient. Unlike the Pearson's correlation coefficient, this statistic takes similarity that may occur by chance into account. The correlation was computed by treating each phrase as an independent observation. Using the SPSS statistics package, the intra-class correlation between the two takes was calculated for each measure. Its associated F statistic and probability is reported in Table 10.

As mentioned, it was intended that data collected in the repetitions of the Song and Aria tasks would be combined to enhance the reliability of the measures. To the extent that the repetitions were consistent, the final calculated measure of each dependent variable (i.e., ILV, TLV, LVE, Te, Ti, Flow, and dB) could be considered reliable.

For each dependent variable (ILV, TLV, LVE, Te, Ti, Flow, and dB), consistency was strong and significant (*ps* < *.001)*. Measures for which consistency indicators are above the .70 magnitude demonstrate acceptable reliability (Nunnally 1978), and support the strategy of combining data from the two takes.

Table 10 below shows the correlations and calculated F values, as well as the confidence intervals for each correlation. It can be seen that the magnitude of the relation between repetitions means that reliability of measures that combine data from the two takes can be considered acceptable. For measures other than Flow, for which the relations between repetitions were .74 (IC condition) to .78 (T condition), the reliability was high (Nunnally 1978).

Table 10. Matched data. Intra-class correlations. Consistency of performance for within-condition repeats (IC and T): correlations and calculated F values.

Variable	Condition	
	IC (Intention to Communicate)	T (Technical)
ILV (Initiation Lung Volume)	.80 [.73-.86] $F = 9.24$, $p < .001$	.84 [.77 -.88] $F = 11.14$, $p < .001$
TLV (Termination Lung Volume)	.89 [.85-.92] $F = 17.60$, $p < .001$	.90 [.85-.93] $F = 18.11$, $p < .001$
LVE (Lung Volume Expired)	.88 [.83-.91] $F = 15.10$, $p < .001$	.90 [.86-93] $F = 18.96$, $p < .001$
Ti (Inspiratory Time)	.99 [.97-.99] $F = 96.09$, $p < .001$	.97 [.96-.98] $F = 79.68$, $p < .001$
Te (Expiratory time)	.98 [.98-.99] $F = 118.94$, $p < .001$	.96 [.94-.97] $F = 49.28$, $p < .001$
Flow (%VC/sec)	.74 [.66-.81] $F = 6.82$, $p < .001$	.78 [.70-.84] $F = 7.98$, $p < .001$
SPL (decibels)	.91 [.87-.94] $F = 21.02$, $p < .001$	.93 [.90 -.95] $F = 27.62$, $p < .001$

6.4.2. Matched respiratory data scattergram

The scattergram shown in Figure 7 (and the scattergrams in Appendix 3 to 6) also use the phrases that could be musically matched (see section 5.3.1). Each group of matched breaths (in other words, each musical phrase) is represented by a point (a black circle for the Aria task, a white circle for the Song task) at the position specified by the parameter values obtained in each of the two conditions compared. The averaged IC condition is compared with the averaged T condition in Figure 7 (and with the TL condition in Appendix 3).

For the matched-phrase data in Figure 7 (and Appendix 3), the most striking effect is seen for Flow, (Figure 7f), which for IC Aria singing shows a significantly larger percentage of VC released per second than T (in other words, for 7f, most of the black dots are on the IC side of the diagonal line).

In Figure 7a, ILV, there is a greater density of points on the IC side of the line, indicating that initiation lung volume was higher for most phrases in the IC condition compared to T. Figure 7e, TLV, shows a greater number of points on the T side of the line, implying that TLV was lower for IC than for T singing. TLV was lower for IC in the Aria task and also slightly lower for Song. Figure 7b, LVE, shows a greater percentage of lung volume (VC) expired per second for IC compared to T singing (especially for Aria). Figure 7c, Te (expiratory duration) shows results lining up without big differences, although IC is slightly longer in duration than T. Although expiratory durations (Te) were more similar than the lung volume and flow parameters, the IC condition shows slightly longer durations than the T condition. Figure 7g shows that inspiratory durations (Ti) were similar.

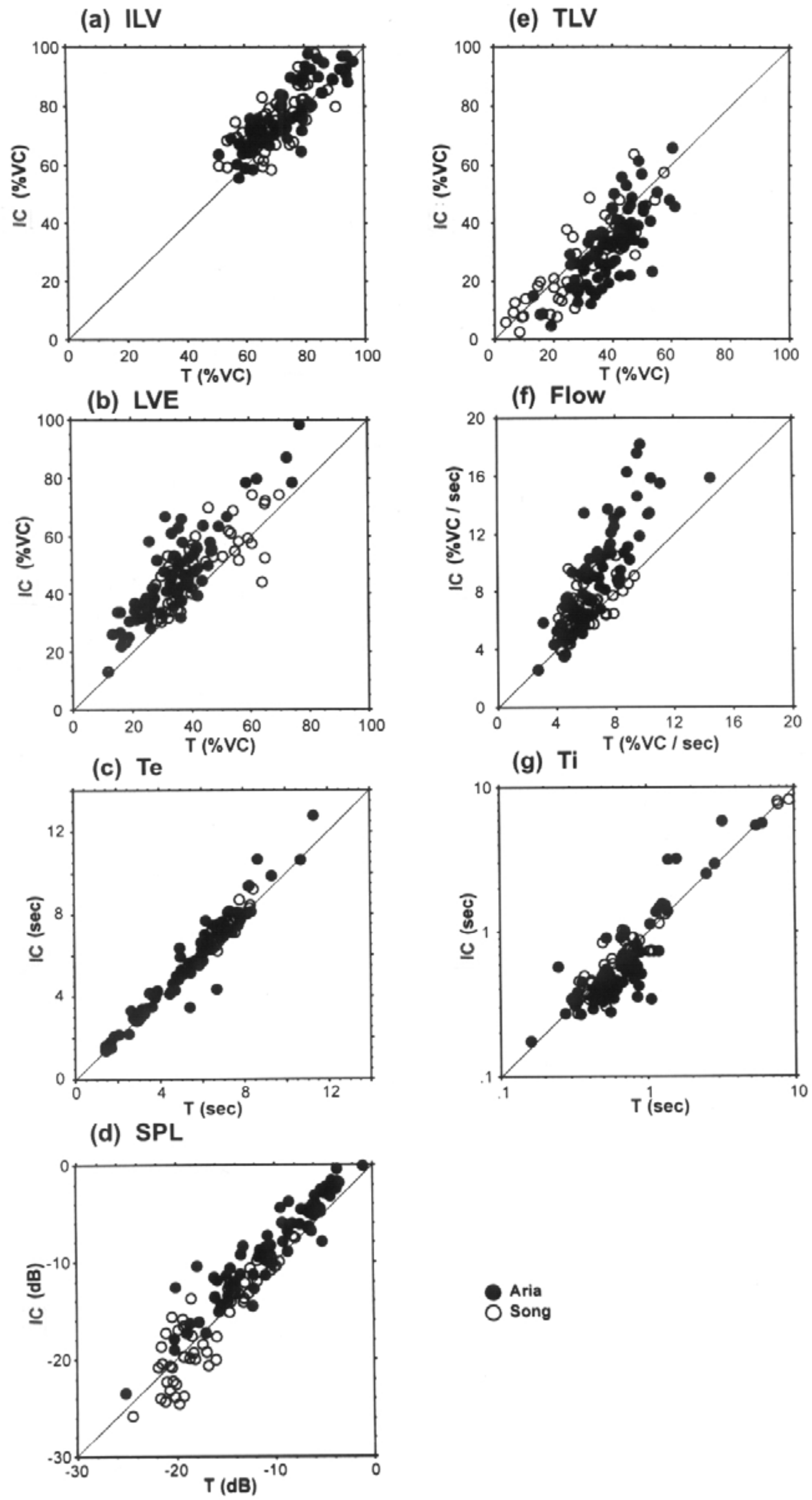


Figure 7 – Matched data. Scattergrams of means using musically matched phrases (breaths), comparing the conditions IC and T across all variables: ILV, TLV, LVE, Flow (%LVE per second), Te, Ti and SPL (normalised dB).

6.4.3. Patterns of breathing

The hypothesis that respiratory parameters would show a consistent pattern that was related to the condition was examined. As described in section 5.2.6., singers sang in four different ways. Two of these were the conditions of primary concern: the IC condition (singing with intention to communicate as if to an audience), and the T condition (singing technically, as if rehearsing). There were also two additional technical conditions; TL (technical loud) and TS (technical soft), resulting in a total of four different conditions.

Because the hypothesis concerned *patterns* of indicators rather than differences in the levels of the respiratory parameters, repeated measures analysis of variance was not appropriate. Rather, distribution-free (non-parametric) tests were used because these tests are specifically designed to test hypotheses about central tendencies and shapes of distributions (e.g. Shavelson 1988), and are not affected by outliers (e.g. Howell 1992). In this context, individual variability will not influence the detection of patterns in the data.

The Friedman test was used in the main analyses that follow. It is the nonparametric equivalent of a standard repeated measures analysis of variance applied to ranks instead of raw scores. The test statistic is based on ranking. Thus, for each dependent measure, calculations involve the ranking of the respiratory parameter for each phrase. For each phrase, the condition in which the parameter is highest would receive the highest ranking (i.e., 4), and the condition in which the parameter is the lowest would receive the lowest ranking (i.e., 1).

In the Friedman test, if the null hypothesis were true, then it would be expected that the rankings would be randomly distributed for each phrase in each condition, implying that for one phrase a respiratory parameter might be higher in the IC condition than in the others, in another the parameter might be higher in the T condition than in the others, and so on. That is, the sum of the rankings in each condition would be approximately equal.

The pattern expected is that lung volume parameters will be greatest when singers are intending to communicate with an audience (i.e., in the IC condition). This is expected to be reflected in higher initiation lung volumes and lower termination lung volumes, greater amount of air flow per second, and longer inspiratory time. These increased lung volume parameters are not expected to be simply caused by increased duration or loudness of sung phrases.

6.4.4. Use of Air: Aria task ranking

6.4.4.1. Aria Task: Lung Volume Expired (LVE)

First, each phrase was examined as an independent observation. As shown in Table 9 earlier, for the Aria task singer 1 produced 19 phrases (x 6 = 114 breaths) that began and ended at the same point in each of the four conditions; singer 2 produced 20 phrases (x 6 = 120 breaths); singer 3 produced 8 phrases (x 6 = 48 breaths); singer 4 produced 12 phrases (x 6 = 72 breaths); and singer 5 produced 17 phrases (x 6 = 102 breaths) in the Aria task.

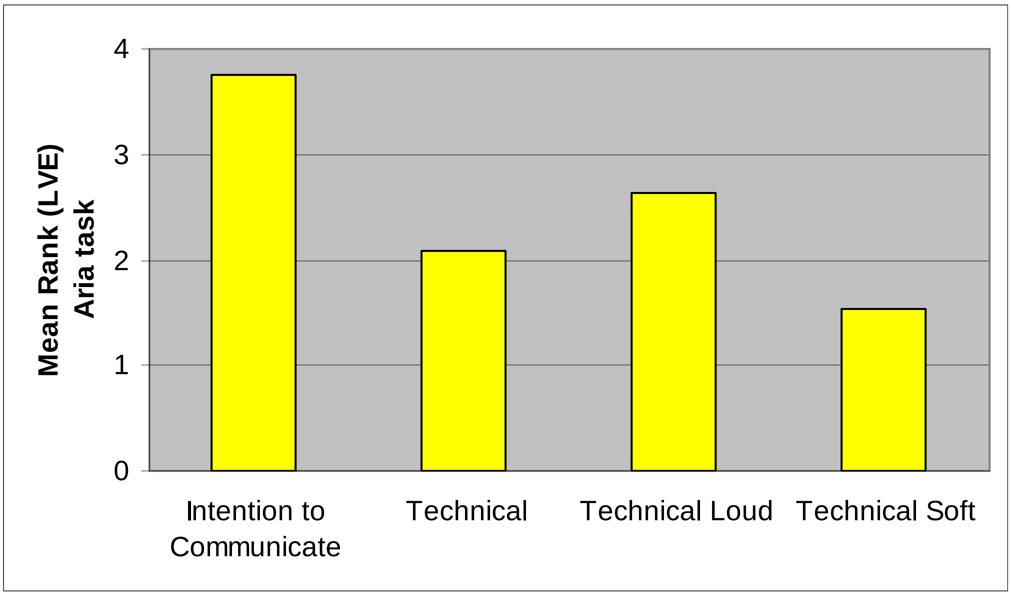
Table 11 below shows the mean and standard deviation, as well as the minimum and maximum score, for LVE in these 76 phrases (456 breaths) for the Aria task. The pattern of means shows that LVE is highest in the IC condition, as expected.

Table 11. Matched data. Aria task: LVE (lung volume expired, in % VC). Mean and standard deviation, minimum and maximum score; for conditions IC, T, TL, TS.

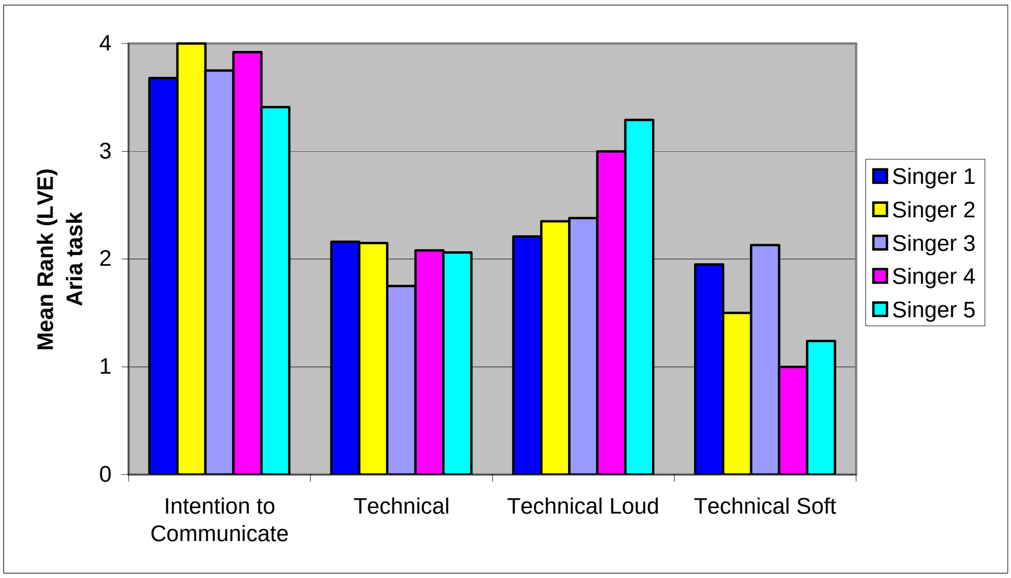
	Mean	Std. Deviation	Minimum	Maximum
Intention to Communicate	45.31	15.62	13.27	98.54
Technical	33.71	13.26	11.84	76.80
Technical Loud	37.56	15.45	9.68	84.57
Technical Soft	30.15	12.09	10.70	79.88

The hypothesis that LVE would be related to condition was supported (X^2_3 = 122.20, $p < .001$). On average, highest ranking (3.75) of LVE was in the IC condition. Figure 8 below shows the average of ranks in each condition.

The more specific hypothesis that LVE would be higher in the IC condition than in the T condition was also supported ($t(75) = 12.98$, $p < .001$).



When phrases were examined for each singer separately, LVE was significantly related to condition (singer 1: X^2_3 = 21.76, $p < .001$; singer 2: X^2_3 = 40.74, $p < .001$; singer 3: X^2_3 = 10.95, $p = .01$; singer 4: X^2_3 = 33.70, $p < .001$; singer 5: X^2_3 = 33.21, $p < .001$). For each singer, ranking was higher in the IC condition than other conditions. Figure 9 below shows the average rank for each singer in each condition.

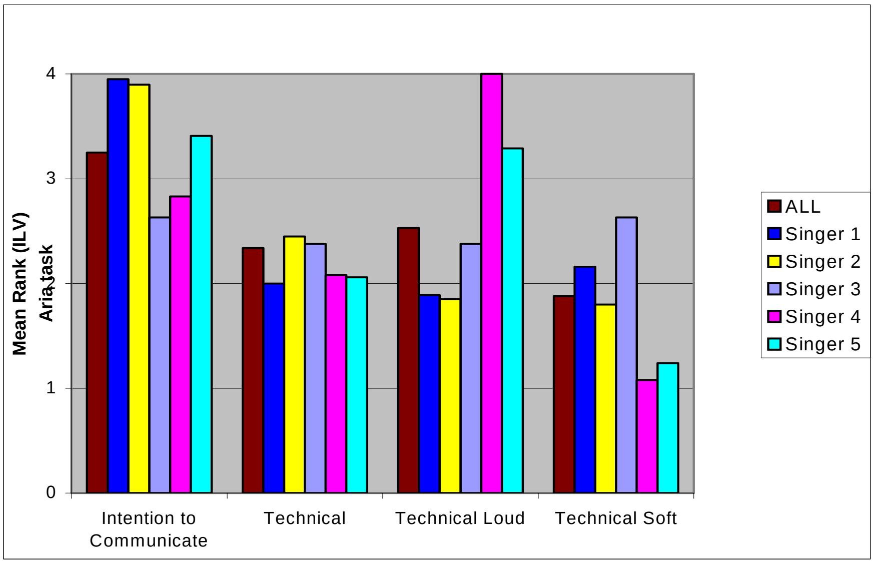


6.4.4.2. Aria Task: ILV and TLV

As described earlier, LVE is Initiation Lung Volume (ILV) minus Termination Lung Volume (TLV). As can be seen from Figure 4, the same amount of LVE could result from either a higher ILV or a lower TLV. Having found that on average, highest ranking of LVE was in the IC condition, the next question is what combination of ILV and TLC is producing this result.

Taken on its own, ILV rankings for the Aria task were significantly related to condition (X^2_3 = 44.26, $p < .001$). Furthermore, as expected, ILV was significantly higher in the IC condition (*M = 76.96)* compared with the T condition (*M* = 72.05; *t*(75) = 7.05, $p < .001$).

However, when singers' ILV for Aria is examined separately, the expected pattern (that the highest ranking would be observed in the IC condition) was observed for singers 1 and 2, with singer 3 also showing the IC condition ranked higher than the T condition. Figure 10 below shows the average ranking of ILV when each observation is treated as independent, as well as the rankings of ILV for each singer separately. Singer 1 (X^2_3 = 24.26, $p < .001$) and singer 2 (X^2_3 = 34.50, $p < .001$) showed the pattern that ILV was ranked highest in the IC condition.

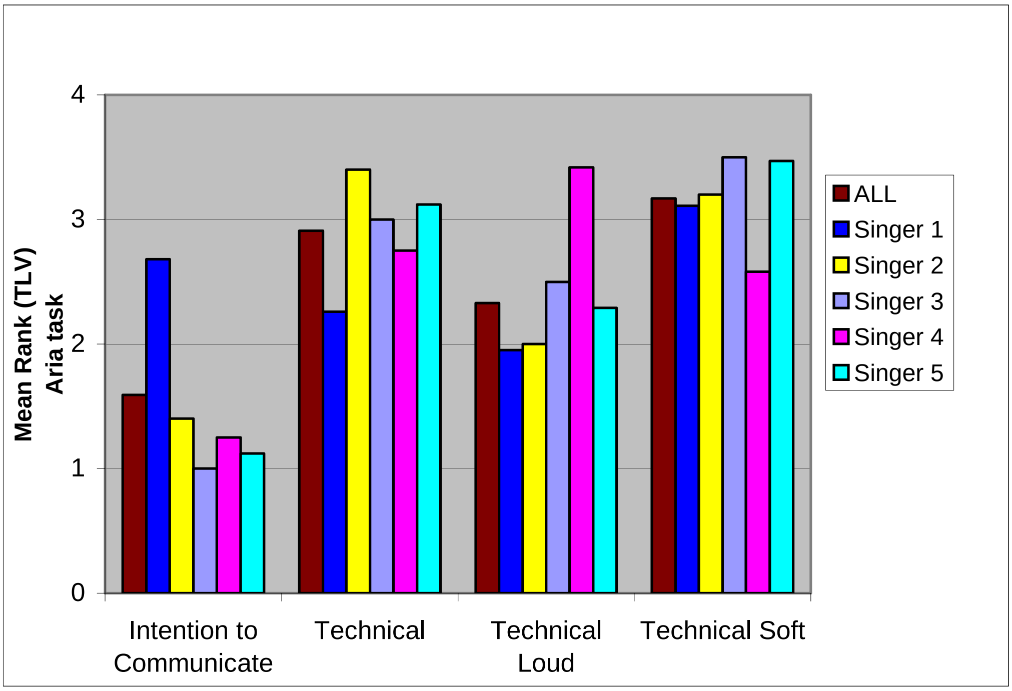


As with ILV, taken on its own, TLV ranking was significantly related to condition (X^2_3 = 67.04, $p < .001$). For this variable, it was expected that TLV would be the *lowest* ranked in the IC condition, and this expectation was supported. Furthermore, as expected, TLV was significantly lower in the IC condition (*M* = 31.65) than in the T condition (*M* = 38.34).

ILV for singer 3 (X^2_3 = .3, p = .96) showed no discernible pattern. For singer 4, a significant pattern emerged (X^2_3 = 32.70, p < .001), but the pattern was not as expected. Rather, the highest ranking occurred in the TL condition (4.00). Singer 5 showed a similar pattern, with a just significant pattern of rankings (X^2_3 = 8.22, p = .04).

When only IC and T conditions are compared, ILV is significantly higher in the IC condition than in the T condition for singer 1 (t(18) = 9.85, p < .001), singer 2 (t(19) = 6.89, p <.001), and singer 4 (t(11) = 4.47, p = .001). The difference was not significant for singer 3 (t(7) = 1.10) or for singer 5 (t(16) = 1.11).

As can be seen in Figure 11 below, for four out of five singers, this pattern was also observed when the phrases they performed were examined separately (singer 2: X^2_3 = 33.12, p < .001; singer 3: X^2_3 = 16.80, p = .001; singer 4: X^2_3 = 17.80, p < .001; singer 5: X^2_3 = 33.42, p < .001).

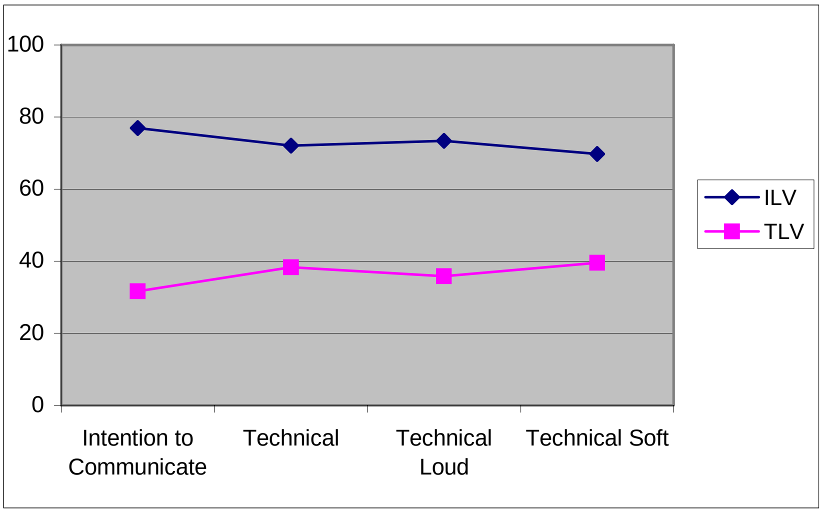


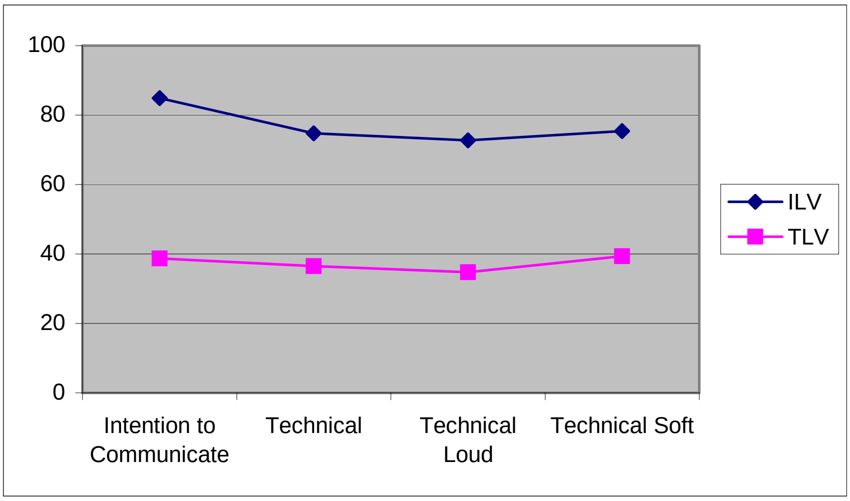
For singer 1, a relatively small but significant relation between TLV and condition was observed (X^2_3 = 8.68, p = .03), but TLV was lowest ranked in the TL condition (1.95).

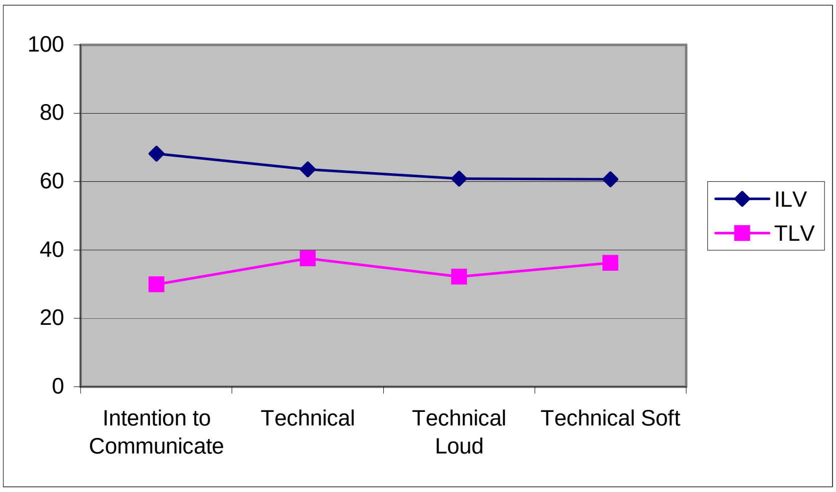
When only IC and T conditions are compared, the difference was significant for all but singer 1 (t(18) = 1.42). The other singers showed a significant difference between IC and T conditions (singer 2: $t(19) = 6.28$ $p < .001$; singer 3: $t(7) = 5.44$ $p = .001$; singer 4: $t(11) = 4.80$ $p = .001$; singer 5: $t(16) = 6.66$ $p < .001$).

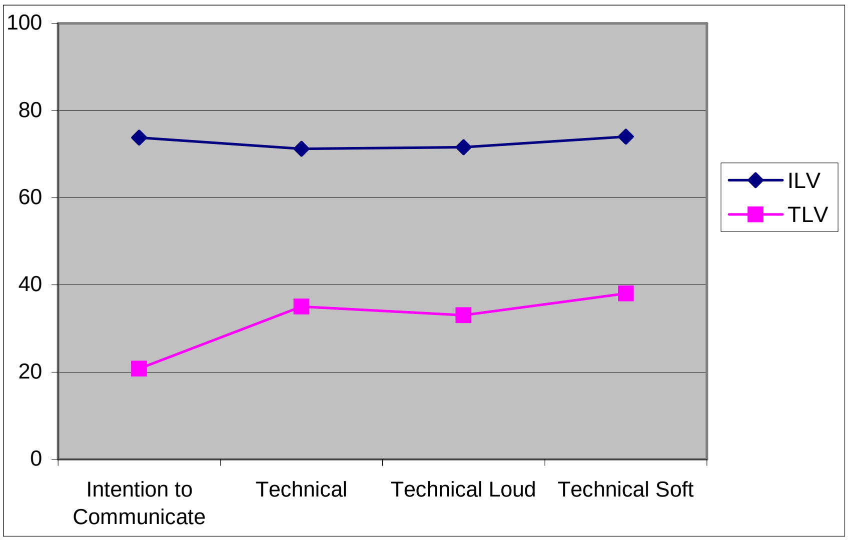
6.4.4.3. Aria task: ILV/TLV relation

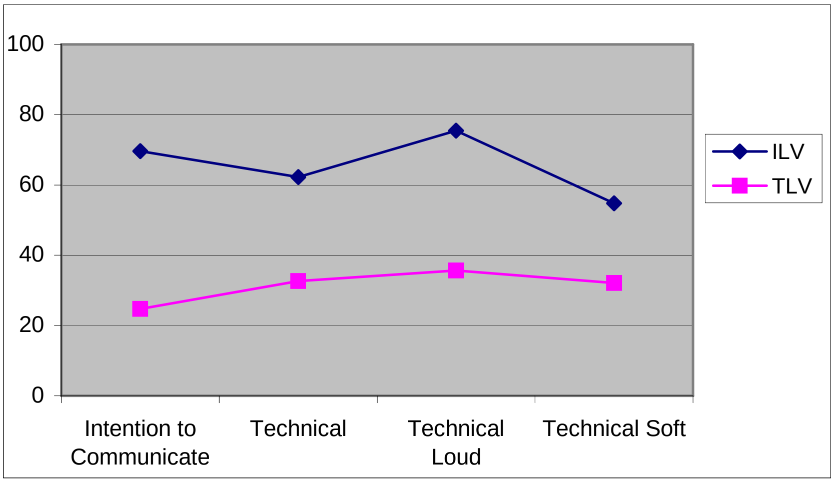
As shown in section 6.4.4.1., LVE was significantly related to condition for each singer. As shown in section 6.4.4.2., some singers produced this result through increasing ILV, some through decreasing TLV, and some through a combination of both. Figure 12 below shows that overall, singers increased ILV and decreased TLV when comparing the IC condition with the T condition. For the IC condition, singers 1 and 2 increased ILV (see Figures 13 and 14), and singer 2 also decreased TLV (see Figure 14), whereas singers 3, 4 and 5 decreased TLV (see Figures 15, 16 and 17).

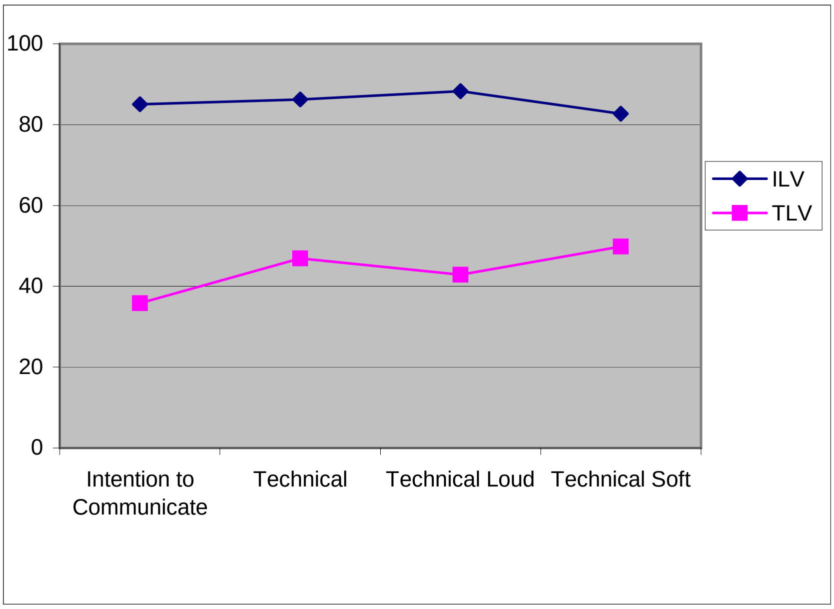



100
80
60
40
20
0
Intention to Communicate
Technical
Technical Loud
Technical Soft
ILV
TLV


100
80
60
40
20
0
Intention to Communicate
Technical
Technical Loud
Technical Soft
ILV
TLV


100
80
60
40
20
0
Intention to Communicate
Technical
Technical Loud
Technical Soft
ILV
TLV


100
80
60
40
20
0
Intention to Communicate
Technical
Technical Loud
Technical Soft
ILV
TLV


100
80
60
40
20
0
Intention to Communicate
Technical
Technical Loud
Technical Soft
ILV
TLV

6.4.4.4. Aria task: is observed pattern of LVE a function of SPL or Te?

As shown in Table 12a below, LVE was significantly different in relation to sound pressure level (SPL) in all conditions. Because there is a significant relation between LVE and SPL in each condition, it is unlikely that the LVE finding reported earlier (LVE is significantly higher in the IC condition than in the T condition, and that in terms of ranking LVE was ranked highest in the IC condition than in the other three conditions) is simply a function of sound pressure level. Similarly, the pattern found for ILV cannot reasonably be attributed to sound pressure level because ILV is similarly significantly related to SPL in all conditions. In addition, there is *no* relation between sound pressure level and TLV. If correlations between LVE, ILV or TLV had been different in the IC conditions than other conditions, it may have been because of sound pressure level.

Table 12a. Matched data. Aria task. Correlation between lung volume expired, initiation lung volume, termination lung volume, and sound pressure level: LVE/SPL, ILV/SPL, and TLV/SPL. For conditions IC, T, TL and TS. (Absence of recorded *p* level shows that result was not significant at .05)

Correlation Type	Intention to Communicate	Technical	Technical Loud	Technical Soft
LVE, SPL	.44 ($p < .001$)	.51 ($p < .001$)	.54 ($p < .001$)	.47 ($p < .001$)
ILV, SPL	.52 ($p < .001$)	.62 ($p < .001$)	.51 ($p < .001$)	.66 ($p < .001$)
TLV, SPL	-.07	.03	-.13	.21

As shown in Table 12b below, LVE, ILV and TLV were also significantly related to duration of expiration (Te) in all conditions. Again, because Te is significantly related to these variables in a similar way across all conditions, the pattern observed (that breathing parameters are greater in the IC condition) cannot be attributed to duration of expiration.

Table 12b. Matched data. Aria task. Correlation between lung volume expired, initiation lung volume, termination lung volume, and duration of phrase: LVE/Te, ILV/Te and TLV/Te. For conditions IC, T, TL and TS. (Absence of recorded *p* level shows that result was not significant at .05)

Correlation Type	Intention to Communicate	Technical	Technical Loud	Technical Soft
LVE, Te	.66 ($p < .001$)	.83 ($p < .001$)	.83 ($p < .001$)	.76 ($p < .001$)
ILV, Te	.54 ($p < .001$)	.57 ($p < .001$)	.60 ($p < .001$)	.41 ($p < .001$)
TLV, Te	-.30 ($p = .008$)	-.41 ($p = .008$)	-.38 ($p = .001$)	-.36 ($p = .002$)

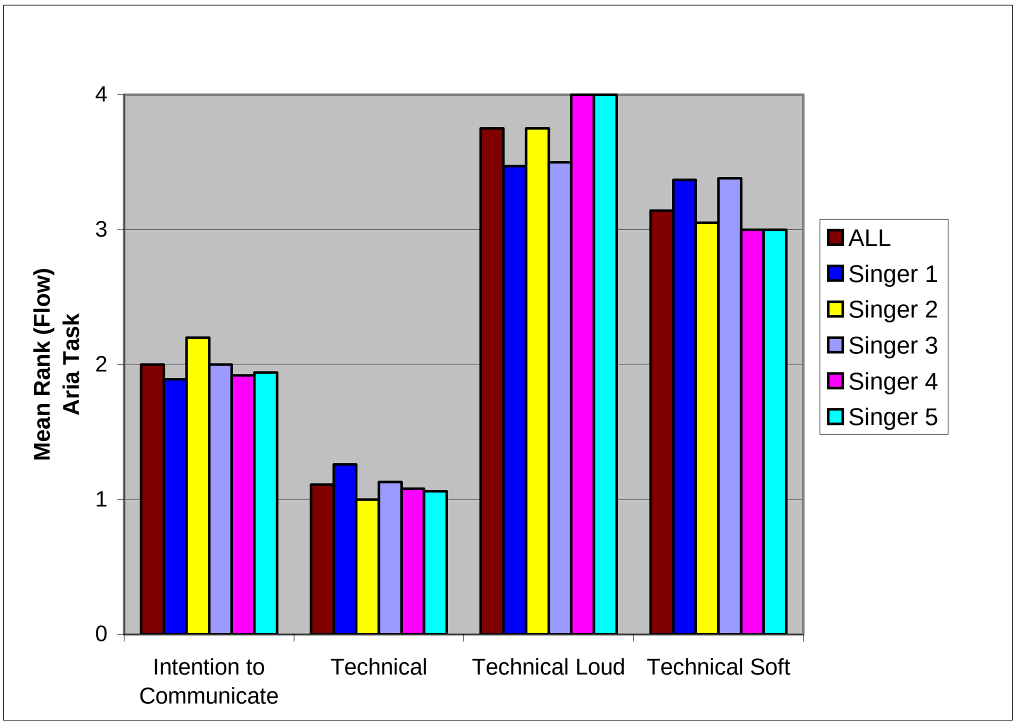
6.4.4.5. Aria task: Flow

Flow is the percentage of vital capacity released per second during singing.

The overall relation between condition and Flow is significant (X^2_3 = 190.31, p < .001). However, as can be seen in Figure 18 below, the pattern is not as expected. Instead, ranks are highest in the Technical Loud condition (3.75), next highest in the Technical Soft condition (3.14), followed by the Intention to Communicate condition (2.00). Rank was lowest in the Technical condition (1.11).

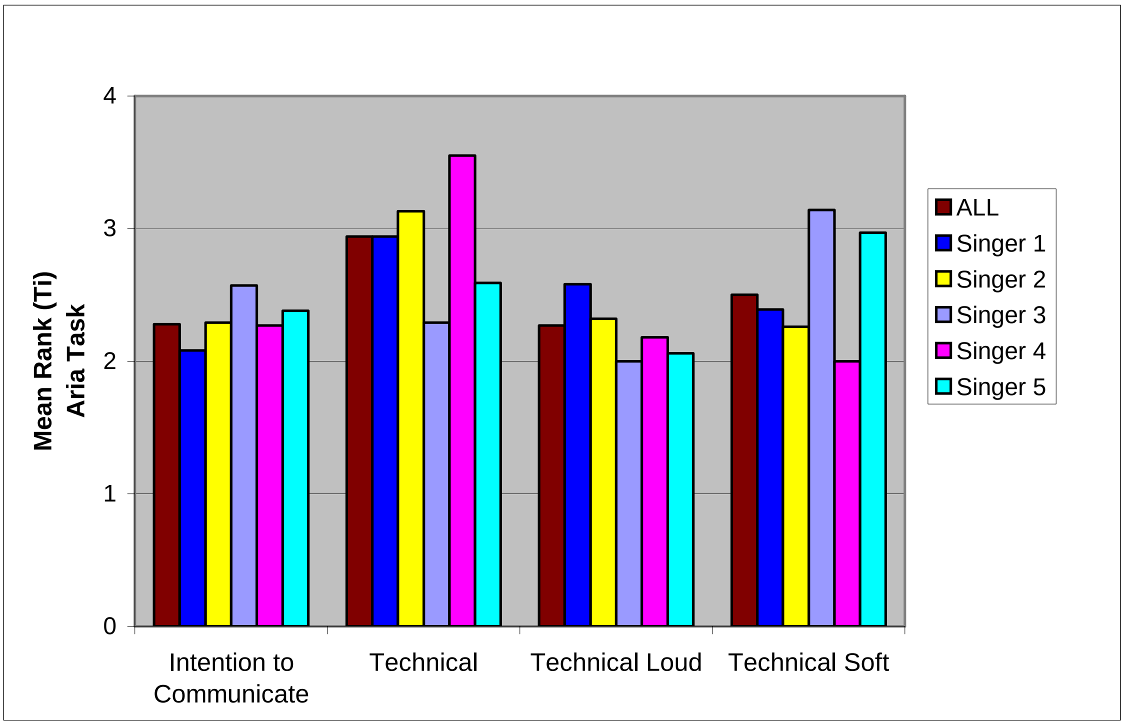
Results show the same significant pattern for all singers, with TL highest ranked (singer 1: X^2_3 = 41.02, p < .001; singer 2: X^2_3 = 50.46, p < .001; singer 3: X^2_3 = 18.75, p < .001; singer 4: X^2_3 = 34.90, p < .001; singer 5: X^2_3 = 49.87, p < .001).

Nevertheless, when the two conditions in which recognized singing technique is used (i.e., in the IC and T condition), the pattern expected—that parameters would be higher in the IC condition—can be observed. The difference between Flow in the IC (*M* = 9.02) and T (*M* = 6.67) conditions is significantly different (t(75) = 9.50, p < .001).



6.4.4.6. Aria task: Inspiratory time (Ti)

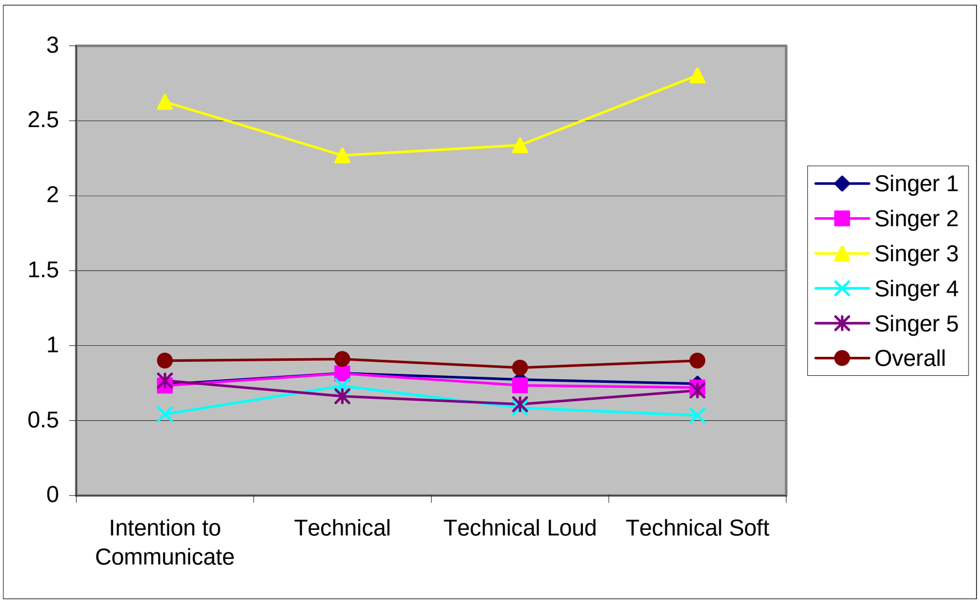
When the relation between Ti and condition was examined treating each phrase as an independent observation, a significant, but unexpected relation was observed (X^2_3 = 12.67, p = .005). This finding was unexpected in relation to the main hypothesis that inspiratory time would be greatest for the IC condition. It was found instead that inspiratory time ranked highest in the Technical condition. Further examination of singers separately showed that only for singer 4 did a significant pattern emerge (X^2_3 = 9.87, p = .02), showing the highest ranking for the Technical condition (see Figure 19 below).



Further examination of this result seemed warranted, especially in view of the main hypothesis, that Ti would take longer in the Intention to Communicate condition than in the Technical condition.

Actual averages overall, and for each singer separately, are shown in Figure 20 below. This again shows an unexpected pattern. Overall, there is no difference in Ti when IC and T conditions are compared ($t(70) = .23$).

In examining each singer separately, results showed that for singer 4, (for whom a significant pattern was reported above), the difference between IC ($M = .54$) and T ($M = .73$) conditions was significant ($t(10) = 2.76$, $p = .02$), and inspiratory time was *longer* in the Technical condition than in the Intention to Communicate condition.



In addition, for singer 2, the difference between IC (*M* = .73) and T (*M* = .81) conditions was significant ($t(18) = 2.75$, $p = .01$). Although for singer 3, the pattern is the reverse—inspiratory duration is longer in the IC condition (*M* = 2.62) than in the T condition (*M* = 2.26), this difference is not significant ($t(6) = .91$), because of the variance in each of these two conditions (*SD* = 2.28 and 1.94, respectively).

6.4.5. Use of Air: Song task ranking

6.4.5.1. Song Task: Lung Volume Expired (LVE)

Lung Volume Expired (LVE) during the Song Task was examined in the same way as in the Aria task, using the Friedman test. First, as before, each phrase was examined as an independent observation. As shown in Table 9 earlier, for the Song task singer 1 produced 14 phrases (x6=84 breaths) that began and ended at the same point in each of the four conditions; singer 2 produced 12 (x6=72 breaths); singer 3 produced 11 (x6=66); singer 4 produced 2 (x6=12 breaths); and singer 5 produced 12 (x6=72 breaths).

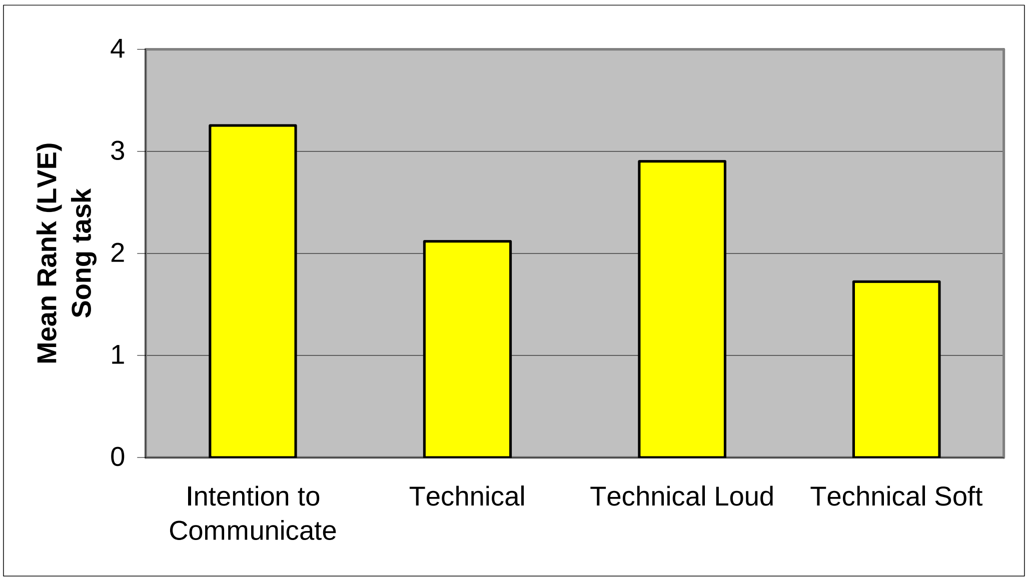
Table 13 below shows the mean and standard deviation, as well as the minimum and maximum score, for LVE (Song task) in these 51 phrases (resulting in 306 breaths). The pattern of means again shows that LVE is highest in the IC condition, as expected.

Table 13. Matched data. Song task: LVE (Lung Volume Expired, in %VC) showing mean and standard deviation, minimum and maximum score; for conditions IC, T, TL, TS.

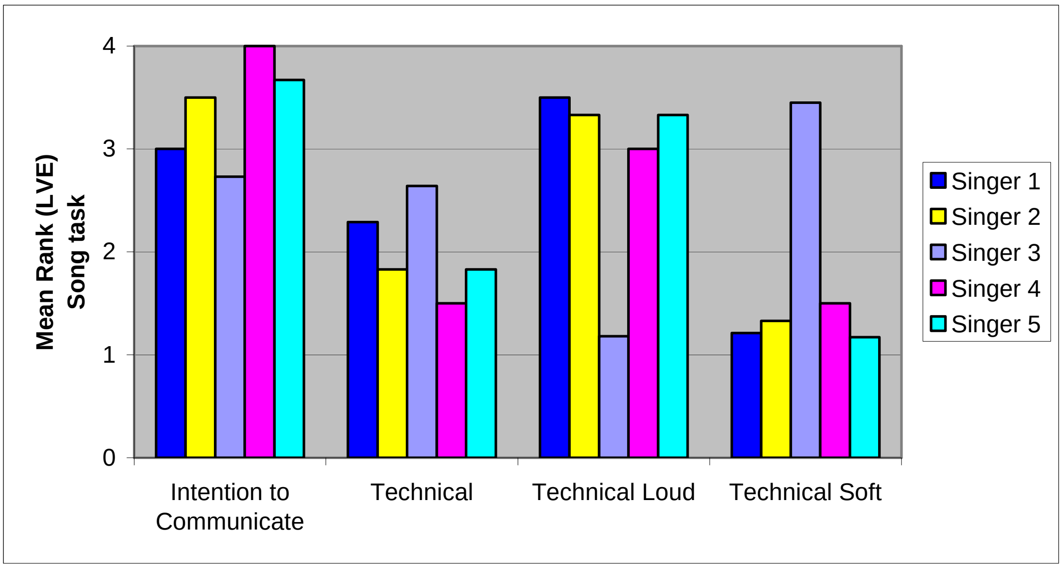
	Mean	Std. Deviation	Minimum	Maximum
Intention to Communicate	50.29	11.74	30.54	74.57
Technical	42.99	11.74	27.96	69.82
Technical Loud	47.08	9.31	32.20	71.22
Technical Soft	42.15	15.78	22.60	79.25

As in the Aria task, the hypothesis that LVE would be related to the type of singing task was supported ($X^2_3 = 45.21$, $p < .001$). On average, highest ranking (3.25) of ILV was in the IC condition. Figure 21 below shows the average of ranks in each condition.

The more specific hypothesis that LVE would be greater in the IC condition than in the T condition was also supported ($t(50) = 6.21$, $p < .001$).



When phrases for each singer were examined separately (see Figure 22 below), the pattern expected was observed for three of the five singers. For singer 2 (X^2_3 = 25.20, p < .001) and singer 5 (X^2_3 = 30.80, p < .001), IC received the highest ranking, and this ordering was significant. Looking only at the difference between IC and T conditions, this difference was significant for singer 2 (*M*= 56.27 and 47.36, respectively; t (11) = 4.25, p = .001) and for singer 5 (*M*= 46.52 and 33.75, respectively; t (11) = 6.95, p < .001)



For singer 4, only two phrases (12 breaths) could be examined, and although the pattern was as expected, the test statistic did not reach significance (X^2_3 = 5.40, *p* = .15).

Singers 1 and 3 showed a significant pattern of rankings, but the pattern was not expected, nor can be easily explained.

For singer 1, the test statistic was significant (X^2_3 = 24.77, *p* < .001), but the rankings were not in the pattern expected, with the highest ranking observed in the Technical Loud condition (3.50) followed by ranking in the Intention to Communicate condition (3.00), followed by the Technical condition (2.29), and then the Technical Soft condition (1.21). However, when the two conditions in which singing was of a type best understood by singers were compared, ILV was significantly higher in the Intention to Communicate condition (*M* = 39.91) than in the Technical condition (*M* = 35.21; *t*(13) = 3.43, *p* < .005).

For singer 3, the test statistic also was significant (X^2_3 = 17.95, *p* < .001), and also the rankings were not in the pattern expected, but the highest ranking was observed in the Technical Soft condition (3.45) followed by ranking in the Intention to Communicate condition (2.73), then Technical (2.64) and then Technical Loud (1.18). Although ILV was higher in the Intention to Communicate condition (*M* = 61.76) than in the Technical condition (*M* = 60.56), this difference was not significant (*t*(10) = .38).

6.4.5.2. Song Task: ILV and TLV

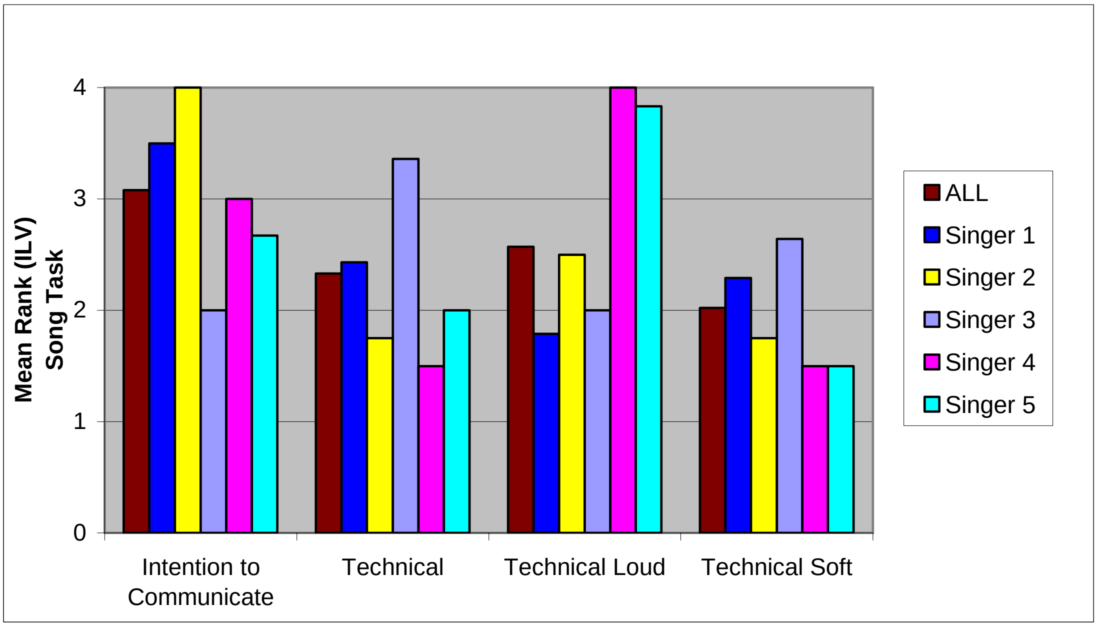
Taken on its own, ILV rankings were significantly related to condition (X^2_3 = 18.29, $p < .001$). Furthermore, as expected, ILV was significantly higher in the IC condition (*M* = 75.90) compared with the T condition (*M* = 71.53; $t(50) = 4.33$, $p < .001$).

When singers' ILV for the phrases they performed in the Song task is examined separately, the expected pattern (that the highest ranking would be observed in the IC condition) is shown only for two out of three singers (singers 1 and 2), as can be seen in Figure 23 below. (singer 1: X^2_3 = 13.11, $p < .004$; singer 2: X^2_3 = 24.30, $p < .001$). For singer 1 and singer 2, the difference between ILV in the Intention to Communicate condition and the Technical condition was significant (singer 1: *M* = 81.32 vs. 73.16; $t(13) = 4.59$, $p = .001$; singer 2: *M* = 73.96 vs. 66.03; $t(11) = 6.21$, $p < .001$).

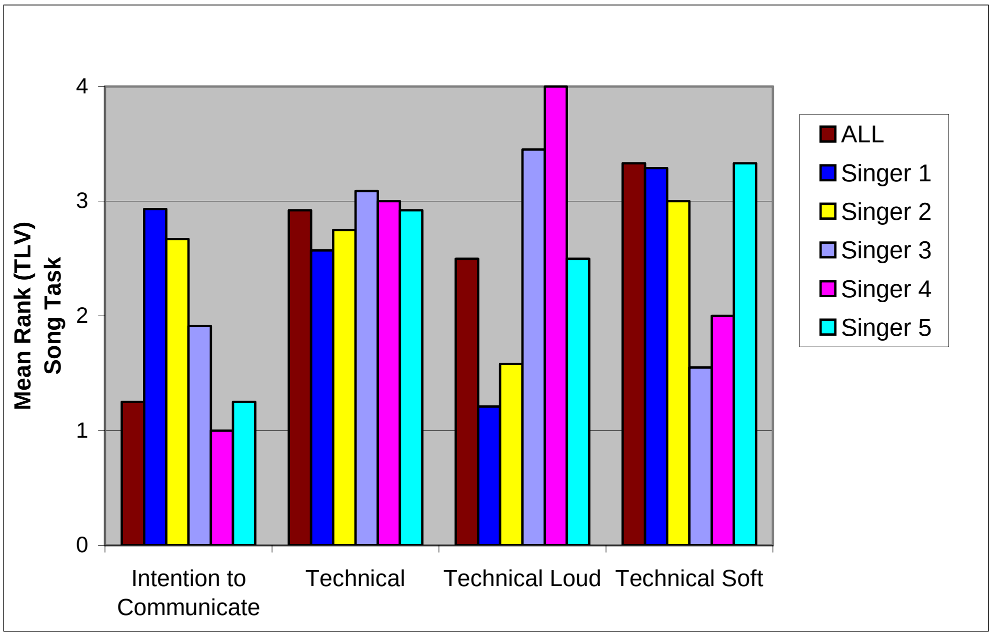
Singer 3 showed a significant relation between ILV and condition (X^2_3 = 8.35, $p = .04$), but not in the way expected: the highest ranking was for T (3.36), followed by TS (2.64) and then a tied ranking for IC (2.00) and TL (2.00). Unexpectedly, ILV in the Technical condition (*M* = 73.76) was significantly higher than in the Intention to Communicate condition (*M* = 69.05, t (10) = 3.68, p = .004).

Singer 4 did not show a significant relation between ILV and condition (X^2_3 = 5.40, $p = .15$) but only two phrases (12 breaths) were analysed due to the matching of phrases (see section 6.2.1.). For singer 4 the highest ranking was for TL (4.00), followed by IC (3.00), and then a tied ranking for T (1.50) and TS (1.50). Nevertheless, as expected, ILV was higher in the Intention to Communicate condition (*M* = 64.90) than in the Technical condition (*M* = 53.88).

Singer 5 showed a significant relation between ILV and condition (X^2_3 = 22.00, $p < .001$) but not in the direction expected. The highest ranking was for TL (3.83), followed by IC (2.67), then T (2.00), and TS (1.50). Nevertheless, the difference between ILV in the Intention to Communicate condition (*M* = 79.62) was significantly higher than in the Technical condition (*M* = 76.01; t (11) = 2.58, $p = .03$).



As in the Aria task, taken on its own, TLV ranking was significantly related to condition (X^2_3 = 17.50, p < .001). For this variable, it was expected that TLV would be the *lowest* ranked in the IC condition, and this expectation was supported (see Figure 24 below, columns labelled 'ALL'). As expected, TLV was significantly lower in the Intention to Communicate condition (M = 25.60) than in the Technical condition (M = 28.53, p = .01; t(50) = 2.64, p = .01).



When singers' TLV for the phrases they performed in the Song task is examined separately, the expected pattern (that the *lowest* ranking would be observed in the IC condition) is shown for three out of five singers, namely singers 3, 4 and 5 (the three who did not show the expected ILV pattern of lowest ranking in the IC condition). A significant relation between TLV and condition - and the pattern expected - was found for singer 3 (X^2_3 = 16.64, p = .001) and singer 5 (X^2_3 = 17.50, p < .001). Singer 4 did not show a significant relation with only two phrases analysed (X^2_3 = 6.00, p = .11), but the pattern was as expected, with IC ranked lowest (1.00), followed by TS (2.00), then T (3.00), and TL (4.00), and TLV was lower in the IC condition (M = 18.23) than in the Technical condition (M = 23.72).

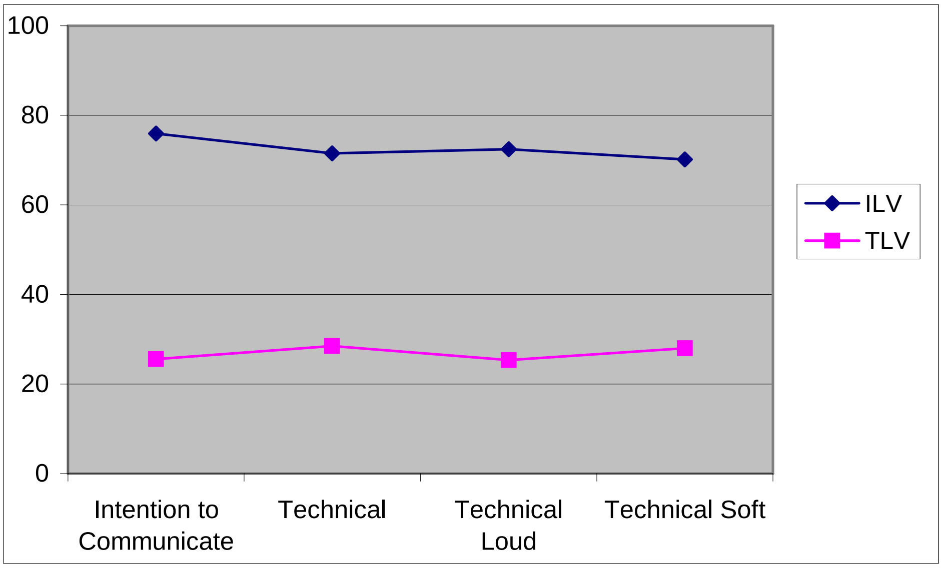
For singers 3 and 5, the difference between TLV in the Intention to Communicate and Technical conditions was significant (singer 3: M = 7.29 vs. 13.20, t (10) = 2.66, p = .02; singer 5: M = 33.09 vs. 42.27, t (11) = 7.94, p < .001).

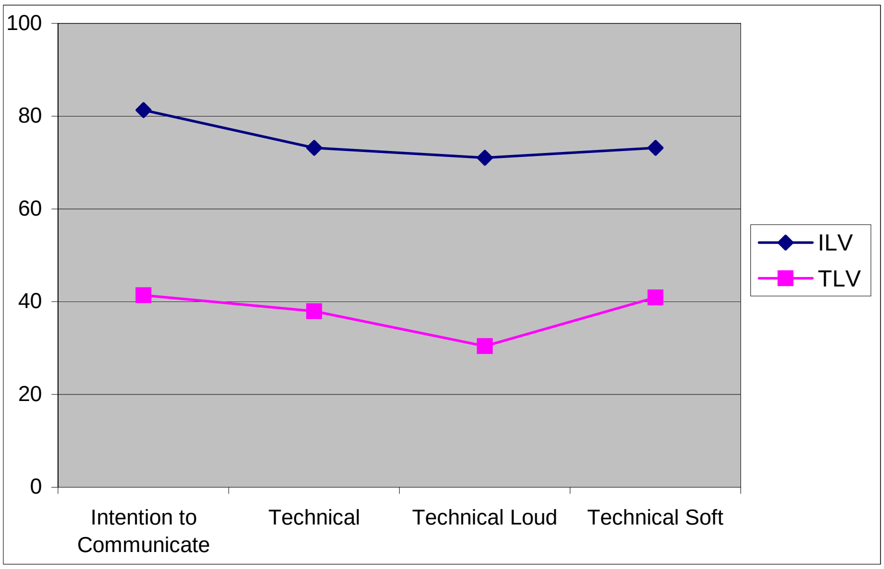
For singer 1, there was a significant relation between TLV and condition, but the pattern was not as expected (X^2_3 = 20.66, p < .001), with TL ranked lowest (1.21), followed by T (2.57), then IC (2.93), and TS (3.29). There was little difference in TLV in the Intention to Communicate (M = 41.41) and the Technical condition (M = 37.95).

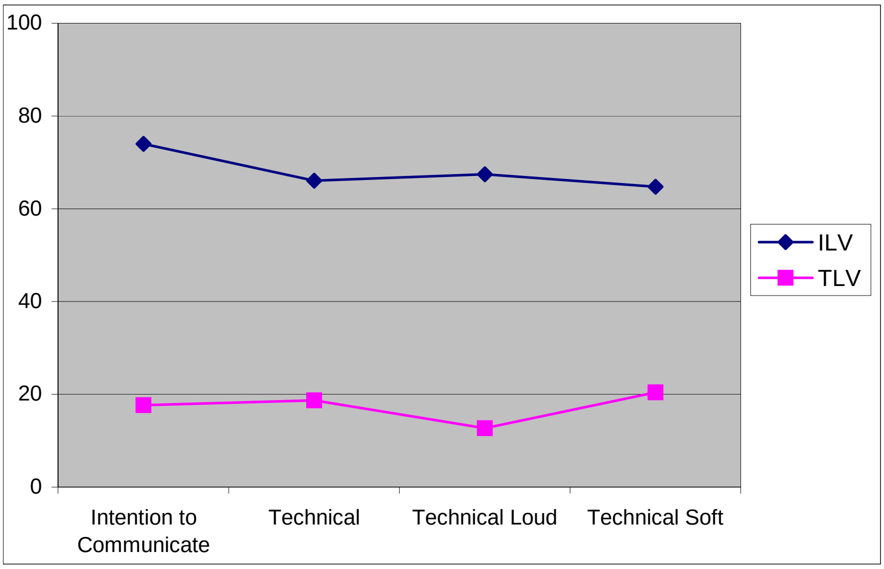
For singer 2, there was a just significant relation between TLV and condition (X^2_3 = 8.50, p =.04), with TL ranked lowest (1.58), followed by IC (2.67), then T (2.75), and TS (3.00). As with singer 4, there was little difference in TLV in the Intention to Communicate (*M* = 17.69) and the Technical condition (*M* = 18.67).

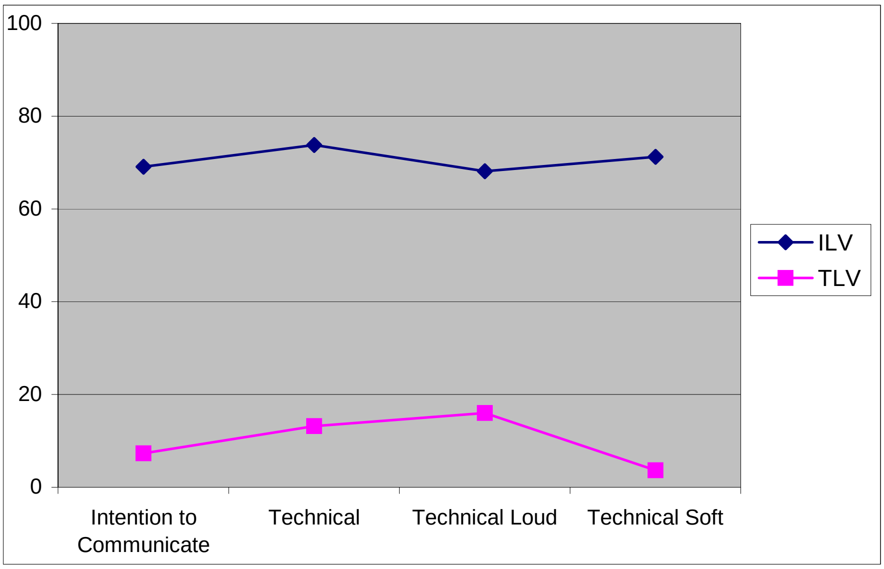
6.4.5.3. Song task: ILV/TLV relation

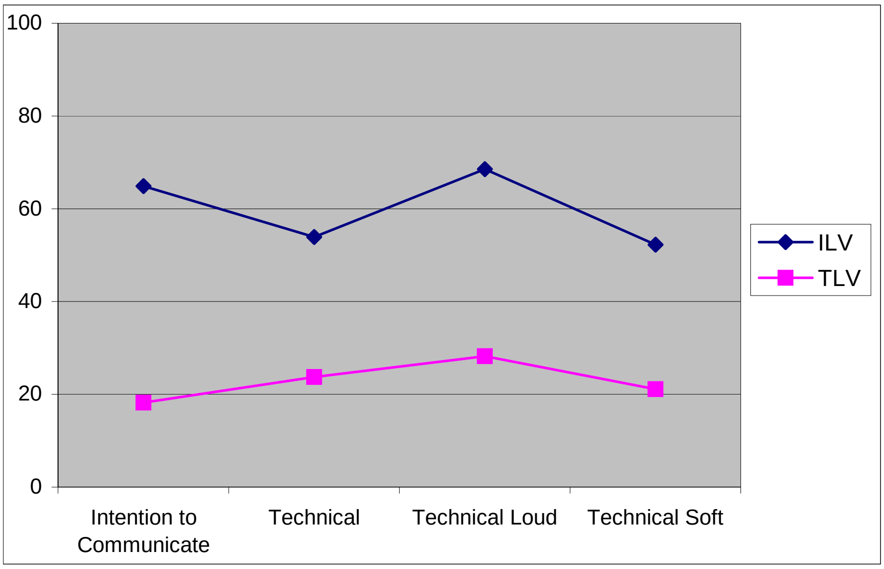
Figure 25 below shows that overall, singers increased ILV and decreased TLV when comparing the IC condition with the T condition. As shown in section 6.4.5.1., LVE in the Song task was significantly related to condition for each singer. Singers 1, 2, 4 and 5 increased ILV for IC compared to T (see Figures 27, 28, 30 and 31), singers 3, 4 and 5 decreased TLV for IC compared to T (see Figures 29, 30 and 31), while singers 4 and 5 both increased ILV and decreased TLV for IC compared to T (see Figures 30 and 31).

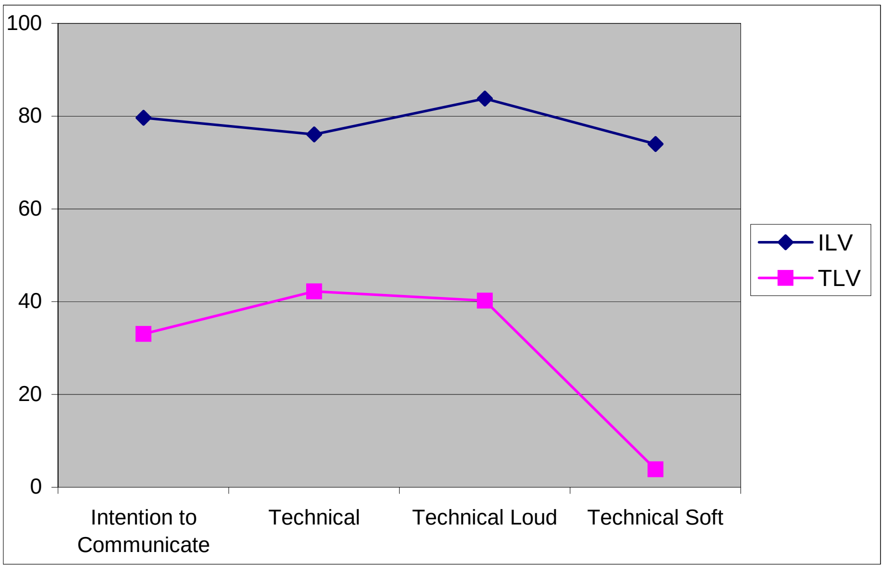

100
80
60
40
20
0
Intention to Communicate
Technical
Technical Loud
Technical Soft
ILV
TLV


100
80
60
40
20
0
Intention to Communicate
Technical
Technical Loud
Technical Soft
ILV
TLV


100
80
60
40
20
0
Intention to Communicate
Technical
Technical Loud
Technical Soft
ILV
TLV


100
80
60
40
20
0
Intention to Communicate
Technical
Technical Loud
Technical Soft
ILV
TLV


100
80
60
40
20
0
Intention to Communicate
Technical
Technical Loud
Technical Soft
ILV
TLV


100
80
60
40
20
0
Intention to Communicate
Technical
Technical Loud
Technical Soft
ILV
TLV

6.4.5.4. Song task: Is observed pattern of LVE a function of SPL or duration?

As in the Aria task, LVE for Song was significantly related to sound pressure level (SPL) in all conditions. As shown in Table 14a below, there is a similar relation between LVE and SPL for all conditions. As for the Aria Task, because there is a significant relation between LVE and SPL in each condition, it is unlikely that the LVE finding reported earlier (LVE is significantly higher in the IC condition than in the T condition, and that in terms of ranking LVE was ranked highest in the IC condition than in the other three conditions) is simply a function of sound pressure level.

There is no significant relation between ILV and SPL in the Song task, and therefore it is unlikely that SPL influenced the pattern of results found. Although TLV is significantly negatively related to SPL in all but the IC condition, the relation between TLV and SPL in the IC condition is in a similar direction and magnitude as the other conditions but is not significant. Thus, again, as for LVE, because there is a similar relation between TLV and SPL in each condition, it is unlikely that SPL is responsible for the pattern of results found.

Table 14a. Matched data. Song task. Correlation between lung volume expired, initiation lung volume, termination lung volume, and sound pressure level: LVE/SPL, ILV/SPL, and TLV/SPL. For conditions IC, T, TL and TS. (Absence of recorded *p* level shows that result was not significant at .05).

Correlation Type	Intention to Communicate	Technical	Technical Loud	Technical Soft
LVE, SPL	.30 (*p* = .04)	.56 (*p* < .001)	.43 (*p* < .001)	.51 (*p* < .001)

ILV, SPL	-.06	.21	-.01	.23
TLV, SPL	-.24	-.31 *p* = .03	-.31 *p* = .03	-.32 *p* = .02

LVE was positively related to expiratory time (Te) in all conditions, and two of the correlations (T and TL) were significant, as shown in Table 14b below. Also, TLV was negatively related to Te in all conditions, and three of the correlations (T, TL and TS) were significant, as shown in Table 14b. However, because the pattern of relations between LVE and Te, and TLV and Te were essentially similar across conditions, it is unlikely that the findings reported for LVE earlier can be simply attributed to expiratory time.

Table 14b. Matched data. Song task. Correlation between lung volume expired, initiation lung volume, termination lung volume, and expiratory time: LVE/Te, ILV/Te, and TLV/Te. For conditions IC, T, TL and TS. (Absence of recorded *p* level shows that result was not significant at .05)

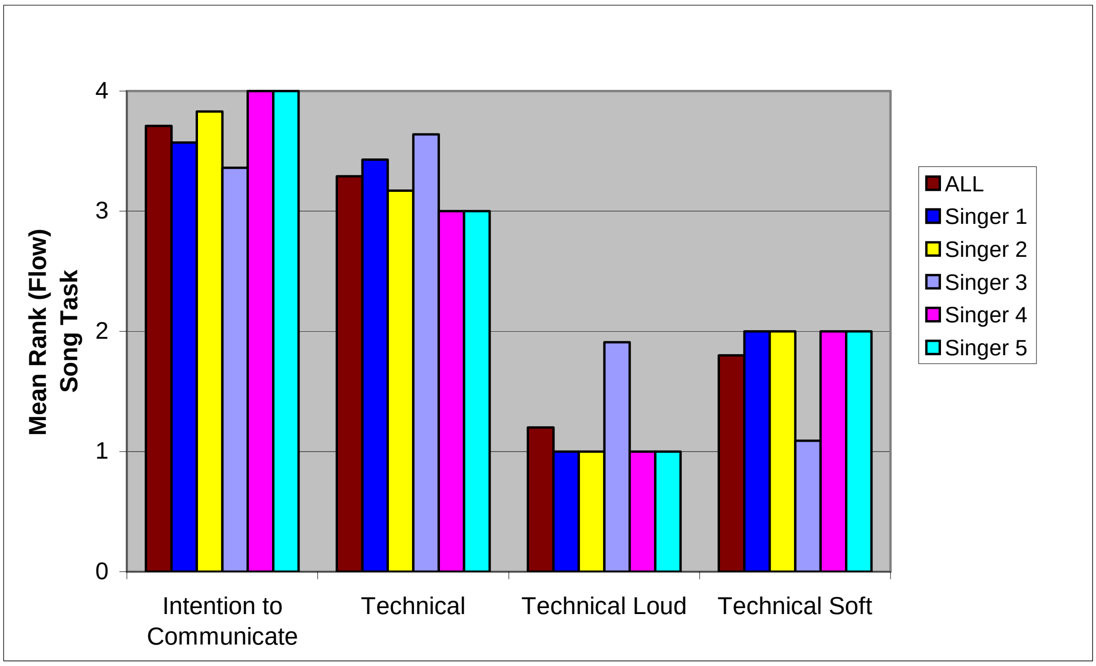
Correlation Type	Intention to Communicate	Technical	Technical Loud	Technical Soft
LVE, Te	.26	.36 (p = .009)	.60 (p < .001)	.26
ILV, Te	-.13	-.22	-.26	-.14
TLV, Te	-.26	-.43 (p = .002)	-.62 (p = .001)	-.29 (p = .04)

There is no relation between ILV and Te, and therefore the findings reported earlier for ILV cannot be attributed to expiratory time.

6.4.5.5. Song task: Flow

When treating each phrase as an independent observation, Flow rankings were significantly related to condition (X^2_3 = 130.65, $p < .001$), with highest rankings observed in the Intention to Communicate condition (see Figure 31 below). As expected, Flow was significantly higher in the Intention to Communicate (M = 6.75) than in the Technical condition (M = 5.77; $t(50)$ = 5.43, $p < .001$). However, when singers' Flow is examined separately, the expected pattern (that the highest ranking would be observed in the IC condition) was observed only for singers 1, 2 and 5. (singer 1: X^2_3 = 37.87, $p < .001$; singer 2: X^2_3 = 34.00, $p < .001$; singer 5: X^2_3 = 36.00, $p < .001$). For these singers, the difference in Flow in the Intention to Communicate and the Technical condition was significant (singer 1: $t(13)$ = 2.53, p = .03; singer 2: $t(11)$ = 2.98, p = .01; singer 5: $t(11)$ = 5.49, $p < .001$).

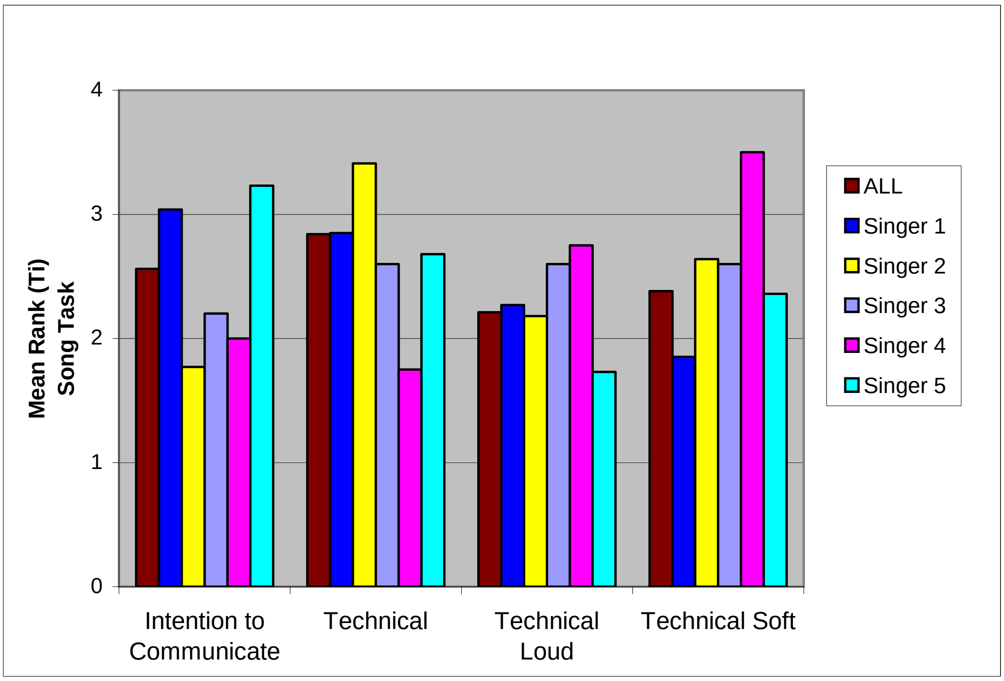
Singer 4 showed the pattern expected (i.e. IC ranked highest), but because only two phrases (12 breaths) were included, the relation did not reach statistical significance (X^2_3 = 6.00, p = .11). Flow was higher in the Intention to Communicate condition (M = 6.28) than in the Technical condition (M = 4.35). For singer 3, the relation between condition and rankings was significant (X^2_3 = 28.86, $p < .001$), but unexpectedly, rankings were highest in the T condition (3.64) followed by the IC condition (3.36).



6.4.5.6. Song task: Inspiratory time (Ti)

When treating each phrase as an independent observation, Ti rankings were not significantly related to condition (X^2_3 = 6.22, *p* = .10). In addition, examination of the average Ti in the Intention to Communicate (*M* = .80) and in the Technical condition (*M* = .81) showed these means to be almost identical.

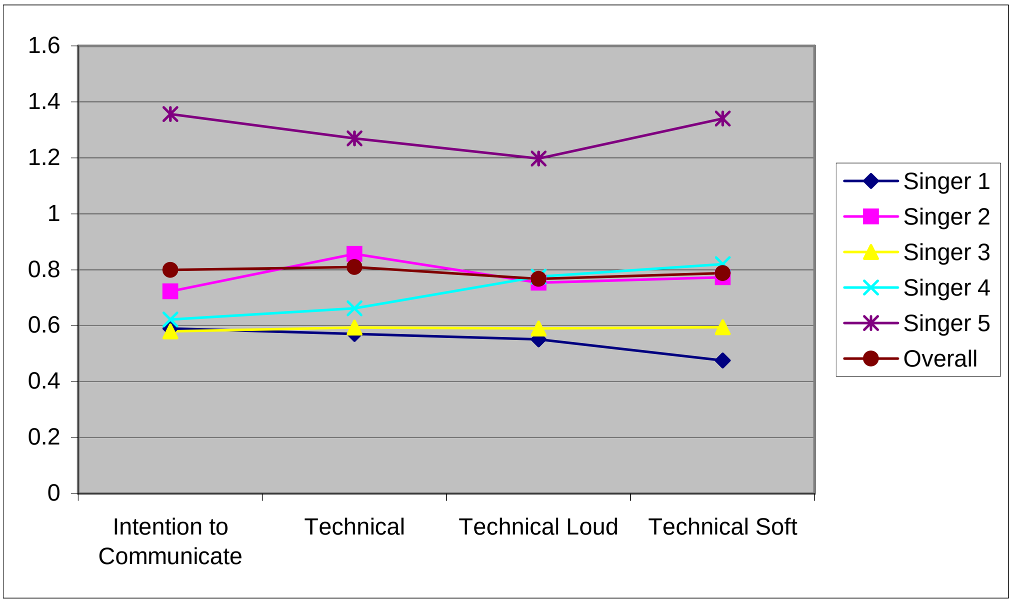
Figure 32 below shows the average rankings in each condition overall, and for each singer.



When singers' Ti was examined separately, a significant pattern emerged only for singer 2 (X^2_3 = 9.83, *p* = .02) and singer 5 (X^2_3 = 8.14, *p* = .04). Nevertheless, for singer 2, the pattern was not as expected, and rankings were highest in the Technical condition (3.41) and lowest in the Intention to Communicate condition (1.77). Indeed, Ti was significantly higher in the Technical condition (*M* = .85) than in the Intention to Communicate condition (*M* = .72; (*t*(10) = 3.15, *p* = .01).

For singer 5, the pattern was as expected, and rankings were highest in the Intention to Communicate condition (3.23). However, the difference between Ti in the Intention to Communicate condition (*M* = 1.36) and the Technical condition (*M* = 1.27) was not significant (*t*(10) = 2.06, *p* = .07).

Figure 33 below shows inspiratory duration in actual averages overall, and for each singer separately.



6.4.6. Summary of individual ranked respiratory results

The aim of the study was to see whether breathing parameters would be different when singers sang with the intention to communicate, compared to singing technically. In this study, two other conditions were included: singers also sang in a technically loud, and in a technically soft way. These conditions were included for SPL comparison, and do not reflect actual singing practice. Indeed, as discussed (section 5.2.6), singing in these styles may be inappropriate for the operatic singer.

Because the focus of the study was on the difference between the breathing parameters when singers sang with the intention to communicate and when they sang in a technical way, a summary was compiled (see Table 15 below) to show where the differences between these two conditions were found. It was expected that in general, the breathing parameters would be higher in the Intention to Communicate condition than in the Technical condition, with the exception of TLV (termination lung volume) where the pattern was expected to be lower (because increasing the amount of lung volume expired is the result of either increasing initiation lung volume, decreasing termination lung volume, or both). (See Figure 4). Table 15 below summarises the observed pattern of rankings for IC and T conditions for Aria and Song tasks in terms of whether or not they were in line with these expectations.

As can be seen in Table 15 below, for all breathing parameters except Ti (inspiratory duration), ranking showed the expected pattern of increased parameters for the IC condition compared to the T condition when each phrase was treated as an independent observation. For all parameters except Ti, when each singer's breathing parameters were examined separately, the majority of singers (i.e., 3 out of 5) showed the expected pattern. These results could not be attributed to either SPL or Te (duration of phrase) in either Aria or Song Tasks.

Breathing Parameter	Task	Participants	Pattern Expected ?	Task	Participants	Pattern Expected ?
LVE (Fig. 8)	Aria	All Observations	Yes	Song (Fig. 23)	All Observations	Yes
		Singer 1	Yes		Singer 1	Yes
		Singer 2	Yes		Singer 2	Yes
		Singer 3	Yes		Singer 3	Yes
		Singer 4	Yes		Singer 4	Yes
		Singer 5	Yes		Singer 5	Yes
ILV (Fig. 9)	Aria	All Observations	Yes	Song (Fig. 24)	All Observations	Yes
		Singer 1	Yes		Singer 1	Yes
		Singer 2	Yes		Singer 2	Yes
		Singer 3	Yes		Singer 3	No
		Singer 4	Yes		Singer 4	Yes
		Singer 5	Yes		Singer 5	Yes
TLV (Fig. 10)	Aria	All Observations	Yes	Song (Fig. 25)	All Observations	Yes
		Singer 1	No		Singer 1	No
		Singer 2	Yes		Singer 2	Yes
		Singer 3	Yes		Singer 3	Yes
		Singer 4	Yes		Singer 4	Yes
		Singer 5	Yes		Singer 5	Yes
Flow (Fig. 19)	Aria	All Observations	Yes	Song (Fig. 34)	All Observations	Yes
		Singer 1	Yes		Singer 1	Yes
		Singer 2	Yes		Singer 2	Yes
		Singer 3	Yes		Singer 3	No
		Singer 4	Yes		Singer 4	Yes
		Singer 5	Yes		Singer 5	Yes
Ti (Fig. 20)	Aria	All Observations	No	Song (Fig. 35)	All Observations	No
		Singer 1	No		Singer 1	Yes
		Singer 2	No		Singer 2	No
		Singer 3	Yes		Singer 3	No
		Singer 4	No		Singer 4	Yes
		Singer 5	No		Singer 5	Yes

6.5. Kinematic results

Figure 34 shows the motions of rib cage versus abdominal dimensions during the singing of the Aria task, comparing IC and T conditions. One complete IC take is compared with a complete T take for each singer.

The takes, chosen at random, are identified on the left of the figure. (Table 6 shows the order of takes chosen by each singer). Both inspiratory and expiratory limbs are included. Movement is shown with an equal scale of 15 cm across all singers. Most singers showed some increased outward movement at anterior/posterior measurement sites for the Aria task when singing with IC, compared to T singing, except for singer 1 who showed very little change.

Lateral measurement sites for the Aria task when singing with IC, compared to T singing, showed dramatic differences for singers 3, 4 and 5, with some increase also for singers 1 and 2 (see Figure 35). Singer 2 increased movement of the abdomen laterals while keeping ribcage laterals movement at a similar level. Singer 3 combined the use of abdomen and rib cage for IC compared to T singing.

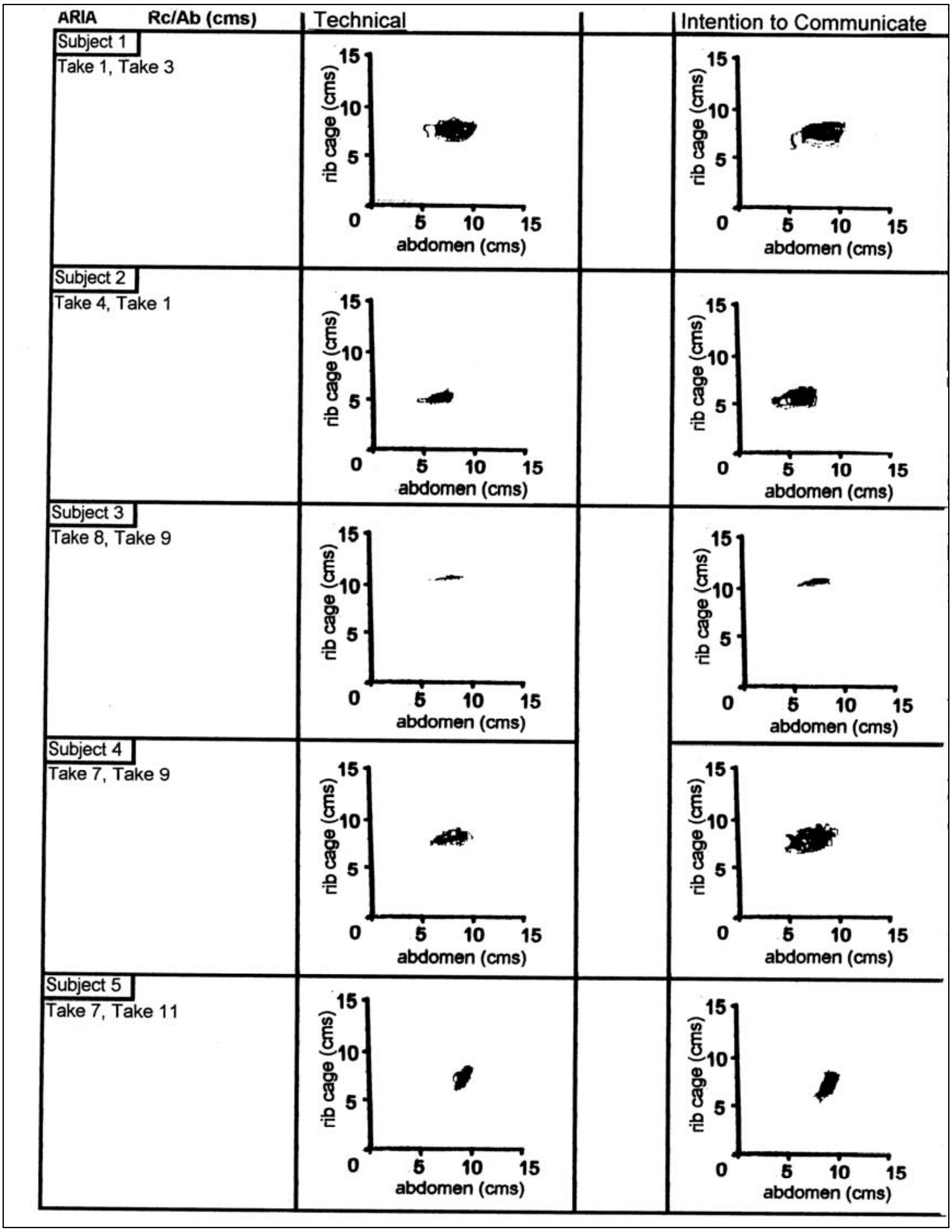


Figure 34. X/Y plots for Aria, anterior/posterior, comparing a Technical take with an IC take for each singer. X axis = abdomen movement, y axis = rib cage movement. Scale is in centimetres.

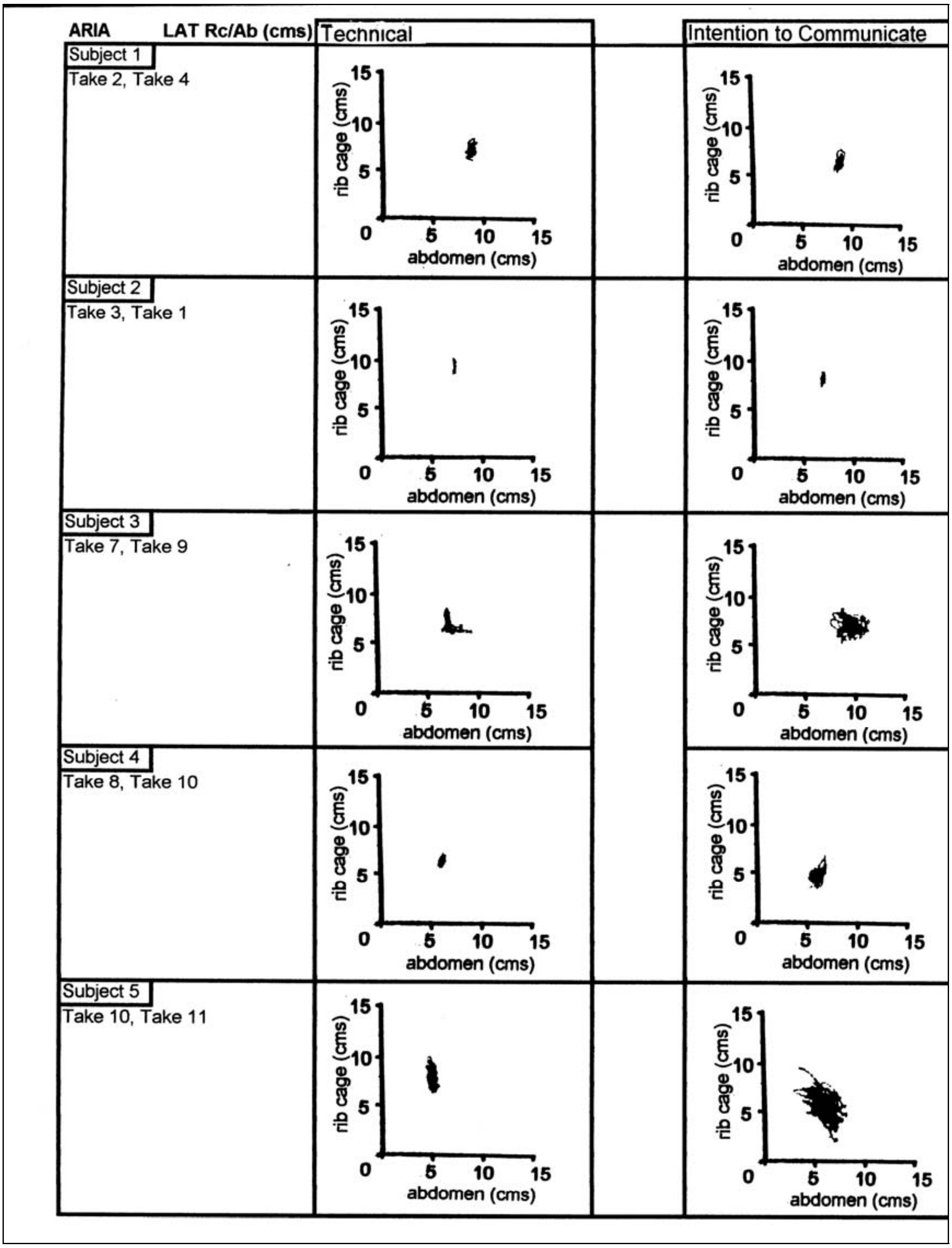


Figure 35. X/Y plots for Aria, laterals, comparing a Technical take with an IC take for each singer. X axis = abdomen movement, y axis = rib cage movement. Scale is in centimetres.

An example of the data is presented in Figure 36, which shows breath phrases 6 and 7 (‘e se l’amassi indarno’, and ‘andrei sul Ponte Vecchio’) from the Aria “O mio babbino caro” sung by singer 4. The first of these two phrases is the phrase used in the acoustic selection for singer 4 (see Table 7). This phrase from singer 4 shows a perfect score for listeners successfully identifying intention to communicate (see Table 17). Figure 36A shows some raw data for this and for the following phrase in the Aria, presenting both T and IC traces for the sides of the rib cage (nipple level) and the sides of the abdomen (navel level) showing that movement in these areas differs between the two conditions. There is more lateral movement in IC than T preparation for the octave leap, where IC shows a tightening (decrease in cm measure) in the lateral rib cage. The lateral abdomen for IC shows tightening after the octave leap, during the following portamento. Neither of these effects are present in the T lateral movement, which is much flatter showing less change throughout. Figure 36B, C and D show phrase 6 only (‘e se l’amassi indarno’) from singer 4’s Aria, using X/Y plots which give an example of how the use of the laterals is greatly increased in IC compared to the two Technical conditions. Increased movement is shown in the AP insets. In the Song task, only singer 4 shows increased LATS movement for IC (compared to T), with decreased LATS movement for TL. There was very little difference between conditions for the other singers.

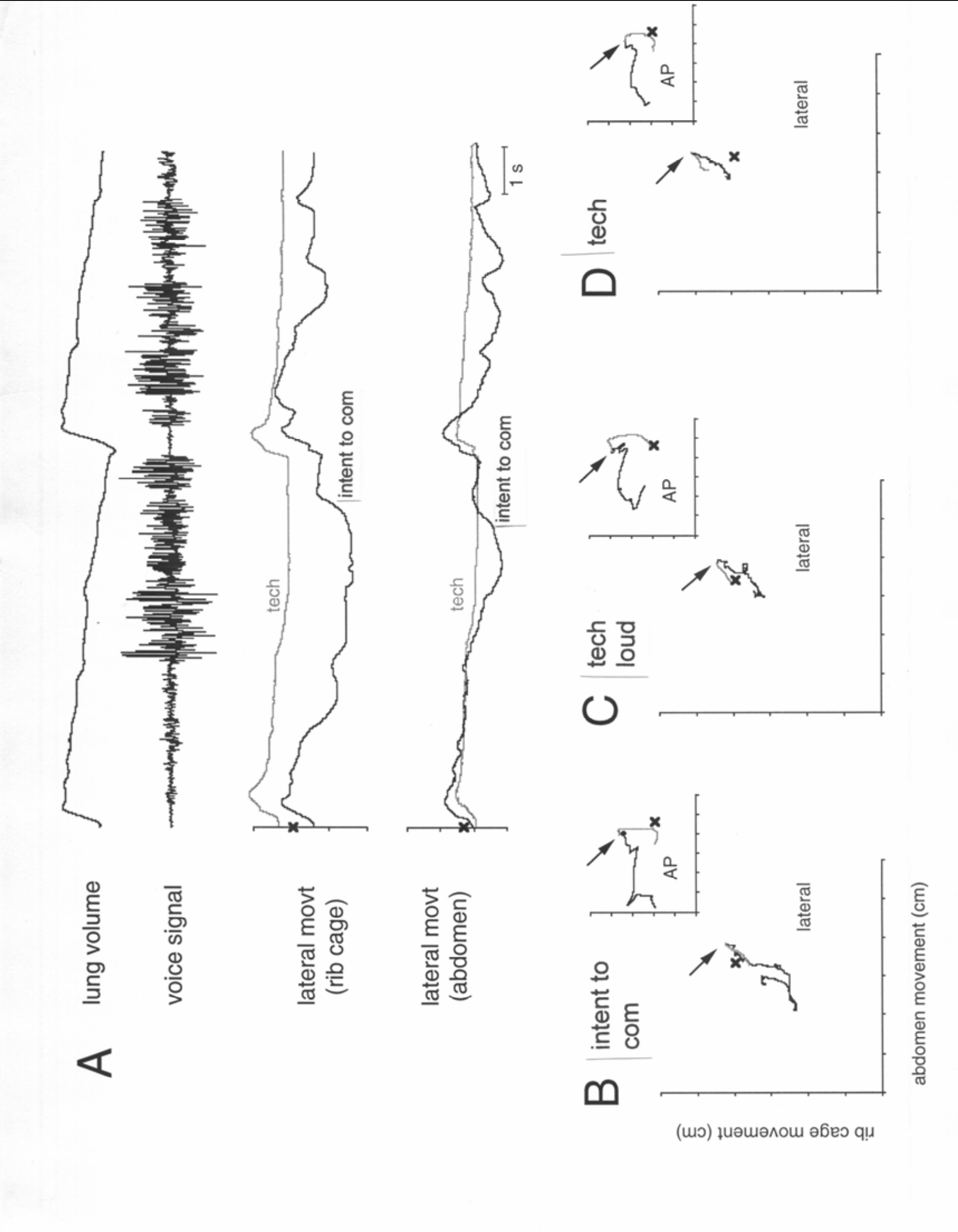


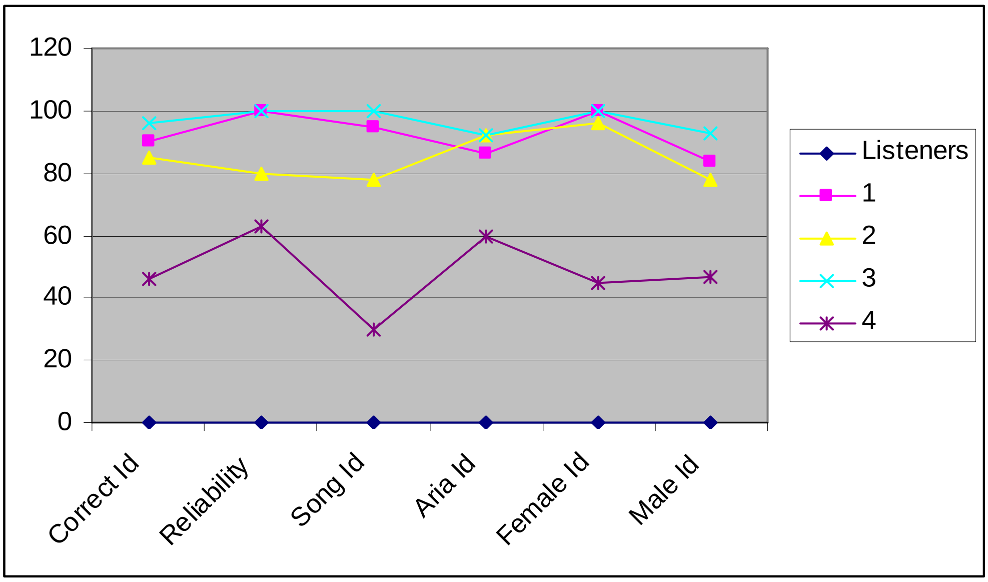
Figure 36 - Kinematic example, singer 4. (A) shows raw data for phrases 6 and 7 from *O mio babbino caro* ('e se l'amassi indarno', and 'andrei sul Ponte Vecchio'). Lung volume is the summed signal from magnetometers at rib cage and abdomen AP (for IC). Voice signal shows audio readout (for IC), with increased amplitude showing increased SPL. LATS (lateral) movement is shown (IC singing in black, T singing in grey) for rib cage and for abdomen. Functional residual capacity (FRC) is marked with a cross. (B), (C) and (D) show IC, TL and T conditions for singer 4, phrase 6 only. X/y plots show LATS movement of abdomen (X axis) and rib cage (y axis), with inset anterior/posterior (AP) plots, all represented in centimetres. Crosses represent FRC, grey line shows inspiratory movement, black line (marked with black arrows) show the onset of phonation.

6.6. Perceptual results

In order to perceptually confirm the conditions of IC versus T, four expert listeners were given a forced choice between pairs of recorded excerpts from each of the performances of the five singers, in which they had to indicate which of each pair was more emotionally convincing. There were a total of 74 excerpt pairs. Intention to communicate was correctly identified by listener 3 in 71 pairs, by listener 1 in 67 pairs, by listener 2 in 63 pairs, and by listener 4 in 34 pairs. Table 16 shows the percentage of correct identification of IC for each listener, and Figure 37 compares listeners' ability to correctly identify IC.

Table 16
Listener identification of Intention to Communicate (IC). Correct IC identification, listener reliability, IC identification in Song, IC identification in Aria, IC identification in female vs male singers.

	Correct Id^n	Reliability	Song Id^n	Aria Id^n	Female Id^n	Male Id^n
Listeners	%	%	%	%	%	%
1	90	100	95	86	100	84
2	85	80	78	92	96	78
3	96	100	100	92	100	93
4	46	63	30	60	45	47



Listener reliability was assessed by repeating 15 of the pairs. Listener reliability followed the same order as accuracy, with 2 listeners achieving 100% reliability. One at 80% (12/15 of the repeated pairs correctly matched) while the 4th listener was consistent only in 67% (10/15 of the repeated pairs). Because of this low reliability score (little more than chance) the results of listener 4 are excluded from subsequent analysis. Listeners 1, 2 and 3 scored reliability scores of 80% or higher, and showed 85% - 96% ability to correctly perceive IC.

Listener 1 (male) and listener 3 (female) identified IC with 100% accuracy for the female singers (see Table 17,) while listener 2 (male) made only one error in identifying IC in female singer/singers (see Table 9). Listener 3 also identified IC with 100% accuracy in the Song task.

Overall, listeners perceived IC in female singer/singers more readily than in male singer/singers for whom there was from 7% - 18% less accuracy, but overall there was no difference in identification of IC in the Song task compared with the Aria task. Listeners 1 (male) and 3 (female) found it 11% - 13% easier to identify IC in Song rather than Aria, with male singer/singers. Figure 38 shows pie charts comparing the number of correct identifications of IC for Song and Aria tasks, and for male and female singers.

Table 17 shows the number of times each individual singer failed to elicit IC perception in the listeners, with listeners 1 (male) and 3 (female) making no errors in perceiving IC in the female singers, and listener 2 (male) making only one error in perceiving IC in female singers. Overall, listener 3 (female) made only 3 errors, all of which were made with singer 1 (male). Two of her three incorrect identifications were comparing IC with Technical singing. Listener 3 correctly identified IC in all other singers across both Song and Aria tasks. Listener 2 (male) also found it difficult to identify IC in singer 1 (male), making 6 errors. Listener 2 (male) displayed a learning effect, in that his ability to correctly identify IC improved throughout the perceptual evaluation. Listener 1 (male) had most trouble in correctly identifying IC in singer 3 (male), making 4 identification errors (as shown in Table 17).

In a post-listening interview, the listeners were invited to say what they thought of the listening test. Listeners 1 (male) and 2 (male) said that it was difficult to separate stylistic interpretation from IC. Listener 1 (male) stated that he perceived IC by listening to the breathing (initial inspiration) for the excerpt. Listener 2 (male) said that the more established singers had integrated IC indissolubly into their technique. Listener 3 (female) showed correct identification of IC in 71 of 74 excerpt pairs. She stated that she perceived IC through increased rubato, lengthening of notes, extension of consonants, and increased number of pitch scoops up to the intended note. Listener 4 said that operatic singers could not be convincing in Song style, and that the Song style was a bad choice of repertoire for singers of this type (see discussion in section 7.5).

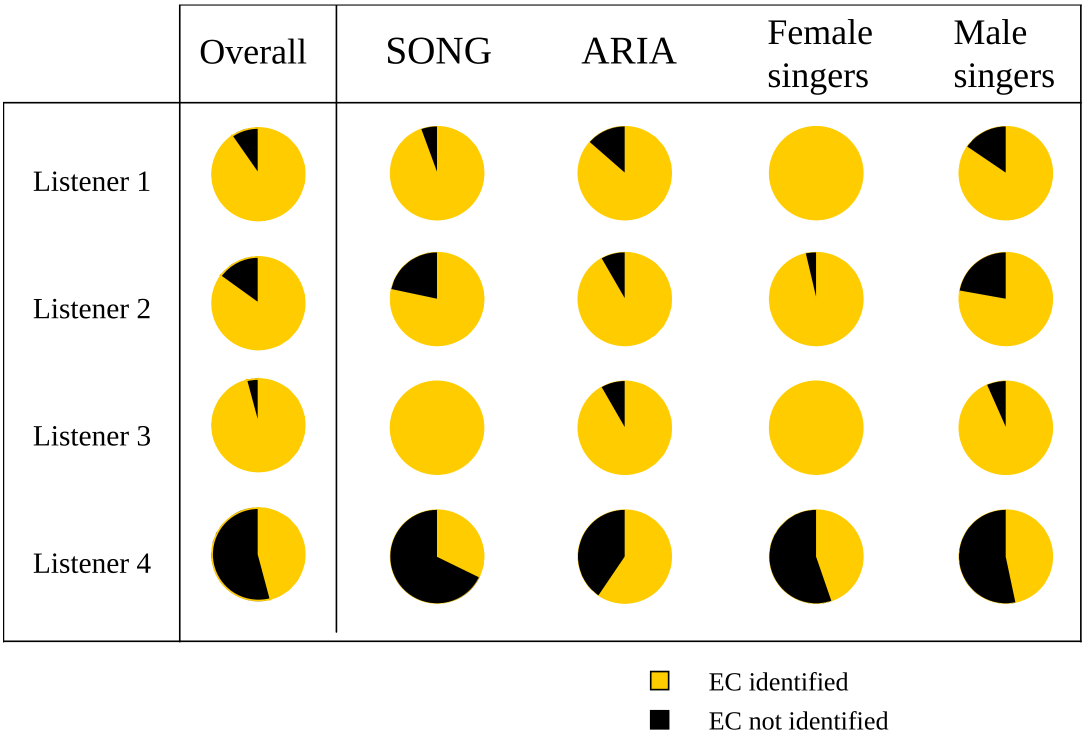


Figure 38 - Pie charts comparing number of correct IC identifications by expert listeners for Song/Aria and for male/female singers.

7. Discussion

7.1. Introduction

As stated in the Preface, the aim of this thesis was to compare lung volume behaviour in operatic singers using intention to communicate (performance mode) with lung volume behaviour in operatic singers using technical singing (rehearsal mode, in which the singer increases awareness of individual technical components). Professional singers are expected to be able to make this differentiation between rehearsing and performing. The main question of this thesis is whether these changes in intention can bring about a measurable difference in respiratory parameters.

The main hypothesis of this thesis is that such changes in intention will be reflected in physiological differences, showing changes in breathing patterns. The secondary hypothesis is that listeners can perceive these changes of intention.

The results of the emotion gauge showed that singers believed they had achieved what they had intended in differentiating between conditions. The matched respiratory data showed that singers were consistent and could reliably repeat respiratory behaviour when they sang with intention to communicate, and when they sang technically. The ranking results showed that patterns of lung volume were greatest when singers intended to communicate compared to singing technically (IC condition compared to T condition). This finding was reflected in higher initiation lung volumes and lower termination lung volumes, and greater flow of air per second, but interestingly, not in longer inspiratory times.

7.2. Summary

This study has shown that when operatic singers performed with the intention of communicating, rather than singing technically, they used a different breathing pattern, with increased respiratory parameters. The respiratory difference cannot simply be explained by sound pressure level differences or expiratory duration. Singing with ‘intention to communicate’ used more air, and got it by starting from a higher initiation point in the vital capacity and continuing down to a lower termination point compared to ‘technical’ or ‘technical loud’ singing, but was quieter compared to ‘technical loud’ singing.

In terms of the literature for both singing and speech, this finding is unexpected because a higher initiation lung volume (ILV) has previously been associated with higher sound pressure level for speech and singing studies (Hixon, Goldman & Mead 1973; Hixon, Mead & Goldman 1976; Winkworth, Davis, Ellis & Adams 1994; Stathopoulos & Sapienza 1997). Previous research shows either a rise in ILV with a rise in SPL, or an unpredictable use of strategies in relation to ILV and SPL. It has been shown that in general increased ILV is used to achieve higher subglottal pressures for louder speech (Hixon et al 1973; Hixon et al 1976). It has also been shown that subglottal pressure increases with increases in loudness (Holmberg et al 1988; Isshiki 1964; 1965; Tanaka & Gould 1983). Various combinations of laryngeal and respiratory factors have been shown to increase SPL (Isshiki 1964;1965; Stathopoulos & Sapienza 1993).

Professional operatic singers are able to increase subglottic pressure for loudness but independently of vocal fold tension (otherwise increased subglottic pressure would increase pitch, as shown by Bouhys et al 1966; Gauffin & Sundberg 1989). Our results have shown that professional operatic singers can increase subglottic pressure (by increasing ILV) not only independently of vocal fold tension (pitch) but also independently of sound pressure level. This was reliably and repeatably achieved through a specified level of intention to communicate.

7.2.1. Patterns in lung volume variation

Our findings are in agreement with the findings for respiration, speech breathing, and operatic singing showing that individuals themselves can show consistency with their own breathing patterns (Watson, Hixon, Stathopoulos & Sullivan 1990; Hixon et al 1973; Thomasson & Sundberg 1999). Our findings are not in agreement with speech breathing findings showing that there is a lot of variation in breathing between individuals, both for quiet breathing (Shea, Walter, Murphy & Guz 1987; Tobin, Mador, Guenther, Lodato & Sackner 1988), and for speech breathing (Wilder 1983; Hodge & 1989; Winkworth, Davis, Ellis & Adams 1994). This is not surprising given that professional operatic singing (compared to speaking and quiet breathing) conforms to specified musical requirements of notated pitch and duration resulting in specific phrase lengths, the speed of which must be consistently repeated. The speed of phrase lengths is initially set by composers using metronome markings. These speeds may be adjusted within basic parameters (for example between 40-60 beats per minute for Largo, 76-108 beats per minute for Andante, 200-208 beats per minute for Prestissimo). Any change (including speed changes) requested by conductor or director must also subsequently be consistently repeated. The conductor will set the speed within the parameters of the metronome marking, so the singer (and also the wind players) must be able to consistently and reproducibly adapt breathing requirements for changes of speed (and therefore phrase duration) that may vary by up to 50% from the singer's original practice. (For example, 6-second Largo phrases at 60 beats per minute, may theoretically be requested up to 50% longer at 40 beats per minute, resulting in up to 9-second phrases). For professional singers and wind players, consistent tone must be produced over a variety of changing circumstances including speed changes requested by the conductor. Performers must be able to reproducibly use anything from large to quite small increments or decrements in lung volume, according to the notation written by the composer, and then taking into account the interpretation of the conductor. It is not surprising to find that the breathing patterns of professionals who are able to fulfil such specific musical requirements, and to change them at a moments' notice, can be reliably repeated. What is surprising in terms of the findings of this study is that change of intention (i.e. rehearsal to performance) also results in changes in lung volume behaviour. This has important ramifications for future respiratory study, showing that changes in intention to communicate can make a measurable difference.

These findings are in agreement with Thomasson and Sundberg (1999) who found highly consistent lung volume behaviour in professional operatic singers singing arias and art songs. These findings also extend the findings of Thomasson & Sundberg (1997), (who found greatly increased lung volume levels for performance mode operatic singing in comparison with speech breathing), and Watson & Hixon (1996) (who showed an increase in lung volume initiation and excursion through rehearsal stages to final performance during stages of learning a new aria by a highly trained classical singer). Table 18 below compares the lung volume results of this study with previous singing studies. Although this study did not have enough subjects to show possible gender effects (see section 4.2.2.) our results have been separated by gender in order to make a comparison with previous studies.

As shown in Table 18, Watson and Hixon (1996) present data from a male singer (baritone) from four learning sessions beginning with sight reading a new aria and progressing to performing the same aria from memory as if to a paying audience. Over these four sessions there is a 21% VC increase in ILV, a 4% VC decrease in TLV, and an overall increase in lung volume of 17% VC. ILV is increased at each of the four stages, reflected in the increase of overall lung volume. TLV is *not* decreased at every stage but unexpectedly increases by 7% between stage 2 (after the initial practice) and stage 3 (singing with the music as if to a paying audience). TLV once more decreases (this time by 2% VC) from stage 3 to stage 4 (singing from memory as if to a paying audience). In summary, Watson and Hixon (1996) show an increase in respiratory parameters (total lung volume increase of 17% VC) from initial learning to final performance.

As shown in Table 18 below, our results for aria singing (Foulds-Elliott et al, 2000) with singers using an already well-learned aria, comparing performance (intention to communicate) with rehearsal (technical singing) on the same day within a few minutes, show an increase of 11% VC in overall lung volume (LVE) for females and an increase of 13% VC lung volume for males. The male singers showed a lung volume change which was only 4% VC different from the total lung volume change in the Watson and Hixon (1996) male singer comparing initial sight reading with final performance (over 2.5 weeks). In other words, singing with and without intention to communicate may give lung volume change which becomes comparable with the lung volume change found over time as a singer learns a new piece to performance standard. Although Watson and Hixon (1996) used only one subject which cannot be said to provide definitive results, they nevertheless provide a context against which our findings become startling.

Comparing our results with Thomasson and Sundberg (1997) whose singers sang with a grand piano ‘as during a concert’, we found 3% VC higher lung volume for women, and for men, a startling 18% VC higher lung volume. Although Thomasson and Sundberg (1997) clearly set up a performance-type concert situation, a singer may or may not actively imagine the presence of an audience unless expressly requested to do so. Singers may also vary in their ability to imagine the presence of an audience. Even so, the 18% VC lung volume difference between these results recorded within minutes of each other is greater than the 17% VC difference gradually built up during 4 sessions over 2.5 weeks between sight-reading and performing in Watson and Hixon (1996). This comparison of results shows that a singer’s change of intention can give an immediate, on-the-spot change to lung volume behaviour which may be comparable to or even greater than the gradual change found in the level of lung volume behaviour throughout the process of learning a new aria. This unexpected finding shows that unless intention is actively specified for professional operatic singers, results may contain large amounts of variability.

Table 18. Initiation lung volume (ILV), termination lung volume (TLV) and lung volume (LV) results comparing this study with previous classical singing studies

				ILV(SD) (%VC)	TLV(SD) (%VC)	LV(SD) (%VC)
Classical professional singing:						
Males	Thomasson & Sundberg (1997)					
		4 baritones:		66(15)	38(13)	28(13)
	Watson & Hixon (1996)					
		1 baritone:	sight reading	60(10)	21(14)	39(14)
			after practice	62(10)	20(15)	42(16)
			as if to paying audience	75(7)	27(17)	48(18)
			as if to paying audience fr. memory	81(15)	25(23)	56(24)
	Watson & Hixon (1985)					
		6 baritones:		60-90	15-35	30-65
	Foulds-Elliott, Thorpe, Cala & Davis (2000)					
		3 baritones:	aria, tech.	69(9)	36(12)	33(15)
			aria, I.C.	76(11)	30(16)	46(18)
Females	Thomasson & Sundberg (1997)					
		3 females:		73(11)	30(13)	43(17)
	Watson, Hixon, Stathopoulos & Sullivan (1990)					
		4 females:		43-93	28-52	15-43
	Foulds-Elliott, Thorpe, Cala & Davis (2000)					
		2 sopranos:	aria, tech.	76(14)	41(10)	35(10)
			aria, I.C.	79(12)	33(13)	46(13)

In terms of perception of IC, two listeners out of three could perceive IC for 72 out of 74 excerpts, showing that it is possible for listeners to perceive intention to communicate. This is not a surprising result in terms of previous research showing that listeners can mostly differentiate between different emotions (Sundberg 1994; 1997; and Scherer 1995), and that most listeners can correctly interpret the emotional intention of singers (Sundberg 1998). These results demonstrate not only that the intention to communicate increases respiratory parameters but that it can be perceived by listeners.

Previous research shows that in the area of respiratory research, there is a relationship between emotion, respiration and speech, but that research in the area of respiration in singing has not yet taken performance intention into account. Our results show that in comparison to technical singing, there was an increase in breathing parameters for tasks in which operatic singers intended to communicate, in the direction of flow phonation (Gauffin and Sundberg 1989). These results demonstrate that although higher initiation lung volume has been associated with higher sound pressure level in respiratory literature, intention to communicate in operatic singing does not reflect a simple relationship between these two variables. These results also demonstrate that the singer's intention to communicate (performance mode in contrast to technical or rehearsal mode) in professional operatic singing can affect respiratory parameters to a surprising degree. Consequently, intention needs to be actively specified for future research in the area of professional operatic singing.

Specific results are discussed below.

7.3. Patterns of breathing: ranking results

7.3.1. LVE, ILV, and TLV

Overall, lung volume expired (LVE) ranked higher when the singers intended to communicate, compared to the technical conditions, for Aria (as shown in Figure 8) and for Song (as shown in Figure 21). This was also the case for each singer individually for Aria (as shown in Figure 9), and for three of the five singers for Song (as shown in Figure 22). These results demonstrate a strong and persistent change in respiratory pattern in the comparison between intention to communicate and technical singing, for Aria. The pattern is the same for Song but is not as strong. For both Aria and Song, lung volume expired was significantly higher for intention to communicate compared to technical singing.

The overall amount of lung volume expired is calculated from the point in the vital capacity at which the subject initiates the breath, down to the point in the vital capacity at which the subject terminates the breath (see Figure 4). Having found that a greater amount of air (lung volume expired) is used when the singers intended to communicate compared to when they were singing technically, the next question is whether the increase in lung volume expired was due to taking the breath from a higher initiation point, continuing on into breath reserve at the end of the phrase by finishing the phrase at a lower breath point (termination lung volume), or a combination of both.

Lung volume expired for each singer was significantly related to the intention to communicate condition compared to the technical conditions. However, different strategies were used in the combination of initiation and termination levels that made up the overall lung volume expired for each singer. Singers 1 and 2 increased the initiation level, and singer 2 also decreased the termination level. Singers 3, 4 and 5 decreased the termination level.

Watson and Hixon (1996) have shown that breathing initiation and termination lung volumes used by one singer when he performed to an audience were higher than on earlier trials when he was initially learning the aria. While this may have been due to a learning effect, another explanation is that performers practise until repetition creates the technical part of a performance, so that primary intention can be focused on what the performance is communicating. It may be that Watson and Hixon's (1996) singer sang with more 'intention to communicate' when he knew the music well enough to put down the score and perform as if to a paying audience. This is consistent with the findings here that initiation lung volumes are higher and termination lung volumes are lower with a greater level of intention to communicate. It could be that in the technical/rehearsal conditions the singer does not have such well-integrated control of the respiratory/phonatory apparatus as during IC/performance conditions, so does not access the full range of possible lung volumes. With IC/performance, the singer accesses greater lung volumes. In everyday terms this may be analogous to the ease with which we take in a large amount of air in a natural sigh, compared to the relative effort in taking a voluntary breath of the same lung volume.

7.3.2. SPL or Te?

The next question is whether or not the increased use of air by singers intending to communicate compared to singing technically was due to either louder singing or longer phrases. In the Aria task, the greater lung volume expired when singers intended to communicate compared to the technical conditions was not caused by louder singing (as shown in Table 12a), or by singers making the phrases longer (as shown in Table 12b). In the Song task, the greater lung volume expired when singers intended to communicate compared to the technical conditions was not caused by louder singing (Table 14a), but some of it may have been caused by singers making the phrases longer (Table 14b).

7.3.3. Flow

Overall, and for singers individually, the amount of air released per second (Flow) in the Aria task was greater when singers intended to communicate than when singers performed technically (as shown in Figure 18). This was also the case for the Song task (as shown in Figure 31). In other words, the singers released more air per second when they intended to communicate than when they sang technically, in both the Aria and the Song task.

Thorpe, Cala, Chapman and Davis (2001) found that operatic singing with increased projection resulted in an increase in acoustic power with a decrease in mean expiratory flow. These results suggest that operatic singers are able to adjust respiratory and acoustic parameters independently.

7.3.4. Ti

An unexpected result was found when examining the relationship between inspiratory time (Ti) and condition, for the Aria task (see Figure 19). There was an overall significant relation between inspiratory time and condition, with inspiratory time being shorter for intention to communicate takes than for technical takes. In other words, singers in the Aria task took a shorter time to breathe when they were using more air, for the intention to communicate condition compared to the technical condition. For the Aria task, all singers except singer 3 showed a shorter inspiratory time for intention to communicate takes than for technical takes. This result may indicate that in the intention to communicate takes for the Aria task, singers were using a reflex reaction to take in more air more quickly than in the technical takes.

In the Song task the result was not clear (as shown in Figure 32). Inspiratory time rankings were not significantly related to condition for Song, and a significant pattern only emerged for singer 2 and singer 5. Singer 2 showed shorter inspiratory time for intention to communicate singing compared to technical, and singer 5 showed the opposite with shorter inspiratory time for technical compared to intention to communicate singing. The results for inspiratory time in Song were therefore inconclusive. The musical demands of the Song task were less extreme than those of the Aria task, thus possibly allowing a greater variety of strategies to be employed. The song used in this experiment was strophic in form, with the same melody repeated on different words for each verse, and a reduced range in comparison to most arias. In terms of pitch it was placed approximately in the middle of the vocal range without extremes of high or low notes. It also did not have extremes of dynamic range (from very soft to very loud) unless the performer chose to put these in, and some did, making the final phrase of the last verse extremely quiet, with a very long extended final note on a decrescendo therefore becoming more and more quiet.

The Aria task comes directly out of the operatic tradition. Each aria is taken from an opera and has been written to convey to the audience the extreme emotional experience of a particular character at that point in the opera. Arias in operatic writing are written to hold up the action of the plot in order to explore the feelings of the character at that point in the plot. The Aria task is therefore technically and artistically more demanding than the Song task (usually with greater pitch range and more variety of phrase lengths, note values, pitch changes and dynamic variations in loudness for dramatic purposes). Moving from technical rehearsal to performance intention in the Aria task, in comparison with the Song task, may well give more encouragement to the taking of the breath as a reflex, reflected in the increased amount of air taken in a shorter amount of time. These findings give some support to the findings of Watson and Hixon (1996) and Bloch, Lemeignan and Aguilera-T (1991) which indicated a reciprocal relationship between breathing and emotion.

7.4. Intention to communicate, and flow phonation

Vocal output is dependent on contributions from three distinct mechanisms: sub-glottal pressure produced by respiratory muscle action; glottal vibration defined largely by the interaction between subglottal pressure and laryngeal configuration; and supra-laryngeal resonances defined by the shape of the vocal tract. The sound level can be changed by each of these mechanisms, increasing with greater sub-glottal pressure, with changes in the pattern of the glottal vibration such that the folds close more rapidly in each cycle, and by adjusting one or more of the vocal tract resonances so that it coincides with one of the harmonics of the voice signal (so-called formant tuning). Adjustment of the glottal vibration pattern so that the glottis is open for only a portion of each cycle increases the vocal efficiency in at least two ways: it reduces the average flow of air because during the closed period the flow is zero; and it can increase the sound energy emitted at higher frequencies because of the steepening of the opening and (especially) closing transients. Sundberg (1987; 1995) presents a phonatory dimension, consisting of pressed phonation to breathy phonation, with the optimal flow phonation in the middle of the continuum. Pressed phonation has a high sub-glottic pressure with a strong adductive force, while flow phonation has a lower sub-glottic pressure and a lower degree of adduction force. If air-flow is excessive, the vocal product is breathy, while at the other end of the continuum a pressed voice is the result of insufficient air-flow. Our findings indicate that TL singing, compared with IC singing, was higher in average sound pressure level but used less air, indicating a position closer to the pressed end of Sundberg's scale. IC singing, on the other hand, related more to flow phonation, which is characterised by coordinated integration of sub-glottal pressure, glottal vibration and vocal tract shape giving a free and unconstricted flow of air with optimum expression and minimum effort.

Our findings also indicate a relationship to Miller's point of fusion whereby the technical aspects of singing are brought together because the singer intends to communicate the emotional meaning of the music to the audience. Miller holds that "A direct result of such conceptual coordination is the emergence of legato in singing" (Miller 1986, p. 204). For operatic singing, this technically desirable result is characterised by Miller as "a constantly flowing stream of uniform vocal timbre" (Miller 1986, p.204). Our finding that singers performing with intention to communicate in comparison with technical singing are using more air with greater flow, may well indicate a better legato in Miller's terms.

7.5. Kinematic results

The increased outward movement at anterior/posterior measurement sites for the Aria task when singing with IC, compared to T singing, reflects the increase of air used for IC.

The relationship between what singers refer to as 'support' (which is still incompletely understood from the scientific point of view) and the use of the laterals is explored further in the example from the data of singer 4 (Figure 36) which gives a raw data illustration of a Puccini-style octave leap (in the phrase 'e se l'amassi indarno') followed by a portamento ('supported' slide), in which changes of the relative lung volume between rib cage laterals and abdomen laterals are evident in the IC condition but not in the technical condition. Musicians will not consider this phrase to be convincing within the style unless the slide is 'supported'. Singer 4 did not use portamento at all in the Technical takes displayed in Figure 36. The first phrase illustrated in Figure 36 is the acoustic selection for singer 4 which the listeners heard and assessed as being more convincing in the intention to communicate than in the technical condition. The intention to communicate condition shows expansion of the rib cage laterals in preparation for the leap, and the tightening of the abdomen laterals during the following supported slide. The technical condition has no supported slide and shows little change in relative lung volume, with a flat line evident in both rib cage and abdomen laterals.

Continuous changes of the relative lung volume between rib cage and abdomen during singing by trained singers (which was not present in singing by untrained singers) were found in four previous magnetometer studies (Watson & Hixon 1985, Watson, Hoit, Lansing & Hixon 1989, Watson, Hixon, Stathopoulos & Sullivan 1990, and Watson & Hixon 1996). It could be that these relative lung volume changes are what singers call 'support' (see section 2.1.1.).

‘Support’ requirements (and therefore, in the light of these results, the type of demand made on changes of relative lung volume between rib cage and abdomen) vary greatly according to the style of composition in the singing of professional operatic singers (see section 2.2.). The emotionally extreme operatic style of the composer Puccini (1858-1924) and somewhat emotionally extreme style of the composer Verdi (1813-1901) increase the variations in ‘support’ requirements demanded from the singer. This demand is found to a much lesser extent (in terms of sudden changes in ‘support’, and other emotional responses such as pitch variability in approach to the note) in earlier composers such as Mozart (1756-1791). Performances of Mozart would be considered unacceptable if these stylistic devices were over-employed. Future research needs to take into account not only the level of IC of the singer, but the vocal demands of the composer’s style.

7.6. Perceptual results

Three listeners perceived from 85% - 96% of the IC of the performers, with 80% - 100% reliability. However, perception of IC was confounded with style for listener 4, who scored only 46% correct identification of IC, with 63% intra-judge reliability. In the post-listening interview listener 4 indicated his belief that opera singers could not communicate emotion in song style (see sections 2.2.2., 7.7.3. and 7.7.4.) This belief was reflected in listener 4's score of only 30% correct identification of IC in the song task, compared with 60% identification of IC in the aria task. In addition to confounding stylistic and emotional factors, the reliability of the judgements of listener 4 (as assessed by the repetitions in the excerpts) was only 63%, compared with 80-100% for the other 3 listeners. In other words, listeners 1, 2 and 3 heard the same excerpts repeated, and judged them the same way, whereas listener 4 heard the same excerpts repeated, and judged them differently. For the three reliable listeners, there were more instances of correct identification of IC, indicating that the vocal signal contained reliable cues for emotional expression.

7.6.1. Individual differences

There are interesting individual differences in the perception of IC between different listeners, and with different performers. Listeners 1, 2 and 3 all found it much easier to perceive IC in the female singers than in the males (as shown in Figure 38) with listeners 1 (male) and 3 (female) scoring 100% correct identification, and listener 2 (male) making only one error in the 30 examples of female singing. Perception of IC was most difficult in listening to singer 1 (male), for whom 10 mistakes in total were made (see Table 17). Five mistakes were made with each of the other male singers. IC was always perceived in female singer 4, and only one error was made in listening to female singer 5. The female singers both sang Arias composed by Puccini, in which stylistic devices to communicate emotion (such as portamento and pitch approach up to the note) are more obvious. Also, the female singers were the youngest of the five operatic singers, and had been performing for less time (see Table 5). They may have been more keen or more able to make a difference between the conditions. The more established singers were the males, who may have had IC already established in their techniques so that even their 'technical' performances still carried enough intention to communicate to convince the listeners. On the other hand, intention to communicate is perhaps more apparent in the female voice. The small number of singers in our study, and the fact that the male singers had been performing for a greater number of years than the females, preclude any judgement on this issue without further study.

7.7. Methodological shortcomings

7.7.1. Use of magnetometers

Care was taken to tape the magnetometers parallel to each other, as the output voltage is linearly related to the distance between the magnetometers of each pair. However, some singers were more curvaceous than others which means that magnetometers may not have been exactly parallel (see Table 5 for singers' height\weight records). Limitations in the use of magnetometers are also related to movement artifacts. Singers were stabilised in an adjustable frame which was adjusted for each singer so that they stood comfortably with their arms resting on the frame (see photo 1). Singers were asked to remain in the same position in relation to the frame while singing, and were also asked not to move their head while singing. A researcher was positioned next to the singer at all times to remind them not to move, and to check that they did not do so. If the singer moved, the researcher was to indicate the fact to the computer operator, who was to note it at that point in the MacLab comment box, and then to ask the singer to start the take again. It is possible that restraining the singers in this fashion may have affected their ability to increase the intention to communicate.

Another possible limitation in the use of magnetometers is that the presence of large metal structures or electric motors in the environment could affect voltage output. The studio chosen for this study contained no structures of this kind.

Use of magnetometers also raises the question of how naïve singers were to lung volume measurement during singing, and whether this had an effect on performance. However, care was taken to ensure that singers were not made aware that magnetometer measurements related directly to lung volume. The information provided to the singers referred rather to measurement of body movement. It therefore seems unlikely that singers would have realised that the magnetometers were measuring lung volume. Even if some singers had deduced this, no indication was given as to the hypothesis (e.g. relating to differences between the IC and T conditions), with the different conditions presented simply as different ways in which we wanted the singers to sing.

7.7.2. Task order

Table 6 (section 5.2.6.) shows the task order chosen by each singer. Some singers performed IC before T takes and others used the reverse order, but there were no systematic differences between the first and second take of either of the repeated conditions. Using professional singers as subjects reduces the expectation of order effects, as these singers are used to changing their approach on demand. The results show no evidence of order effects.

7.7.3. Style effects

It is expected that in professional performance, emotional effect must be communicated within the parameters of the style of music being performed, so that increasing intention to communicate in Puccini style for example, will increase the telling elements of that style such as vibrato and portamento. Increasing intention to communicate in the Mozart style will not be expected to give such variation in vibrato, but may in fact result in a completely different strategy such as increasing one parameter (for example getting louder) while not increasing another parameter (for example not getting faster). Puccini style singing would most typically increase or decrease on both the speed and dynamic parameters simultaneously, while the Mozart style would be more likely to hold speed constant while changing sound pressure level. This study allowed singers to choose their own aria in order to have them perform something very familiar and therefore easily able to be performed in the various ways required. This gave a variety of operatic styles and therefore a variety of strategies. Future studies may be better served if not only the language but the composer was specified by the experimenters.

7.7.4. Expert listeners

This study found that the expert listeners who were able to perceive the intention to communicate were also teachers. The expert listener with low reliability was an opera critic. Effective teachers are not prejudiced by particular stylistic likes or dislikes and must be able to teach effective communication within a variety of different musical styles. Although the small number of listeners in this study precludes any judgement about the relative merits of using teachers or critics for future studies, the results indicate that it may be important for future work in this area to use expert listeners who are able to differentiate between convincing singing and stylistic preference.

8. Pedagogical speculation

8.1. Emotion

Emotions are expressed and communicated through changes in the autonomic, somatic and endocrine systems. Emotion has not been defined satisfactorily at either linguistic, psychological or neuroanatomical levels. The number of emotions that can be reliably identified satisfactorily at either linguistic or neuroanatomical levels is uncertain, and there has been little understanding of the influence of cognitive, higher brain processes in emotional experience and its expression (Saper 1986). The hypothalamus has been thought to play a key role in integrating emotional expression although this view has been challenged and it is now thought that an unconscious part of our brain, the midbrain periaqueductal gray (PAG) plays a major role in emotional expression (Bandler & Shipley, 1994) and may also play a role in the motor control of voice for speech and song (Zhang, Davis, Bandler & Carrive, 1994; Davis, Zhang & Bandler 1996; Holstege & Ehling, 1996; Davis 1998; Chapman & Davis, 1998). It is important to note that stimulation of the PAG produces complex integrated patterns of involuntary changes in blood pressure and heart rate, as well as changes in the activity of muscles under voluntary control, including the breathing, laryngeal, facial, and oral muscles which are always activated simultaneously in a coordinated manner and may be accompanied by body movement (Bandler & Carrive, 1988; Zhang et al., 1994). The implication of these experimental results for our study is the possibility that when the professional performer taps into the emotional recall required in performance mode (e.g. when the performer intends to communicate), it may be that a co-ordinated pattern of breathing, postural, oro-facial and other physiological changes is induced which is different to that which can be voluntarily recruited and which may then be perceived by the audience in some equivalent way, triggering remembered emotional experience. Indeed, the breathing patterns associated with IC employ a greater variety of parameters than the breathing patterns associated with the T conditions, with a greater amount of air inspired, and a greater variation in sound level. Listeners perceived the sound as being more emotionally connected. It may also be that the raw material of the operatic singing sound comes from involuntary reactions caused by recall of emotion and that this physiologically co-ordinated sound is shaped by the learned patterns of music and language. If this is so, it would endorse the pedagogical importance of the relationship between emotional recall and technique, pointing out that the basic operatic sound itself needs to originate from emotional recall, which shapes and can be shaped by technique and the specific demands of musical style.

8.2. Respiration and emotion

Everyday experience shows in broad terms that different emotional responses are associated with different breathing patterns. This has been explored with actors (Bloch, Lemeignan & Aguilera-T, 1991; Stanislavsky 1963; Grotowski 1968; Linklater 1976). Voice work of any kind usually begins by addressing the breathing. Singing teachers find that changing breathing patterns is often the way voice function is improved (Sundberg 1987). In the teaching of operatic singing, some of the great teachers hold that in engaging with the emotional content of the music, the technique of the singer will develop (Manen 1974, Hemsley 1998). These teachers also find that if the student does not engage with the emotional content, technical development can be impeded. Specific technical information is of course vital in voice work but must ultimately be brought together and co-ordinated by the intention to communicate, expressed by Linklater (1976) as letting the thought bring in the breath.

8.3. Emotional motor system

Teaching singing involves the challenging task of teaching students to use muscles which are not able to be accessed voluntarily, but can be accessed as a reaction. To perform convincingly, students must also be able to resist using voluntarily accessible muscles in a voluntary manner (though this may be useful in practice and rehearsal). Instead, the student is expected to develop the same discipline as an actor - muscle activation must be made as a reaction. Holstege's (1996) hypothesis that there are at least two motor systems (a voluntary motor system and an emotional motor system) is an exciting concept for actors and singers, because it suggests a possible physiological reason for the difference between IC and T conditions. In the light of the results of the present study, application of Holstege's theory suggests that in the IC condition the singers were, at least partially, invoking their emotional system and so obtaining a more convincing and coordinated pattern of respiratory and vocal activation than was possible in the technical conditions, where presumably they utilised a more 'conscious' control of their singing apparatus.

Some operatic singing teachers state specifically that operatic singing uses primal sound which makes involuntary demands on the body (Chapman 1986, Brown 1996, Chapman & Davis 1998). From this viewpoint, voluntary muscle use represents, at best, an unconvincing technical performance.

8.4. Summary

The experimental study in this research was based on the ability of operatic singers to sing in two ways, namely to sing technically as if rehearsing (T) and also to sing with intention to communicate as if performing (IC). The most important finding was that the IC condition compared to the T condition increased lung volumes, and resulted in sound that listeners recognised as carrying more emotion. Singing pedagogy displays a great variety of different approaches (Miller 1986: 1998) and yet the ultimate aim is of course to communicate with the listeners. This research suggests that when singers "intentionally" focus on communication, rather than singing as if rehearsing, there are measurable differences both in their breathing patterns and in how listeners perceive their singing. This finding supports the view of all effective pedagogies as exemplified by the two quotes from Miller (1986) in the Preface (see page 10). The first quote defines technique as a tool for communication, while the second quote shows the importance of the singer's focus on phrase inception – on what the imminent musical phrase has been created to communicate. Both these quotes illustrate that there must be a relationship between these two aspects of singing, and that effective singing is the product of the union of the body and the artistic imagination. This experimental study gives support to the notion that even a professionally developed technique is perceived as more communicative emotionally when the singer focuses intentionally on the emotional import of the message being communicated through the singing.

The findings of this study are in agreement with Thomasson and Sundberg (1999) who showed the consistency of respiratory patterns in professional operatic singing. Our study has extended this finding by differentiating between performance in which the singers intended to communicate, and rehearsal in which the singers sang technically. Comparison between these two conditions showed a difference in the respiratory behaviour observed, and a change in the quality of the vocal output that was accurately perceived by listeners. As the history of opera shows, operatic performance developed out of the intention to communicate emotion through the human voice. These results demonstrate that intention to communicate as in performance, compared to rehearsal, results in a measurable difference in respiratory parameters.

9. Conclusion

9.1. Effects of IC

The research described here has shown that when operatic singers sang with the intention to communicate compared to singing technically, they increased initiation lung volumes and decreased termination volumes, thereby increasing the flow of air expired during singing. These effects, combined with a perceived difference in the quality of the sound produced (as evidenced by the perceptual results), were not simply associated with sound pressure level or length of phrase.

In singing with the intention to communicate, singers were able to access both higher and lower lung volumes, and produce sound that was reliably identified as being more convincing, than singing technically. These results demonstrate that intention to communicate in operatic singing does not reflect a monotonic relationship between initiation lung volume and sound pressure level. These results also demonstrate that the intention to communicate in professional operatic singing can affect respiratory parameters, and therefore must be taken into account in future respiratory studies.

REFERENCES

Apel, W. (1969). *Harvard Dictionary of Music*. Cambridge: Harvard University Press.

Agostini, E., & Mead, J. (1964). Statics of the respiratory system. In: *Handbook of Physiology,* Section 3, Respiration 1*.* Washington DC: American Physiological Society, 387-409.

Averill, J.R. (1969). Autonomic response patterns during sadness and mirth. *Psychophysiology 5(4)*:399-414.

Bandler, R., & Carrive, P. (1988). Integrated defence reaction elicited by excitatory amino acid injection into the midbrain periaqueductal grey region of the unrestrained cat. *Brain Res.439*:95-106.

Bandler, R., Carrive, P., & Zhang, S.P. (1991). Integration of somatic and autonomic reactions within the midbrain periaqueductal grey: viscerotopic, somatotopic and functional organisation. In: *Progress in Brain Research.* Ed. G.Holstege. Amsterdam: Elsevier (87), 269-305.

Bandler, R., & Shipley, M.T. (1994). Columnar organization in the midbrain periaqueductal gray: Modules for emotional expression? *Trends in Neurosciences 17*:379-389.

Bloch, S., Lemeignan, M., & Aguilera-T, N. (1991). Specific respiratory patterns distinguish among human basic emotions. *International Journal of Psychophysiology 11*:141-154.

Bode, F.R., Dosman, J., Martin, R.R., Ghezzo, H., & Macklem, P.T. (1976). Age and sex differences in lung elasticity and in closing capacity in non-smokers. *Journal of Applied Physiology 41:*129-135.

Bouhys, A., Proctor, D.F., & Mead, J. (1966). Kinetic aspects of singing. *Journal of Applied Physiology 21(2)*:483-496.

Brown, 0. (1996). *Discover Your Voice - How to Develop Healthy Voice Habits.* San Diego: Singular Publishing Group, Inc.

Bukofzer, M. (1947). *Music in the Baroque era.* New York: W.W.Norton.

Caccini, G. (1602). *Le nuove musiche.* Ed. H. Wiley Hitchcock. Madison: A-R Editions, 1970.

Chapman, J. (1986). Making connections - Primal singing. *Proceedings of Voice Conservation Symposium*: London.

Chapman, J., & Davis, P. (1998). Primal singing. *Australian Voice 4:*9-11.

Cotes, J.E. (1974). Genetic component of lung function. *Bull.Physio.Pathol.Respirat.10*:109-117.

Davis, P.J. (1998). Emotional influences on singing. *Australian Voice 4*:13-18.

Davis, P.J., Zhang S.P., & Bandler, R. (1993). Pulmonary and upper airway afferent influences on the motor pattern of vocalisation evoked by excitation of the midbrain PAG of the cat. *Brain Research 607*:61-80.

Davis, P.J., Zhang, S.P., & Bandler, R. (1996). Midbrain and medullary regulation of respiration and vocalization. *Progress in brain research 107*:315-325.

Davis, P.J., Zhang, S.P., Winkworth, A.L., & Bandler, R. (1996). Neural control of vocalisation: respiratory and emotional influences. *Journal of Voice 10(1)*:23-38.

Duey, P.A. (1951). *Bel Canto in its Golden Age.* Dacapo Press: New York.

Ekholm, E., Papagiannis, G.C., & Chagnon, F.P. (1998). Relating objective measurements to expert evaluation of voice quality in western classical singing: critical perceptual parameters. *Journal of Voice 12(2):*182-196.

Foulds-Elliott, S.D. (1999). Review of the book “Singing and Imagination”. *Australian Voice 5*:77.

Foulds-Elliott, S.D. (2000a). Review of the book “Singing and Voice Science”. *Postwest 17*:60.

Foulds-Elliott, S.D. (2000b). Emotional connection in operatic singing: traditional and scientific insights. *Australian Voice 6*: 9-15.

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.

Galliver, D. (1969). Favolare in Armonia - a speculation into aspects of 17th century singing. *Miscellania Musicologia;IV* (Adelaide):130-146.

Galliver, D. (1972). Vocal colour in C17th Italy: the contribution of Caccini. *International Musicological Society Congress Report* (Copenhagen):385-388.

Galliver, D. (1973). Cantare con la gorga - the coloratura technique of the renaissance singer. *Studies in Music 7,* University of W.A. Dept. of Music:10-18.

Galliver, D. (1974). Cantare con affetto - keynote of the bel canto. *Studies in Music 8*; University of W.A. Dept. of Music:1-7.

Galliver, D. (1987). Vocal colour in C19th operatic singing: a pioneer role for Caccini. *International Musicological Society Congress Report* (Bologna):477-481.

Gauffin, J., & Sundberg, J. (1989). Spectral correlates of glottal voice source waveform characteristics. *Journal of Speech and Hearing Research 32,* Sept:556-565.

Gerratt, B.R., Kreiman, J., Antonanzas-Barroso, N., & Berke, G.S. (1993). Comparing internal and external standards in voice quality judgements. *Journal of Speech and Hearing Research 36*, Feb:14-20.

Gibson, G.J., Pride, N.B., O’Cain, C., & Quagliato, R. (1976). Sex and age differences in pulmonary mechanics in normal nonsmoking subjects. *Journal of Applied Physiology 41*(1), July:20-25.

Gould, W.J. (1984). Clinical application of voice research. *Ann.Otol.Rhinol.Laryngol.93*: 346-350.

Grotowski, J. (1968). *Towards a poor theatre.* USA: Simon and Schuster.

Grout, D.J. (1960). *A history of Western Music.* USA: Dent.

Heim, E., Knapp, P.H., Vachon, L., Globus, G.G., & Nemetz, S.J. (1968). Emotion, breathing and speech. *Journal of Psychosomatic Research 12*:261-274.

Hemsley, T. (1998). *Singing and imagination.* Oxford: Oxford University Press.

Hirano, M. (1974). Morphological structure of the vocal chord as a vibrator and its variations. *Folia Phoniatrica 26*: 89-94.

Hirano, M. (1975). Phonosurgery: Basic and clinical investigations. *Otologia (Fukuoka) 21*: 239-440.

Hirano, M. (1977). Structure and vibratory behaviour of the vocal folds. In: *Dynamic aspects of speech production.* Eds. M. Sawashima & S.C. Fanklin. Tokyo: University of Tokyo Press, 13-30.

Hirano, M. & Sato, K. (1993). *Histological color atlas of the human larynx.* San Diego: Singular Publishing Group, Inc.

Hixon, T.J., Goldman, M.D., & Mead, J. (1973). Kinematics of the chest wall during speech production: Volume displacements of the rib cage, abdomen and lung. *Journal of Speech and Hearing Research 16*:78-115.

Hixon, T.J., Mead, J., & Goldman, M.D. (1976). Dynamics of the chest wall during speech production: Function of the thorax, rib cage, diaphragm, and abdomen. *Journal of Speech and Hearing Research 19*:297-356.

Hodge, M.G., & Rochet, A.P. (1989). Characteristics of speech breathing in young women. *Journal of Speech and Hearing Research 32:*466-480.

Hoit, J.D., & Hixon, T.J. (1986). Body type and speech breathing. *Journal of Speech and Hearing Research 29*:313-324.

Hoit, J.D., Hixon, T.J., Altman, M.E.. & Morgan, W.J. (1989). Speech breathing in women. *Journal of Speech and Breathing Research 32:*353-365.

Hoit, J.D., Jenks, C.L., Watson, P.J., & Cleveland, T.F. (1996). Respiratory function during speaking and singing in professional country singers. *Journal of Voice 10(1)*:39-49.

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 35:*454-460.

Holstege, G. (1991). Descending motor pathways and the spinal motor system. Limbic and non-limbic components. In: *Progress in Brain Research*. Ed. G. Holstege. Amsterdam: Elsevier (87), 307-421.

Holstege, G. (1996). The somatic motor system. In: *Progress in brain research; The emotional motor system*. Eds. G. Holstege, R. Bandler, C.B. Saper. Amsterdam: Elsevier, 9-26.

Holstege, G., & Ehling, T. (1996). Two motor systems involved in the production of speech. In: *Controlling Complexity and Chaos.* Eds. N. Fletcher, P. Davis. San Diego: Singular Publishing Group, Inc., 121-136.

Howell, D.C. (1992). *Statistical methods for psychology,* third edition*.* Belmont, California: Duxbury Press, Wadsworth, Inc.

Isshiki, N. (1964). Regulatory mechanism of voice intensity variation. *Journal of Speech and Hearing Research 7*:17-19.

Isshiki, N. (1965). Vocal intensity and airflow rate. *Folia Phonatricia 17*:92-104.

Juslin, P.N. & Laukka, P. (2000). Improving emotional communication in music performance through cognitive feedback. *Musicae Scientiae 4(2*):151-183.

Konno, K., & Mead, J. (1967). Measurement of the separate volume changes of rib cage and abdomen during breathing. *Journal of Applied Psychology 22*:407-422.

Kotlyar, G.M., & Morosov, V.P. (1976). Acoustical correlates of the emotional content of vocalized speech. *Sov.Phys.Acoust.22*:208-211.

Laukkanen, A.M., Vilkman, E., Alku, P., & Oksanen, H. (1997). On the perception of emotions in speech: the role of voice quality. *Log.Phon.Vocol.22*:157-68.

Leanderson, R., Sundberg, J., & von Euler, C. (1987). Role of diaphragmatic activity during singing: a study of transdiaphragmatic pressures. *Journal of Applied Physiology* 62(1), March:259-270.

LeDoux, J.E. (1987). Emotion. In *Handbook of Physiology. Section 1: The Nervous System. Vol. 5; Higher Functions of the Brain.* Ed. F. Plum. Bethesda, MD: American Physiological Society, 419-60.

Ley, R. (1994). Breathing and the Psychology of Emotion, Cognition and Behavior. In *Behavioral and Psychological Approaches to Breathing Disorders.* Eds. B.H. Timmons and R. Ley. New York and London: Plenum Press, 81-95.

Linklater, K. (1976). *Freeing the natural voice.* New York: Drama Book Publishers.

Manen, L. (1974). *The Art of Singing.* London: Faber.

Miller, R. (1986). *The structure of singing. System and art in vocal technique*. New York: Schirmer Books.

Miller, R. (1998). Historical overview of vocal pedagogy. In Sataloff, R.T. *Vocal health and pedagogy* (Ch. 26, pp. 301-313). San Diego: Singular Publishing Group, Inc.

Monsen, R.B., & Engebretson, A.M. (1977). Study of variations in the male and female glottal wave. *Journal of Acoustical Society of America 62*:981-993.

Nunnally, J.C. (1978). Psychometric theory (2nd Ed.) New York: McGraw-Hill.

Palisca, C.V. (1989). *The Florentine Camerata: Documentary studies and translations.* New Haven: CT.

Pirrotta, N. (1954). Temperaments and tendencies in the Florentine Camerata. *Musical Quarterly 40*:169-189.

Randel, D.M. (ed). (1986). *The New Harvard Dictionary of Music.* Cambridge: Harvard University Press.

Ringqvist, T. (1966). The ventilatory capacity in healthy subjects. *Scand.J.Clin.Lab.Invest.Suppl.88*:10-179.

Sadie, S. (ed). (1980). *The New Grove Dictionary of Music and Musicians.* London: Macmillan.

Sadie, S. & Brown, H.M. (eds). (1989). *The New Grove Handbooks in Music, Performance Practice, Music after 1600.* London: Macmillan.

Sadie, S. & Tyrell, J. (eds). (2001). *The New Grove Dictionary of Music and Musicians*, second edition. London: Macmillan.

Saper, C. (1986). Role of the cerebral cortex and striatum in emotional motor response. In: *Progress in brain research; the emotional motor system.* Eds. G. Holstege, R. Bandler, C. Saper. Amsterdam: Elsevier, 537-550.

Sataloff, R.T. (1998). *Vocal health and pedagogy.* San Diego: Singular Publishing Group, Inc.

Scherer, K.R. (1995). Expression of emotion in voice and music. *Journal of Voice 9(3),* Sept:235-48.

Shea, S.A., Walter, J., Murphy, K. & Guz, A. (1987). Evidence for individuality of breathing patterns in resting healthy man. *Respiration Physiology 68:*331-344.

Shavelson, R.J. (1988). *Statistical reasoning for the behavioural science,* second edition. Massachusetts: Allyn & Bacon, Inc.

Silva, G. (1922). The beginnings of the art of bel canto. *The Musical Quarterly 7:*53-68.

Stanislavski, K.S. (1963). *An Actor's Handbook.* New York: Theatre Arts Books.

Stark, J. (1999). *Bel canto: a history of vocal pedagogy.* Toronto: University of Toronto Press.

Stathopoulos, E.T., & Sapienza, C. (1993). Respiratory and laryngeal function of women and men during vocal intensity variation. *Journal of Speech and Hearing Research 36*:64-75.

Stathopoulos, E.T., & Sapienza, C. (1997). Developmental changes in laryngeal and respiratory function with variations in sound pressure level. *Journal of Speech, Language and Hearing Research 40,* June:595-614.

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

Sundberg, J. (1994). Perceptual aspects of singing. *Journal of Voice 8(2*):106-122.

Sundberg, J. (1995). Vocal fold vibration patterns and modes of phonation. *Folia.Phoniatr.Logop.47*:218-228.

Sundberg, J. (1997). Expressivity in singing. *TMH-QPSR 2-3*. Royal Institute of Technology, Dept. of Speech, Music and Hearing; Stockholm:13-19.

Sundberg, J. (1998). Expressivity in singing. *Log.Phon.Vocol.23*:121-127.

Sundberg, J., Iwarsson,.J., & Hagegard, H. (1995). A singer's expression of emotions in sung performance. In: *Vocal Fold Physiology*. *Voice quality and control.* San Diego: Singular Publishing Group, Inc., 217-231.

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

Thomasson, M., & Sundberg, J. (1997). Lung volume levels in professional classical singing. *Logopedics Phoniatrics Vocology 22*:61-70.

Thomasson, M., & Sundberg, J. (1999). Consistency of phonatory breathing patterns in professional operatic singers. *Journal of Voice 13(4)*:529-541.

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

Timcke, R., von Leden, H., & Moore, P. (1958). Laryngeal vibrations: Measurements of the glottic wave. *AMA Archives of Otolaryngology 68,* July:1-19.

Titze, I.R. (1994). *Principles of voice production.* USA: Prentice-Hall Inc.

Tobin, M.J., Mador, M.J., Guenther, S.M., Lodato R.F. & Sackner, M.A. (1988). Variability of resting respiratory drive and timing in healthy subjects. *Journal of Applied Physiology 65:*309-317.

Wapnick, J., & Ekholm, E. (1997). Expert consensus in solo voice performance evaluation. *J.Voice 11(4)*:429.

Watson, P.J., & Hixon, T.J. (1985). Respiratory kinematics in classical (opera) singers. *Journal of Speech and Hearing Research 28*:104-122.

Watson, P.J., Hoit, J.D., Lansing, R.W., & Hixon, T.J. (1989). Abdominal muscle activity during classical singing. *Journal of Voice 3*:24-31.

Watson, P.J., Hixon, T.J., Stathopoulos, E.T., & Sullivan, D.R. (1990). Respiratory kinematics in female classical singers. *Journal of Voice 4(2)*:120-128.

Watson, P.J., & Hixon, T.J. (1996). Respiratory behaviour during the learning of a novel aria by a highly trained classical singer. In: *Vocal Fold Physiology/Controlling Complexity and Chaos.* Eds. P.J. Davis, N.H. Fletcher. San Diego: Singular Publishing Group, Inc., 325-343..

Wilder, C.N. (1983). Chest wall preparation for phonation in female speakers. In: *Vocal fold physiology – Contemporary research and clinical issues*. Eds. D.M. Bless, J.H. Abbs. San Diego: College-Hill Press, 109-123.

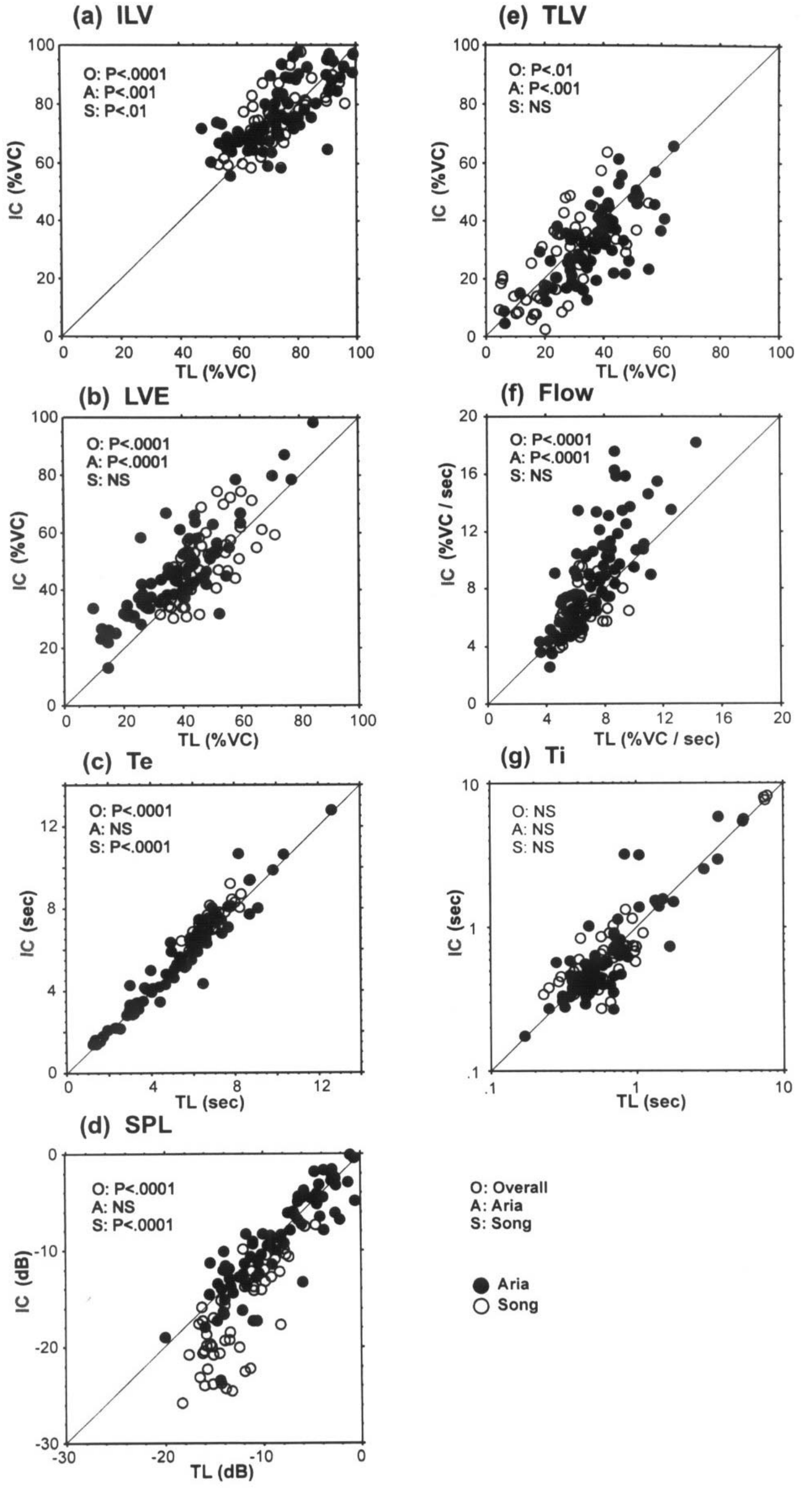
Winkworth, A.L. (1995). *Respiratory activity during speech.* PhD thesis, Health Sciences Library, Sydney University.

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*:535-556.

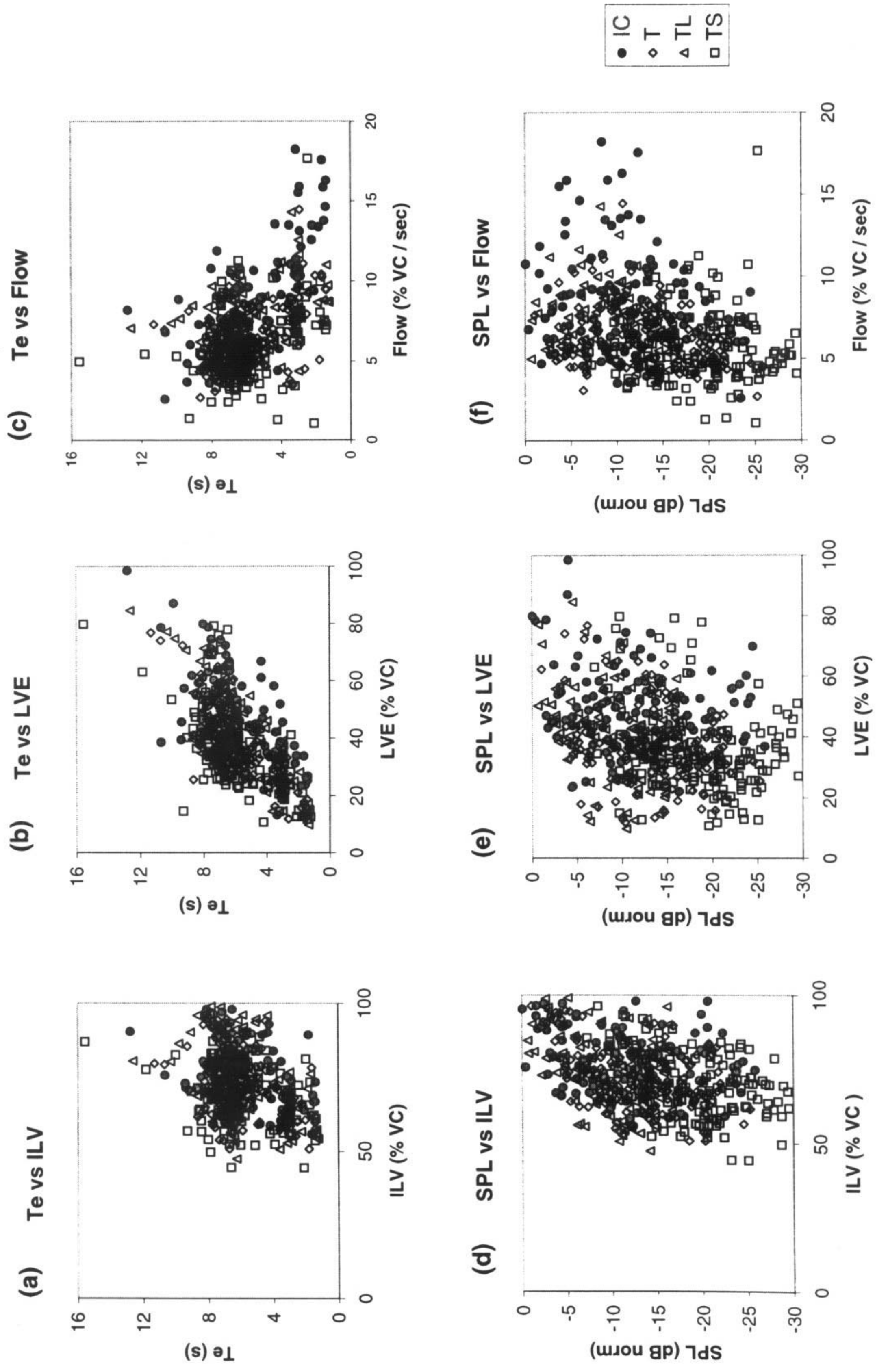
Winkworth, A.L., Davis, P.J., Adams, R.D., & Ellis, E. (1995). Breathing patterns during spontaneous speech. *Journal of Speech and Hearing Research 38*:124-144.

Zhang, S.P., Davis, P.J., Bandler, R., & Carrive, P. (1994). Brain stem integration of vocalization: Role of the midbrain periaqueductal gray. *J. Neurophysiol.72*:1337-1356.

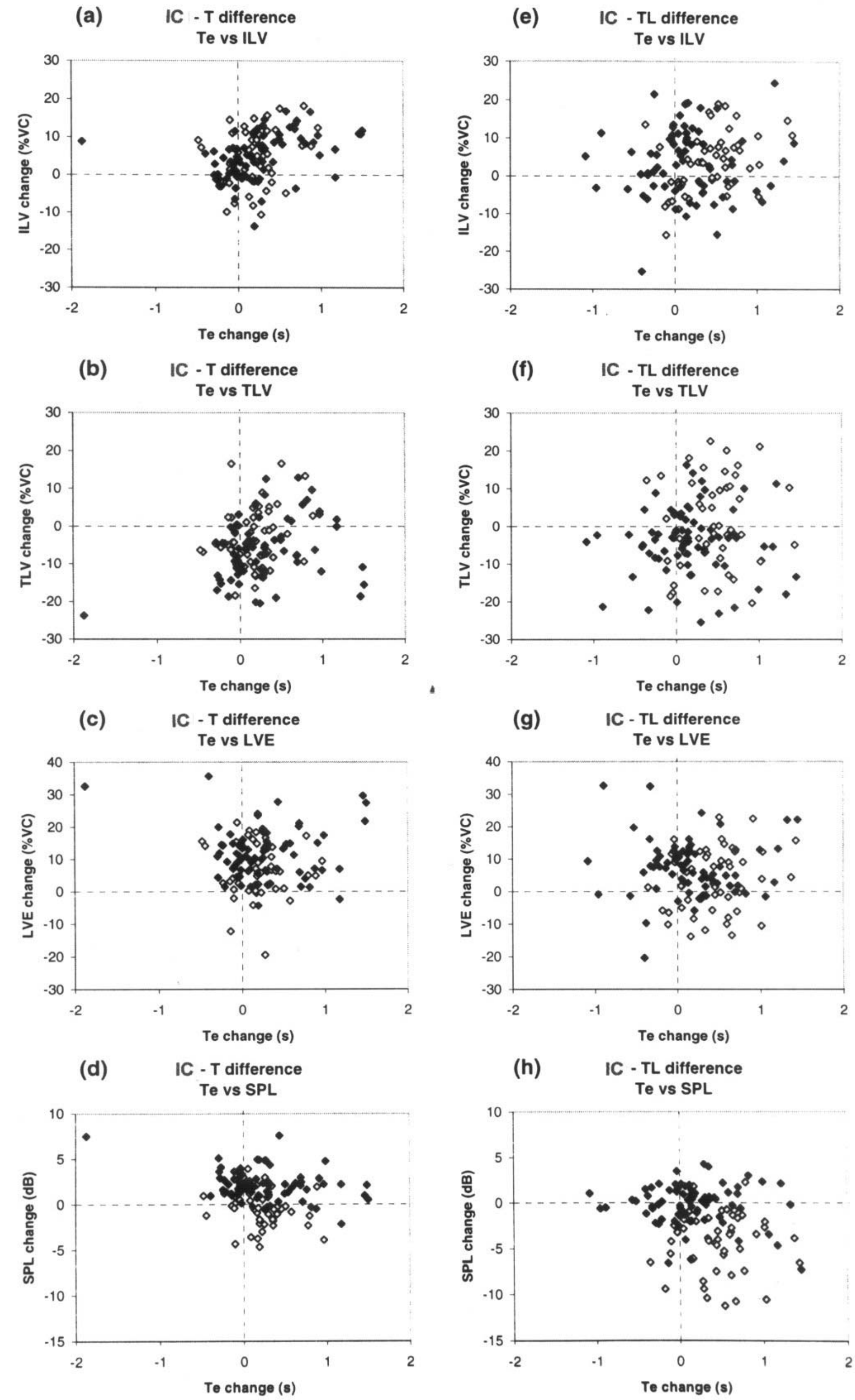
APPENDIX



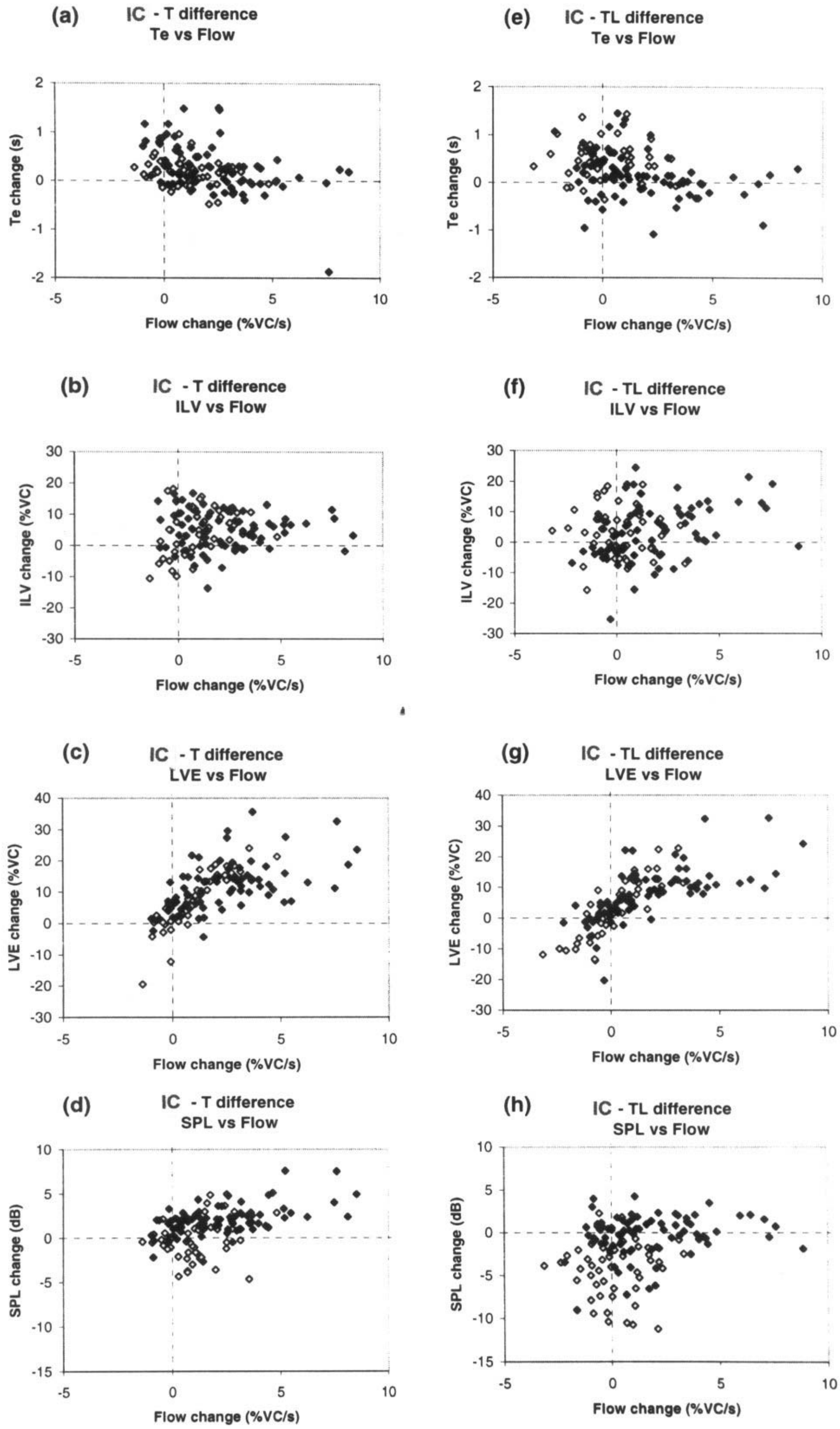
Appendix 3 – Matched data. Scattergrams using musically matched phrases (breaths), comparing the conditions IC and TL across all variables: ILV, TLV, LVE, flow (%LVE per second), Te, Ti and SPL (normalised dB).



Appendix 4. – Matched data. Scattergrams using musically matched phrases (breaths) to compare pairs of variables, showing a different symbol for each condition (IC, T, TL and TS). (a), (b) and (c) show Te/ILV, LVE, flow. (d), (e) and (f) show SPL/ILV, LVE, flow.



Appendix 5. – Matched data. Scattergrams using musically matched phrases (breaths) comparing IC/T for Te/ILV, TLV, LVE, SPL: and IC/TL for Te/ILV, TLV, LVE, SPL.



Appendix 6. – Matched data. Scattergrams using musically matched phrases (breaths) comparing IC/T for Flow/Te, ILV, LVE, SPL: and IC/TL for Flow/Te, ILV, LVE, SPL.

Appendix 7. Perceptual results showing each listener response (correct identification of intention to communicate = ‘yes’, incorrect identification = ‘no’, for 74 excerpts, with marked doubles (where the same excerpt was repeated twice), identified excerpts, subjects and takes.

same as:		Singer	Aria/Song			Listener 1	Listener 2	Listener 3	Listener 4
	1	S2	A	IC1	TL	yes	yes	yes	yes
	2	S3	S	T2	IC2	yes	yes	yes	yes
dble (26)	3	S1	S	IC1	T1	yes	no	yes	yes
dble (45)	4	S2	A	T2	IC2	yes	yes	yes	yes
	5	S2	A	IC1	T1	yes	yes	yes	yes
	6	S3	A	TL	IC2	no	yes	yes	no
dble (9)	7	S1	S	TL	IC2	yes	no	yes	no
dble (36)	8	S3	A	IC1	T1	no	yes	yes	no
	9	S1	S	TL	IC2	yes	no	yes	yes
dble (16)	10	S3	S	IC1	T2	yes	no	yes	no
	11	S2	A	T1	IC2	yes	no	yes	no
	12	S1	A	IC1	T1	yes	no	no	yes
	13	S2	S	TL	IC2	yes	yes	yes	no
dble (41)	14	S1	A	T1	IC2	yes	yes	yes	yes
	15	S2	S	T2	IC2	yes	no	yes	no
	16	S3	S	IC1	T2	yes	yes	yes	no
	17	S2	S	IC1	T1	no	yes	yes	yes
	18	S1	S	IC1	TL	yes	no	yes	no
dble (27)	19	S2	S	IC1	TL	yes	yes	yes	no
	20	S3	S	T1	IC2	yes	yes	yes	no
dble (22)	21	S3	S	TL	IC2	yes	yes	yes	no
	22	S3	S	TL	IC2	yes	yes	yes	no
	23	S1	A	IC1	TL	yes	yes	no	no
	24	S3	S	IC1	T1	yes	yes	yes	no
	25	S1	A	IC1	T2	yes	yes	no	no
	26	S1	S	IC1	T1	yes	yes	yes	yes
	27	S2	S	IC1	TL	yes	yes	yes	yes
dble (40)	28	S2	S	T1	IC2	yes	yes	yes	no
	29	S2	S	IC1	T2	no	no	yes	yes

same as:		Singer	Aria/Song			Listener 1	Listener 2	Listener 3	Listener 4
	30	S3	A	IC1	TL	yes	yes	yes	no
	31	S1	A	TL	IC2	yes	yes	yes	yes
	32	S1	A	T2	IC2	no	yes	yes	no
	33	S2	A	IC1	T2	yes	yes	yes	yes
	34	S3	A	T1	IC2	no	yes	yes	no
	35	S1	S	IC1	T2	yes	no	yes	no
	36	S3	A	IC1	T1	no	yes	yes	yes
	37	S3	S	IC1	TL	yes	yes	yes	no
	38	S3	A	T2	IC2	yes	yes	yes	yes
	39	S1	S	T1	IC2	yes	yes	yes	yes
	40	S2	S	T1	IC2	yes	yes	yes	no
	41	S1	A	T1	IC2	yes	yes	yes	yes
	42	S2	A	TL	IC2	yes	yes	yes	no
	43	S1	S	T2	IC2	yes	yes	yes	yes
	44	S3	A	IC1	T2	yes	yes	yes	yes
	45	S2	A	T2	IC2	yes	yes	yes	yes
dble (61)	46	S5	A	IC1	T2	yes	yes	yes	yes
	47	S4	A	IC1	T2	yes	yes	yes	no
	48	S4	S	IC1	T1	yes	yes	yes	yes
dble (66)	49	S4	A	IC1	TL	yes	yes	yes	no
	50	S5	A	IC1	TL	yes	yes	yes	no
	51	S4	S	IC1	TL	yes	yes	yes	yes
	52	S5	S	TL	IC2	yes	yes	yes	no
	53	S5	A	TL	IC2	yes	yes	yes	yes
dble (62)	54	S5	S	IC1	TL	yes	yes	yes	no
	55	S4	A	TL	IC2	yes	yes	yes	no
dble (58)	56	S5	A	IC1	T1	yes	yes	yes	no
	57	S4	S	TL	IC2	yes	yes	yes	no
	58	S5	A	IC1	T1	yes	yes	yes	yes
dble (68)	59	S4	S	T2	IC2	yes	yes	yes	no
dble (65)	60	S4	A	T1	IC2	yes	yes	yes	yes
	61	S5	A	IC1	T2	yes	yes	yes	yes

same as:		Singer	Aria/Song			Listener 1	Listener 2	Listener 3	Listener 4
	62	S5	S	IC1	TL	yes	yes	yes	no
	63	S4	A	IC1	T1	yes	yes	yes	no
	64	S4	S	IC1	T2	yes	yes	yes	no
	65	S4	A	T1	IC2	yes	yes	yes	yes
	66	S4	A	IC1	TL	yes	yes	yes	yes
	67	S5	S	T1	IC2	yes	yes	yes	yes
	68	S4	S	T2	IC2	yes	yes	yes	no
	69	S4	A	T2	IC2	yes	yes	yes	yes
	70	S5	S	T2	IC2	yes	yes	yes	no
	71	S5	A	T1	IC2	yes	no	yes	yes
	72	(no data)							
	73	S4	S	T1	IC2	yes	yes	yes	no
	74	S5	A	T2	IC2	yes	yes	yes	yes
	75	S5	S	IC1	T1	yes	yes	yes	no