University of Alberta

THE ACOUSTICAL EFFECTS OF THE CORE PRINCIPLES OF THE *BEL CANTO* METHOD ON CHORAL SINGING

by

Laurier Fagnan ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of

Doctor of Music

Department of Music

Edmonton, Alberta

Fall 2005

0-494-08601-7

Your file Votre référence
ISBN:
Our file Notre référence
ISBN:

University of Alberta

Library Release Form

Name of Author: *Laurier Fagnan*

Title of Thesis: *The Acoustical Effects of the Core Principles of the Bel Canto Method on Choral Singing*

Degree: *Doctor of Music*

Year this Degree Granted: *2005*

University of Alberta

Faculty of Graduate Studies and Research

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **The Acoustical Effects of the Core Principles of the *Bel Canto* Method on Choral Singing** submitted by **Laurier Fagnan** in partial fulfillment of the requirements for the degree of **Doctor of Music**

Date approved: Sept 30/05

Abstract

The vocal principles of the *bel canto* method of singing have been accepted and advanced for centuries in the field of opera and classical solo singing. However, it is usually with much hesitation that choir directors consider applying these same principles to the vocal technique of their ensembles. This study presents findings on the acoustic merit of these principles in the choral context as revealed in experiments with five different types of choirs.

The validity of Manuel Garcia's theory of *le coup de glotte* and how it affects vocal vibration and consequently spectral energy was examined. It was found to improve the level of upper spectrum energy in choral singing quite significantly (4.08 dB on average) while lowering levels of energy used in the region of the fundamental frequency, pointing to a more efficient use of spectral energy in the singing process.

The effects of *chiaroscuro* (bright-warm) resonance upon the intrinsic pitch of vowels and articulatory perturbation patterns, both of which are known to have a negative effect on intonation, were studied. It was found that by applying this paradoxical quality of brightness and warmth to all vowels equally, spectral energy and vocal timbre were rendered more consistent throughout the entire vowel spectrum, affording choral groups a more homogeneous sound and improved intonation. In several cases, intonation errors in 'before' examples were corrected in the 'after' samples to the point of being undetectable (< 1 Hz).

The combination of increased glottal energy and balanced spectral energy through complete *chiaroscuro* resonance were then applied to soft singing

through the principle of *messa di voce.* As choristers sought to maintain both glottal closure (*coup de glotte*) and *chiaroscuro* resonance during gradual decrescendos, they were far more successful in maintaining the spectral energy and, consequently, the carrying power and complete timbre in their soft singing which they had enjoyed in their *forte* passages.

Due to the overall acoustical enhancements offered to choral singing through application of these principles, it was found that the *bel canto* principles used in this study were effective tools in improving the overall vocal technique of choral groups.

Acknowledgements

The author wishes to acknowledge the vital contribution of Dr. Xavier Rodet of IRCAM in Paris to the success of this study. As a choral conductor with no background in acoustics, I would definitely have been unable to test the theories and quantify the results effectively without his expert guidance in the acoustical aspects of this paper. His patience in explaining 'simple' concepts yet again, and designing the tools that became indispensable to the success of this dissertation are extremely appreciated.

I also wish to mention the expert technical support of Dr. Axel Roebel, also of IRCAM. His intellect and constant willingness to design just the right software for the analyses that needed to be carried out for my research are both admired and appreciated.

The assistance of the conductors and choirs that participated in this study is very much appreciated. Without your invaluable contribution, the theories outlined in these pages would have remained untested. Thank you for having made this process possible and so enjoyable.

Thanks also to Dan Marek of the Mannes College of Music in New York City who helped me to apply some of the vocal principles in this study to my own voice so that I might understand them better myself and consequently help others to grasp them more clearly and powerfully.

To Dr. Leonard Ratzlaff of the University of Alberta, for his support in both the practical aspects of my doctoral degree as well as for his expertise as a supervisor. His willingness to jump in as principal reader at the last minute after the departure of the committee member serving this function is also much appreciated.

To my incredible wife Jane. How can I thank you for your undying patience and the tolerance of all the demands that this degree has placed on you? Your ever-present smile and unconditional belief in me and in the hope that this would all one day possibly be finished are treasured. You are a great friend and I hope to make it all up to you soon!

To my children Alicia, Matthieu and Stéphane, who have seen their Papa become somewhat of a stranger over the past few years. I love you dearly and hope that you know how important you are to me. Here's to spending much more time with you in the near future than in the near past.

To my Lord and my God for making all of the above possible and for so much more, including the wonders of the human voice and the incomparable beauty of choral music.

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Chapter I - Introduction

Preface

This study is borne out of years of consistent observation on the author's part that certain vocal principles of the *bel canto* manner of singing have a very positive effect on the overall sound and vocal energy of choral groups when correctly applied. After conducting over three hundred workshops in the application of *bel canto* principles to choral singing, the author has noticed a very consistent trend in the improvement of ensemble acoustic energy, timbre and intonation, as well as in ensembles' abilities to sing well at softer dynamic levels. This progress appears to have little or no pejorative effect on that all-important component of choral singing: *ensemble blend.* As very little research has been undertaken in choral acoustics to date, a quantification and documentation of the acoustical changes produced by the application of these principles to choral singing seemed an excellent topic for this study.

The Specific Research Problem To Be Addressed:

Choral acoustics is a relatively nascent field and many of its salient questions have yet to be answered. In his landmark text *The Science of the Singing Voice,* Johan Sundberg states:

> The reader has probably already observed that most of the questions regarding choral singing were not mentioned in this chapter. This is not surprising, because of the scarcity of choral research in the past, as mentioned. Here we can only mention some of the questions that seem possible not only to pose but also to answer... Evidently, choral singing offers a large field for scientific research, full of questions that can both be formulated and answered. Let us hope that it will attract the attention of a greater number of researchers in the future than in the past.[1]

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[1] Johan Sundberg, *The Science of the Singing Voice* (DeKalb, IL: Northern Illinois University Press, 1987), 144-5.

In his article "Physical and Acoustic Factors that Interact with the Singer to Produce Choral Sound," Sten Ternström also points to the need for research in this area:

> All this musical activity notwithstanding [the fact that choral singing is second only to music listening as far as being the musical activity involving the most people worldwide], choir singing has attracted little attention from acousticians...There seem to be few instances of research done specifically on the acoustics of choir singing.[2]

In his article "An Acoustical Study of Individual Voices in Choral Blend," Goodwin also laments the fact that there is virtually no empirical data available to researchers and choral directors on how certain vocal factors affect choral blend.[3] These statements by three of the world's most prominent vocal scientists validate the view that there exists a paucity of research on this subject. A review of publications over the last decade reveals that this continues to be the case. Also, most of the studies that have been undertaken to date seek to analyze how choirs already sing – very few introduce an actively pedagogical element which attempts to improve the technique of choral singers. Any studies casting light on this domain, especially those offering a method of vocal pedagogy for choirs combined with modern acoustic analysis techniques, will therefore be of benefit to the fields of choral singing and vocal science. This study addresses the issue of how to improve choral sound through application of some of the time-proven, foundational principles of the *bel canto* method while offering acoustical validation to support its findings.

It is the author's belief that within the choral setting, singers are often counselled by well-intentioned directors to remove much of the vibration and resonance energy from their voices in an attempt to achieve a pure choral tone and ensemble blend. This aim is sometimes achieved. However, the result is often simply a lowering of the standard of singing in the ensemble to that of the less

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[2] Sten Ternström, "Physical and Acoustic Factors that Interact with the Singer to Produce Choral Sound," *Journal of Voice* 5, 2 (1991): 129.

[3] Allen W. Goodwin, "An Acoustical Study of Individual Voices in Choral Blend," *Journal of Research in Singing* 13, 1 (1989): 25.

developed voices with much being sacrificed in the name of tonal homogeneity; *blend* often leads to *bland.*

For instance, singers with stronger voices are often encouraged to sing more softly and introduce more breath into their vocal production, an action which reduces the closed quotient of the vibratory cycle of the glottis, effectively removing energy and carrying power from their voices. Aside from a curtailing of acoustic power and efficiency, such vocal limitations imposed on choir members often produce pejorative vocal side-effects with singers tiring more quickly and overall ensemble performance diminishing in quality. As Coffin so aptly states, "there is no reason to have a Stradivarius sound like a cigar-box violin so that both will sound the same. Instead of removing the singer's formant from voices that have it, one should try to establish the formant in all voices of the choir in which it is lacking."[4]

The approach followed in experiments designed to teach choristers to use their voices according to the *bel canto* principles outlined below definitely encouraged the Stradivarius approach over that of the cigar-box violin. It has been the author's experience that homogeneity of timbre can be effectively achieved without sacrificing vocal power and completeness of tone when these vocal principles are consistently put into practice by all members of an ensemble.

Bel Canto Definition

The term '*bel canto*' has been used in so many different contexts that its intended meaning must be clarified from the outset. For some this term will signify the period of the nineteenth century that gave us the operas of Rossini, Bellini and Donizetti. For others it will hearken back much further to the *opere serie* of Handel and Porpora, and yet again, it may denote a particular style of singing rather than a period.

For the purpose of this study, *Bel canto* is defined as the manner of singing prevalent in Italy in the eighteenth and nineteenth centuries which incorporated

[4] Berton Coffin, *The Sounds of Singing* (Metuchen N.J.: Scarecrow Press, 1976), quoted in Stephen C. Bolster, "The Fixed Formant Theory and Its Implications for Choral Blend and Choral Diction," *The Choral Journal* 23, 6 (1983): 30-31.

certain very specific vocal principles that augmented spectral energy while enhancing beauty of vocal tone. It was the application of these principles that led to the great pinnacle of singing enjoyed in Italy and much of Europe during the aforementioned period. This study will examine the vocal and acoustical principles advocated by the original masters of the *bel canto* or Old Italian Method of Singing (Porpora, Mancini, Garcia, Lamperti) as documented primarily in the writings of Manuel Garcia and the father-son team of Francesco and Giovanni Battista Lamperti, as well as their students and pedagogical descendants.

More specifically, this study will ultimately test whether certain *bel canto* vocal principles pertaining to vocal vibration and resonance advanced by these writers are effective in positively influencing vocal efficiency, power and group intonation within the choral context. It will further test the principles' effectiveness in improving an ensemble's ability to sing at lower dynamic levels without relinquishing spectral energy.

Method and Collection of Data

The anachronistic nature of this study, that is to say testing the merits of the old by means of the capabilities of the new, provides some intriguing scientific insights into the truths that the old masters took for granted on mostly intuitive grounds. The approach used in collecting and analyzing data also reflects the dual nature of the study. All samples were collected within choral workshop situations where the aim was to achieve beauty and freedom of tone and maximization of vocal energy brought about by regular vibration and complete resonance, in accordance with *bel canto* practices and methodology. The process was very much in keeping with the teaching method of the masters of the Old Italian Method whereby the basic and foundational principles of proper breathing, vibration and resonance were taught in the middle voice before going on to more difficult concepts and exploring a wider pitch range.[5] As the choristers of the

[5] David C. Taylor, *New Light on the Old Italian Method: An Outline of the Historical System of Voice Culture, with a Pleading for its Revival* (New York: Novello, 1916), 114.

participating choirs had varying degrees of technical ability, this approach of singing most of the exercises in a comfortable middle range seemed favourable for overall success and gave all singers a fair chance to apply the principles at hand.

The means by which choral sound, in its acoustic complexity, could be effectively analyzed and quantified presented a technical challenge to the feasibility of this study. To overcome this impediment, Dr. Xavier Rodet and his team of acoustic engineers at IRCAM (Institut de recherche et coordination acoustique/musique) in Paris were consulted. The author spent six months at this institute, conducting experiments with choirs and assisting its engineers in the development of some of the software that would ultimately be used in the analysis process of this study. The contribution of Drs. Xavier Rodet and Axel Roebel to the technical aspect of this study were absolutely invaluable and rendered possible the quantitative analyses and subsequent conclusions that are drawn in this paper.

In order to test the vocal principles at hand in as broad and objective a manner as possible, the following different types of vocal ensembles were used in this study:

1) A community children's choir
2) A mixed youth choir
3) A university mixed choir
4) A men's choir
5) A mixed seniors' choir

Several of the experiments in this study were conducted in the very acoustically-malleable *Espace de projection* at IRCAM in Paris, France. During these experiments, and whenever possible when they took place in other locations, the acoustic used was not very reverberant, so as to minimize the effects of room reverberation on the sound samples recorded. However, as singers are known to sing with less assurance when no room resonance is present, a slight amount was utilized.

Choirs were asked to sing at the same dynamic level (a comfortable *mezzo forte*) in both the *before* and *after* portions of experiments. However, it was noticed that several 'after' examples were louder, due in part to the increased vibration and resonance energy at the choir's disposal with the application of *bel canto* principles. Such sound files were normalized, that is to say the intensity of the *before* files was raised to match that of the *after* files so that acoustical analyses would not be based on faulty premises.

Each experiment lasted approximately two-and-one-half hours. Following an extensive vocal warm-up period, each choir was asked to sing a series of exercises. This 'before' segment of each session, including the warm-up, was led by the choir's own conductor. Conductors were counselled to ensure that their groups were at least as well warmed up as they normally would be and to take the time needed to ensure they would be at their best from the very first exercise.

Each conductor received the series of exercises to be sung several days prior to the experiment and each was contacted for any clarification he/she might require prior to the actual experiment. These carefully chosen exercises were sung by each ensemble in order to test the effectiveness of each of the *bel canto* principles described below (see Annexe B for a list of exercises sung by the ensembles). One to three exercises were specifically chosen for each principle. These were designed to uncover possible flaws in singing when the principle in question was not being observed. Some of these vocalises were drawn from previous studies in which researchers consistently noted specific vocal and acoustical weaknesses when a certain exercise was sung by choirs. The reasoning behind their inclusion was to test whether *bel canto* methods might have a positive effect on these seemingly inherent weaknesses. Other exercises were employed because the author had noticed, with experience, certain phrases and vowel combinations as having intrinsic pitfalls in the areas of intonation and general vocal energy.

It was made clear to each conductor that the aim of this initial recording of exercises was to have each choir sing to the best of its ability, thereby providing as fair and appropriate as possible a basis for comparison with post-*bel canto* data.

The conductors were asked to demonstrate each exercise and then to have their choir sing each one several times until he/she was satisfied that his/her ensemble had sung it as well as could reasonably be expected. This portion of the experiment, including initial warm-up period, lasted approximately sixty minutes.

The next segment of the experiments consisted of teaching each ensemble, in a systematic fashion, the *bel canto* principles outlined in the following chapters, namely:

1) *Il respiro* – The proper *bel canto* method of breathing in which inhalation is a passive gesture with breath 'falling into the body' rather than being 'sucked into the body' through the half-closed throat. Although the effects of this principle were not separately analyzed, they were deemed so foundationally important to the success of the other principles that proper respiration was the first principle to be taught.
2) Core vibration and the *coup de glotte* – Beginning each attack with the vocal folds in an initially closed position. The first vibration therefore begins in a more energized and controllable fashion.
3) *Chiaroscuro* resonance balancing – A complete and balanced resonance quality, possessing at once the paradoxical properties of brilliance and roundness, both of which permeate the entire vocal range and vowel spectrum.
4) *Messa di voce* – A gradual and well controlled crescendo - decrescendo in which elements of vibration and resonance are to remain constant.

The first three of these principles form the foundation of *bel canto* vocal technique and together make up the holistic *appoggio* approach to singing comprised of the perfect marriage of breath control, vibration and resonance. Other important yet somewhat secondary principles such as the *messa di voce* examined in this study depend on the prior mastering of these pedagogical pillars for success.

During experiments, I first offered a verbal explanation of each concept. This usually included some historical and vocal/physiological information. I would then demonstrate the principle by singing an example of its proper execution myself. This is very much in keeping with the practices of the Old Italian masters, as modeling was a staple of their teaching method.[6]

It might be argued that the use of this technique led to pure imitation with the principles themselves having only a secondary effect on ensemble singing. However, most of the choirs' conductors were fine singers themselves and gave excellent vocal examples to their groups before the recording of the exercises in the first segment of the experiments. The ultimate difference between the before and after portions of the experiments was the presentation of each of the principles being advanced with immediate application to the ensembles' singing. A subsequent study could very well examine similar concepts with a purely verbal explanation of the principles, however this would not be in keeping with the pedagogical process of the Old Italian School.

In this second segment, choirs worked on incorporating each of the separate principles or concepts into their singing, mostly on unison sounds, for approximately five to ten minutes. After this period, the group was asked to sing between one and three of the exercises they had sung in the original series, depending on what principle they were working on, while applying the new vocal knowledge associated with the given principle. These versions were again recorded. As had been the case in the 'before' portion of the experiment, the ensemble was asked to sing the exercise several times until it had rendered what was determined to be its best performance under the current conditions. We then proceeded to learning and applying the next principle in the series and recording the related exercises.

In generating the acoustical analyses that are found in chapters 3, 4 and 5 of this study, the choirs' third attempt at the exercise was used as much as possible in both the *before* and *after* versions. This was done so that choirs would have an equal amount of time adapting to the new exercise or skill being learned. When this was not possible due to extenuating circumstances (e.g. one voice singing a large scoop or a chorister sneezing, or an ensemble giving a particularly

[6] Taylor, 112.

bad rendition on its third attempt), the next best attempt was used. The underlying philosophy was to compare the best of the *before* to the best of the *after*. At no time was a choir's first attempt in the *before* portion of experiments ever used in analyses.

It is important to mention that at no time was the choir's attention directly drawn to a by-product of the principle that would later be analysed. For example, when testing what impact the correct usage of *chiaroscuro* resonance might have on group intonation, the fact that the choir might be singing out of tune was never mentioned. Rather, the direct application of the principle to their singing was the only aim. For instance, in the case of *chiaroscuro* resonance, a consistent balance between brightness and darkness in resonance quality was sought in all vowels with the *bel canto* assumption that a consistent resonance throughout the vowel spectrum would improve intonation. It was only in the subsequent analysis process that the principle's effect on by-products such as intonation was examined.

Another *bel canto* pedagogical technique was sometimes employed to sensitize the singers to the presence or absence of the principle's application to their singing. Singers were occasionally asked to sing an exercise with a deliberate absence of the principle's benefits in their sound. For example, while attempting to sing an effective *messa di voce* (controlled decrescendo), they might be asked to allow breath flow to sharply increase and vowel resonance to collapse while effecting the decrescendo. During this process, their attention would have been drawn to the pejorative elements in both sound and sensation. In subsequent attempts, they were asked to ensure that these elements not infiltrate their singing, and were rather encouraged to maintain core vibration and consistency of *chiaroscuro* resonance while decreasing loudness. This technique is in keeping with the *bel canto* tenet that one must know the enemy in order to avoid it.[7]

[7] G. B. Mancini, *Practical Reflections on the Art of Singing* (Boston: Gorham Press, 1912), quoted in Taylor, 53.

General Limitations

1. Certain acoustical research conventions that one would expect to observe have been purposely overlooked in this study for one important reason: it was the author's wish to keep the experiment environment as close as possible to that which choristers actually experience in an actual choral setting. Under this paradigm, it was therefore of little value to measure a singer's mode of singing in an anechoic chamber with a choir 'fed' to her through headphones. It has rather been the aim to teach and evaluate an entire ensemble in as realistic a choral environment as possible. This, of course, places certain limitations on the sound data gathered. However, as most studies in the past have concentrated on recording individual singers while they are singing along with an 'artificial' choir, this approach seemed more unique and possibly of more immediate and applicable value for choirs and their conductors.

2. The effect of the principles examined in this study is cumulative. The success of one principle builds on what has been learned previously. For instance, it is impossible to have complete *chiaroscuro* resonance without first ensuring that vibration is pure and efficient, for it is vibration that excites resonance. It is similarly unfeasible to perform an effective *messa di voce* (controlled decrescendo) and sing softly well without first mastering both core vibration and *chiaroscuro* resonance, not to mention breath control. For this reason, the effect of the principles has been measured in a cumulative fashion, each being added to the effect of the preceding principle. If this were not the case, one could not state that this study was based on the holistic *bel canto* manner of singing.

3. As this study was carried out in two countries, it was difficult to keep acoustical conditions exactly the same. For experiments that took place at IRCAM (Institut de recherche et coordination acoustique/musique) in Paris, the same room was used for all sessions. A very modest amount of room reverberation was used so that singers would benefit from some acoustic feedback and therefore sing with

confidence. The inclusion of this slight room resonance was also to respect rule #1 above: to maintain as realistic a typical choral environment as possible. For experiments in the Edmonton area, the choir's typical rehearsal room was used as long as it provided a feasible environment for a stable recording.

What is important to note is that conditions remained exactly alike between the *before* and *after* portions of experiments. Microphones were not moved, recording levels and distances remained exactly the same and singers were not added or removed. Microphone placement was quite close and rooms were not so reverberant that the sound looping back into the microphones would give an unfair reading with increased intensity.

4. The author would like to explain from the outset that he is not an experienced acoustician, but rather a vocal pedagogue/choral conductor. His expertise is in teaching vocal technique to choral ensembles and soloists. Specialized signal processing analysis programs were written for this project by qualified engineers and acousticians at IRCAM in Paris. Some of the programs used were designed prior to this project's commencement. All have been used to verify and quantify as objectively as possible the validity and appropriateness of *bel canto* principles for choral singing.[8]

5. It was not practical to measure absolute Sound Pressure Levels during experiments with choirs. As is often the case when dealing with groups, a relative intensity scale is used in this study's analyses with *before* and *after* analyses comparing easily and accurately to each other. In all of the *enerSimple* analyses dealing with spectral energy in specific bands, levels are usually negative with 0 decibels as the maximum intensity level of the sound file.

6. Early writings on the Italian method are often somewhat unclear in their language and method of conveying acoustical and physiological concepts. The

[8] The reader can consult IRCAM's website at www.ircam.fr for detailed information on the programs outlined in this study.

writings of some of the nineteenth-century masters such as Manuel Garcia (1800-1901) and the father-son team of Francesco Lamperti (1811-1892) and Giovanni Battista Lamperti (1839-1910) tended to expound on the same pedagogical principles yet explain them in a fashion that has greater clarity and is more immediately understood than the writings of earlier authors such as Pier Francesco Tosi (1653-1732) or Giovanni Battista Mancini (1716-1800). For this reason, the pedagogical aspect of this study is based on Garcia and the Lampertis as well as more recent *bel canto* pedagogues such as Richard Miller, Cornelius Reid, Berton Coffin and James Stark.

7. While there are many sound examples on the accompanying CD that show significant improvement when comparing *before* and *after* files, one must remember that experiments were relatively brief (2 - 2 1/2 hours in length). Because choral directors tend to guard precious rehearsal time quite diligently, there was generally only this one brief window of time available with each choir. As there was much to learn and apply in a short period, these amateur ensembles can at times be heard struggling to control their voices under new vocal circumstances. For instance, in some *after* files, a singer may be heard scooping as he learns to sing with new richness of resonance. This generally improved as time went on and the later sound examples are consequently better in quality.

8. The author has conducted approximately three hundred workshops in the area of vocal technique for choirs in recent years. These have been undertaken with almost every type of choral ensemble including children's choirs, adult mixed choirs, symphonic choirs, youth choirs, men's and women's choirs, barbershop groups and seniors' choirs. Many of the suppositions found in this paper are based on repeated experience working with vocal ensembles. The phrase "it is the author's experience" thus Figures quite frequently in this study and provides a basis upon which certain comparisons can be made with the norm.

Basic Assumptions

Certain assumptions were made during the experimental and evaluation periods of this study.

1) That the choral groups sang, as they were instructed, to the best of their ability and that the *before* sound samples were good representations of the abilities of the participating vocal ensembles prior to working *bel canto* vocal principles.
2) That the electronic analysis programs used for the acoustic analyses in this study provided true and accurate graphs and numeric data from which the conclusions of this research are drawn.

Other important Information

1) When italicized throughout the text of this thesis, the words *before* and *after* always refer to a sound file or its generated analysis recorded before the choir in question worked on *bel canto* principles, and after, respectively.
2) When studying the intonation patterns of mixed choirs (chapter 3), it was necessary to pick either the men's note or the women's note as present software cannot analyze both simultaneously. The version picked will be evident by the frequency in Hertz along the vertical axes of each graph: 190-260 Hz would indicate that the men's note was used while a frequency in the range of 380-520 Hz would rather signify use of the women's note.
3) In this study, the terms *bel canto* and *Old Italian Method* will be used interchangeably, as will *singer's formant* and *upper spectrum energy*.
4) International Phonetic Alphabet (IPA) symbols are used throughout this study to denote specific vowel sounds. Whenever a vowel is enclosed within square brackets such as [i], this indicates an IPA symbol. Those used in this study are:

[ɑ] as in the English *father*

[e] as in *may* (without diphthong)

[ɛ] as in *depth*

[i] as in *he*

[o] as in *go*

[u] as in *moon*

[y] as in the French *tu* or the German *Früh*

Chapter II – Review of the Related Literature

Preamble

As noted earlier, choral acoustics is a fairly nascent field. While scientists and vocal practitioners alike have delved into the study of solo vocal acoustics very actively for the past seventy years or more (one-hundred-fifty if one returns to the pioneering work of Manuel Garcia), choral acoustics has attracted attention only sporadically over the past thirty years. This can be attributed at least partly to the fact that researchers encounter, even at present, considerable technological limitations when attempting to analyze sound that is as complex as that emanating from a large vocal ensemble.

This chapter will briefly report on studies and works that consider both vocal technique for choirs and acoustics. It will not be concerned with works that have a purely acoustical emphasis without studying the type of tone an ensemble is making. For instance, it will not deal with studies that mainly consider the synthesis of choral sound (i.e. the ability to create it artificially through electronic means). Nor will it examine research dealing purely in the area of acoustical perception, for example, how choristers sing differently if their hearing is impaired during choral rehearsals or experiments. Daugherty's important work on the acoustics of choral seating will not be addressed as this research is chiefly concerned with the effect that seating and placement of choristers have upon their sound and output. In this way, the research is more concerned with geographical acoustics than vocal acoustics.[9]

The studies referenced below were aimed at gaining a clearer understanding of how the human voice works from an acoustical standpoint within the choral setting. They are presented in chronological order of publication.

In a review of literature dealing with choral acoustics, one must acknowledge the significant pioneering work of Sten Ternström of the Royal Institute of Technology in Stockholm, Sweden. His own research, as well as

[9] For example, see Daugherty, J.F. "Spacing, Formation and Choral Sound: Preferences and Perceptions of Auditors and Choristers." *Journal of Research in Music Education*, 47, 3 (1999) 224-238.

studies carried out in partnership with his colleague, Johan Sundberg, has served to define and richly expand the field of choral acoustics.

Literature Review

Hunt, W.A. "Spectrographic Analysis of the Acoustical Properties of Selected Vowels in Choral Sound." Ph.D. Diss., North Texas State University, 1970.

This study seems to have been the first to have analyzed a choir's sound from the acoustical perspective and, as such, represented truly groundbreaking research. Hunt sets out to put an objective and quantifiable face on the very subjective acoustical concept of choral blend. The study had a multi-faceted purpose that included: 1) a grouping of recordings of certain vowel sounds into well-blended and poorly-blended categories; 2) a spectrographic analysis of distinguishing acoustic properties leading to this categorization; 3) a listing of the qualities and properties of the two categories; 4) a set of suggestions and implications for the teaching of choral singing.

The author began with the premise that vocal timbre should not be altered in order to achieve better blend. He thus worked only with vowel sounds stating that vowel unity seems to be accepted as the most important factor in vocal blend. As data for the listening group, he recorded 216 examples of choral sound, 72 each from junior high school choirs, senior high school choirs and college choirs. Each choir sang a C major scale on the vowels [i], [ɑ] and [ɛ], first with the male singers only, second, with females and last as a mixed choir.

In listening to the taped examples, the jury was asked to 1) identify the vowel sound being sung; and 2) rate the blending quality of the ensemble as Good, Acceptable or Poor. Judges were fairly consistent in their opinions on blending quality. The female voices rated far higher in their blending quality than did the male voices which scored only 15% overall in the 'good' category. The judges were almost always unanimous in their correct identification of the vowel sound being sung.

Spectrograms were then made from each of the taped examples and each spectrogram was categorized and labeled according to the mean rating of the jury's opinions on blending qualities. The salient acoustic features of the spectrograms were identified and correlations between the jury's judgments of sound examples and their corresponding spectrograms were drafted.

The investigator found that the spectrographic traits of the examples that were deemed to have 'good' blend included tonal clarity – all sound that was emanating from the ensemble fit into the natural harmonic series of the pitch being sung. There was no extra 'acoustic noise' between overtones causing sound that did not fit into the natural frequency bands for that particular sung sound.

On the other hand, spectrographic traits of sound examples associated with 'poor' blend were found to have much more acoustic energy *between* the overtones of the sung sound's natural harmonic series. The horizontal frequency bands were not as clear and showed definite acoustical confusion. Acoustical factors that were not in tune with the fundamental frequency were quite apparent in the analyses.

The junior high group received the most 'good' ratings from the judges (although the groups were fairly close statistically), as did the women singing alone across all age groups. The vowels [i] and [ɑ] were most often rated as having a 'good' blending quality while [ɛ] was seldom found in the 'good' category.

Hunt draws three general conclusions from his study:

1) unity of vowel sound is of utmost importance in the attainment of ensemble blend;
2) vowel unity is achieved through the tuning of vowel formant frequencies;
3) good vocal blend is dependent on all of an ensemble's acoustic energy falling into the frequency bands of the fundamental frequency's natural harmonic series.

<u>Bolster, Stephen C. "The Fixed Formant Theory and Its Implications for Choral Blend and Choral Diction." *The Choral Journal* 23,6 (1983): 27-33.</u>

Bolster begins this seminal article with a good general account of vocal acoustics which is useful for the choral conductor and in fact anyone interested in the study of vocal acoustics. He is principally preoccupied with the fact that all voices are governed by the same laws of nature when it comes to resonance and that ensembles must work as efficiently as possible within these laws if they are to enjoy acoustic success. This article includes a very complete and useful account of the properties of vowels and their intricacies according to the very specific spectral pattern each exhibits. As in many other published works, he discusses the manner in which the intelligibility of each vowel is surmised from the frequency of its first two formants. He subscribes to the view that the fact that vowels maintain constant formant frequencies regardless of the fundamental frequency signifies that vowels have pitch and the specific pitch of vowels must be dealt with in any form of singing, but particularly in choral singing.

The author also launches into the subject of vowel modification, but does so slightly differently than others. He presents some important acoustical peculiarities among each of the sections of a mixed chorus. For instance, because the fundamental frequency sung by sopranos is often above the frequency of the first formant, they are unable to properly sing the vowel. "Instead, they must modify the vowel to create an illusion of the vowel intended by raising the lowest formant frequency to match the fundamental".[10] According to Bolster, the sopranos in any choir have very few vowels at their disposal to sing a proper sound above the pitch F^5. According to the author, the aim of vowel modification in choral singing is to ensure that all sections are singing at optimum resonance at all times.

He also discusses the fact that men and women modify vowels differently and that men must open their vowel space at the bottom of their range and close the same as they approach their upper voice (d#4-f#4). Women on the other hand must open their vowel space at the top of their range and progressively close it in descending the scale if they are to maintain optimum resonance by matching formant frequencies. The different sections of an ensemble will essentially need to

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[10] Stephen C. Bolster, "The Fixed Formant Theory and Its Implications for Choral Blend and Choral Diction," *The Choral Journal* 23, 6 (1983): 28.

be pronouncing words in a slightly different fashion at the same time if beautiful, full choral sound is to be the aim.

In terms of vocal blend, he strongly supports vowel unification as the most important issue in choral blend. However, in his view, singers do not all need to sing exactly the same vowel for the tone to be unified, but must sing *the illusion of the same vowel* according to the vowel modification sections must undergo to stay within optimum resonance at the pitches they are required to sing.

He also vehemently opposes having the good singers in an ensemble undersing in order to not stick out from the rest of the choir's sound. He maintains that it is unhealthy to ask choristers to remove singer's formant energy from their voices if it comes to them naturally. Instead he advocates teaching all the singers of an ensemble to sing with good glottal closure and optimal resonance so that by all producing similar vocal energy and timbre, a blended but energized sound might result.

Rossing, Thomas D. et al. "Voice Timbre in Solo and Choir Singing: Is There a Difference?" *Journal of Research in Singing* 8,2 (1985), 1-8.

See Rossing article below ("Acoustic Comparison") as this is an earlier and condensed version of that article with the same data, analyses and results.

Rossing, Thomas D. et al. "Acoustic Comparison of Voice Use in Solo and Choir Singing." *J. Acoust. Soc. Am.* 79, 6 (1986): 1975-1981.

The investigators begin with the premise that singing in the solo mode and choral modes are two distinctly different vocal activities that make different demands on the singer. They acknowledge the fact that some voice teachers will not even allow singers under their tutelage to participate in choral singing due to the lowered amounts of vocal energy demanded of its members. This study serves to uncover some of the major differences between these two modes of singing by delving into and comparing their acoustical properties.

Eight subjects having both extensive solo and choral singing backgrounds were chosen for the study. It is important to note that while singing in the 'choral mode,' these singers had the rest of the 'choir' fed to them aurally through headphones while sitting in an anechoic chamber and were told to sing along with this ensemble as they normally would in an actual choral setting. The same conditions existed in the solo mode where singers had the sound of a piano accompaniment in the headphones and were asked to sing as they would in a solo setting with this accompaniment.

The investigators go into great detail in comparing the amount of vocal energy used in the areas of the fundamental frequency and the singer's formant. For the former, sound samples were passed through bandpass filters of 100-315 Hz while filters of 2-4 kHz were used for the latter. They discovered that in general, under these conditions, choral singers use much more energy in the region of the fundamental frequency and far less in the region of the singer's formant than do soloists. This was at least partly attributed to the fact that choristers would naturally sing at lower intensity levels when attempting to blend, and that higher frequency energy tends to drop more substantially at lower volume than energy in other spectral bands. There was also a marked increase in formant clustering between formants 3 and 5 in solo singing, an event that is associated with the concentrated type of upper spectrum energy typical for soloists in this region known as the singer's formant. This type of clustering did not occur when subjects sang in choral mode. In the choral mode, singers tended to have lower intensity levels in general as they attempted to 'blend' with their colleagues in the headphones whereas the soloists seldom adjusted their volume levels to that of the accompaniment.

It was also noted that one of the main differences between the two modes of singing was related to glottal closure. In the choral situation where choristers attempted to blend with others around them, there was a tendency toward flow phonation and reduced glottal closure. This of course is one of the principal causes of reduced singer's formant in choral singing. Due to these suspected differences in glottal *closure* and articulation, the investigators found it to be reasonable that voice teachers tend to be wary of letting their singers who aspire to be soloists participate in choral singing.

Ternström, Sten, Johan Sundberg and Anders Colldén. "Articulatory F_0 Perturbations and Auditory Feedback." (*Journal of Speech and Hearing Research* 31 (June, 1988), 187-192.

The aim of this study was to determine if there was validity to the theory of the *intrinsic pitch of vowels* in choral singing and if specific information could be collected on the causes of this phenomenon. Another aspect of the experiment was to calculate the extent to which a masking noise introduced through headphones (making it difficult for the subject to hear his/her own voice) affected a singer's ability to deal with the 'intrinsic pitch' phenomenon.

Singers were asked to sing twelve different vowel pairs in legato fashion on the same note. The investigators studied the effects on the fundamental frequency of these changes in vowel and articulation. They identified two different manners of effecting vowel changes during the experiment which they labeled as *F_0 transient* and *bimodality*. *F_0 transient* was the label used for instances in which the subject showed a temporary change of pitch at the moment of vowel transition, but then recovered fairly quickly to the pitch of the original vowel. *F_0 bimodality* was used as the label for pitch excursions that were less temporary and continued into the singing of the entire duration of the second vowel, i.e. the second vowel of the series was noticeably higher or lower than the first vowel in its entirety. The study showed that transitions falling into the *F_0 transient* category were more common than those considered *bimodal* (55% to 40% respectively).

Compilation of data showed that the two vowels [i] and [y] had the highest average fundamental frequencies when paired with another vowel. The largest deviations in F_0 which created a *bimodal* effect quite consistently occurred on transitions from [i] to [ε] and [i] to [α]. When averaged out, these transitions were responsible for a 34.6 and 22.3 cent loss in pitch respectively.

Another facet of these experiments helped to clarify whether the frequency changes were caused by *perceptual* factors (e.g. the vowel *sounds* different therefore vocal changes need to be made to properly pronounce that vowel) or by *articulatory* factors (e.g. jaw dropping causes change in vibration). The investigators used sound masking to determine whether or not the changes in pitch had a perceptual basis, reasoning that if the changes were caused by articulatory movements, they should be more extreme and occur more often when the singers' own voice is masked during experiments. This was indeed found to be the case with all subjects but one exhibiting greater deviations in pitch when their auditory feedback was masked.

The investigators also found that vowel changes necessitating a large vertical movement of the tongue caused considerable deviations. They found this to be in keeping with previous studies advancing the "tongue-pull" hypothesis which supposes that the raising of the tongue for the high vowels ([i], [y]) causes a longitudinal stretching of the vocal cords bringing with it a rise in fundamental frequency.

Ternström, Sten and Johan Sundberg. "Intonation Precision of Choir Singers." *J. Acoust. Soc. Am.* 84, 1 (1988): 59-69.

This study tested two major hypotheses from the outset: 1) how does the intensity of sound, measured in SPL (Sound Pressure Level), experienced by singers from within a choir affect their ability to sing in tune in a choral situation? 2) do changes in the spectral make-up of the sound coming from a choir which surrounds choristers affect their ability to sing in tune?

The average SPL *reference* experienced by most choral singers within a choral rehearsal or concert was surmised by placing an experimenter wearing a pair of calibrated binaural microphones in different positions among choir members during a rehearsal. The *reference* refers to the sound a singer hears coming from the entire choir around him. The *feedback* was also measured and factored into the total sound intensity experienced by a singer within a choir. The *feedback* is the sound that a chorister hears coming from his or her own voice from within the choral context. SPL was averaged from among the data collected. It was found that both of these values varied rather significantly (40 dB).

During the experiment, a reference tone was fed to the subjects via headphones at six different amplitudes within the noted 40 decibel range. While the reference tone was sounded, subjects were to sing their own sound into an SPL meter at approximately 90 decibels which was then mixed in with the reference tone in the headphones they were wearing. They were to match the pitch and vowel of the reference tone.

Investigators found that subjects had little difficulty in accurately matching F_0 values when the reference tone was relatively soft. However, when the stimulus tone's intensity was increased, singers began to sing *below* the target pitch at a rate of 1.9 cents per decibel (a semi-tone is comprised of 100 cents). This occurred in eight out of the nine subjects. It was noted that singers had more difficulty with this on the vowel [u] than [α].

Investigators then turned to certain spectral properties that might affect group intonation. They tested whether stimulus tones of harmonic intervals that contained common partials were easier for singers to tune to than intervals with no common partials (stimulus tones were artificially synthesized and had no high partials). They also tested whether or not the absence of vibrato in the stimulus tone might aid choristers in matching pitch more successfully.

It was found that adding the first common partial to a simple stimulus tone was helpful for choristers who were attempting to tune a 5th above that tone. This procedure was even more helpful when singers were attempting to tune a major 3rd to the stimulus tone. Adding upper partials seemed a very successful aid in helping singers tune more accurately to the given tone as did removing its vibrato.

Ternström, Sten and Johan Sundberg. "Formant Frequencies of Choir Singers." *J. Acoust. Soc. Am.* 86,2 (1989): 517-522.

Ternström and Sundberg studied the formant habits of eight bass choral singers in both speaking and singing modes. Basses were chosen for the study because their lower fundamental frequencies generate more closely spaced overtones, making formant peaks easier to identify. Spectrograms were made of all the recordings and formant frequencies for formants one through four were collected and plotted for analysis.

Results showed that the singers tended to naturally alter their formant frequencies when moving from speech to singing. In general, the second formant tended to be lower, especially for the front vowels [i] and [æ]. Although they found several differences between speaking and singing modes, the investigators were able to deduce, with the help of previous studies, that the first two formant frequencies were close to identical for singers whether in the solo or choral singing mode. It was also found that the frequencies of formants 3 and 4 were lower in professional singers than in non-trained singers. These upper formants tended to behave in a similar fashion for non-trained choral singers whether they were speaking or singing. Professional singers, on the other hand, tended to have much more pronounced singer's formant in the singing mode.

The researchers also noted a definite clustering of the 3^{rd} to 5^{th} formants in singing mode, particularly in the professional singers. Further, they determined that the deviations of formant frequencies among the eight subjects were greater in speech than they were in singing where they enjoyed greater resonance homogeneity, i.e. when they sang together, the subjects assumed a "choral dialect" of sorts. Subjects were found to adjust their formant frequencies, especially for the lower formants, when singing with their colleagues, apparently with an aim to achieve vowel purity and blend.

Goodwin, Allen W. "An Acoustical Study of Individual Voices in Choral Blend." *Journal of Research in Singing and Applied Vocal Pedagogy* 13, 1 (1989): 25-34.

The main purpose of this study was to analyze the spectrums of both solo singing and unison choral singing in order to determine what acoustical differences exist between blended choral singing and solo singing. After an excellent summary of the important concepts of vocal acoustics, Goodwin launches into the experiment which involved thirty experienced choral sopranos.

First, each soprano sang a sustained tone as she normally would in a solo context. She was then asked to sing the same sustained tone and vowel, but this time to attempt to blend with the sound of the pre-recorded ensemble she was hearing via headphones.

Differences in the two modes of singing were quite substantial with subjects using less and more irregular vibrato when attempting to blend. In spectrograms taken during the two portions of experiments, there was a definite paucity of spectral energy above the first formant frequency in the samples related to blended sound. This Goodwin explains by stating that choral singers forego producing upper spectrum energy in their sound in order to provide the listener with fewer aural cues to separately identify their particular voice. He also identifies this technique as being effective in reducing the overall intensity of a sound, as a sound with more partials, though it may be at the same physical intensity as a sound with fewer partials, will be perceived as louder by the ear.

It was also discovered that formant frequencies remained basically the same for the two modes of singing. Due to this consistency, the author concludes that vowel modification for blending purposes has more to do with varying the proportionate strengths of the formants than altering the actual formant frequencies. Not surprisingly, the overall intensity of singing levels dropped noticeably in the choral context as did the level of vibrato used.

Ternström, Sten. "Physical and Acoustic Factors that Interact with the Singer to Produce Choral Sound." *Journal of Voice* 5, 2 (1991): 128-143.

This is a very important and comprehensive article covering many of the central questions relating to choral acoustics. The author begins by saying that next to music listening, choral singing is the musical activity that engages the greatest number of people worldwide. Because of this fact, he finds it deserving of far more research than has been carried out in the past.

Ternström first deals with the issue of a chorister's personal loudness when singing in an ensemble situation, acknowledging that it can be neither too loud, lest it become individually audible outside of the ensemble, nor too soft as the chorister will be unable to hear herself from within the choral context and therefore probably not sing to the best of her abilities. He examined the ideal 'self to others' ratio for choral singing and found that choristers performed best when they could hear the *reference* (the rest of the choir) and the *feedback* (their own voice) to fairly equal extents. As soon as the reference became more than 5 decibels louder than the feedback, choristers' intonation errors began to register at greater than 20 cents. Intonation errors occurred more gradually when the singers' own voices were louder than the reference.

He also tested if certain vowels were more likely to adversely affect group intonation than others. It was found that vowel transitions requiring large tongue and jaw movements such as [i] to [ɑ] or [i] to [ɛ] caused the fundamental frequency to drop with the tongue and jaw for lower vowels [ɑ, ɛ], or to rise for the higher vowels [i, y]. This he found fully supported the theory of the *intrinsic pitch of vowels*. The worst vowel combination attempted in the study was [i] to [ɛ] which caused a loss in pitch on the order of 35 cents.

The author continues by studying the effects of timbre and homogeneity of resonance on ensemble singing. Matching of formant frequencies among singers is advanced as a method of increasing vowel intelligibility and improving vocal blend. In experiments, he found that a more neutral pronunciation of vowels was used than in solo singing. This was determined by the distance between the first two formants as well as their strengths which were closer together and slightly weaker respectively in choral singing. It was thought that this acoustic neutrality probably enables singers to blend fairly successfully. Ternström attests to the fact that he has rarely seen evidence of a singer's formant in the spectra of choral singers in the choral context and that solo and choral singing seem to require different training.

Next the author considers the effect that room acoustics has on choral singing. It was discovered that choristers tended to sing louder in absorbent rooms to compensate for the decrease in the resonance feedback of the room. Singers also regularly raised the frequency of their lower three formants in an attempt to hear the type of sound to which they were accustomed. Having choristers sing with their backs against a hard wall was found to increase the ensemble's intensity by 6 decibels without changing any aspect of their singing.

The author coins a new term when mentioning the acoustical phenomenon of the chorus effect, i.e. the summing of many slightly asynchronous vocal signals coming together to produce one blended ensemble sound. He finds this sound property so important to choral singing that he calls it the *chorusness* of the choral sound. This acoustical phenomenon was seen as an amalgamation of the phase incoherencies of several aspects of the choristers' sound (pitch, vowel, vibrato) combined with the sound of the room to "magically dissociate the sound from its sources and endow it with an independent, almost ethereal existence of its own."[11] It was found that the beating of partials caused by the flutter of independent voices was mostly responsible for the "chorusness" in a choir's sound.

This brings the author to the subject of group intonation. While it is understood that not all choristers will be singing exactly the same note at exactly the same phase in time, it is important that the averaged sound of the choir be perceived to be on the proper pitch. Ternström explains how it was possible in experiments for there to be an acceptable amount of *scatter* (individual, momentary deviation from target pitch) without the group's intonation being adversely affected. He found that scatter levels in the area of 10-20 cents were typical with choirs deemed to have acceptable intonation.

Ternström, Sten. "Perceptual Evaluations of Voice Scatter in Unison Choir Sounds." *Journal of Voice* 7, 2 (1993): 129-135.

In this article, Ternström first launches into a lengthy explanation of the differences between vocal *flutter* and *scatter*. Flutter he describes as being quick fluctuations in fundamental frequency in an individual voice (vibrato fits into this definition). Scatter is defined as being the standard deviation in mean F_0 when all of the voices are compared with each other.

The main objectives of the study were to test two main hypotheses: 1) that pitch scatter is not aurally acceptable to the same degree for different F_0 values (this was to determine the importance of this phenomenon for the various sections

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[11] Sten Ternström, "Physical and Acoustic Factors that Interact with the Singer to Produce Choral Sound." *Journal of Voice* 5, 2 (1991): 141.

in a vocal ensemble); 2) that pitch scatter is not equally acceptable for different vowel sounds.

Subjects in the experiment had the ability to independently electronically synthesize the amount of scatter with which they could play back the tone and come to a judgment of what type of deviation they 'preferred' and what they were willing to 'tolerate.' It was determined that voice category and vowel had only a limited effect on the subjects' opinions. For example, while the amount of scatter judged acceptable for the vowel [u] received the highest rating for bass, tenor and alto voices, it was deemed the least acceptable vowel for scatter in soprano voices. It was found, however, that in general pitch scatter was deemed acceptable if it was confined to deviations of 0 to 5 cents, and would be tolerated until it reached 15 cents.

Ford, Joseph K. "The Preference for Strong or Weak Singer's Formant Resonance in Choral Tone Quality." Ph.D. Diss., Florida State University, 1999.

The objective of Ford's dissertation was to determine if a very broad spectrum of university undergraduate students prefer a choral tone quality that has a strong and measurable singer's formant as an important component of its tone, or a less resonant tone, produced by the same singers using much less singer's formant energy. The three subgroups that were used as listening test subjects for this study were: 1) college undergraduate choral or vocal majors with choral training; 2) college undergraduate music majors with instrumental training but no choral training; 3) college undergraduates with no music training.

A small mixed ensemble of two voices per part sang eight choral excerpts. They were asked to sing each excerpt in two ways: 1) in a fully resonant, solo-like fashion, complete with good glottal closure and singer's formant; 2) in a much less resonant fashion with reduced glottal intensity. They were aided in this recording task by a hand-held Singer's Formant Analyzer which enabled them to visually monitor and manipulate the level of singer's formant they were utilizing in their singing. Among the directions given the singers prior to the recording of the test recordings to be used by future subjects were: "You will sing all 8 examples with full resonance, then you will go back to the first example and sing all 8 examples with tone quality that is lacking the resonance, ring, or singer's formant (which ever term you are familiar with)."[12] The singers were also instructed to maintain the same tempos and vibrato rates between the two modes of singing.

A panel of six judges comprised of music faculty and doctoral conducting students had difficulty rating which examples were sung in a more resonant fashion after the sound samples had been normalized (volume and intensity adjusted so that the files being compared were at the same volume). However, when the non-normalized versions were used, the identifying success rate was 100%. Although the panel was instructed to ignore volume differences in the selections, they may have been mostly responding to differences in intensity levels rather than the difference in tone quality. Ford decided to discard the normalized files altogether and have the actual test group listen only to the original files.

As augmented volume is only one of the by-products of increased singer's formant energy, it is difficult to ascribe total reliability to the results of this study which seems flawed in several ways. For instance, table 1 on page 76 seems to indicate an average of approximately 4.5 dB increase in singer's formant energy in the resonant version of the four recorded excerpts. However, when looking at the long-term average spectra also measuring the singer's formant energy for the same four excerpts (Figures 3, 6, 9 and 12), they appear to be on average 10 to 12 decibels stronger in singer's formant energy. This increased energy seems to begin very close to the fundamental frequency, which indeed suggests that files were not normalized prior to analysis.

Each of the excerpts was placed in pairs of resonant and non-resonant versions. These versions were placed in random order with each pair being played three times. There seems to have been a marked preference for the non-resonant version over the resonant version across all three test groups (mean score of 7.95

[12] Joseph K. Ford, "The Preference for Strong or Weak Singer's Formant Resonance in Choral Tone Quality" (Ph.D. Diss., Florida State University, 1999), 73-74.

to 4.05 respectively). Interestingly, this preference for non resonance grew as experience in choral singing increased with the test groups involved in the study.

The reliability of findings is once again stretched when one considers the remarks of the test subjects included in Appendix H: "I didn't hear a whole lot of difference between pairs," "It is difficult to separate tone quality from volume," and "So many sounded like there was no difference whatsoever."[13] Whether or not these difficulties arise from the singers having been unable to carry out the original instructions, or are more easily ascribed to difficulties in the technical set-up for the listening portion remains unknown. It would seem, however, that the study's results should be used with a certain amount of discretion.

As one can surmise from the fairly short list above, there are still many subjects to consider and many questions to answer in the field of choral acoustics. It is hoped that the present study will help to answer some of the remaining issues and that the Future Studies section will offer insight into areas still needing investigation.

[13] Ibid., 207-208.

Chapter III – *Le coup de glotte* and Focused Core Vibration

Introduction and Problem

Whether in festival, competition or concert settings, choirs have often been reproached for the lack of acoustic energy in their sound. Many choirs and choral conductors operate under the false assumption that everything must be relaxed when singing properly, including the vocal cords (see note 35). This can lead to a vocal production lacking in energy and carrying power with mediocre intonation. Choral singing is often devoid of the focused vibratory energy which was the foundation of all fine singing in the *bel canto* school.

There is a trend in amateur choral singing, particularly with young choirs, that encourages beginning the first tone in each phrase with an aspirated 'h' to 'get the breath flowing' to prepare for the sound. Some have equated this with the age-old notion of 'singing on the breath.' This concept is in complete contrast with both Garcia and Lamperti who always focused on the beauty and energy inherent in efficient vibration and resonance never being compromised by breath flow.

Rossing, Ternström and Sundberg comment on the compromised vocal spectrum typical in choral singing as opposed to solo singing, and that this phenomenon arises due to the fact that choral singers use more 'flow phonation' and a less efficient glottal adjustment in order to achieve better vocal blend, i.e. a less individualistic sound.[14] These authors also comment on the fact that many voice teachers are reluctant to allow their students to participate in choral singing because of the reduced energy and vocal colour often demanded in this mode of singing. It has also been noticed that choral singing is far less likely to have any pronounced energy in the region of the singer's formant (2.3-3.5 kHz) than that which is typical in fine solo singing.[15] In seeking a solution for this deficiency,

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[14] Thomas D. Rossing, Johan Sundberg, and Sten Ternström, "Acoustic Comparison of Voice Use in Solo and Choir Singing," *J. Acoust. Soc. Am.* 79, 6 (1986): 1979.
[15] Jack Morris and Rudolph Weiss, "The Singer's Formant Revisited: Pedagogical Implications Based on a New Study," *Journal of Singing* 53, 3 (1997): 24

one must first ask the question "what is the source of vocal energy in singing and how may one, or many, exploit it efficiently and effectively in choral singing?"

The *bel canto* Ideal

In *bel canto* vocal pedagogy, efficient and regular vocal vibration was one of the primordial principles of fine singing. This energized mode of voice production was to be devoid of the pejorative effects of muscular tension and excessive breath pressure or flow. It was the quality of the initial source vibration that determined the beauty, power and accuracy of intonation of any singer's voice. It was a known fact that complete resonance could not be realized without efficient vocal fold vibration, and that in fact all vocal success originated in the mastering of this foundational principle. "Until you feel the permanency of your vibration you cannot play on your resonance... the voice rides on its own vibration."[16]

The proper marriage of compressed (as opposed to flaccid) breath to efficient glottal vibration was the very foundation upon which the *bel canto* school of singing was built and success with this principle led to the eventual mastery of all the other elements of vocal technique. It was primarily the ingrained efficiency of this acoustic relationship that permitted many of the famous *castrati* to sing for over one minute on the same breath.[17]

Just as a diffuse source of light will not excite a full colour spectrum when it passes through a prism, a relaxed phonation caused by a superfluous quantity of breath flowing through the glottis will not excite the full resonance possibilities of the voice. It is rather in providing a very economical and compressed column of breath that pure vibration can be fed rather than spread. Just as a beam of concentrated light excites a full colour spectrum when shone through a prism, *a concentrated core of focused vocal vibration* is able to excite all of the colouristic capabilities of the vocal tract and provide a more complete harmonic spectrum.

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[16] Giovanni Battista Lamperti, *Vocal Wisdom; Maxims of G.B. Lamperti* (New York: W.E. Brown, 1931), 31, 78.
[17] Charles Burney, *An Eighteenth-Century Musical Tour in France and Italy*, ed. Percy A. Scholes (London: Oxford University Press, 1959), 153.

Garcia's penchant for efficient glottal vibration is very clear. He even put its importance ahead of that of resonance when describing the importance of developing a complete vocal tone:

> If after each explosion [of breath] the glottis closes completely... the sound heard is bright or ringing... The rush of air, however, that is escaping through the half-open orifice [lazy glottis], will be quite perceptible, and will give the sound a veiled character, at times extremely dull... we may hence conclude that brilliancy of voice results from the entire closing of the glottis after each beat. Economy of breath is another advantage derived from this complete closing of the glottis.[18]

Garcia's most famous pupil from the pedagogical standpoint, and arguably the most successful teacher of female singers in vocal history[19], Mathilde Marchesi maintains that the vocal cords should be anything but relaxed if efficient, energized singing is to occur:

> After the lungs are filled, it is necessary, for the production of a sound that the pupil should hermetically close the glottis so that its extreme edges, called the vocal cords, may be set vibrating by the air which bursts through at the moment of expiration. The *coup de glotte* requires, then, a sudden and energetic approximation of the lips of the glottis, an instant before expiration commences...The pupil needs do no more than endeavour to keep the glottis contracted after its lips have been brought together...We repeat then, that if the pupil would require a good attack, the glottis must be closed an instant before expiration commences; in other words, it should be prepared.[20]

Marchesi goes on to say that when the cords do not adequately resist against the impulse of the breath and superfluous air is allowed to escape, the resulting sound is usually weak and intonation is compromised.[21]

G.B. Lamperti offers possibly the most complete and convincing argument for efficient vocal vibration in *bel canto* literature:

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[18] Manuel Garcia, *Hints on Singing*, trans. Beata Garcia (New York: Patelson's Music, 1982), 7.
[19] Henry Pleasants, *The Great Singers: From the Dawn of Opera to Caruso, Callas and Pavarotti* (New York: Simon and Schuster, 1981), 272.
[20] Mathilde Marchesi, *Bel Canto: A Theoretical and Practical Vocal Method* (New York: Dover Publications, 1970), xii.
[21] Ibid., xii.

> All processes seem reversed when your tone drives *you.* Your voice begins first. Your breath comes next...The energy in regular vibration is constructive. The violence in irregular vibration is destructive. Regular vibration causes the voice to be true in pitch, ringing in quality, and rich in character. When it appears in the voice, it re-educates the entire process of singing because it becomes master. It is this that makes the voice feel like one register, one mechanism from top to bottom... Memory of how it feels makes your only method.[22]

There can be no doubt as to the foundational position awarded to core, focused vibration in *bel canto* singing. Whether at the beginning of a tone or for the duration of an entire phrase, the vocal cords were to fully participate in creating an energized tone that would in turn exploit all of the resonance potential of the vocal tract. This vocal and acoustical ideal was sought above all others as it rendered possible all other aspects of energized singing.

Breathing for Vibration

Because of the important foundational position placed on efficient vocal vibration by Garcia and Lamperti, it was the first principle to be taught and tested during choral experiments. However, before embarking on any serious application and testing of focused vibration, proper respiration needed to be presented and taught. "In the Italian school, one does not separate breath management from tone production; the focus of the tone and the control of the breath are considered to be one action."[23]

Although the direct acoustical effects of proper breathing and breath control were not tested in this study, their underlying contribution to the success of all other vocal principles, especially focused vibration, was so important that approximately ten minutes at the beginning of the second portion of each experiment was spent communicating and practising proper breathing techniques. In general, choristers breathed in quite a shallow fashion during the first phase of

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[22] G.B. Lamperti, 48-50.
[23] Richard Miller, *The Structure of Singing: System and Art in Vocal Technique* (New York: Schirmer Books, 1986), 79.

experiments. This needed to be corrected as breath that is taken in too high, thereby overfilling the top portion of the lungs, is not controllable and creates an abundance of pressure in the lungs and trachea too near the larynx. Upon expiration and phonation, this accumulated back pressure finds its logical exit place through the glottis thereby compromising the focused vibratory action of the vocal cords.

Another pejorative aspect of breathing that needed to be addressed was the choristers' habit of taking noisy, gasping breaths. It was explained that the source of the noise during inhalation was the abundance of friction in the vocal tract as breath attempted to enter the lungs through a very constricted tube. In addition to its artistic faults, this action has quite a drying effect upon the vocal cords.

The true *respiro* of the *bel canto* method is an inhalation in which the bottom portion of the lungs is filled, with the upper chest and vocal tract maintaining a sense of emptiness which only the voice is to fill. Rather than gasping for air that is in the room and overcrowding the lungs with it, choristers were taught to *breathe from within.* That is, the descent of the diaphragm and subsequent expansion of the bottom of the rib cage naturally creates a vacuum in the bottom of the lungs. Nature abhors a vacuum and seeks to fill it. No 'sucking' or 'gasping' is needed. Rather than this, singers were asked to allow breath to drop into the bottom of their lungs, which had been drawn lower and more open with the descent of the diaphragm, while maintaining a feeling of openness in the throat. They were also encouraged to do so silently with the premise being that a silent inhalation is indicative of an absence of friction-causing obstructions in the vocal tract. Many singers commented on the fact that this type of a breath was much more pleasing and comfortable than that to which they were accustomed. With the breath in their lungs now in a more comfortable state, work on controlling the breath could begin in earnest.

One must establish a sense that the energized voice leans into the open body and is connected to the feeling of retaining the breath in the body by the inhalatory muscles *before* these muscles have a chance to collapse. First coined *la* *lutte vocale* by Francesco Lamperti,[24] this equilibrium ensures that superfluous breath flow is not allowed to compromise the efficient vibration and resonance of the voice. To this end, choristers worked on proper posture and maintaining an open rib cage, thereby keeping most of the breath in the lungs and utilizing only the small amount that was needed to sustain efficient core vibration.

> Breath is 'held back' by two fundamentals: vibration (pulsating of the vocal lips) opposing the exit of compressed air from the lungs, and concerted action of the entire muscular covering of the body restraining the energy of the escaping air... Either relaxation or rigidity will destroy the focusing power of the glottis. Loose breath will furnish no rays of vibration."[25]

Just as one would not attempt to set a violin string into vibration with flaccid bowhair, one cannot expect the vocal folds to be set into efficient vibration by an overabundance of loose breath.

After a greater sense of control was gained on proper inhalation and a sense of being able to retain most of the air in the body rather than feed it through the vocal cords, attention was turned to the acquisition of a properly focused vocal tone.

Experimental Procedure

Choristers were made aware of the fact that they were, in most instances, using too much breath in the ideal breath-vibration equation advanced by *bel canto* masters. Lazy vibration with superfluous breath flow was likened to whistling lips which rely on breath rather than vibration to make sound. Singers were asked to duplicate this type of exaggerated breath flow as they sang, essentially whistling with their vocal cords. This, admittedly, was quite a familiar feeling for some of the participants.

We then began to move toward a more focused sound, one which included a much more active participation of the vocal folds and a higher retention of breath in the body. This was first accomplished by having the groups alternate

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[24] Francesco Lamperti, *The Art of Singing* (N.p.: Kalmus, n.d), 25.
[25] G.B. Lamperti, 23, 70.

between voiced and unvoiced consonants such as the *th* sound in Theodore (unvoiced) and the *th* sound in the word *thee* (voiced). Attention was drawn to the difference in sensation and vibration mode of the vocal cords during these paired sounds with the unvoiced consonant cluster having no vibration and the voiced version having a definite and definable feeling of vibration.

A vowel was then added and the singers were asked to sing the unvoiced *th* (in which breath escapes through the vocal cords) followed immediately by an [i] vowel on the same note which continued allowing breath to flow through the glottis. This resulted in a rather flat, lifeless tone devoid of acoustic intensity. The group was then asked to sing the voiced *th* sound (in which the cords vibrate efficiently) followed immediately by an [i] vowel which this time was to maintain a concentrated and focused core, with this sound and feeling staying intact between the *th* and the vowel. Attention was drawn to the improved clarity and focus of the tone. They were asked, as Garcia and Marchesi admonish in the above citations, to maintain this energized tone for the entire duration of the sung vowel. This feeling was thereafter referred to as the *core of vibration.*

During this process the vowel [i] was used as it is the most inherently focused of all the vowels. We then purposely alternated between a very focused [i] with a concentrated core of vibration and a breathy [ɑ] with a fairly spread sound, the purpose being to sensitize the singers as to the presence or absence of core vibration. Attempts were then made to retain the feeling of focused vibration in the transition between the [i] and the [ɑ]. This is a difficult maneuver for the average chorister with little vocal training. It has been observed that as soon as the mouth opens to sing a 'larger' vowel, the focus in the vibration tends to open as well and breath tends to flow through the glottis and dissipate the tone's energy. "When a tone "opens," the "focus" of vibration does not change."[26]

Confident that singers were beginning to gain a solid grasp of core vibration, we turned our attention to a more specific *bel canto* vibratory principle, that of Manuel Garcia's *coup de glotte* explained above. In a technical sense, the main acoustic goal of the *coup de glotte* and the vocal core is to increase the

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[26] G.B. Lamperti, 53.

closed quotient of the vocal cords' vibratory cycle and to seek the perfect balance between this glottal closure and breath supply.[27] According to the statements made by Marchesi and Garcia above, beginning the vibratory cycle with the vocal cords in a closed position while emphasizing the importance of efficient breath management tends to encourage a greater closed quotient of the cords. This increased vibratory contact time leads to a more stable vibratory cycle which in turn gives way to more complete resonance possibilities and an overall more energized sound.

During experiments, singers were asked to take a regular, low and silent breath (during which the vocal cords are open), and to immediately *allow* the cords to return to a lightly closed position prior to phonation (as opposed to *clamping* them closed). They were then asked to begin the vibrant tone they had felt during the initial [i], [ɑ] exercise, but now from this closed position, thinking not about supplying breath to produce the tone, but rather about spontaneously awakening an energetic, focused tone from this closed position.

This pedagogical concept seemed to be new to almost all of the singers involved and therefore took some time to coordinate properly and meet with success. Yet after several attempts, and once choristers had grown accustomed to the sensation of beginning the tone in this manner, attacks became cleaner and more immediately focused. Singers were cautioned to allow only the cords, and not the throat, to draw together for preparation of the sound. The throat was to be in the open position needed for the vowel to be sung in a resonant fashion. As the singers grew accustomed to this manner of beginning the tone, their sound improved and the following analyses resulted.

It was unfortunately not possible to accurately test and quantify the actual closed quotient during these group sessions. Such a process would have required special means such as access to multiple electroglottograph devices. The decision to remain in a totally choral environment served as somewhat of a limiting factor in this sense in that it would have been quite difficult to collect very specific

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[27] David M. Howard, "Variation of Electrolaryngographically Derived Closed Quotient for Trained and Untrained Female Singers," *Journal of Voice* 9, 2 (1995): 166.

acoustic information from individuals. Although this information would have provided valuable, objective information pertaining to open/closed quotient values in choral singing, acoustic information is easily obtained indirectly through the observation of the principle's by-products such as how increased vibratory efficiency affected the vocal spectrum. Separating the initial glottal source from secondary vocal tract resonance will be reserved for a future study.

Analysis of Sound Data

It was thought that the most effective way of measuring glottal efficiency was to examine the intensity of spectral energy in the band ranging from 2.3-3.5 kHz. This region is commonly referred to as the 'singer's formant,' an energy unique to the singing voice which tends to reinforce upper spectrum activity when efficient glottal vibration is realized. Let us recall that formants are natural resonance peaks within the vocal tract that amplify certain overtones or groups of overtones more than others. This concept can be likened to singing a scale in a reverberant room where one note which coincides with the room's resonant frequency will suddenly be louder than the rest. The singer's formant is generally recognized as being a super formant that is produced when good glottal closure and focused vibration excite the resonance capacity of the larynx when it is in proper relationship to the pharynx's resonating abilities. The presence of increased resonance in this spectral band would therefore indicate that good glottal closure was occurring.

The frequency values used for calculating energy in the region of the singer's formant remained constant for each group: 2.3 - 3.5 kHz. It was felt that this band included the central frequency of the singer's formant for all voice types used in this study as reported by Morris and Weiss.[28] These authors found that this treble-boosting energy was far more naturally present in trained than in non-trained singers. It has also been found that the human ear is particularly sensitive

[28] Jack Morris and Rudolph Weiss, "The Singer's Formant Revisited: Pedagogical Implications Based on a New Study," *Journal of Singing* 53, 3 (1997): 22-23.

to frequencies in this range.[29] It is this energy that enables a well produced human voice to carry over a large orchestra.

The following analyses graphically display the amount of energy in the region of the singer's formant as measured by the program EnerSimple, designed at IRCAM in Paris, which is able to isolate spectral energy in any given band. The measurements were taken on the same portion of vocal exercises both before and after choral groups had implemented the principle of the *coup de glotte* and core vibration. The lighter gray line illustrates the energy in the spectral band associated with the singer's formant *before* working on the principle while the darker, dotted line represents this energy *after* its application. The vertical (y) axis indicates intensity in decibels while the horizontal (x) axis represents time. The intensity scale in decibels is measured in relation to the loudest component of the sound file (usually the fundamental frequency) and is therefore shown as a negative value with the *'least negative' having the greatest intensity.* All files being compared were first normalized (their intensities were equalized) to remove any disparities that discrepancies in volume might engender and to draw the listener's attention to the *quality of tone* rather than the *quantity of tone*. Due to software limitations and also because a long-term average spectrum (LTAS) was not desired, but rather a more specific spectral reading, these analyses are rather brief in duration. They are either drawn from the [i] vowel of the first exercise in this section or an [ɛ] vowel.

[29] Ibid., 22.

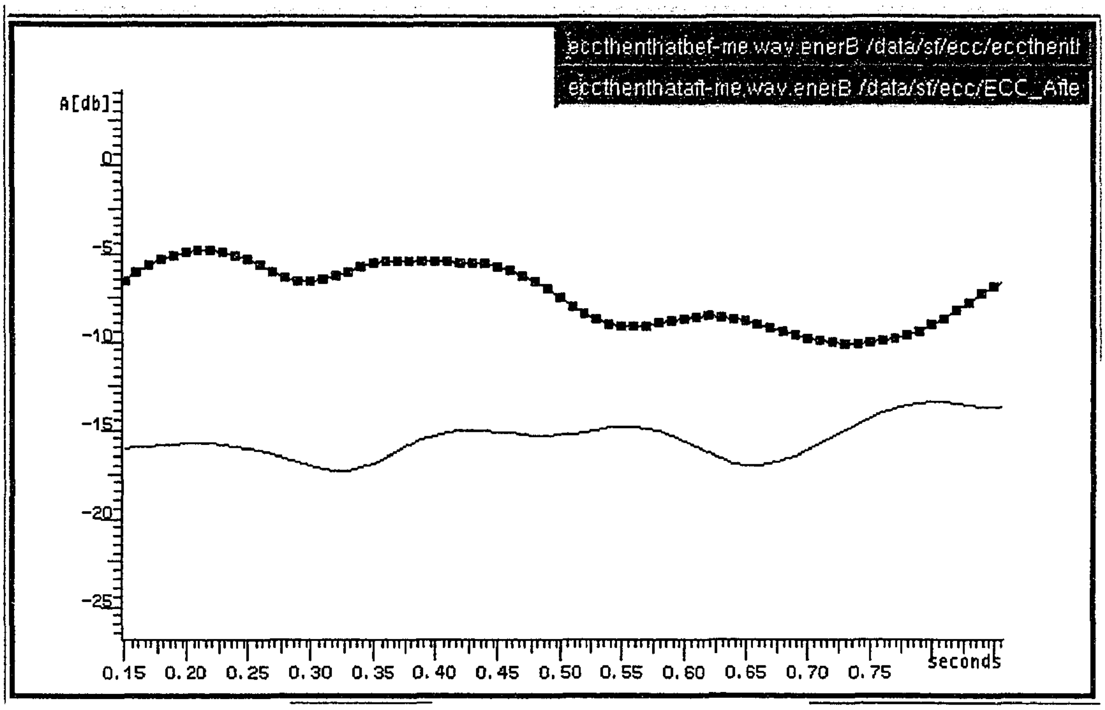

Figure 3.1. Children's Choir singing [ɛ] during *then-that* exercise. Grey line = singer's formant energy in choir's sound *before* having worked the *coup de glotte,* black line = *after*

Recorded Examples # 1 & 2 on accompanying CD

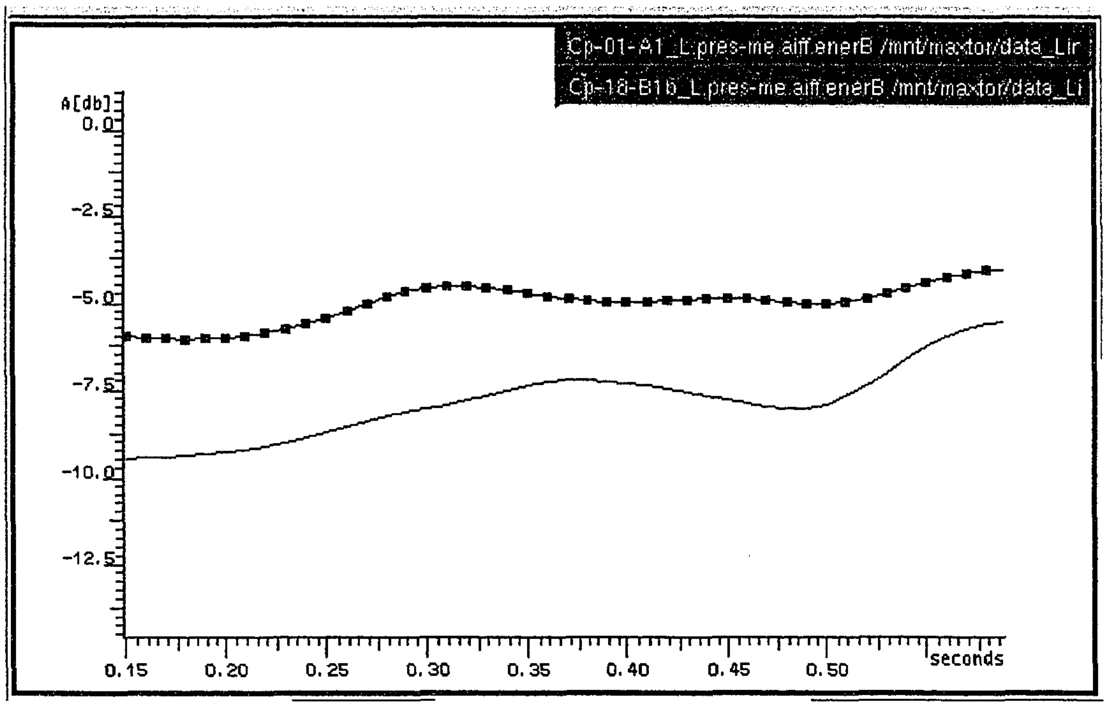

Figure 3.2. Youth Choir singing [i] Grey line = singer's formant energy in choir's sound *before* having worked the *coup de glotte,* black line = *after*

Recorded Examples # 3 & 4 on accompanying CD

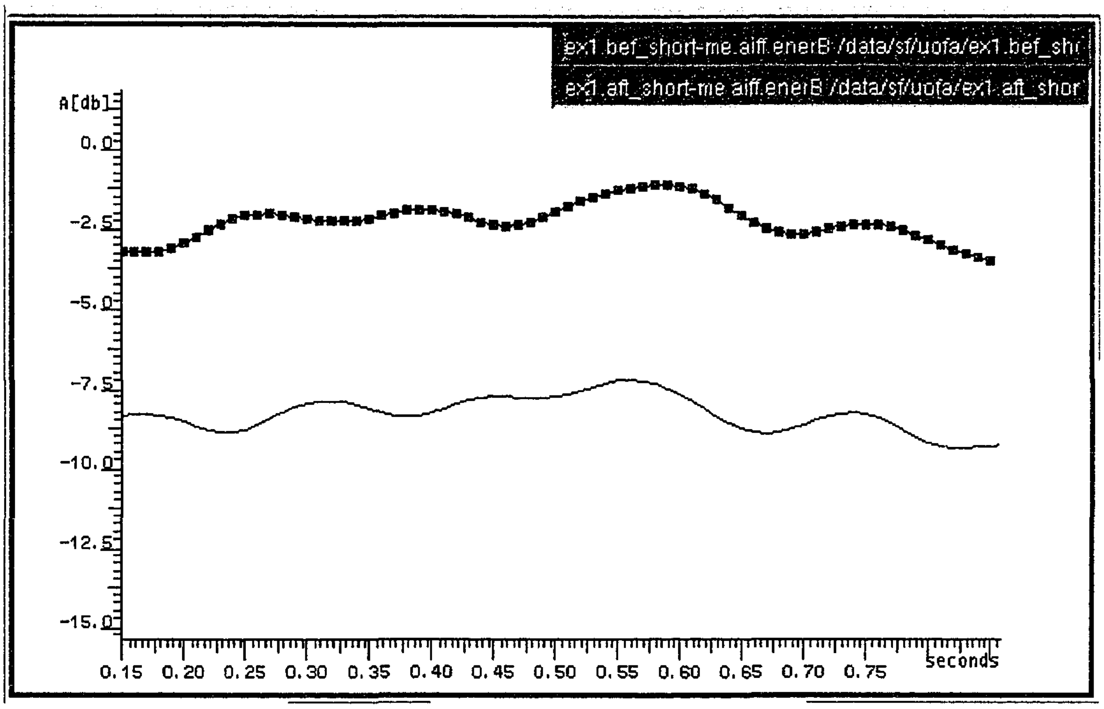

Figure 3.3. University Mixed Choir Singing [i].Grey line = singer's formant energy in choir's sound *before* having worked the *coup de glotte*, black line = *after*

Recorded Examples # 5 & 6 on accompanying CD

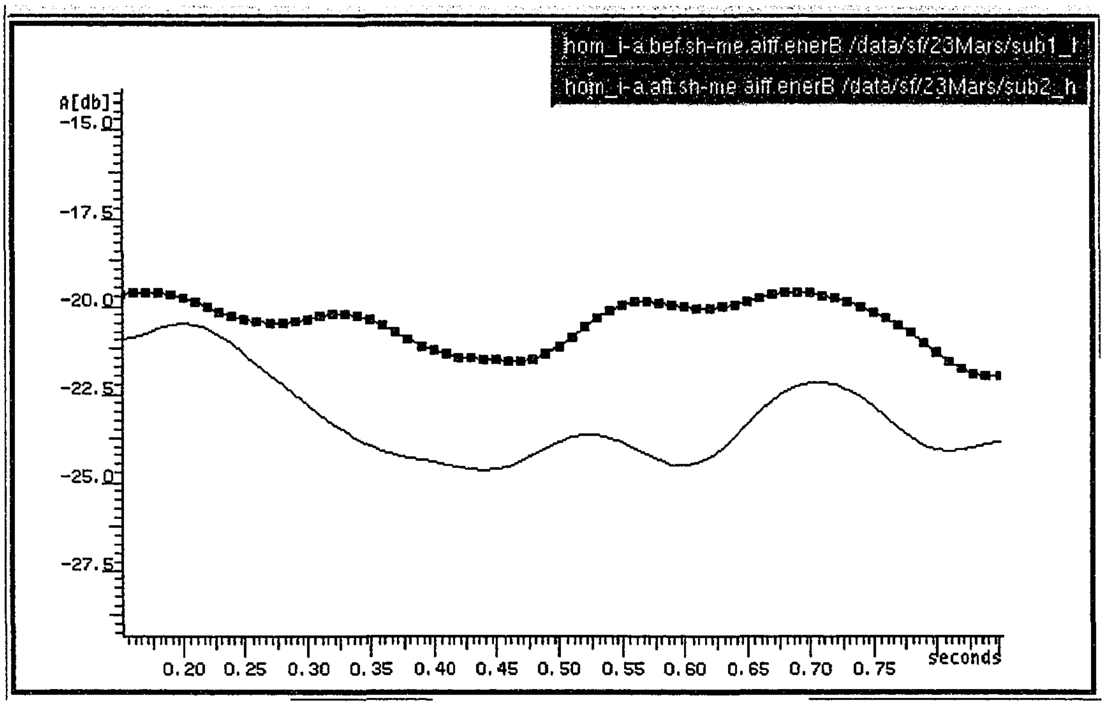

Figure 3.4. Men's choir singing [i].Grey line = singer's formant energy in choir's sound *before* having worked the *coup de glotte*, black line = *after*

Recorded Examples # 7 & 8 on accompanying CD

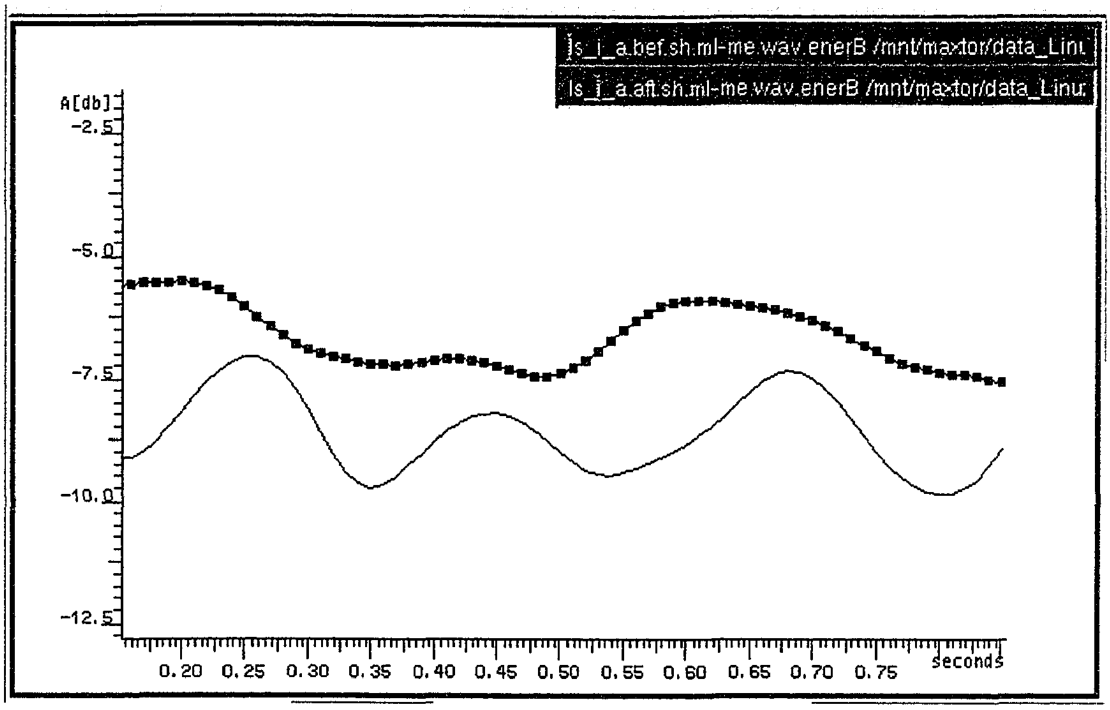

Figure 3.5. Seniors' choir singing [i].Grey line = singer's formant energy in choir's sound *before* having worked the *coup de glotte*, black line = *after*

Recorded Example # 9 & 10 on accompanying CD

Although a significant improvement is more evident with certain groups than it is with others, there is a pattern showing that all ensembles benefit from an increase in upper spectrum energy after having worked on the *coup de glotte* and core vibration. Table 3.1 below quantifies these increases numerically. Once again, intensity increases as the numbers approach zero.

Table 3.1 Statistical Comparison of Singer's Formant Energy

Choral Group:	Children's Choir	Youth Choir	University mixed	Men's Choir	Seniors' Choir
Intensity of S.F. Energy *Before*	-15.6dB	-7.79dB	-7.11dB	-23.17dB	-8.63dB
Intensity of S.F. Energy *After*	-7.38dB	-5.04dB	-2.3dB	-20.53dB	-6.65dB
Change in After (+ or -)	**+ 8.22dB**	**+2.75dB**	**+4.81dB**	**+2.64dB**	**+1.98dB**

The average increase of energy in this spectral band for these groups was **4.08 decibels**. Although this may not appear significant purely on a numerical basis, one must remember that decibel values are based on a logarithmic scale. Backus reports that doubling the intensity of a sound quantifiably raises its intensity level by 3 decibels, regardless of whether the original sound is loud or soft.[30] It can therefore be claimed that after having worked the aforementioned *bel canto* principles of vibration, spectral energy in the region of the singer's formant more than doubled overall with only one group showing significantly less than a doubling in intensity.

It has often been noted that choral singing typically lacks energy in the singer's formant region. In a study carried out to measure the presence of the singer's formant in singers of differing vocal abilities, including choral singers, Morris and Weiss state that "it is unlikely that a consistent singer's formant will be produced naturally, even with years of exposure and activity in a choral setting."[31]

Although it is not within the scope of this study to measure the long-term effects of the *coup de glotte* and increased vibration on choral singing, it is quite evident from the analyses in this section that spectral activity in the region of the singer's formant has been increased quite consistently within a very short period of time. It can only be expected that with consistent work on techniques of proper vocal vibration as set forth by Lamperti and Garcia, this increased energy, contrary to the above remarks, would become the norm in a choral environment in which this type of singing is encouraged.

Comparison of Intensities: Fundamental Frequency vs. Singer's Formant

Another important approach to analyzing acoustical differences in before and after segments is that of comparing the energy present in the singer's formant region with that of the fundamental frequency (F_0). It has been shown that classical singers who exhibit a high level of mastery in the area of vocal technique

[30] John Backus, *The Acoustical Foundations of Music* (New York: W.W. Norton, 1969), 84.
[31] Morris and Weiss, 24

concentrate less spectral energy in the region of the fundamental frequency and more in the band associated with the singer's formant. This ratio has always been associated with good glottal closure and a high level of vocal efficiency.[32] It was therefore natural to test how heightened attention to glottal vibration affected this important relationship.

The following analyses measure and juxtapose the energy present in each of these two regions as worked on during the 'core vibration and *coup de glotte*' portion of experiments with choirs. In each analysis, the window to the left represents the exercise as it was sung *before* the work on core vibration was done, and the window to the right, *after*. The lighter, top line in each of the windows represents the intensity (in decibels) in the region of the fundamental frequency (or frequencies)[33] sung by the groups. This is the amount of energy that choral groups put into the actual note they were singing, independently of the complex spectral energy that may or may not have been generated dependent on the fashion in which they sang that note. The frequency parameters run through the program for the calculation of this energy allowed for 20 Hz on either side of the actual fundamental being sung. In other words, in the case of a group singing A 440, the low and high frequency parameters given the program to calculate F_0 energy would have been 420 and 460 Hertz respectively. In the case of a mixed choir with the men singing 220 Hz and the women 440 Hz, the values would have been 200 and 460 Hertz. Although this is somewhat imperfect as the women's fundamental frequency is also the men's first harmonic, it is a fairly accurate measurement and was used in the same way for all choirs. The darker line on the bottom represents the intensity of the energy in the region of the singer's formant. It increases in intensity as it rises and approaches zero. The more these two lines approach each other, the more efficient the singing in general.

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[32] Rossing et al., "Acoustic Comparison," 1979.

[33] *Frequencies* is used in the plural sense when dealing with a mixed voice choir where the men and the women sang essentially the same note, but an octave apart. Therefore if the men sang A_3 at 220 Hz, the women sang A_4 at a frequency of 440 Hz.

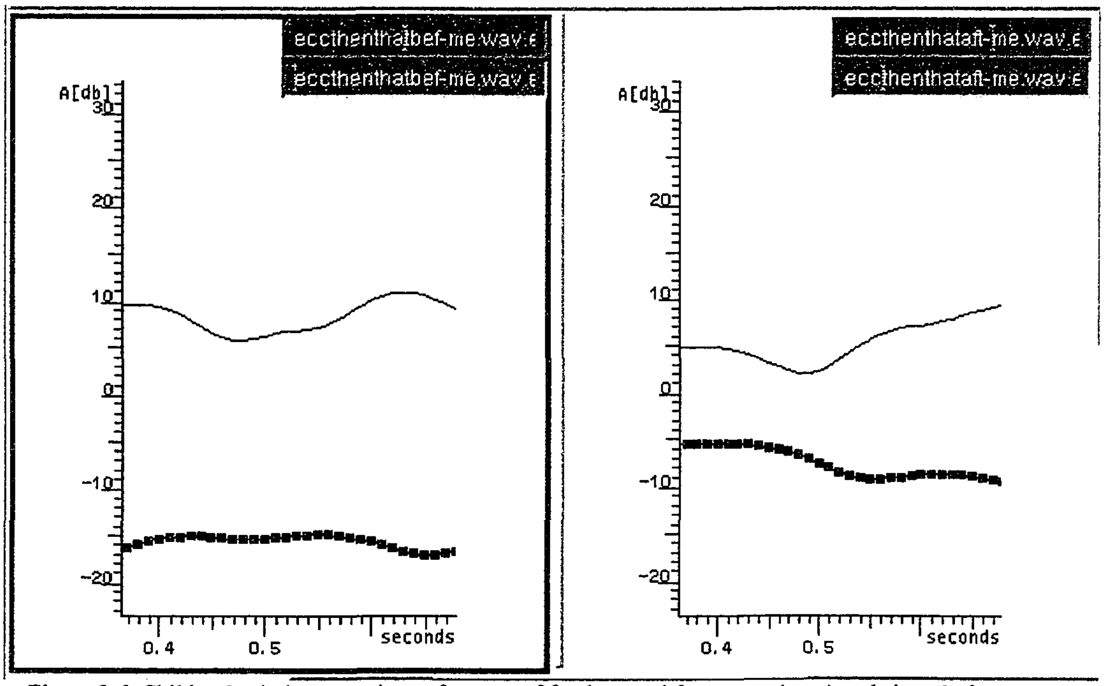

Figure 3.6. Children's choir comparison of energy of fundamental frequency (grey) and singer's formant (black). Left window is *before*, right, *after*

Recorded Example # 1 & 2 on accompanying CD

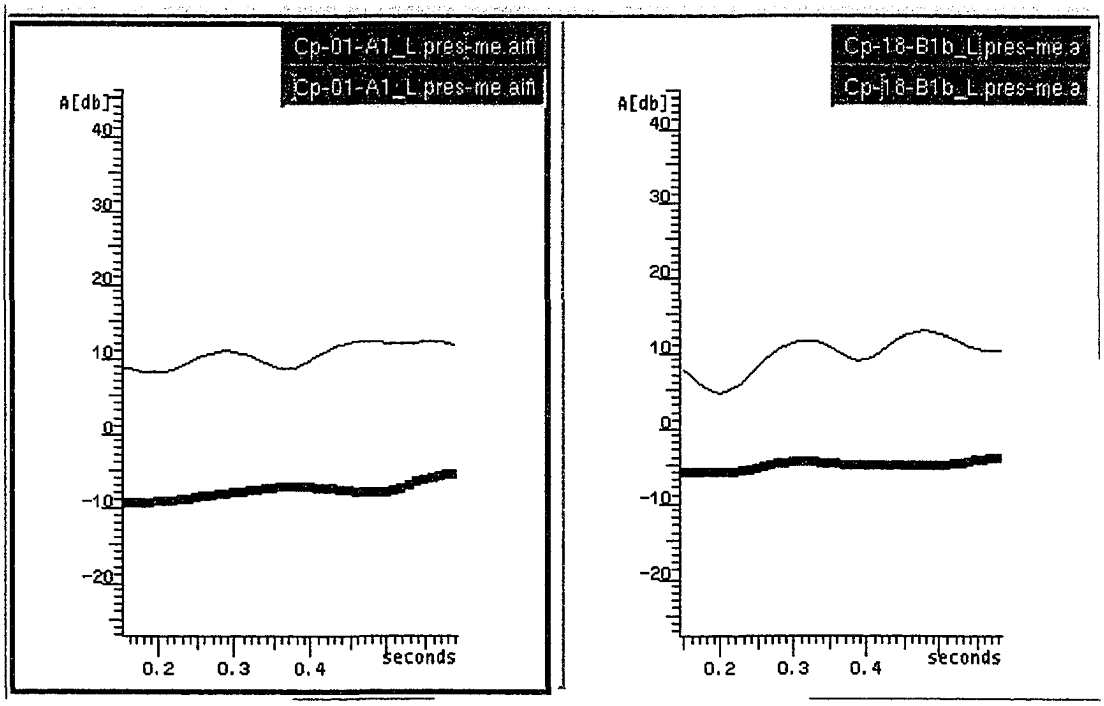

Figure 3.7. Youth choir comparison of energy of fundamental frequency (grey) and singer's formant (black). Left window is *before*, right, *after*

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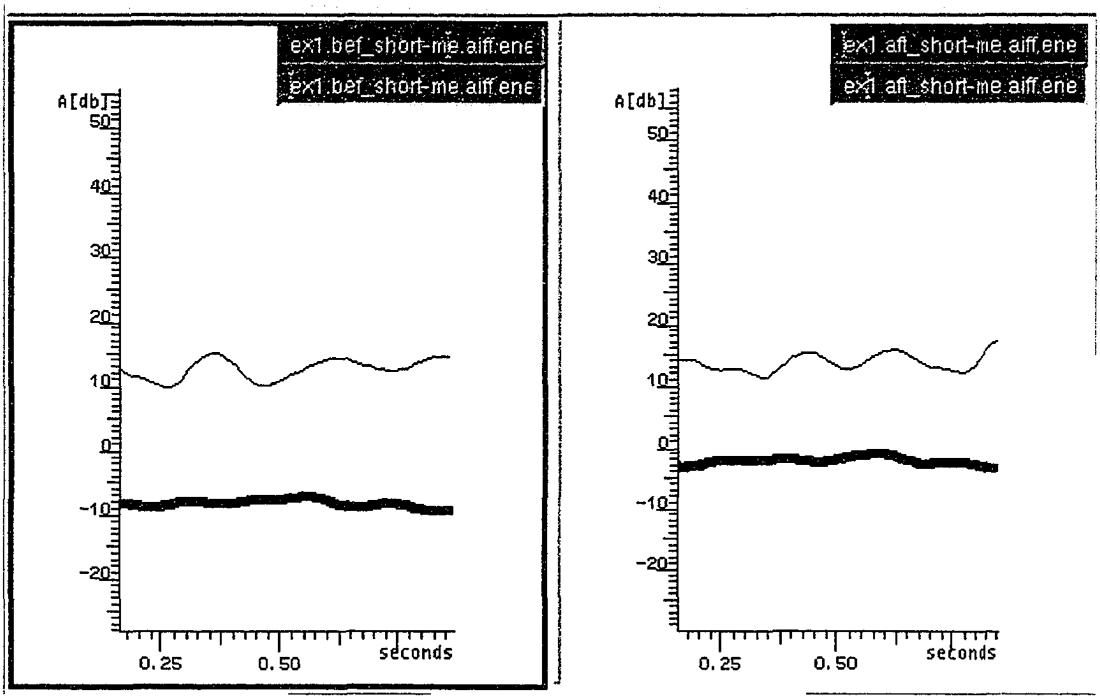

Figure 3.8. University mixed choir comparison of energy of fundamental frequency (grey) and singer's formant (black). Left window is *before*, right, *after*

Recorded Example # 5 & 6 on accompanying CD

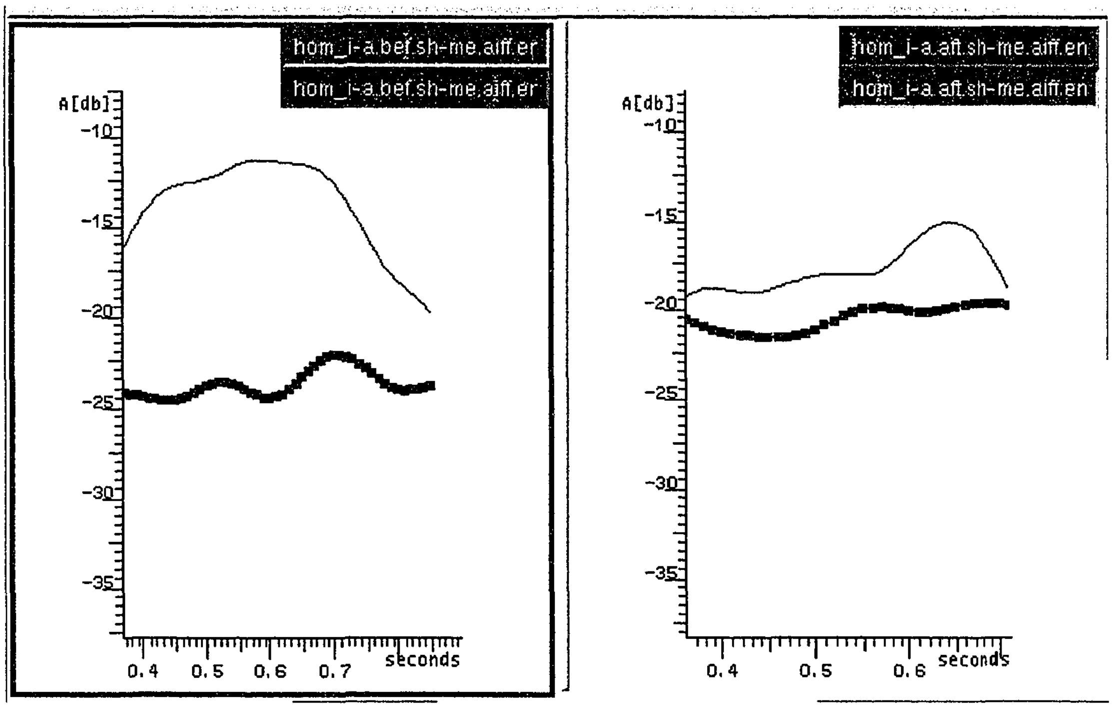

Figure 3.9. Men's choir comparison of energy of fundamental frequency (grey) and singer's formant (black). Left window is *before*, right, *after*

Recorded Example # 7 & 8 on accompanying CD

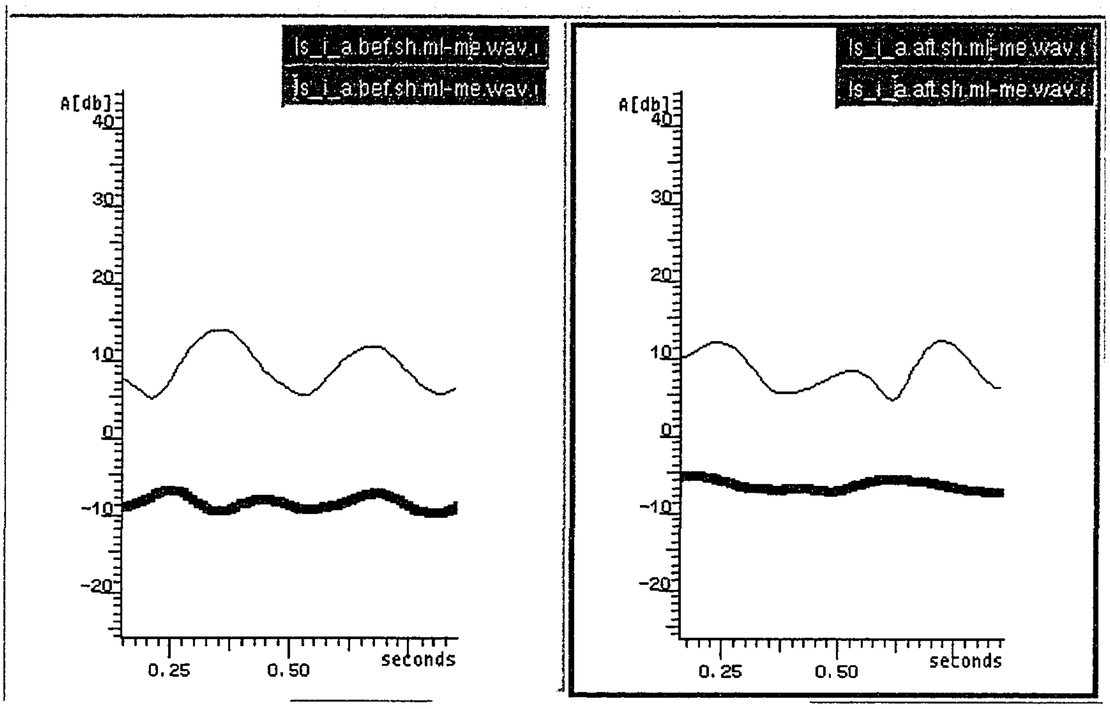

Figure 3.10. Seniors' choir comparison of energy of fundamental frequency (grey) and singer's formant (black). Left window is *before*, right, *after*

Recorded Example # 9 & 10 on accompanying CD

Table 3.2 Comparison of F_0 Energy and Singer's Formant Energy

		Type of Ensemble				
		Children's Choir	Youth Choir	University Mixed Choir	Men's Choir	Seniors' Choir
Amount of Harmonic Energy in Tone	1. Bef.F0 Intensity	7.73 dB	10.45 dB	12.55 dB	-16.14 dB	8.62 dB
	2. Bef. S.F. Intensity	-15.60 dB	-7.79 dB	-7.11 dB	-23.17 dB	-8.63 dB
	3. Difference	**23.33 dB loss**	**18.24 dB loss**	**19.66 Db loss**	**7.03 dB loss**	**17.25 dB loss**
	4. Aft.F0 Intensity	4.9 dB	9.66 dB	13.74 dB	-18.92 dB	8.29 dB
	5. Aft. S.F. Intensity	-7.38 dB	-5.04 dB	-2.3 dB	-20.53 dB	-6.65 dB
	6. Difference	**12.28 dB loss**	**14.7 dB loss**	**16.04 dB loss**	**1.61 dB loss**	**14.94 dB loss**
	7. Increase (+) or Reduction (-) in energy	**+ 11.05 db**	**+ 3.54 dB**	**+3.62 dB**	**+5.42 dB**	**+2.31 dB**

When taking into account the decrease in energy in the region of the fundamental frequency, the net gain in upper spectrum energy in relation to fundamental energy was **5.19 decibels.** It has been shown that fine artistic singing generally concentrates less energy in the region of the fundamental frequency and far more in that of the singer's formant. This seems to increase the acoustic efficiency of the singing voice, a production demanding less effort and yielding more energy. However, Rossing, Sundberg and Ternström found that quite the opposite usually occurs in amateur choral singing.

> Our results show that some spectral differences remain between solo and choral singing, even when vowels are sung at the same sound pressure level. The main differences observed are (1) a stronger amplitude of the source spectrum fundamental and (2) a lower amplitude in the frequency range of the singer's formant in choral singing.[34]

As can be gleaned from both the graphs (Figures 3.6-3.10) and the table above, the after samples from experiments show that choristers have moved toward a more energized mode of singing. In four out of five ensembles, the intensity in the region of the fundamental has dropped in comparison with the same excerpt drawn from the *before* portion (compare rows 1 and 4), while singer's formant intensity has increased in all five groups (rows 2 and 5) in the *after* samples. This type of spectral energy will ensure that a choir's sound is much more complex and colourful than when the fundamental accounts for most of the tone's acoustic envelope. Tones that overemphasize the fundamental's energy are typically flat and monochromatic sounding while those with a relatively higher singer's formant to fundamental frequency ratio enjoy more breadth of tone, greater vowel definition and tend to carry more easily.

General Observations and Conclusions

The application of the *coup de glotte* and focused core vibration has resulted in a systematic increase in upper spectrum energy in the vocal tones of participating choirs. In applying this principle, ensembles have been able to

[34] Rossing et al., "Acoustic Comparison," 1979.

increase their vocal efficiency and carrying power without sacrificing much in the area of good vocal blend (as can be heard in many of the sound examples).

Although this type of heightened vocal vibration and upper spectrum energy have long been looked upon with stylistic malaise in certain choral circles, Bolster assures that the benefits of such a production outweigh the disadvantages for choral singing.

> Choir singers often become vocally fatigued when asked to sing continually with an open glottis without the relief of some glottal closure. Some conductors attempt to eliminate the "2800" ring [singer's formant] by continually insisting on soft dynamic levels. This procedure is unhealthy for the voice. Conductors are frequently warned of the dangers of oversinging but are seldom warned about the dangers of undersinging. The latter is just as bad as the former ... Elimination of "2800" from the voices in group singing in order to achieve choral blend is certainly inadvisable.[35]

This has indeed been the approach taken in this study: to endeavour to have all singers exploit the full acoustic potential of focused vibration so that all might sing in an energized, healthy manner and contribute equally and fully to the ensemble's sound. The increased intensity and spectral energy that naturally result when choristers concentrate on each applying focused core vibration to their singing will do much to enliven the voice's colours and resonance capabilities. It will also enable an ensemble's sound to compete more successfully with orchestras on an acoustical basis. The important acoustical byproduct of decreased energy in the region of the fundamental frequency and increased energy in the upper spectrum ensures that a choir's tone will be complex and colourful, and therefore quite possibly more capable of expressive interpretations.[36]

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[35] Stephen C. Bolster, "The Fixed Formant Theory and Its Implications for Choral Blend and Choral Diction," *The Choral Journal* 23, 6 (1983): 30-31.
[36] Richard Miller and Juan Carlos Franco, "Spectrographic Analysis of the Singing Voice," *The NATS Journal* 48, 1 (1991): 5.

Chapter IV - *Chiaroscuro* Resonance Balancing

Introduction and Problem

The concept of balance has always been extremely important in fine singing. This is certainly true when it comes to the technical issue of resonance. The principle of *chiaroscuro* (bright-warm) resonance balancing was one of the major acoustical features of *bel canto* vocal pedagogy.

The actual term finds its origins in Renaissance Italy where great artists such as Leonardo da Vinci used bold combinations of light and shadow to convey a more realistic, three-dimensional ambience to their scenes. In the same way, the old masters of *bel canto* combined opposite poles of bright and dark resonance qualities to lend voices a much more complete, three-dimensional tone that was at once more pleasing to the ear and more emotionally absorbing.

These same pedagogues recognized that certain vowels were incontestably more *chiaro* ('bright' or 'clear'; e.g. [i] and [e]) or *oscuro* ('dark' or 'warm'; e.g. [o] and [u]) than others by nature. However, the *chiaroscuro* principle seeks to establish a somewhat even proportion of brightness and darkness to a singer's voice quality across the entire vowel spectrum regardless of individual vowel characteristics, thereby affording the singer a more homogeneous tone as well as a consistent balance of upper and lower spectral energy. This chapter will examine some of the acoustic benefits of respecting this paradoxical principle while singing in a choral context.

The application of this principle has several distinct advantages for choral singing: 1) clarity of diction is improved due to the increased acoustic information made available to the ear through the resonance of a fuller spectrum; 2) ensemble blend is enhanced as all choristers learn to produce a similar, unified sound; and 3) group intonation improves significantly when the multiplicity of acoustic variables associated with vowel transitions is diminished through the consistent application of *chiaroscuro* resonance balancing.

Although the first two elements of diction and blend will be presented at the beginning of this chapter, it is the effect of *chiaroscuro* resonance balancing upon group intonation that is of greater interest to this study. This effect was analysed in a detailed fashion with the sound data collected from the participating choral groups. The results and interpretation of these tests will form the bulk of this chapter.

1) <u>Vocal Timbre - Diction</u>

As mentioned, one of the aims of *chiaroscuro* resonance is to attain a fairly consistent vocal quality throughout the full gamut of vowels. This is not to say that vowels are to become so similar that they all begin to sound alike; quite the contrary. Each vowel is to maintain its own distinct, individual character, with an [i] vowel having its own acoustic properties and sounding quite different from an [e]. Yet according to this principle, all vowels are to be coloured with one underlying vocal timbre, to some extent equalizing the inherent differences within the harmonic spectrum of vowels. Each vowel is to have at once both elements of clear brightness and rounded warmth. The *chiaroscuro* principle thus becomes a system of constant vowel modification as dictated by the equalizing ability of the human ear.

When asked whether modifying vowels to make them adhere to this balanced principle would not make diction seem unnatural, Garcia astutely responded:

> the answer is that in the utterance of a thought all the vowels are modified in the same proportion; their mutual relation remains unaltered; only as a whole have they taken the tint harmonizing with the passion expressed. A landscape lighted by the sun or darkened by the clouds [chiaroscuro] presents quite different aspects, yet every object keeps its place and outline all unchanged.[37]

It is the author's experience that this constant modification of vowels toward tonal homogeneity actually improves diction, as long as the *oscuro* element is counterbalanced with sufficient brilliance or *chiaro* to provide vowel clarity. One likely reason for this greater linguistic perceptibility is that the ear need not

[37] Manuel Garcia, *Hints on Singing* (New York: Joseph Patelson, 1982), 46

constantly adjust itself to the endless variations in quality of tone in order to surmise the vowel sounds being sung, but rather becomes accustomed to the acoustical consistency emanating from an ensemble using balanced resonance.

2) Vocal Timbre - Blend

Quite often in amateur choral singing, it is the *oscuro* or roundness that seems to be lacking in the tone. In an attempt to blend their voices with those around them, choristers often tend not to exploit the full capacity of their pharynx to amplify the full harmonic spectrum of a given vowel. Some conductors and authors have in fact commented on *chiaroscuro* being almost the antithesis of typical choral resonance.[38] Garcia, however, fully appreciated the pharynx's leading role in vocal resonance and went so far as to call it "the real mouth of the singer," maintaining that it was primarily in this cavity that "is found the causation of timbres."[39] Lamperti also warns against allowing diction to remove the *oscuro* element: "To bring word and tone to the lips, without losing the darker resonance is an absolute necessity."[40]

Many choral groups are regularly admonished by their conductors to 'get the tone out of their throats' and 'into the mask.' What many of them do not realize is that this type of specific, high placement, while making the voice sound very clear and 'forward,' encourages a higher laryngeal position and a more superficial resonance with a limited harmonic spectrum. It is almost akin to asking a rainbow to only allow three of its colours to shine. This unbalanced, frontal resonance can itself be detrimental to ensemble singing in that it is usually the overly brilliant voices that tend to penetrate an ensemble's sound.

Stark's definition of this concept recalls the importance of balance, and is at once acoustically sound and artistically appealing:

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[38] James Stark, *Bel Canto: A History of Vocal Pedagogy* (Toronto: Toronto University Press, 1999), 34.
[39] Garcia, *Hints,* 12-13.
[40] Giovanni Battista Lamperti, *Vocal Wisdom; Maxims of G.B. Lamperti* (New York: W.E. Brown, 1931), 53.

> ...The 'bright' element is associated with firm glottal closure, which produces a tone that is rich in high-frequency components...But this bright edge is only part of *chiaroscuro.* Simultaneously the voice must have a roundness and depth that gives it a dark quality. This dark quality is provided by the resonances of the vocal tract. *Chiaroscuro* is a voice quality that bears within itself a dynamic that is both complex and striking. It might be compared to the vivid contrast of silvery white and deep red on each petal of a fire-and-ice rose... Even though there are many individual differences between the voices of trained singers, one quality which many singers have in common is the bright-dark tone of *chiaroscuro.*[41]

The *chiaroscuro* principle could be of immense benefit to choral conductors and singers in striving for the often elusive acoustical virtue of ensemble blend. By seeking an even vocal timbre throughout the full vowel spectrum, this principle encourages a common denominator of voice quality throughout the different voices and sections of an ensemble. Too often the issue of *blend* is confused with the quality of *bland* in choral singing, with too much of the group's vocal colour being removed so that all voices become equally devoid of any quality that would make them individually audible within a group situation. The *bel canto chiaroscuro* model, however, attempts to give each chorister the ability to sing in a fully resonant fashion, simultaneously adding the same proportion of warmth and brightness to each voice while removing any superfluous muscular interference and tension in the vocal tract that often accounts for the unbalanced resonance or 'edge' responsible for making a voice penetrate the choral envelope.

Garcia warns against allowing either the 'open' or bright timbre, or the 'closed' or dark timbre to become too dominant in one's singing.

> As all the modifications they [variables in timbre] undergo are the result of two distinct and opposite cases, they may be divided into two leading classes - the open, or clear [*chiaro*], and the closed or sombre timbre [*oscuro*], *the character of each* being impressed upon the whole compass of the voice. The open timbre imparts much brilliancy to the chest register, but when exaggerated, makes the voice shrieky and shrill: whereas the closed gives it breadth and roundness - for by means of the latter only, the rich quality of the

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[41] Stark, 34.

> voice is attained. This, however, when exaggerated, muffles the sounds and makes them dull and hoarse.[42]

Garcia, like the masters before him, advocated a balanced approach to vocal resonance where the best qualities of both timbres were to be present in the voice at all times. The exaggeration of *chiaro* resonance of which he speaks has always been the nemesis of balanced, blended choral singing, for this type of sound defies the natural acoustic properties of vowel sounds and encourages amplification of harmonics which are not appropriate for the given vowel and pitch being sung.

It may be helpful at this point to quickly review the acoustics of vocal resonance and the source-filter theory. All of the overtones that the voice can produce (in conventional Western singing) are already present in the initial vibration which emanates from the vocal folds. The vocal tract (mouth, oro- and naso-pharynx), however, exercises enormous influence on the acoustical management of these overtones. The position assumed by articulators and buccal components during the act of phonation decides which of the overtones present in the initial vibration will be amplified and which will be dampened. Along with the quality of vibration mentioned in the previous chapter, this amplifying/filtering process of the vocal tract is largely responsible for personal vocal quality and vowel formation.

Balancing the *chiaroscuro* resonance in each of the sung vowels enables the vocal tract to tune its filtering/amplifying process to most adequately acoustically encourage the overtones that are needed for a beautiful, balanced and well tuned vocal tone while dampening those that do not contribute to this objective. "Only when the attack is precise and the resonators are tuned to resonate harmonically with the sung pitch, will the tone be resonant, free, powerful and agile."[43] The flexibility of *chiaroscuro* vowel resonance tracking *is* the *bel canto* vehicle for tuning the resonators to the vibration of the cords on any given pitch. An incomplete vowel will typically yield a muscularly tense setting of the resonators which will in turn amplify harmonics that are not

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[42] Manuel Garcia, *A Complete Treatise on the Art of Singing: Part One* (New York: Da Capo Press, 1975), lii.
[43] Dan Marek, *Appoggio: The Bel Canto Method of Breathing* (New York: The author, 1993), 8

complementary to the note and vowel being sung, resulting in acoustical noise and voices that penetrate the ensemble's tonal envelope. On the other hand, a beautifully pure, bright-warm vowel will set up the resonators to amplify only those overtones that are naturally part of the harmonic series of the vowel and note being sung with voices harmoniously blending together.

Reid believes this principle to have powerful technical ramifications on the voice.

> The constant striving of the early masters of singing toward the goal of vowel purity, therefore, was in effect an effort guided by instinct whose purpose was to duplicate a favorable acoustic condition. To form a 'pure' vowel is to set the vocal organs in a favorable adjustment, and this adjustment then awakens a desirable harmonic response increasing the beauty and purity of the tone quality. This is the only means at the singer's disposal for gaining a satisfactory control over the acoustical condition of the voice.[44]

Hopkin, one of the only conductors to write on the acoustic benefits of this principle within the choral setting, states:

> Vowel unification creates an easily followed path that leads to mastery of a number of vocal skills. It enhances the *chiaroscuro* balance in the voice; it offers the potential to reveal the Singer's Formant (F3) and to increase ring in the tone; it gives a tangible way to establish the abstract concept of placement, and it provides a usable tool for choral directors to create new levels of choral blend...Choir directors spend most of their rehearsal time developing blend, both among the sections and within each section. Vowel equalization offers an approach to choral blend that yields immediate and noticeable results.[45]

According to the above theory, once the balance of *chiaroscuro* is established in the individual voices in an ensemble, the resonance of the entire group becomes more homogenous and ensemble blend improves significantly. A later study complete with an independent panel of judges will test the effectiveness of this aspect of *chiaroscuro* resonance on ensemble blend choral singing.

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[44] Cornelius Reid, *Bel Canto: Principles and* Practices (New York: J. Patelson Music, 1978), 38.
[45] J. Arden Hopkin, "Vowel Equalization," *NATS Journal of Singing* 53 (1997): 12-13.

3) *Chiaroscuro* Resonance Balancing and Ensemble Intonation

It is a well-known acoustical fact that all vowels were not created equal. Individual vowels do not resonate in quite the same way, or at the same frequency. To effect a vowel change, the articulators must change position and the vocal tract must alter its shape. These movements bring with them a plethora of muscular adjustments which often have a pejorative effect on the stability of the fundamental frequency. This phenomenon has often been observed and commented upon by vocal acousticians under the headings of "intrinsic pitch of vowels" and "articulatory F_0 disturbances."[46] For example, several experiments have shown that the change from [i] (heed) to [ε] (head), is often accompanied by a rather significant drop in fundamental frequency. There are various theories that attempt to explain this correlation, one of them being the "tongue-pull" hypothesis which suggests that the higher tongue position required for frontal vowels might also cause a longitudinal stretching of the vocal folds which would tend to raise the fundamental frequency.[47] Whatever the precise reason(s) might be, the relationship between changes in resonance and alterations in vibration of the vocal cords (frequency) seems to be quite strong.[48]

Because of the fact that all vowels have their own unique harmonic pitch stamp, attacking ensemble intonation purely from the perspective of the fundamental frequency (i.e. ensuring that everyone is singing the 'right note') has definite acoustic limitations. Sundberg has shown that vowels have their own unique 'pitch trends,' quite distinct from, and somewhat independent of, the actual pitch of the fundamental frequency.[49] In general, too much attention in choral singing is centered on the precision of the fundamental frequency, and far too little on producing a tone that is alive with the presence of a complete harmonic spectrum, an important detail that is often overlooked when studying

[46] Sten Ternström, "Physical and Acoustic Factors that Interact with the Singer to Produce Choral Sound," *Journal of Voice*, 5, 2 (1991): 137.
[47] Sten Ternström and Johann Sundberg, "The Acoustics of Choir Singing," *Collection of Papers Published by the Royal Swedish Academy of Music* 52 (1986): 22.
[48] Sten Ternström, Johan Sundberg, and Anders Colldén, "Articulatory *Fo* Perturbations and Auditory Feedback," *Journal of Speech and Hearing Research* 31 (1988): 191.
[49] Johan Sundberg, *The Science of the Singing Voice* (DeKalb, IL: Northern Illinois University Press, 1987), 143.

ensemble intonation. Bolster links the concept of vowel unity and vowel pitch as a combined pitch-blend problem: "Since each vowel has a specific pitch and is a specific timbre, the simultaneous use of different vowels or vowel colours simply will not blend. The human ear will perceive the different vowel sounds." [50]

Therefore, the vocal tract's amplifying/filtering process presents another variable that needs to be brought under control when dealing with ensemble intonation. If choristers are singing the same fundamental frequency but different versions of the intended vowel, each will be amplifying the overtones of the vowel and pitch somewhat differently, resulting in mismatched vocal spectra. Singers may very well perceive that they are all singing the right note, yet if their overtones are not in sync due to misaligned vowels, their sound will not be truly in tune.

Ternström and Sundberg's research further supports the fact that resonance plays an important role in intonation: "The perceived pitch follows fundamental frequency more closely when there are strong high partials in the sound, especially at extremes of loudness. This indicates that the presence of high partials could be of importance to intonation."[51] As *chiaroscuro* singing tends to enjoy a fuller spectrum than typical choral singing, especially in the higher partials, it seemed natural to test the benefits of the application of this principle to intonation problems within the choral setting.

Another acoustical factor related to possible intonation problems is that of over-articulation. It was observed during experiments that focusing on the consistency of tone so germane to *chiaroscuro* singing also seemed to diminish the range of mouth movements necessary for certain vowel changes. It is undeniable that the articulators must move when a vowel change takes place with certain combinations demanding more movement than others. For instance, when moving from an [ɑ] to an [i] vowel, the large vertical buccal opening on the first vowel will typically be greatly reduced and the mouth will assume a more slender and horizontal position for the [i]. However, when concentrating on consistency

[50] Stephen C. Bolster, "The Fixed Formant Theory and Its Implications for Choral Blend and Choral Diction," *The Choral Journal* 23, 6 (1983): 29.
[51] Ternström et al., "The Acoustics of Choir Singing," 19.

of resonance quality within the vowels, the mouth tends to remain in a more rounded and vertically aligned position in order to retain the warmth in the [i] with the tongue not being pulled up quite as high. This reduction in extraneous and unnecessary articulatory changes provides a more stable environment for the vibrating vocal folds which can lead to improved intonation. This is especially important in amateur choral singing as choristers often tend to exaggerate the mouth movements that they perceive as necessary for vowel changes, usually in the meritorious aim of clarity of diction.

In other words, when properly applying the *chiaroscuro* principle, the singers move only that which truly needs to be moved to bring about a change in vowel while avoiding the changes in vocal quality that typically accompany such movements. By concentrating on the *quality of the vowel* and the *consistency of vocal resonance* when changing from one vowel to another, the singer's attention is more acutely aware of other changes that take place, such as *changes in pitch.* These elements of *chiaroscuro* resonance tend to play an important role in reversing the pejorative effect that articulatory changes can have on fundamental frequency, as demonstrated by the analyses in this chapter.

<u>Experimental procedure</u>

Though certain vowels are incontestably more *chiaro* (bright) or *oscuro* (dark) than others by nature, this portion of choral experiments sought to establish an equal proportion of brightness and darkness across the complete vowel spectrum, even when the exercises were designed to render this quite difficult (i.e. placing very bright vowels adjacent to very dark vowels). Concentrating on equalizing the consistency of this "bright-dark" quality appears to even out the upper spectrum activity among the different vowels, thereby removing one of the limiting variables in the singers' vocal technique.

Several strategies were employed in an attempt to have choristers gain both an awareness of and a capacity to apply the *chiaroscuro* principle to their singing. After singing the vowel series [ɑ-e-i-o-u] in unison, the group was asked to identify both the brightest and the darkest of these vowels. The answer was usually [i] for the brightest and [o] for the darkest. They were then asked to sing these two vowels alternatively several times while attempting to add all of the inherent brightness of the [i] to the [o] vowel. After several repetitions, singers were asked to do the inverse and maintain all of the darkness or roundness of the [o] while singing the [i]. They were not asked to find a 'happy medium' vowel with no definition, but rather two very distinct vowels, each tainted with the same dose of brightness and roundness. This bi-polar type of resonance was then applied to all of the vowels in the above series.

Another tactic was to have choristers sing the same vowel – usually [ɑ] because it is perhaps the most naturally *chiaroscuro* of all the vowels – first in an overly brilliant manner, followed immediately by the same vowel sung in an overly dark fashion. During the third stage, they were asked to sing a fully resonant vowel, combining all of the brightness of the overly *chiaro* version as well as all of the warmth of the overly *oscuro* version.

Some time was then spent on convincing singers that they could effect a change from the larger vowels [ɑ, o] to the smaller vowels [i, e] without allowing the smaller buccal space to limit the *chiaroscuro* character of the resonance. Conversely, work was also done in the opposite direction to ensure that choristers were not allowing the *chiaro* element to decrease as the jaw dropped when moving from the brighter to the darker vowels. This was a very natural tendency which proved somewhat difficult to reverse.

Throughout this portion of experiments, choristers were encouraged to maintain a consistency in vocal timbre and resonance placement while allowing the articulators to make only the most economical movements necessary to realize the different vowel sounds. Their attention was in no way drawn to the fact that there might be an *intonation* problem, but rather a *resonance* problem. One can draw the conclusion from the graphs below that after having worked on the principle of *chiaroscuro* resonance balancing for approximately fifteen minutes, the articulatory perturbations that were exercising a negative influence on fundamental frequency stability in the *before* samples are greatly reduced in the *after* samples.

Samples for the university choir are not included in this chapter. This experiment had been conducted some months previous to the others in this study and the articles on choral intonation by Ternström had not yet been discovered. Consequently different exercises were employed to test the effectiveness of *chiaroscuro* resonance with regards to ensemble intonation. As different vowel combinations were used in these exercises, it was thought that to spare the confusion, the results should be shown on their own (see appendix A).

Exercises and Analysis of Sound Data

The graphs and tables below compare intonation accuracy in *before* and *after* segments of choirs singing three exercises/phrases: 1) [i]-[ɛ]-[y]-[ɑ]; 2) *Christus factus est pro nobis;* and 3) *Kyrie eleison.* These phrases were chosen because of their combination of *chiaro* and *oscuro* vowels as well as for their frequency of appearance in the choral literature. Ternström also found that phrases such as these are particularly difficult for choirs to sing in tune.

> Six experienced choir singers sang sustained tones with a change of vowel in midtone... The vowel change was found to affect F_0 in 63% of the tokens. In particular, the front vowels [i] and [y] were found to raise F_0, whereas it was lowered by [ɛ] and [ɑ]...Certain combinations of vowels were found to be potent pitch perturbers. The "worst" vowel combination used in the experiment was [i] and [ɛ], as in kyrie eleison, which in almost half of the cases caused a change in F_0 on the order of 35 cents. Such articulatory perturbation of F_0 could be one reason why choirs sometimes find themselves repeatedly going out of tune at a particular place in a piece.[52]

In order to test what effect *chiaroscuro* resonance might have on these phenomena, the vowel combinations Ternström found to be most problematic were used in this study. To ensure as accurate an assessment of intonation adjustments as possible, and to deal with software limitations, choirs sang these exercises in unison. In all cases, the red line is placed at the average frequency of the first vowel of the series in order to enable a visual reference point for ensuing

[52] Ternström, "Physical and Acoustic Factors," 137.

drops and rises in pitch. For all graphs, the y axis displays frequency in Hertz (cycles per second) while the x axis represents time.

1. [i]-[ɛ]-[y]-[ɑ]

In the exercise resulting in the graphs below, choristers were asked to maintain, to the extent possible, an equal amount of brightness and darkness (*chiaroscuro*) in all of the four consecutively sung vowels [i-ɛ-y-ɑ] on the same pitch. In his study on the intonation precision of choral singing, Ternström found that choristers were more susceptible to lose pitch in these two combinations of vowels [i-ɛ] and [y-ɑ] than with any other pairs. It was therefore logical to test what effect *bel canto* resonance balancing would have on intonation using these problematic combinations.

The graphs were generated using the *Additive* program from the *Institut de Recherche et coordination acoustique/musique* in Paris. This analysis program measures the pitch of the fundamental frequency at approximately one hundred fifty points per second, the results of which are plotted by the program *Xspect* on graphs such as those below. The variations in pitch were also calculated numerically, the results of which are displayed and interpreted in the tables below each group of graphs.

* See next page for analyses.

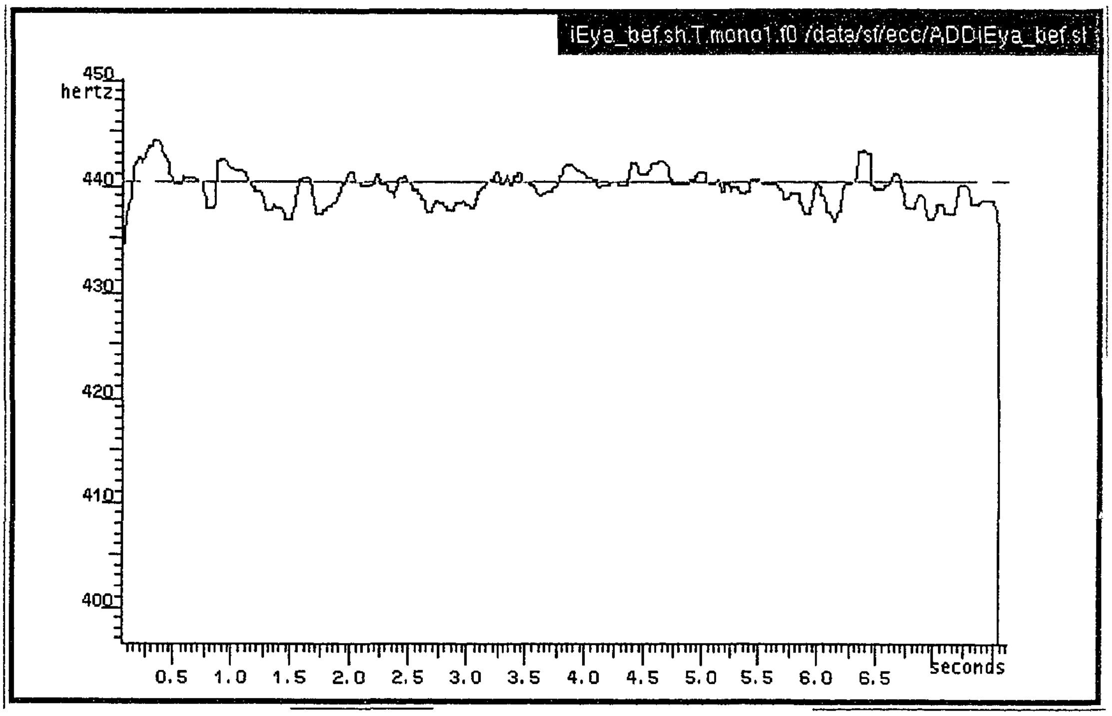

Figure 4.1. Children's choir singing [i – ɛ – y – ɑ], each vowel at approximately 1.5 second intervals along the 'x' axis, ***before*** working on the *chiaroscuro* principle (compare with 4.2 below).

Recorded Example # 11 on accompanying CD

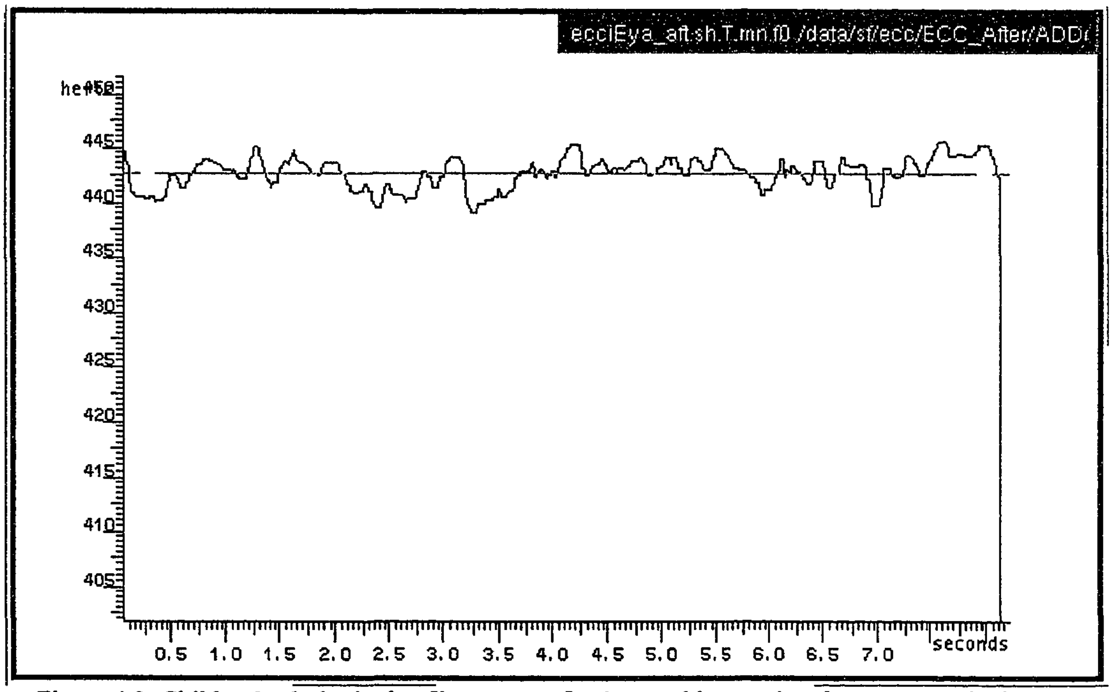

Figure 4.2. Children's choir singing [i – ɛ – y – ɑ] *after* working on the *chiaroscuro* principle (compare with 4.1)

Recorded Example # 12 on accompanying CD

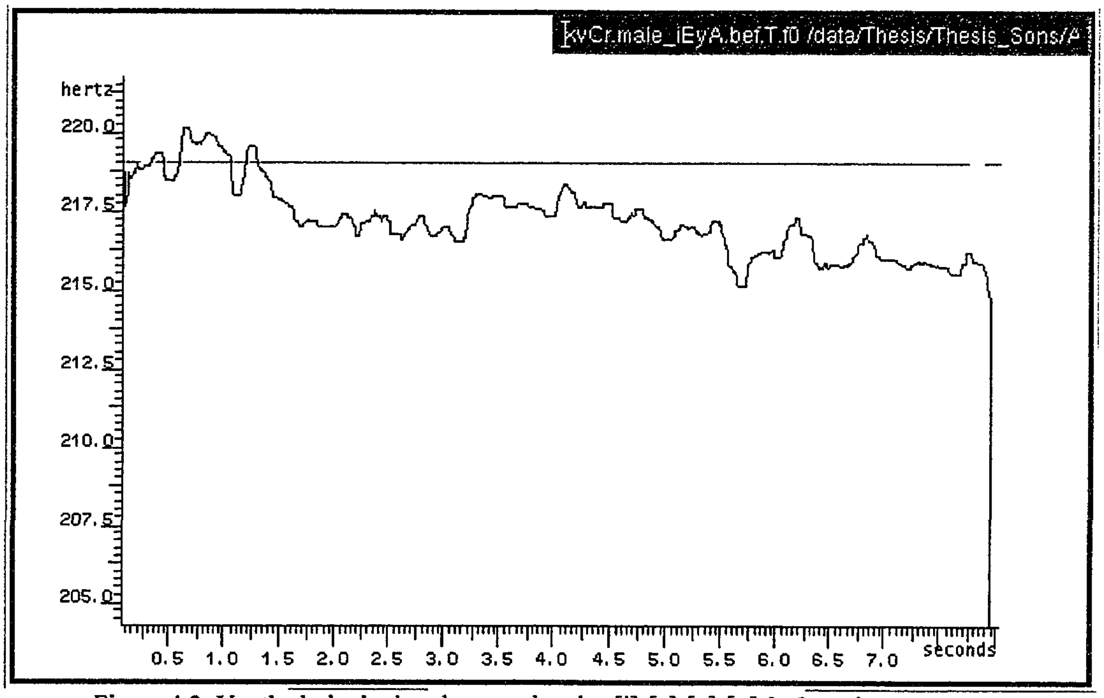

Figure 4.3. Youth choir singing the vowel series [i]-[ɛ]-[y]-[ɑ] ***before*** *chiaroscuro* (compare with 4.4).

Recorded Example # 13 on accompanying CD

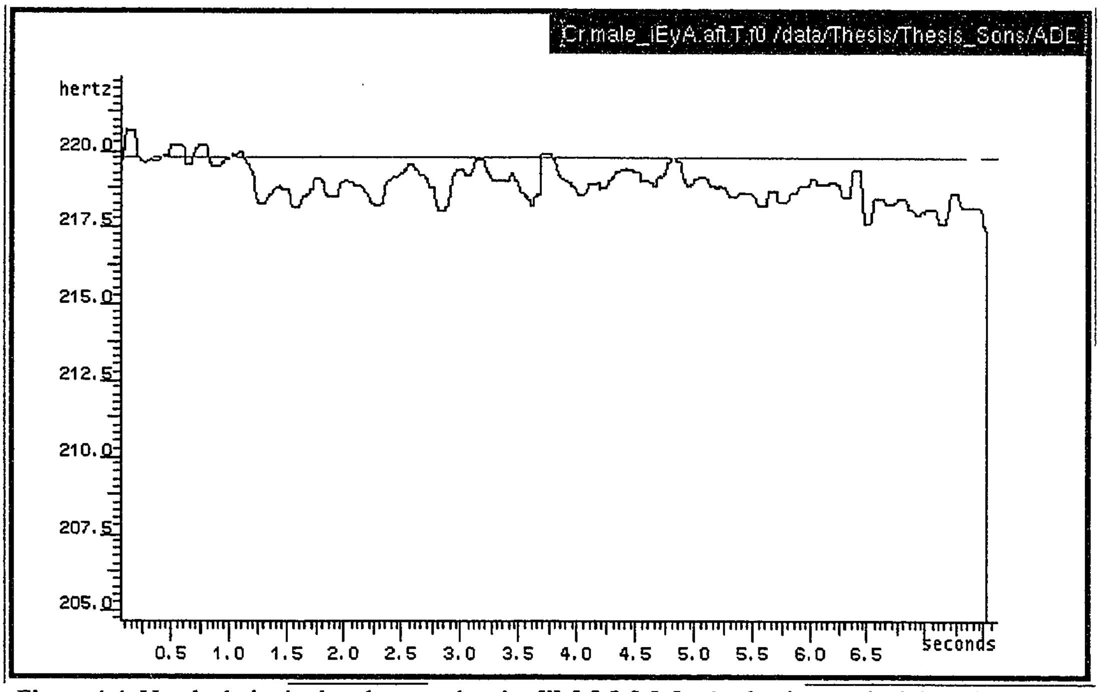

Figure 4.4. Youth choir singing the vowel series [i]-[ɛ]-[y]-[ɑ] ***after*** having worked the principle of *chiaroscuro* resonance balancing (compare with 4.3).

Recorded Example # 14 on accompanying CD

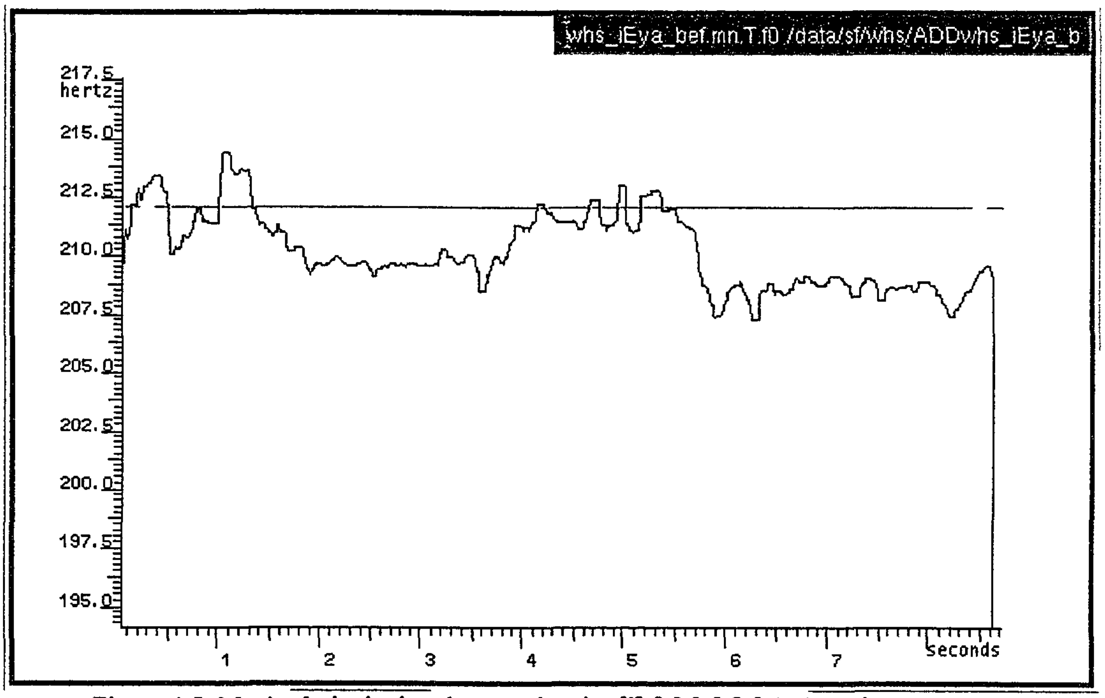

Figure 4.5. Men's choir singing the vowel series [i]-[ɛ]-[y]-[ɑ] ***before*** *chiaroscuro* (compare with 4.6).

Recorded Example # 15 on accompanying CD

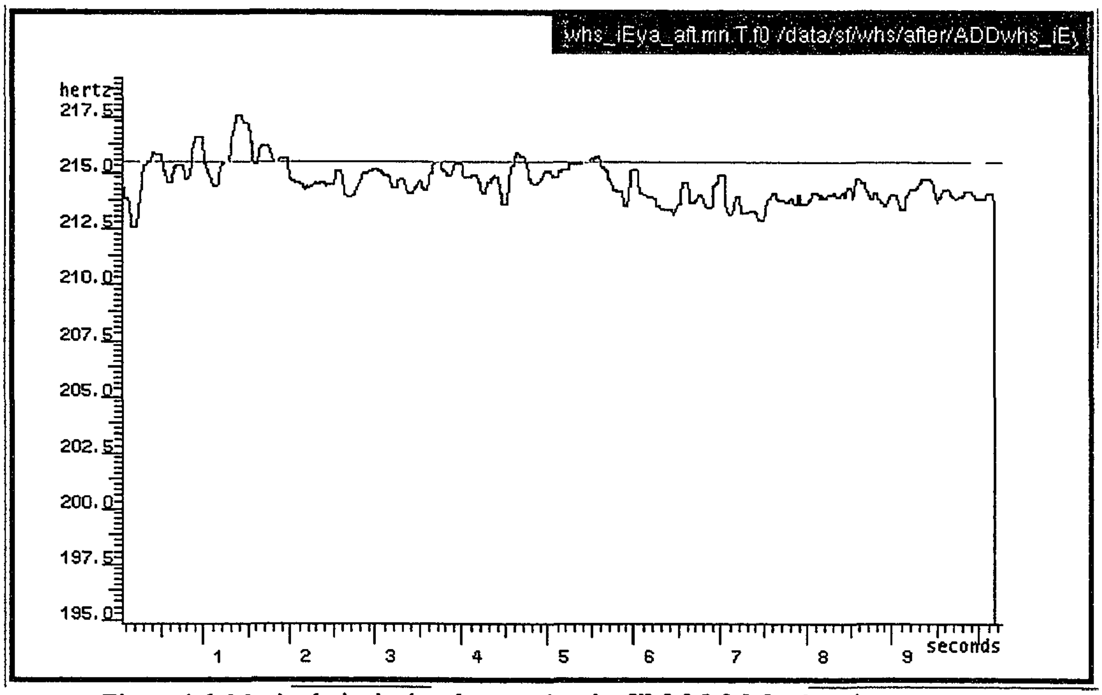

Figure 4.6. Men's choir singing the vowel series [i]-[ɛ]-[y]-[ɑ] ***after*** *chiaroscuro* (compare with 4.5).

Recorded Example # 16 on accompanying CD

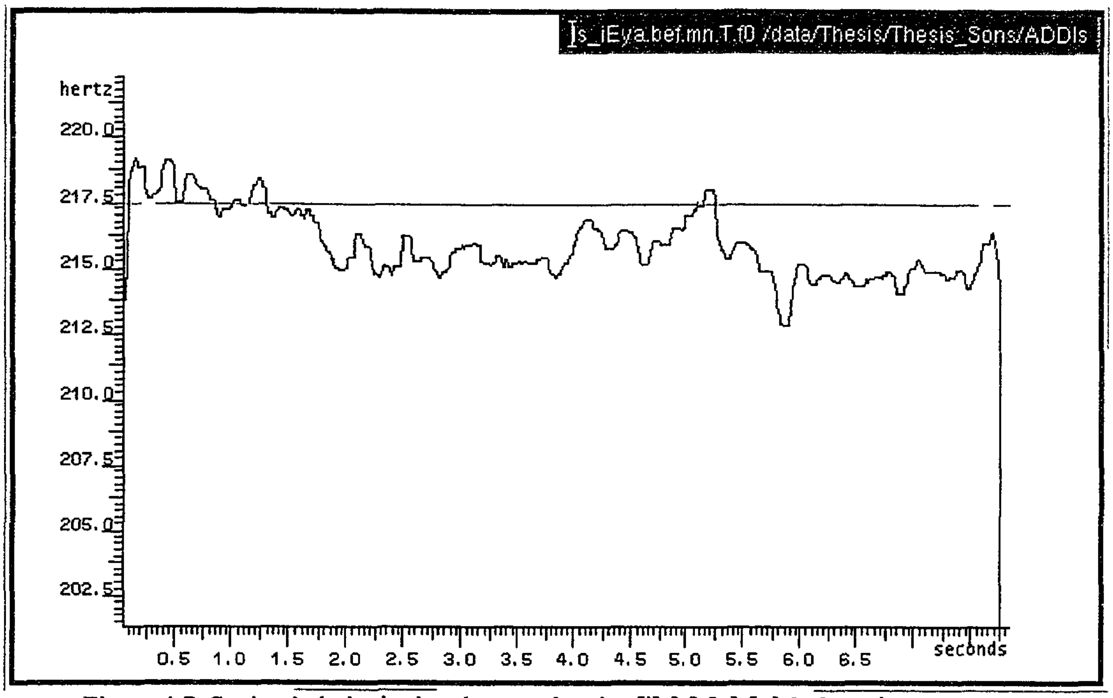

Figure 4.7. Seniors' choir singing the vowel series [i]-[ɛ]-[y]-[ɑ] ***before*** *chiaroscuro* (compare with 4.8).

Recorded Example # 17 on accompanying CD

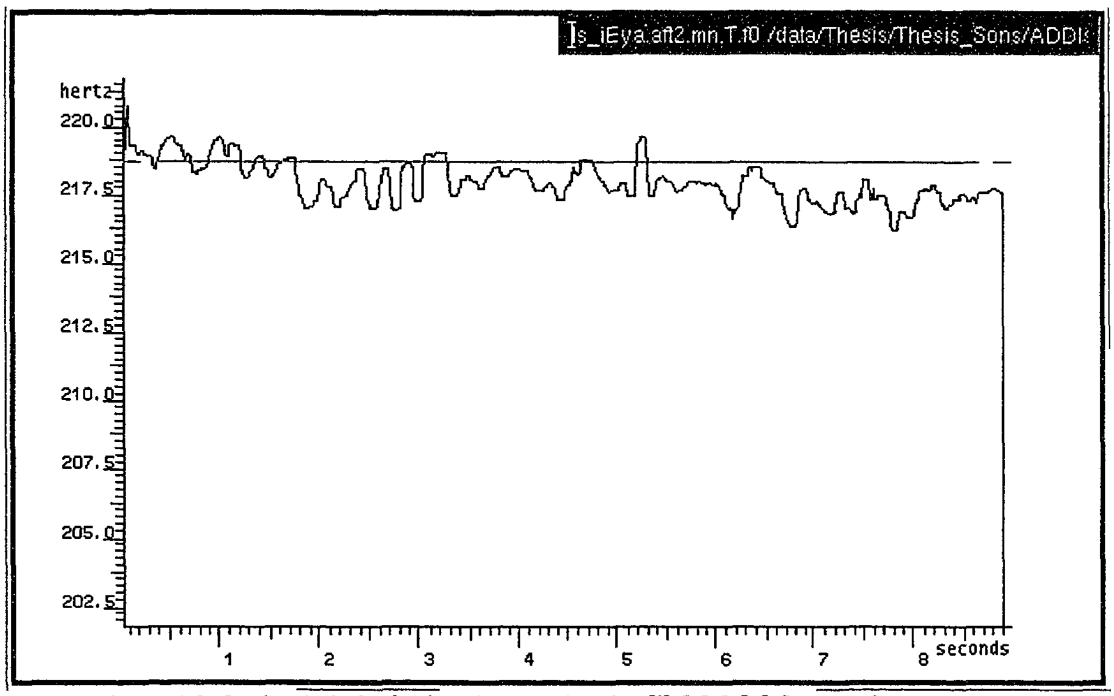

Figure 4.8. Seniors' choir singing the vowel series [i]-[ɛ]-[y]-[ɑ] ***after*** *chiaroscuro* (compare with 4.7).

Recorded Example # 18 on accompanying CD

Of special interest in the preceding set of graphs is the fact that many of the vowel changes in the *before* samples are distinctly visible. Figures 4.3, 4.5 and 4.7 particularly show very clearly defined moments when the ensembles effected transitions from one vowel to another. This is due to the fact that the articulatory movements that bring about the changes in vowel have an immediate and very noticeable effect on fundamental frequency. There also seems to be very little, if any, recovery of lost pitch once it is lost at the moment of vowel transition.

When studying what effect vowel transitions had on pitch, Ternström identified two different acoustical paradigms. The first he labelled ***F_0 transient,*** a term he coined to describe instances where the pitch rose or fell fairly sharply at the moment of transition to a new vowel, but then recovered to the original pitch, or fairly close to it. The second label, ***bimodality***, described a similar situation, but one in which the pitch did not recover, causing the entire second vowel to be sung at a slightly different frequency.[53] Three out of four of the *before* graphs above are distinctly bimodal in nature. The youth choir in particular (Figure 4.3) exhibits the opposite of F_0 transient recovery behaviour in that the pitch drops with the arrival of the new vowel, but then continues to drop as the vowel is sustained.

In the *after* samples, the majority of these changes have been quite successfully diminished after singers have experimented with allowing their articulators to make only the efficient movements that are necessary for vowel changes while simultaneously concentrating on homogeneity of vocal timbre and harmonic stability. Although there are still slight drops and rises in pitch after having worked on *chiaroscuro* resonance balancing, it is quite evident that ensembles are more successful in remaining faithful to the fundamental frequency as can be attested to by the proximity of their pitch contour to the red line. Although possibly still falling under the category of bimodality, the gradual and smaller slides in pitch noticeable in these after graphs (Figures 4.4, 4.6 and 4.8) will be more easily forgiven, and perhaps even go unnoticed, by the ear than the more jagged and pronounced drops during the *before* segments.

[53] Ternström et al, "Articulatory F_0 Perturbations," 189.

As a complement to the preceding graphs, fundamental frequency was analyzed more precisely from a numerical point of view. The table below illustrates the average pitch in Hertz (cycles per second) of the fundamental frequency for each of the vowels listed. To simplify reading, the first line of each *before* and *after* vowel in the series is displayed in bold.

Table 4.1 Frequencies sung by ensembles for [i- ε -y-ɑ] exercise

***Chiaroscuro* Resonance Balancing** – Frequencies sung by ensembles for: **[i]-[ε]-[y]-[ɑ] exercise** Type of Ensemble						
		Children's Choir	Youth Choir	University Mixed Choir	Men's Choir	Seniors' Choir
Fundamental Frequency Comparison before/after *Chiaroscuro* work	**1. Bef.F0 – [i]**	**440.30 Hz**	**219.00 Hz**	**n/a**	**212.10 Hz**	**217.69 Hz**
	2. Bef.F0 – [ε]	438.95 Hz	217.04 Hz	n/a	209.66 Hz	215.37 Hz
	3. Bef.F0 – [y]	440.28 Hz	217.34 Hz	n/a	211.52 Hz	216.32 Hz
	4. Bef.F0 – [ɑ]	438.79 Hz	215.65 Hz	n/a	208.48 Hz	214.66 Hz
	5. Aft. F0 – [i]	**442.45 Hz**	**219.78 Hz**	**n/a**	**215.43 Hz**	**218.79 Hz**
	6. Aft. F0 – [ε]	441.54 Hz	218.71 Hz	n/a	214.68 Hz	217.96 Hz
	7. Aft. F0 – [y]	443.35 Hz	218.54 Hz	n/a	214.44 Hz	217.97 Hz
	8. Aft. F0 – [ɑ]	442.96 Hz	218.70 Hz	n/a	213.99 Hz	217.26 Hz

Table 4.2. Comparison of loss/gain in pitch for [i- ε -y-α] exercise

Comparison of loss/gain in Fundamental Frequency for: **[i]-[ε]-[y]-[α] exercise** Type of Ensemble						
		Children's Choir	Youth Choir	University Mixed Choir	Men's Choir	Seniors' Choir
Loss/gain in Fundamental Frequency for [i]-[ε]-[y]-[α] Refer to table 4.1.	**1. Bef. change from [i] to [ε] (1 minus 2 above)**	**-1.35 Hz**	**-1.96 Hz**	**n/a**	**-2.44 Hz**	**-2.32 Hz**
	2. Bef. change from [y] to [α] (3 minus 4)	-1.49 Hz	-1.69 Hz	n/a	-3.04 Hz	-1.66 Hz
	3. Bef. change from [i] to [α] (1 minus 4)	-1.51 Hz	-3.35 Hz	n/a	-3.62 Hz	-3.03 Hz
	4. Aft. change from [i] to [ε] (5 minus 6)	**-0.91 Hz**	**-1.07 Hz**	**n/a**	**-0.75 Hz**	**-0.83 Hz**
	5. Aft. change from [y] to [α] (7 minus 8)	-0.39 Hz	+0.16 Hz	n/a	-0.45 Hz	-0.71 Hz
	6. Aft. change from [i] to [α] (5 minus 8)	+ 0.51 Hz	-1.08 Hz	n/a	-1.44 Hz	-1.53 Hz
	7. Improvement (+) or deterioration (-) over amount of total pitch deviation from [i] to [ε] -Percentage of improvement	+ 0.44 Hz 1.35 Hz 33%	+0.89 Hz 1.96 Hz 45%	n/a	+1.69 Hz 2.44 Hz 69%	+1.49 Hz 2.32 Hz 64%
	8. Improvement (+) or deterioration (-) over amount of total pitch deviation from [y] to [α] -Percentage of improvement	+1.1 Hz 1.49 Hz 74%	+1.53 Hz 1.69 Hz 91%	n/a	+2.59 Hz 3.04 Hz 85%	+0.95 Hz 1.66 Hz 57%
	9. Improvement (+) or deterioration (-) over amount of total pitch deviation from [i] to [α] -Percentage of improvement	+1.0 Hz 1.51 Hz 66%	+2.27 Hz 3.35 Hz 68%	n/a	+2.18 Hz 3.62 Hz 60%	+1.5 Hz 3.03 Hz 50%

Deviation in pitch from the fundamental frequency in either direction was interpreted as having an equally negative effect on intonation. It was slightly more likely for ensembles to sing sharp in *after* segments than *before*, however both types of deviation were interpreted as unnecessary acoustic digressions.

The mean improvement in intonation fluctuations across all vowel transitions in this exercise for all choirs was 63.5%. The lowest level of improvement (53%), was experienced in the transition from [i] to [ɛ]. This is completely in keeping with Ternström's findings that this combination was the worst for losing pitch between any two vowels. However, the 53% improvement due to application of the *chiaroscuro* principle will be of immense benefit in masking the inherent acoustic flaw in this vowel transition. The highest level of improvement occurred between the [y] and [ɑ] vowels which enjoyed a 77% recovery when choristers attempted to maintain the brightness and concentration of the [y] when moving to the [ɑ].

2. *Christus factus est pro nobis*

We now move on to a slightly more complex phrase in which the vowel sounds are linked by consonants, the Latin *Christus factus est pro nobis.* Once again, the phrase was chosen because it featured juxtapositions of typically *chiaro* and *oscuro* vowels. Each vowel of *Christus* lasts approximately 1.5 seconds on the *x* axis while those of *factus est pro* last approximately one second. The last two vowels (*nobis*) return to 1.5 second durations (see exercise 5 in Annexe B). The outline of the phrase can be seen more clearly with certain graphs than others, e.g. Figure 4.11.

* See next page for analyses.

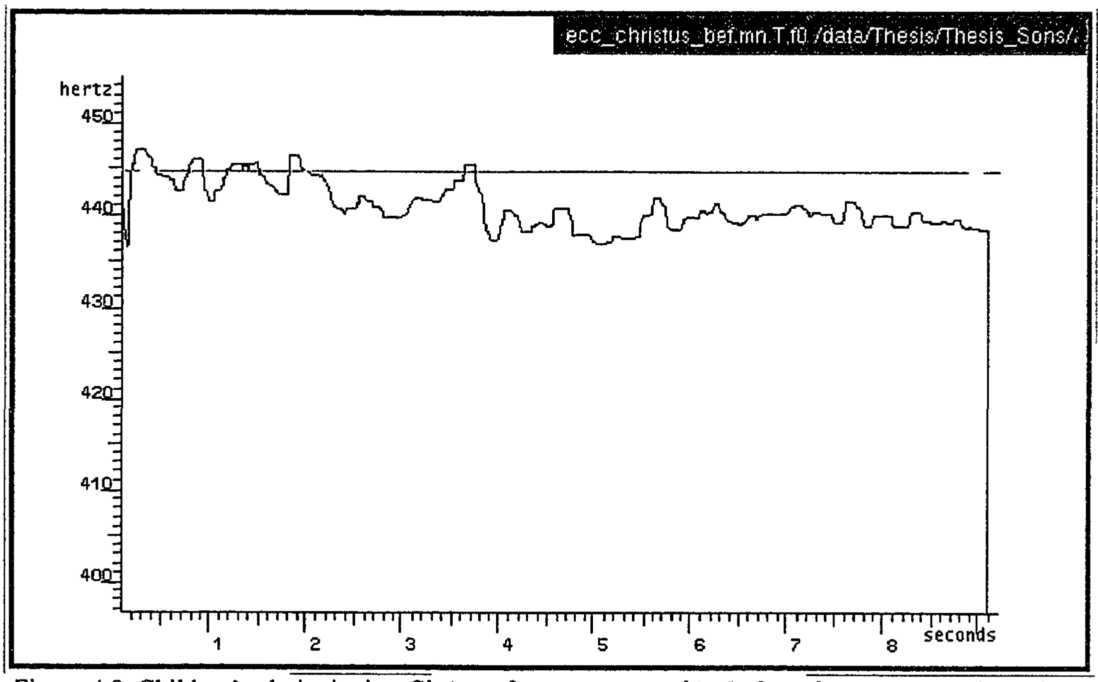

Figure 4.9. Children's choir singing *Christus factus est pro nobis*, ***before*** *chiaroscuro* work, each vowel at approximately 1 second intervals along the x axis (compare with Figure 4.10).

Recorded Example # 19 on accompanying CD

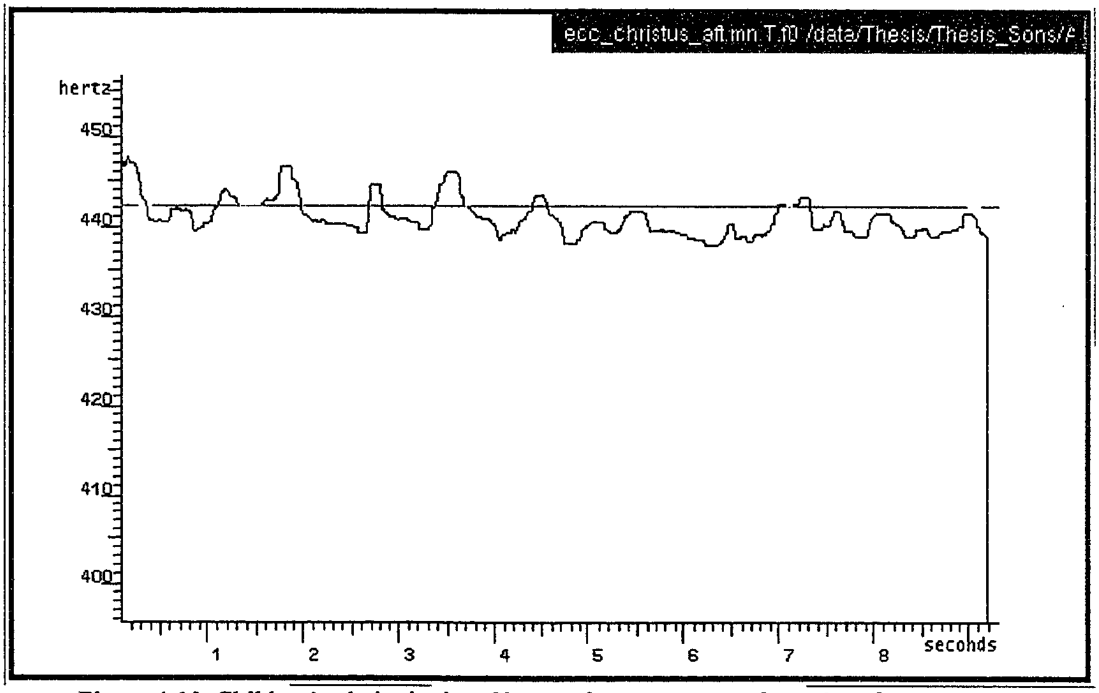

Figure 4.10. Children's choir singing *Christus factus est pro nobis*, ***after*** *chiaroscuro* work(compare with Figure 4.9).

Recorded Example # 20 on accompanying CD

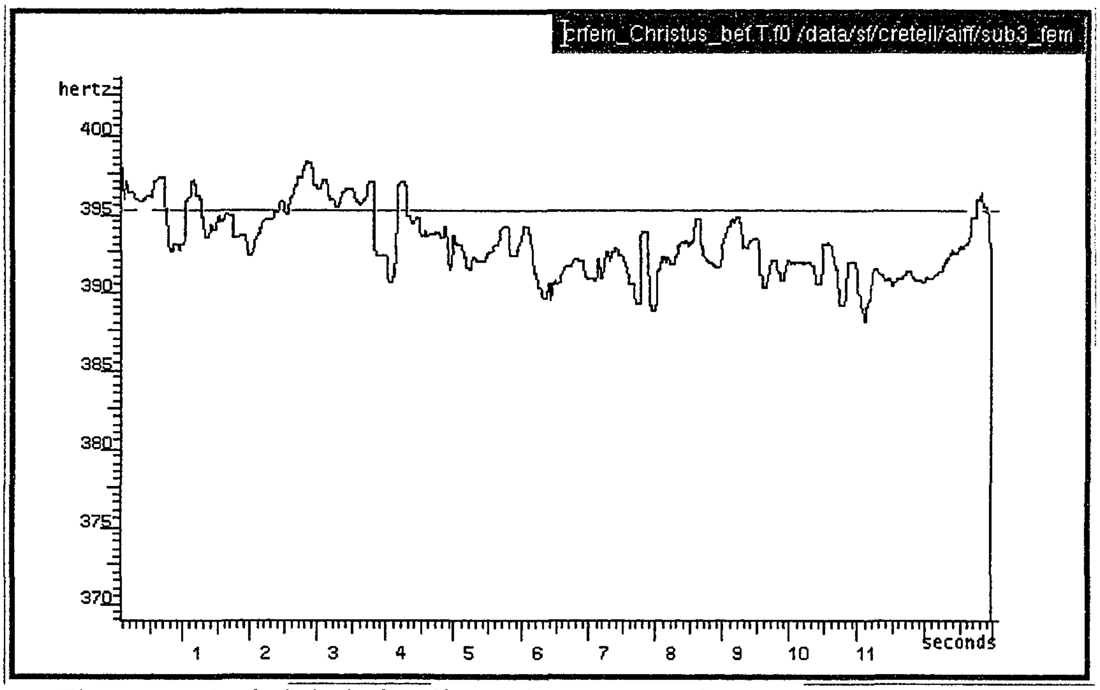

Figure 4.11. Youth choir singing *Christus factus est pro nobis*, ***before*** *chiaroscuro* work (compare with Figure 4.12).

Recorded Example # 21 on accompanying CD

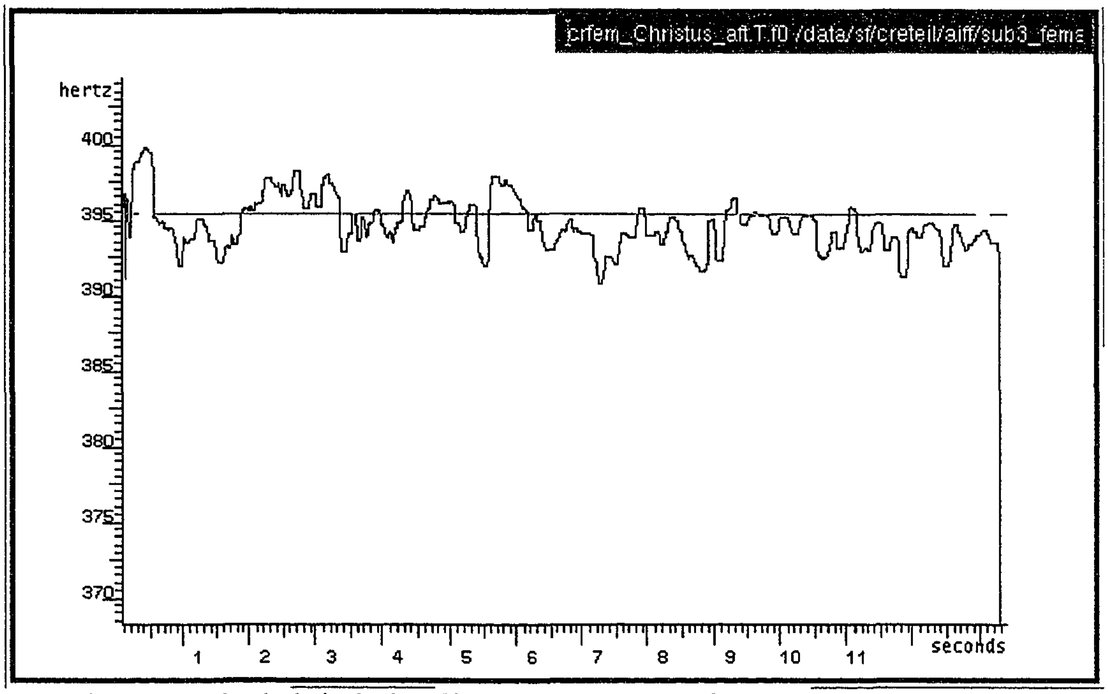

Figure 4.12. Youth choir singing *Christus factus est pro nobis*, ***after*** *chiaroscuro* work (compare with Figure 4.11).

Recorded Example # 22 on accompanying CD

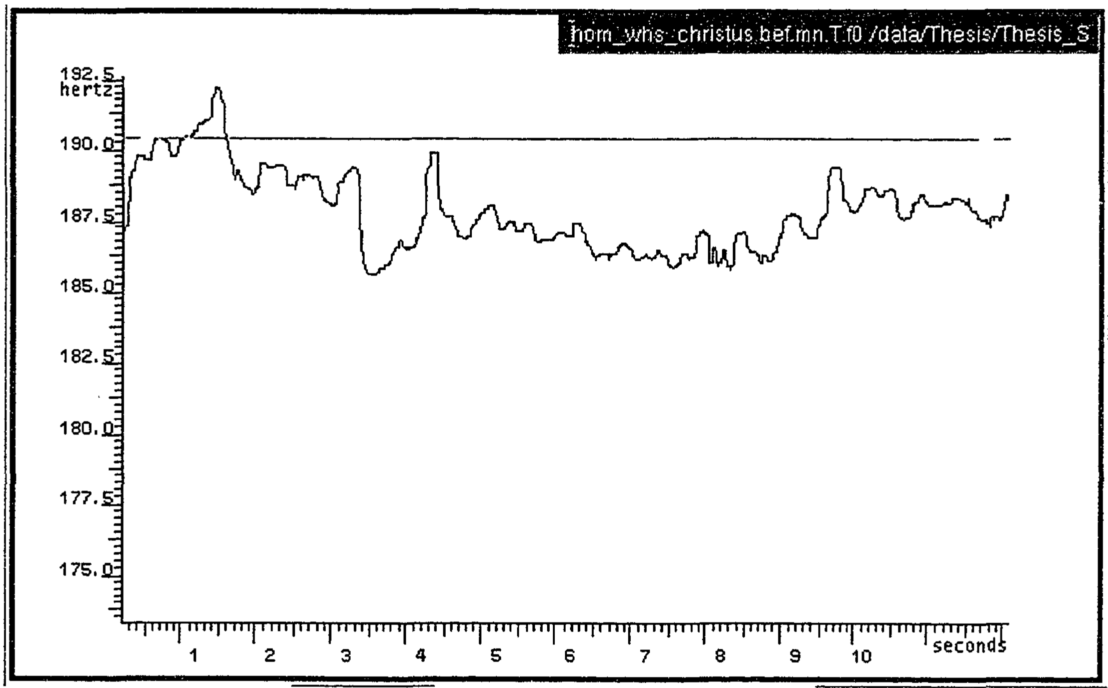

Figure 4.13. Men's choir singing *Christus factus est pro nobis*, ***before*** *chiaroscuro* work (compare with Figure 4.14).

Recorded Example # 23 on accompanying CD

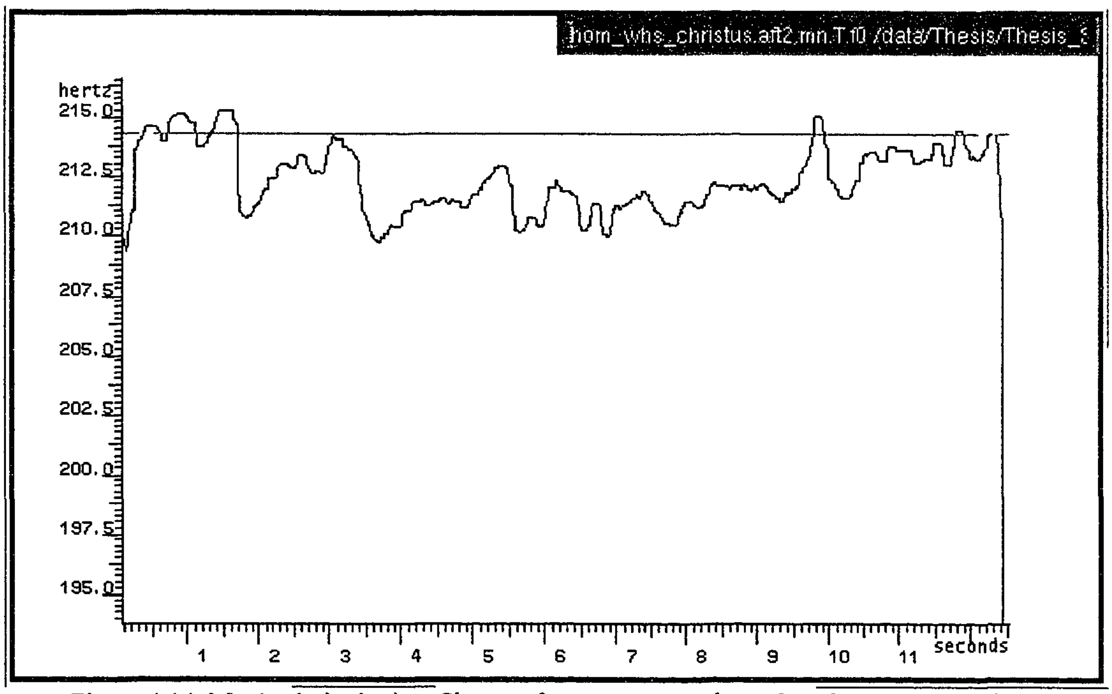

Figure 4.14. Men's choir singing *Christus factus est pro nobis*, ***after*** *chiaroscuro* work (compare with Figure 4.13).

Recorded Example # 24 on accompanying CD

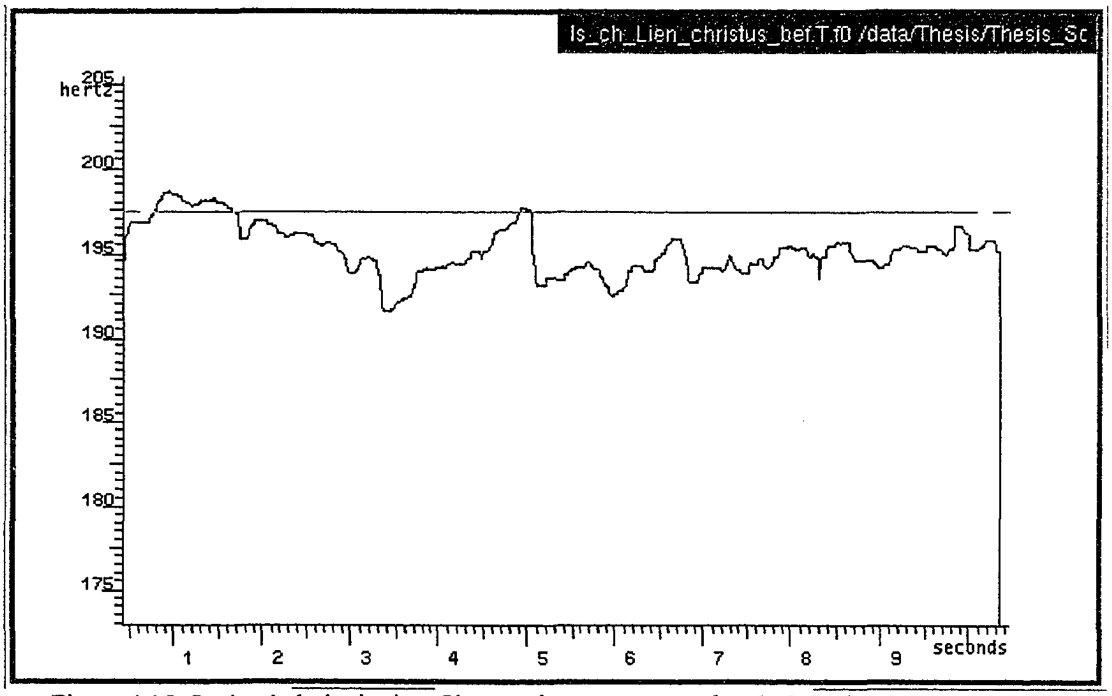

Figure 4.15. Seniors' choir singing *Christus factus est pro nobis*, ***before*** *chiaroscuro* work (compare with Figure 4.16).

Recorded Example # 25 on accompanying CD

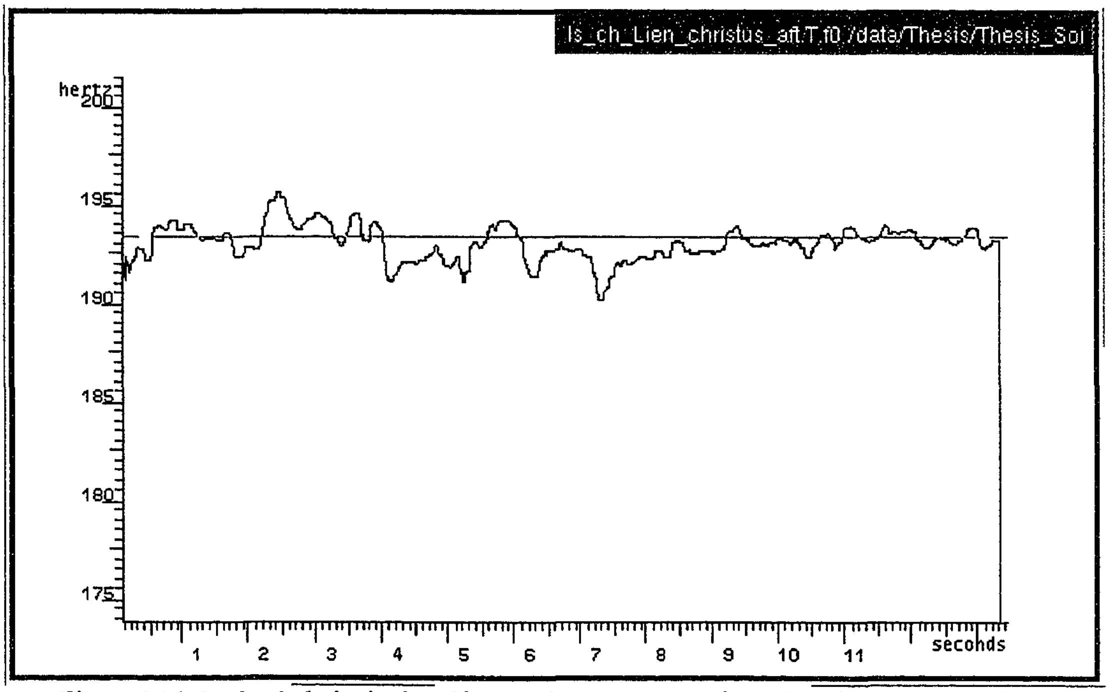

Figure 4.16. Seniors' choir singing *Christus factus est pro nobis*, ***after*** *chiaroscuro* work (compare with Figure 4.15).

Recorded Example # 26 on accompanying CD

It is once again quite evident that the fluctuations in fundamental frequency are improved in the *after* portions of this exercise. While the *after* segments exhibit more stability in intonation than the *before* samples, they also retain more of the perturbation effects than the *after* portions of the previous exercise [i-ε-y-α] and vowel transitions are somewhat more visible. It is reasonable to hypothesize that the inclusion of consonants in this exercise, with their added articulatory movements, is at least partially responsible for this difference. The fact that all but the last two consonants are unvoiced adds to the articulatory perturbation effect as the articulators must move ***while*** the vibration and resonance of the voice (its inherent energy) must stop. Although this may not necessarily have a long-term pejorative effect on pitch, it does momentarily affect frequency as can be seen in the early portions of the above graphs.

Table 4.3. Frequencies sung by ensembles for *Christus factus est pro nobis* exercise

Chiaroscuro Resonance Balancing ***Christus factus est pro nobis* exercise** Type of Ensemble						
		Children's Choir	Youth Choir	University Mixed Choir	Men's Choir	Seniors' Choir
Fundamental Frequency Comparison before/after *Chiaroscuro* work	**1. Bef.F0 – [i]**	**444.78 Hz**	**395.18 Hz**	**n/a**	**190.39 Hz**	**197.62 Hz**
	2. Bef.F0 – [u]	444.37 Hz	395.98 Hz	n/a	188.87 Hz	195.62 Hz
	3. Bef.F0 – [α]	440.59 Hz	394.00 Hz	n/a	186.32 Hz	193.82 Hz
	4. Bef.F0 – [u]	442.84 Hz	392.82 Hz	n/a	187.90 Hz	196.66 Hz
	5. Bef. F0 – [ε]	439.41 Hz	391.27 Hz	n/a	187.12 Hz	193.74 Hz
	6. Bef. F0 – [o]	439.01 Hz	392.26 Hz	n/a	186.48 Hz	194.51 Hz
	7. Bef. F0 – [i]	439.95 Hz	391.17 Hz	n/a	188.12 Hz	195.20 Hz
	8. Aft. F0 – [i]	**441.82 Hz**	**395.40 Hz**	**n/a**	**214.35 Hz**	**193.38 Hz**
	9. Aft. F0 – [u]	443.04 Hz	395.77 Hz	n/a	212.93 Hz	194.02 Hz
	10. Aft. F0- [α]	441.04 Hz	395.48 Hz	n/a	211.05 Hz	192.13 Hz
	11. Aft. F0- [u]	442.35 Hz	396.24 Hz	n/a	212.20 Hz	193.49 Hz
	12. Aft. F0- [ε]	440.44 Hz	393.33 Hz	n/a	211.20 Hz	192.56 Hz

	13. Aft. F0-[o]	439.30 Hz	394.27 Hz	n/a	211.54 Hz	192.77 Hz
	14. Aft. F0 [i]	440.42 Hz	393.70 Hz	n/a	213.30 Hz	193.35 Hz

As is evidenced in the table and graphs above, it seems that vowels requiring a larger buccal opening [α, ε, o] exercise a detrimental effect on precision of intonation. As with the tongue perturbation effect mentioned earlier, it is also possible that the lowering of the jaw for the larger vowels exercises a negative influence on the vibrating vocal folds thereby creating fluctuations in fundamental frequency.

One error in procedure must here be pointed out. The men's choir sang this exercise one full tone higher in the *after* portion of the experiment as can be seen in table 4.3 above as well as heard in sound examples 23 and 24. All of the *after* samples were sung at this pitch by mistake. It is included here nonetheless as the effect on intonation is still noticeable and pertinent.

The following table compares the consistent downward (flatting) trend observed in experiments with choirs when moving from the [i] vowel toward the [α], [ε] and [o] vowels that follow it in the phrase *Christus factus est pro nobis.* Changes in intonation are first shown with a simple frequency comparison between the initial [i] and each ensuing 'larger' vowel. This comparison is first made with the vowels in the *before* portion (nos. 1-4), followed immediately by those for the *after* portion of the experiment (nos. 5-8). The final section of the table expresses the change as a fraction (the amount of movement in the proper direction over the amount that needed to be regained for perfect intonation to have been maintained), before finally converting this fraction to a percentage. A 100% improvement would signify the maintenance of perfect intonation between vowel transitions.

Table 4.4. Comparison of loss/gain in pitch for *Christus factus est pro nobis exercise*

Comparison of loss/gain in Fundamental Frequency for: [***Christus factus est pro nobis***] **exercise** Type of Ensemble						
		Children's Choir	Youth Choir	University Mixed Choir	Men's Choir	Seniors' Choir
Loss/gain in Fundamental Frequency for *Christus factus* Refer to table 4.3	**1. Bef. Change from [i] to [ɑ] (1 minus 3 above)**	**-4.19 Hz**	**-1.18 Hz**	**n/a**	**-4.07 Hz**	**-3.8 Hz**
	2. Bef. change from [i] to [ɛ] (1 minus5)	-5.37 Hz	-3.91 Hz	n/a	-3.27 Hz	-3.88 Hz
	3. Bef. change from [i] to [o] (1 minus 6)	-5.77 Hz	-2.74 Hz	n/a	-3.91 Hz	-3.11 Hz
	4. Bef. change from beg. to end [i-i] (1 minus 7)	-4.83 Hz	-4.01 Hz	n/a	-2.27 Hz	-2.42 Hz
	5. Aft. Change from [i] to [ɑ] (8 minus 10)	**-0.78 Hz**	**-0.08 Hz**	**n/a**	**-3.3 Hz**	**-1.25 Hz**
	6. Aft. change from [i] to [ɛ] (8 minus 12)	-1.38 Hz	-2.07 Hz	n/a	-3.15 Hz	-0.82 Hz
	7. Aft. change from [i] to [o] (8 minus 13)	-2.52 Hz	-1.13 Hz	n/a	-2.81 Hz	-0.61 Hz
	8. Aft. change from beg. to end [i-i] (8 minus 14)	-1.4 Hz	-1.7 Hz	n/a	-1.05 Hz	-0.03 Hz
	9. Improvement (+) or deterioration (-) over amount of possible improvement from [i] to [ɑ] -Percentage of improvement	+ 3.41 Hz 4.19 Hz 81%	+1.1 Hz 1.18 Hz 93%	n/a	+0.77 Hz 4.07 Hz 19%	+2.55 Hz 3.8 Hz 67%
	10. Improvement (+) or deterioration (-) over amount of possible improvement from [i] to [ɛ] -Percentage of improvement	+3.99 Hz 5.37 Hz 74%	+1.84 Hz 3.91 Hz 47%	n/a	+0.12 Hz 3.27 Hz 1%	+3.06 Hz 3.88 Hz 79%
	11. Improvement (+) or deterioration (-) over amount of possible improvement from [i] to [o]	+3.25 Hz 5.77 Hz 56%	+1.61 Hz 2.74 Hz 59%	n/a	+1.1 Hz 3.91 Hz 28%	+2.5 Hz 3.11 Hz 80%

	-Percentage of improvement					
	12. Improvement (+) or deterioration (-) over amount of possible improvement from beg. to end [i-i] -Percentage of improvement	+3.43 Hz 4.83 Hz 71%	+2.31 Hz 4.01 Hz 58%	n/a	+1.22 Hz 2.27 Hz 54%	+2.39 Hz 2.42 Hz 99%

In keeping with the previous exercise [i-ɛ-y-ɑ], the [ɛ] vowel seems to have been the most difficult to keep in tune in both *before* and *after* portions of experiments. Although there is a 50% improvement in intonation between the [i] and [ɛ] after *chiaroscuro* resonance balancing has been learned and applied, this compares to 56% for [o], 65% for [ɑ] and a 71% recovery when returning to the final [i]. Because this second [i] vowel is the final vowel in the phrase being sung and that pitch had been generally dropping throughout the phrase, one would expect that the final phoneme would be the lowest in the phrase. However, in three out of four ensembles, this final [i] tends to recover a significant portion of the frequency loss encountered throughout this phrase in both *before* and *after* segments. The choir that does not enjoy this recovery is the same in both portions and might therefore habitually sing [i] flat. This observation seems to add validity to the theory of the intrinsic pitch of vowels which points to [i] as having the highest 'intrinsic pitch' of any vowel due to its harmonic make-up.

3. ***Kyrie eleison***

Kyrie eleison was the last phrase to be tested. Ternström found that this was one of the worst phrases he had studied for articulatory perturbations affecting pitch (see note 52). Because of its frequent occurrence in choral literature, as well as its two juxtapositions of [i] and [ɛ], it seemed natural to use this text in testing the *chiaroscuro* intonation-improvement theory. Each vowel lasts approximately 1.25 seconds along the *x* axis.

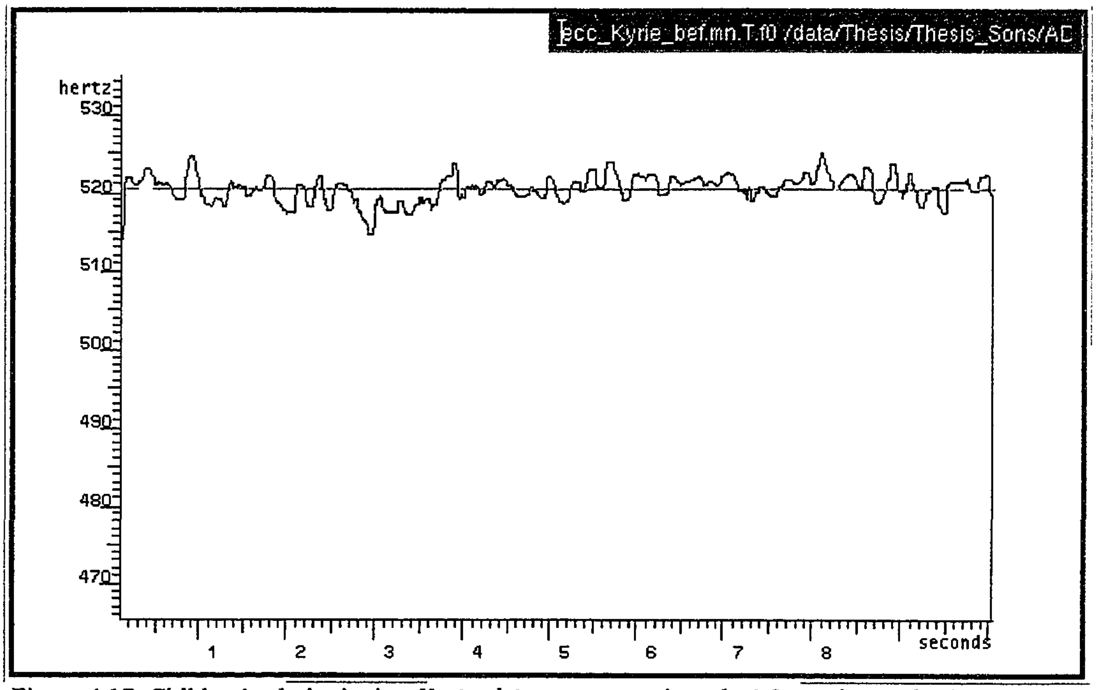

Figure 4.17. Children's choir singing *Kyrie eleison* at approximately 1.2 sec. intervals along the x axis ***before*** *chiaroscuro* (compare with Figure 4.18)

Recorded Example # 27 on accompanying CD

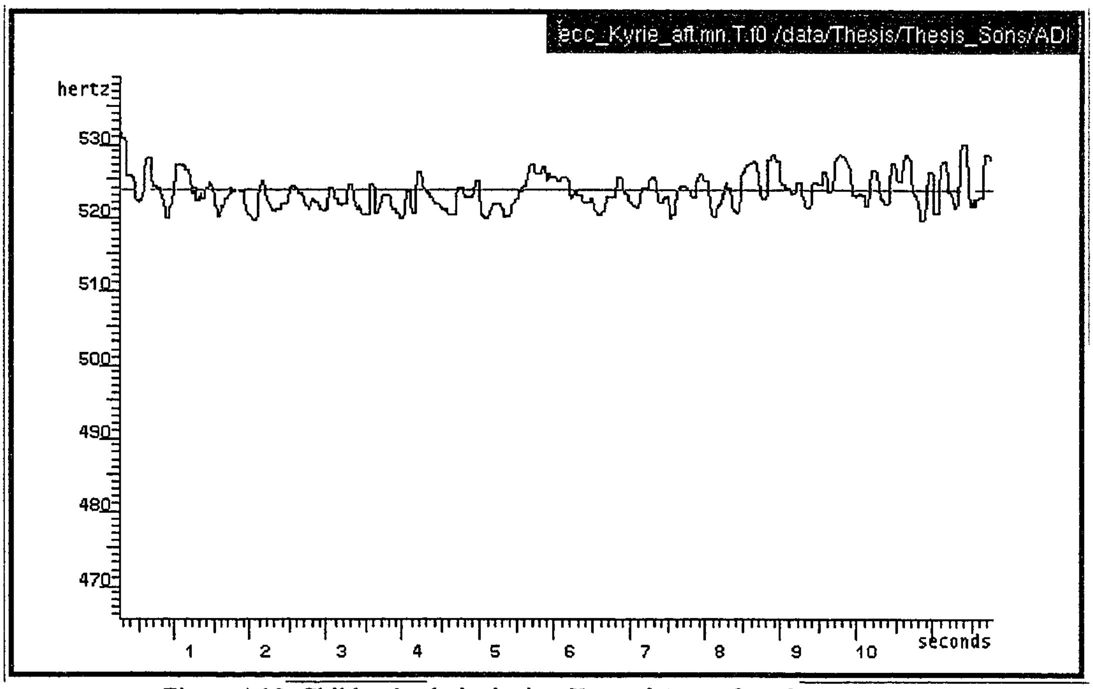

Figure 4.18. Children's choir singing *Kyrie eleison* ***after*** *chiaroscuro* (compare with Figure 4.17)

Recorded Example # 28 on accompanying CD

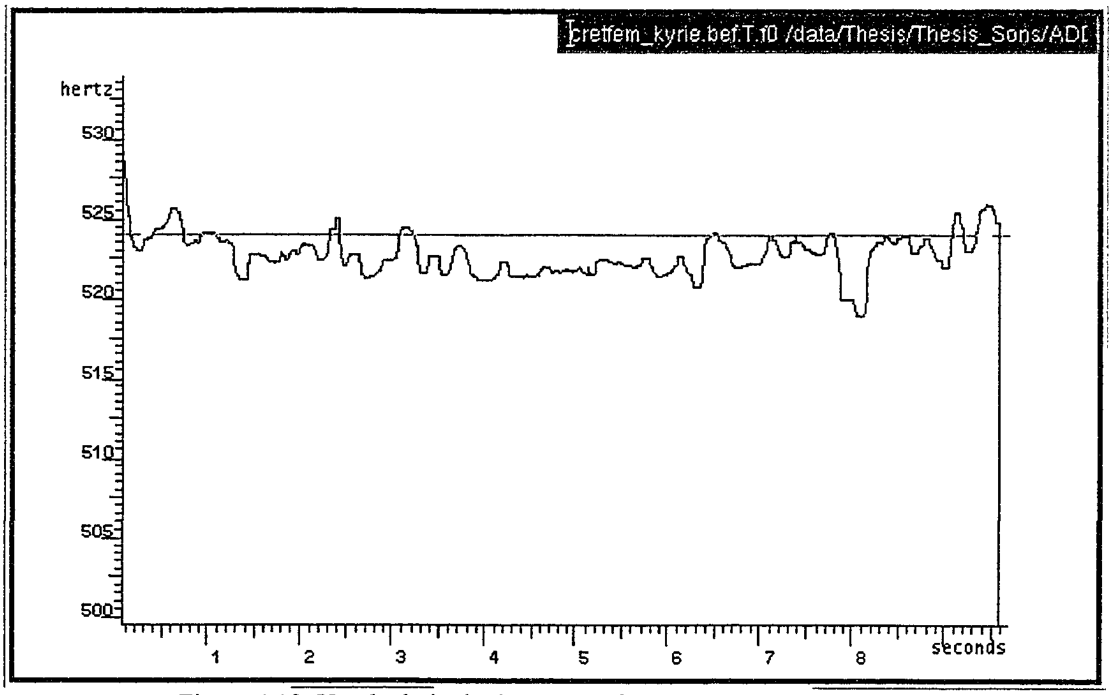

Figure 4.19. Youth choir singing *Kyrie eleison* ***before*** *chiaroscuro*
(compare with Figure 4.20)

Recorded Example # 29 on accompanying CD

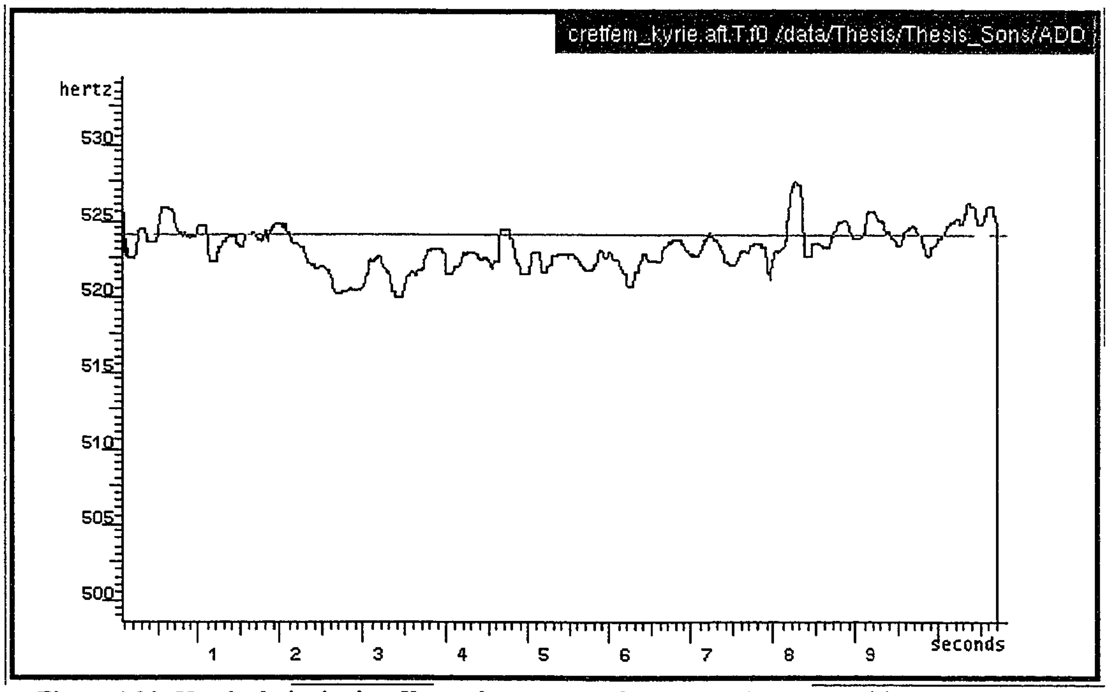

Figure 4.20. Youth choir singing *Kyrie eleison* ***after*** *chiaroscuro* (compare with Figure 4.19)

Recorded Example # 30 on accompanying CD

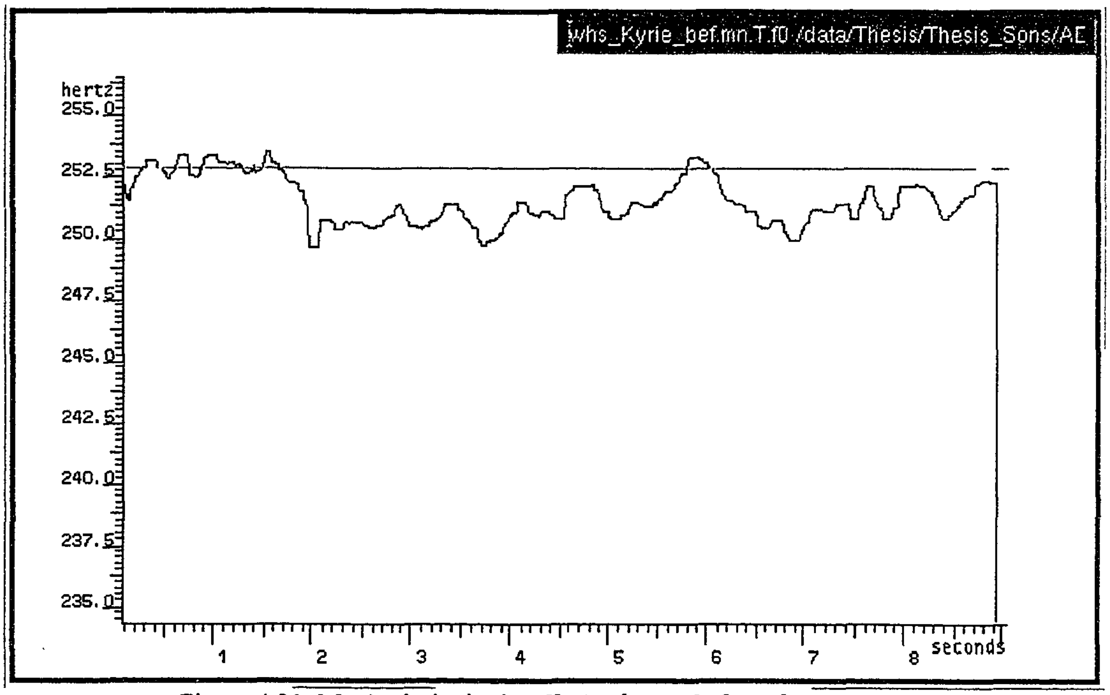

Figure 4.21. Men's choir singing *Kyrie eleison* ***before chiaroscuro***
(compare with Figure 4.22)

Recorded Example # 31 on accompanying CD

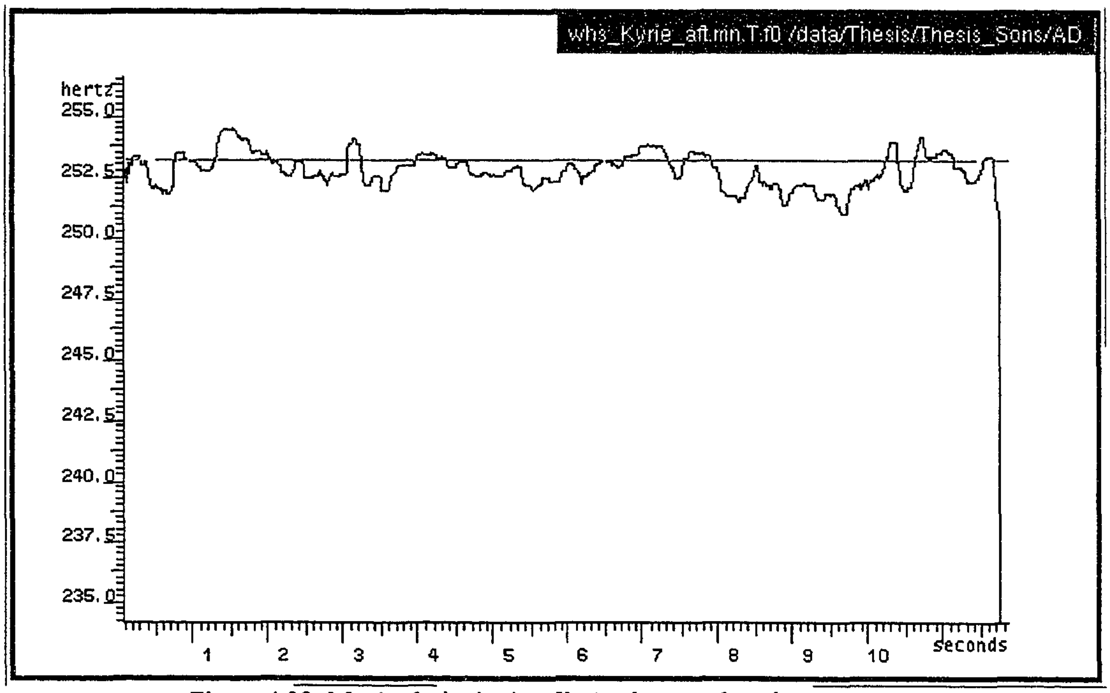

Figure 4.22. Men's choir singing *Kyrie eleison* ***after chiaroscuro***
(compare with Figure 4.21)

Recorded Example # 32 on accompanying CD

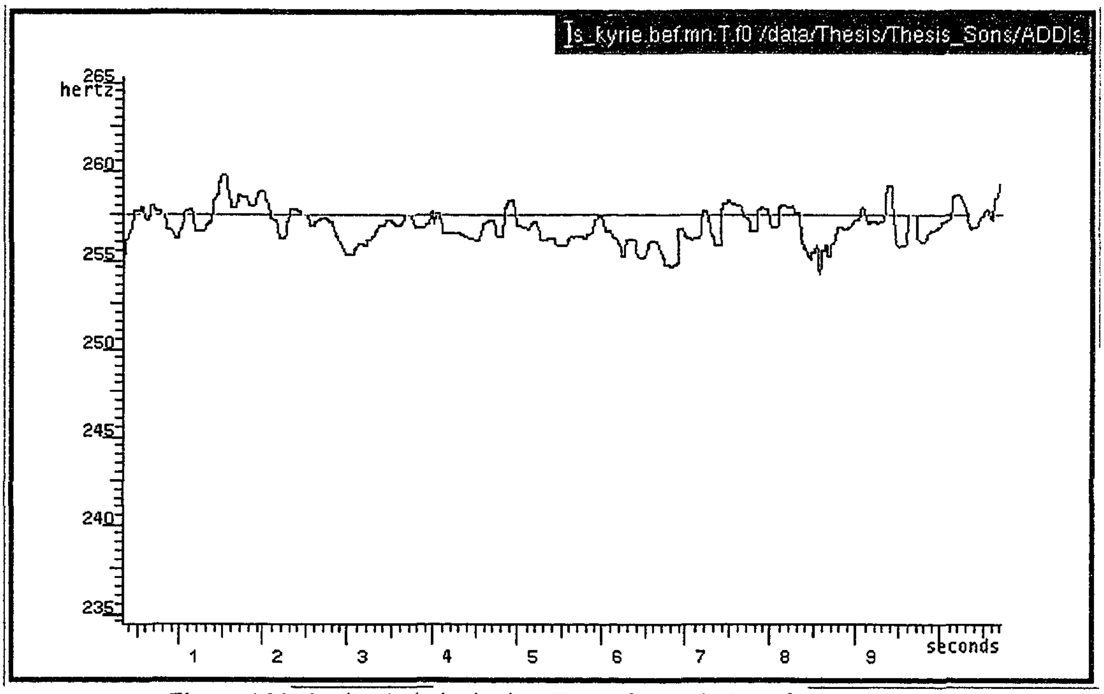

Figure 4.23. Seniors' choir singing *Kyrie eleison* ***before chiaroscuro***
(compare with Figure 4.24)

Recorded Example # 33 on accompanying CD

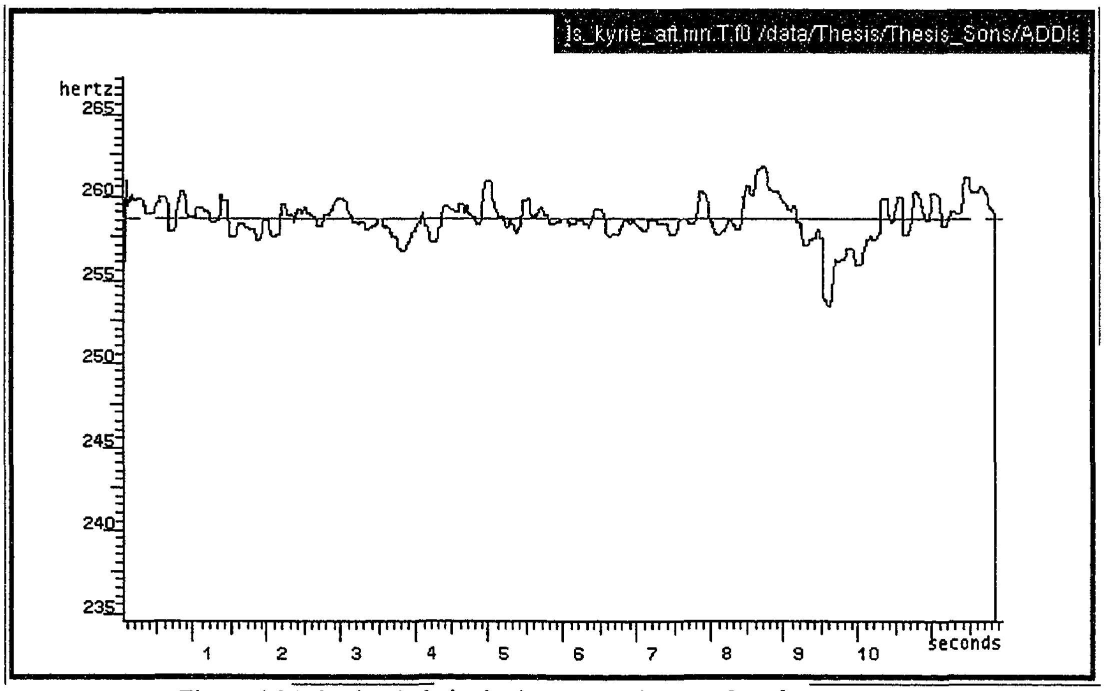

Figure 4.24. Seniors' choir singing *Kyrie eleison* ***after chiaroscuro***
(compare with Figure 4.23)

Recorded Example # 34 on accompanying CD

Table 4.5. Frequencies sung by ensembles for *Kyrie eleison* exercise

Chiaroscuro Resonance Balancing – Frequencies Sung by Ensembles for: ***Kyrie eleison* exercise** Type of Ensemble						
		Children's Choir	Youth Choir	University Mixed Choir	Men's Choir	Seniors' Choir
Fundamental Frequency Comparison before/after *Chiaroscuro* work	**1. Bef.F0 – [i]**	**520.56 Hz**	**524.01 Hz**	**n/a**	**252.83 Hz**	**257.58 Hz**
	2. Bef.F0 – [ε]	519.50 Hz	522.05 Hz	n/a	250.82 Hz	256.54 Hz
	3. Bef.F0 – [i]	521.44 Hz	523.01 Hz	n/a	251.74 Hz	257.14 Hz
	4. Bef.F0 – [o]	520.94 Hz	523.32 Hz	n/a	251.28 Hz	256.93 Hz
	5. Aft. F0 – [i]	**523.04 Hz**	**524.14 Hz**	**n/a**	**253.21 Hz**	**258.76 Hz**
	6. Aft. F0 – [ε]	522.67 Hz	522.07 Hz	n/a	252.76 Hz	258.59 Hz
	7. Aft. F0 – [i]	523.66 Hz	523.25 Hz	n/a	253.01 Hz	259.20 Hz
	8. Aft. F0 – [o]	524.39 Hz	524.34 Hz	n/a	252.45 Hz	258.99 Hz

Table 4.6. Comparison of loss/gain in pitch for *Kyrie eleison* exercise

Comparison of loss/gain in Fundamental Frequency for: ***Kyrie eleison* exercise** Type of Ensemble						
		Children's Choir	Youth Choir	University Mixed Choir	Men's Choir	Seniors' Choir
Loss/gain in Fundamental Frequency for *Kyrie eleison* exercise	**1. Bef. Change from [i] to [ε] (1 minus 2 above)**	**-1.06 Hz**	**-1.96 Hz**	**n/a**	**-2.01 Hz**	**-1.04 Hz**
	2. Bef. Change from [i] to [i] (1 minus 3)	+0.88 Hz	-1.0 Hz	n/a	-1.09 Hz	-0.44 Hz
	3. Bef. Change from [i] to [o] (1 minus 4)	+0.38 Hz	-0.69 Hz	n/a	-1.55 Hz	-0.65 Hz
	4. Aft. Change from [i] to [ε] (5 minus 6)	**-0.37 Hz**	**-2.07 Hz**	**n/a**	**-0.45 Hz**	**-0.17 Hz**

	5. Aft. change from [i] to [i] (5 minus 7)	+0.62 Hz	-0.89 Hz	n/a	-0.2 Hz	+0.44 Hz
	6. Aft. change from [i] to [o] (5 minus 8)	+1.35 Hz	+0.20 Hz	n/a	-0.76 Hz	+0.23 Hz
	7. Improvement (+) or deterioration (-) over amount of total pitch deviation from [i] to [ɛ] -Percentage of improvement	+ 0.69 Hz 1.06 Hz 65%	-0.11 Hz 1.96 Hz -1%	n/a	+1.56 Hz 2.01 Hz 78%	+0.66 Hz 1.04 Hz 63%
	8. Improvement (+) or deterioration (-) over amount of total pitch deviation from 1st [i] to 2nd [i] -Percentage of improvement	+1.1 Hz 1.49 Hz 74%	+0.11 Hz 1.0 Hz 11%	n/a	+2.59 Hz 3.04 Hz 85%	+/-0 Hz 0.44 Hz 0%
	9. Improvement (+) or deterioration (-) over amount of total pitch deviation from [i] to [o] -Percentage of improvement	+1.0 Hz 1.51 Hz 66%	+0.49 Hz 0.69 Hz 71%	n/a	+2.18 Hz 3.62 Hz 60%	+0.42 Hz 0.65 Hz 65%

On the whole, ensembles tended to lose less pitch in making vowel transitions during the *before* portions of experiments while singing *Kyrie eleison* than in previous exercises. One likely reason for this is that many of the syllables were connected with voiced consonants such as 'r', 'l' and 's' (z) which allowed for a better legato line between phonemes, thereby enabling a more constant flow of vibration and similar resonance throughout the exercise. Of course, there is the distinct possibility that as this was the third exercise of its kind to be sung consecutively, ensembles may have become accustomed to singing juxtaposed vowels of uneven acoustic character in *before* examples thereby having slightly less to improve upon.

Although improvements in intonation were slightly less remarkable in this exercise, there were still very noticeable audible and visual enhancements in the retention of the original fundamental frequency throughout the exercise in the *after* sound files. A mean improvement in intonation of 51% was experienced in making the transition from [i] to [ε] for the four ensembles that executed this exercise. The mid-phrase return to [i] saw a 42.5% improvement across the ensembles while the drop experienced from the initial [i] to the final [o] enjoyed an average of 66% improvement in frequency retention.

General Observations and Conclusions

The present testing of *chiaroscuro* resonance balancing shows that the pejorative influence that necessary articulatory changes exercise on vocal vibration and fundamental frequency can be effectively reduced, and in some cases, eliminated when the *bel canto* principle of *chiaroscuro* resonance is observed.

It is evident that choirs will always, to a certain extent, sing out of tune. The application of the *chiaroscuro* principle has, however, improved the intonation of the participating groups in a significant fashion. If we interpret the results from a psycho-acoustics perspective, these results may be more consequential than they at first appear:

> Investigations have revealed that the ear is extremely rigid in this respect. Phonation frequency errors exceeding 3 cents are detected by the most skilled musical ears, and musically trained listeners hear errors of 5 cents. This implies that the singer's phonation frequency average must match the ideal value within 1 Hz, if the pitch is A4 (440Hz). How is it possible to train phonation frequency control so that this is possible?[54]

If one examines the tables above, there are many instances where pitch deviations well in excess of 1 Hz in *before* samples have been brought under the important 1 Hz threshold in the *after* samples. While choristers may still be singing slightly out of tune, the improvement realized by the application of *chiaroscuro* resonance may in fact bring these slight errors into the realm of the indiscernible.

Of all the vowels sung by choirs in the *chiaroscuro* portion of choral experiments [ɑ, i, ε, o, u, y], [i] demonstrated the highest intrinsic pitch. For

[54] Sundberg, *The Science of the Singing Voice*, 177.

whatever reason, including those mentioned previously in this section, its properties seem to raise the fundamental frequency in choral singing. Miller asserts that the Italian Method derived from *bel canto* masters was designed with this truth in mind.

> Many Italian vocalizes, especially those of a more sustained nature, follow the vowel spectrum from its highest to its lowest vowel (i-e-ε-ɑ-o-u), with the high vowels initiating the series. Frequently vocalizes not only begin with the high formant vowels but return to them, as for example (i-e-ɑ-e-i).[55]

Hypothesizing that this might be the case, [i] was placed at the beginning of phrases during experiments with the rationale being to test whether *chiaroscuro* resonance balancing might enable choristers to retain the naturally higher partials associated with this vowel throughout sung phrases, thereby improving consistency of intonation. As Ternström discovered in his experiments, choristers tended to naturally sing flat as they migrated from this high vowel to darker vowels. However, after having come to a preliminary understanding of the application of *chiaroscuro* resonance balancing, it is evident that choristers who had not naturally retained the higher pitch of the [i] in the vowel series during *before* segments were more able to do so in the *after* portion of the experiment. Based on the consistency of improvements noted in the analyses above, a case could certainly be made for the implementation of *chiaroscuro* resonance in the vocal training of choral singers in an effort to improve ensemble intonation.

At the other end of the spectrum, [ε] (as in b*e*d) and [ɑ] (as in f*a*ther) seem to have had the most pejorative effect on group intonation. Again, this is in keeping with Ternström and Sundberg's findings.[56] It is commonly accepted that these vowels are the most spread of all sung sounds, naturally lacking a sense of focus and upper harmonics. Although this tendency was not completely removed, choirs in this study displayed significant improvement in maintaining accuracy of

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[55] Richard Miller, *National Schools of Singing: English, French, German, and Italian Techniques of Singing Revisited* (Oxford: Scarecrow Press, 1997), 56-57.
[56] Sten Ternström and Johann Sundberg, "The Acoustics of Choir Singing," 21.

intonation throughout phrases containing these problematic vowels after concentrated work on *chiaroscuro* resonance balancing had taken place.

Another interesting factor that has come to light is that in 9 out of 12 cases, choirs began the *after* portion of vocal exercises a few Hertz higher than when the same exercise had been executed prior to having worked on *chiaroscuro* resonance balancing. This concurs with the author's experience that beginnings of phrases are immediately more in tune when choirs have the concept of complete vowel resonance somewhat mastered and when they are encouraged to begin their phrases with this type of balanced resonance. The Italian masters even went so far as to admonish breathing in the full resonance of the vowel and vividly imagining complete *chiaroscuro* resonance prior to making a sound. "To anticipate the *feel* of resonance before singing, and to keep the sensation during pauses and after singing, is the lost art of the Golden Age of Song."[57]

An acoustic element that was not tested in dealing with *chiaroscuro* resonance was intensity. Although choristers were never asked to sing more loudly after having worked this principle, almost all sound files exhibited greater intensity in the *after* portions. However, the sound resulting from this increase in intensity does not merely manifest itself in greater volume, but rather in a fuller, more resonant tone. Subsequent studies might determine a more accurate relationship between the application of this principle and natural increases in intensity.

Attempting to teach several vocal concepts within a group situation in a very limited period of time certainly has its limitations. Although intonation undeniably improved significantly during work on balanced resonance, certain choristers had slight difficulty controlling their voices during experiments. As they learned to exploit their voices' resonance capacity more fully, excessive vibrato sometimes came into play and the sound is somewhat less refined in certain of the *after* sound examples. However, on the whole, ensembles adapted quite quickly to the more energized style of singing asked of them and were quite able to stay within the acceptable norms for choral singing. Having more time

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[57] Lamperti, *Vocal Wisdom*, 54

with each ensemble would guarantee a greater honing of these skills toward an energized yet beautifully controlled ensemble sound.

It would also be helpful for subsequent studies to examine the relationship of this principle to voice quality and its effect on vocal blend within an ensemble. As the overall goal is a homogenizing of harmonic activity throughout the vowel spectrum in all voices, it is anticipated that spectral noise elements leading to 'edgy' voices within sections would be at least partially eliminated, thereby lending a more blended (but not 'blanded') sound to ensemble singing. A panel of judges would be helpful in determining whether ensembles have a more blended and homogeneous sound after applying the principle of *chiaroscuro* resonance balancing. This same panel could also determine whether or not group diction had been improved.

Chapter V: *Messa di voce* and Dynamic Soft Singing

Introduction and Problem

Next we come to the hallmark of all *bel canto* exercises and principles: the *messa di voce*. In Italian historical vocal pedagogy, it has always been assumed that a voice which is freely produced and has mastery over the breath, will be capable of effecting a smooth crescendo from the softest to the loudest dynamic, and return gradually once again to *pianissimo* in one sustained, seamless tone and on one pitch without any loss in vocal quality (vibrancy and resonance) or any deviation in pitch. This is the *messa di voce.*

It is fitting that the *messa di voce* be reserved as the final *bel canto* principle to be examined in this study for several reasons. Aside from being one of the most important techniques in the *bel canto* artist's interpretive arsenal, this ability to skilfully swell and diminish a tone at will was the true test of a singer's overall vocal skill as it demanded mastery over many previously studied technical facets of vocal training. A student needed to possess definite skill in the areas of vibration, resonance and breath control – as outlined in chapters three and four of this study - before any earnest work on the *messa di voce* could begin.

The *messa di voce* is and was spoken of in two slightly different yet interrelated contexts: the *principle* and the *exercise*. In a more superficial manner, the exercise itself requires a controlled and gradual crescendo from a *piano* dynamic up to a full *forte*, returning again very smoothly and slowly to *piano*, all on one vowel and one note. The *principle* requires that the exercise be performed while maintaining: 1) a focused, concentrated, self-sustaining core of vibration so that increase or decrease in intensity need not require any pushing or extra vocal effort; 2) a consistent vocal quality and vowel colour as manifested through continual *chiaroscuro* resonance; 3) adequate breath control so as never to push too much breath through the cords but rather supply only the proper amount of compressed breath to feed the vibration.

The ability to perform the *messa di voce* also ensured that the singer was able to maintain maximum vocal energy while singing at soft dynamics. Choral singing has often been reproached for doing the opposite, that is, losing large amounts of spectral energy as volume of tone diminishes. Rudolph's and Weiss' observations show that spectral energy typically diminishes rather substantially with volume:

> It should be noted that the common disappearance of the F_S [singer's formant] at low volume levels in the non-trained voices makes any data comparison between the advanced and the beginning groups relatively meaningless... The summative effect of dynamics seems to be that a decrease in volume tends to lower the frequency of the F_S and adversely affects the amplitude of the F_S, to the degree that it is most often no longer measurable in the production of most non-trained singers.[58]

Rossing brings this acoustical fact closer to the choral setting. In studying the acoustical differences between solo singing and choir singing, he found that the singer's formant often appeared during crescendos in choral singing, but much less frequently in sustained loud passages and almost never in passages of soft singing.[59]

In addition to what would seem to be a low level of important upper spectrum energy in soft choral singing, Ternström and Sundberg remind us that with diminishing amplitude, the human ear naturally perceives a slight drop in pitch, i.e. the softer we sing, the lower our ear thinks the frequency of the tone is, even if the frequency remains the same.[60] The fact that it is also vocally natural for pitch to drop while singing softly places a doubly heavy vocal and acoustical burden on the singer to ensure that everything possible is done to maintain purity of intonation with diminishing amplitude.

In general then, it has been observed that most components of vocal energy (vibration, vowel resonance, intonation) tend to naturally diminish at lower dynamics in amateur singing. It was therefore the purpose of this portion of experiments to test whether the *bel canto* principle of *messa di voce* could be of value in reversing or offsetting this natural acoustic flaw.

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[58] Jack Morris and Rudolph Weiss, "The Singer's Formant Revisited: Pedagogical Implications Based on a New Study," *Journal of Singing* 53, 3 (1997): 23.
[59] Thomas D. Rossing, Johan Sundberg, and Sten Ternström, "Voice Timbre in Solo and Choir Singing: Is There a Difference?" *Journal of Research in Singing* 8, 2 (1985): 4.
[60] Sten Ternström and Johan Sundberg, "Acoustics of Choir Singing," *Collection of Papers Published by the Royal Swedish Academy of Music* 52 (1986): 17.

The *bel canto* Ideal

The old masters believed that this exercise was the supreme test of a singer's vocal abilities, and that when practised properly, could lead to a plethora of vocal benefits for the singer. For instance, Mancini maintained that the *messa di voce* was excellent for assuring a proper use of the breath in singing:

> I then will say, that if the student wishes to conceive the *messa di voce* without defects, it will be necessary for him to not push his breath violently, but to start it very quietly. Furthermore, he must economize the breath, by producing it in small degrees, so that in this way, he will be able to graduate the first tone with more security, by taking it in low voice, and increasing it to his full strength of loudness. From there, start to retire it with the same degree in which he developed it. In this way, he will find it easy to sustain the tone from the beginning to the end, and will avoid that inconvenience which usually happens to singers, of finding themselves exhausted at the end of the tone.[61]

In fact, Mancini was so convinced of the overall value of the *messa di voce* that he speaks of it as somewhat of a vocal panacea, one which brings the singer's art to a higher level:

> Mancini reiterated the importance of the *messa di voce,* saying that it 'lends great excellence to singing and enables the singer to sustain and graduate without any defect. In it lies the secret no less than the art of beautiful singing'... 'I have gone far beyond the call of duty, reasoning so much on the *messa di voce*, but I tell you, studious youths, that it is so close to my heart that I could speak of it forever.'[62]

The old masters also believed this exercise to be of excellent value in the blending of vocal registers:

> In advanced stages of training the performance of the *messa di voce* must be practiced continually until there is an exact matching of both quality and intensity at the point of transition. After this technique has been mastered the 'break' disappears, and the singer is able to pass freely from one register to the other, from soft to loud and from loud to soft, without difficulty. This is the kind of

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[61] G.B. Mancini, *Practical Reflections on the Art of Singing*, trans. by Pietro Buzzi (Boston: Gorham Press, 1912), 120.
[62] G.B. Mancini, quoted in Stark, 96.

> technique that the early masters described as the 'art of producing the voice.' This is the singing style known as 'Bel Canto'.[63]

The vocal demands and benefits ascribed to the *messa di voce* are indeed numerous. Yet its most important contribution was in imparting a beautiful, full and consistent vocal timbre throughout the entire gamut of dynamics made available to each individual voice. The *bel canto* masters were first and foremost concerned with beauty of tone and were unwilling to compromise on this regardless of the range or dynamic being sung:

> *Piano* should in all respects, with the exception of intensity, resemble the *forte*; it should possess the same depth, character, and feeling; it should be supported by an equal quantity of breath, and have the same quality of tone, so that even when reduced to *pianissimo* it may be heard at as great a distance as the *forte.*[64]

In fine *bel canto* singing therefore, *quality of tone* is never affected by *quantity of dynamic*. Whether singing *forte* or *piano*, the tone is to be beautiful, at all times enjoying as complete a harmonic spectrum as possible. The aim of this portion of the study was to determine if *piano* resembles *forte* to a greater degree (with the exception of intensity) when choristers rely on the *bel canto* principles of vibration and resonance associated with the *messa di voce.*

Experimental Procedure

During exercises related to the *messa di voce*, singers were asked to remember and attempt to apply all that they had learned in the sections relating to vibration and *chiaroscuro* resonance balancing as this knowledge and ability were to be crucial to the application of this new principle. In fact, all of the exercises and principle sections in this study were designed in a cumulative fashion in keeping with *bel canto* pedagogical process.

Choristers were asked to sing two exercises leading up to a successful execution of an actual *messa di voce.* The first exercise was to have them sing a

[63] Cornelius Reid, *Bel Canto: Principles and* Practices (New York: J. Patelson Music, 1978), 98.
[64] Francesco Lamperti, *A Treatise on the Art of Singing,* transl. J.C. Griffith (London: Ricordi, 1877), 19.

long, sustained tone on one note at a comfortable *mezzo forte.* They were asked to begin with focused core vibration as well as with complete *chiaroscuro* resonance. They were to ensure that there were no sudden bursts of breath, or loose, collapsing ribcages, but rather a dynamically open body which fed only the amount of breath necessary to sustain a smooth, vibrant and resonant sound.

Singers were then asked to sing eight tones in succession, all on the same note (A 220 for men, 440 for women) and on the same vowel [ɑ]. The overall series of tones was to experience a gradual decrescendo so that the first began *ff* while the last was to begin *pp.* Each tone was to begin, according to Garcia's *coup de glotte*, with the vocal folds in the closed position and a core focus of vibration immediately apparent in the sound. Each tone was also to enjoy complete *chiaroscuro* vowel resonance. It was clear that these elements of vibration and resonance became increasingly difficult to maintain as groups sang more and more softly, and that more concentrated effort was required, both by their ears and their vocal physiology, if a smooth and consistent sound was to be sustained.

Next, the rest between each utterance was removed as choristers were asked to sing the entire decrescendo in a sustained fashion on one breath, essentially combining the first two exercises. Each group sang a long, gradual decrescendo in unison on the vowel [ɑ] for approximately twelve seconds. For the men, the frequency sung was 220 Hz (A_3), for the women, 440 Hz (A_4), which was also the frequency sung by the children's choir. Each ensemble was encouraged to recall the renewed and increased energy and concentration it had taken to restart each tone at a softer dynamic and to apply that increase of vibration and resonance energy in a graduated fashion to the long decrescendo. They were to maintain three factors - actually to increase them because of the voice's natural propensity to relinquish them - throughout the gradual decrease in intensity: 1) a focused core of vibration without any seepage of breath or spreading of tone as outlined in chapter two; 2) a complete, *chiaroscuro* resonance that maintained both brilliance and warmth as advocated in chapter three (choristers were also admonished to very attentively listen to and maintain the sound of the vowel itself); 3) control over the breath which was to remain low in the body and be expended in an economic manner and not allowed to 'flow' loosely as the decrescendo advanced. Only the small amount of breath needed to feed the concentrated vibration was to be expended. This last component demanded some attention to posture and breathing. It was this third and final version of the exercise that was recorded and analysed below.

Analysis of Sound Data

The following graphs and tables display the spectral energy produced, and forfeited, by choirs during the second half of a *messa di voce* exercise, that is to say the decrescendo portion. It was decided to perform and subsequently analyze only this latter half of the exercise as untrained voices typically experience substantial difficulty in performing a slow, controlled crescendo followed immediately, and in one breath, by a similar decrescendo. It was also thought that any findings would be inconclusive at best if singers were running out of breath at precisely the moment that was of most interest for the analyses, i.e., the *piano* portion.

The spectrograms that follow display the total spectral energy during this exercise as performed by each participating choir. Each horizontal line of a spectrogram represents a single overtone generated by the tone's fundamental frequency which is the lowest line in each spectrogram. The relative strength of each overtone can be surmised by its darkness and colour according to the colour scale on the right of each spectrogram file. The horizontal axis represents time, affording an accurate graphic illustration of exactly how spectral energy decays as the ensembles' intensity diminishes in time. A vertical marker has been placed at the 9-second point in the analyses to provide a visual reference for comparing spectral strength at what would correspond approximately to a *mezzo piano* dynamic.

Following the spectrograms are *enerSimple* graphs which, as in chapter two, display more specifically the isolated energy in the spectral band from 2.3-3.5 kHz, i.e., the singer's formant. Many researchers have found that this upper spectrum energy does not commonly occur in choral singing, especially at softer dynamics. Yet this type of energy would be so helpful in boosting an ensemble's carrying power at softer dynamics that it was natural to test how its presence and level were affected by the *messa di voce*. In these graphs, the thicker, black line represents the ensemble's maintenance of singer's formant energy while performing a gradual decrescendo *after* having worked the principle of *messa di voce,* while the thinner grey line is linked to their best effort *before* working this principle. The greater the distance between the two lines as the decrescendo progresses, the more positive the acoustic impact this principle had on the ensemble's soft singing.

* *See next page for analyses*

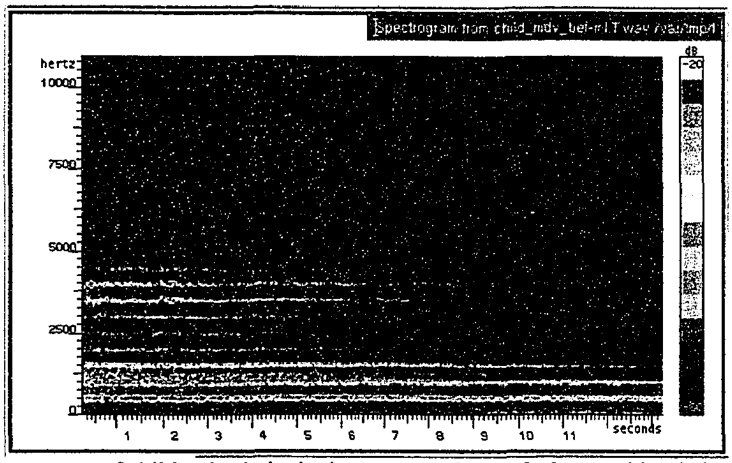

Figure 5.1. Spectrogram of children's choir singing a *messa di voce* ***before*** working *bel canto* technique. *Y* (vertical) axis = frequency of fundamental and overtones, *x* (horizontal) axis = time. Compare to Figure 5.2. Visual marker placed at 9 secs. to facilitate comparison.

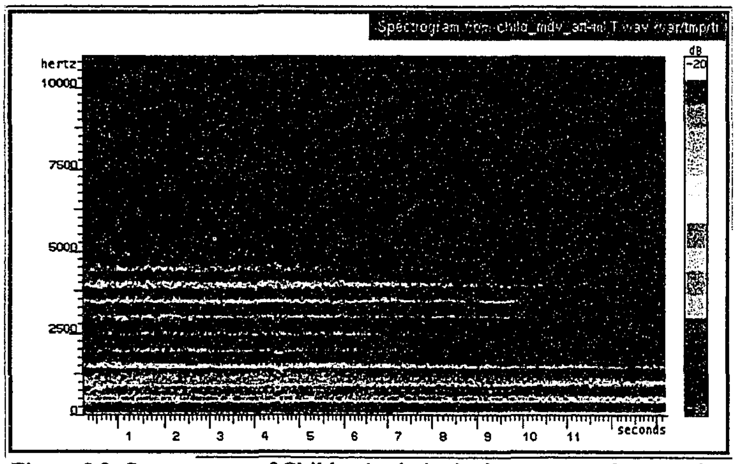

Figure 5.2. Spectrogram of Children's choir singing a *messa di voce* ***after*** working *bel canto* technique. Compare to Figure 5.1.

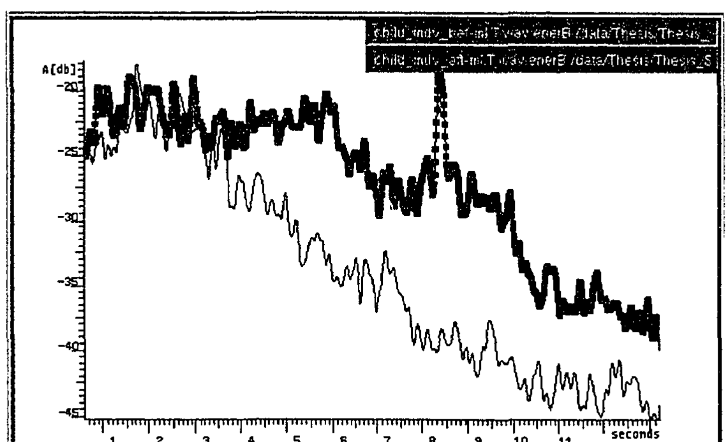

Figure 5.3. Comparison of isolated singer's formant energy of a children's choir singing a *messa di voce*. Grey line = *before*, Black = *after*. *Y* axis = amplitude in dB, *x* = time.

For this page, recorded examples # 35 & 36 on accompanying CD

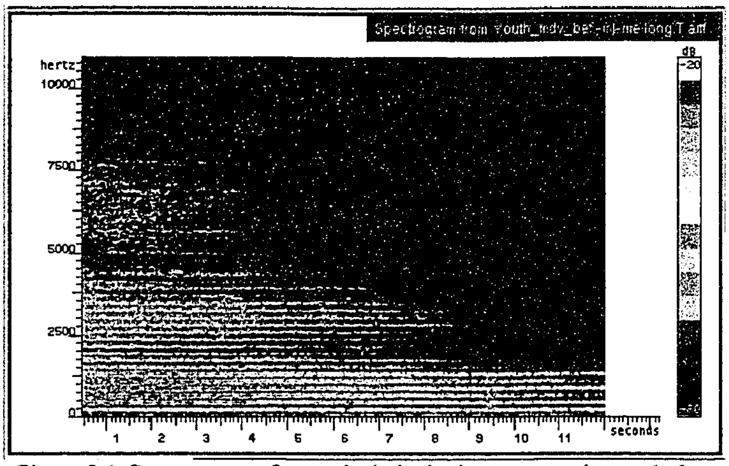

Figure 5.4. Spectrogram of a youth choir singing a *messa di voce* ***before*** working *bel canto* technique. Compare to Figure 5.5.

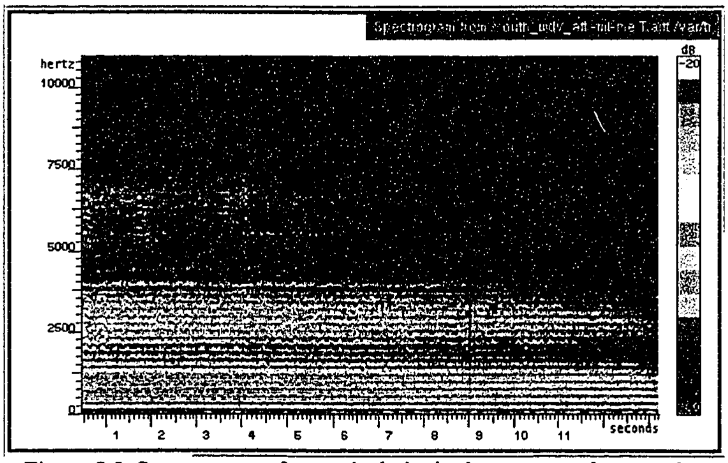

Figure 5.5. Spectrogram of a youth choir singing a *messa di voce* ***after*** working *bel canto* technique. Compare to Figure 5.4.

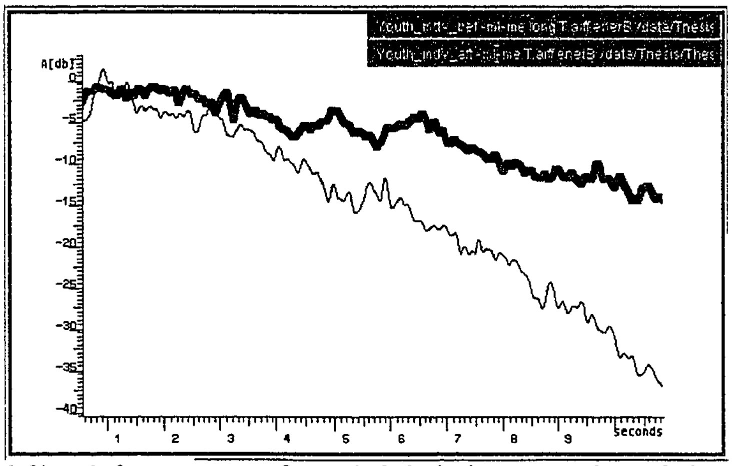

Figure 5.6. Singer's formant energy of a youth choir singing a *messa di voce* ***before** and **after*** working *bel canto* technique. Grey line = before, Black = after.

For this page, recorded examples # 37 & 38 on accompanying CD

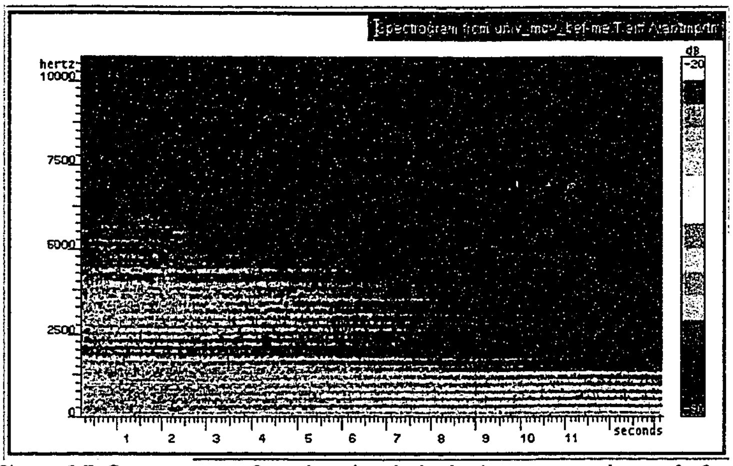

Figure 5.7. Spectrogram of a university choir singing a *messa di voce* ***before*** working *bel canto* technique. Compare to Figure 5.8.

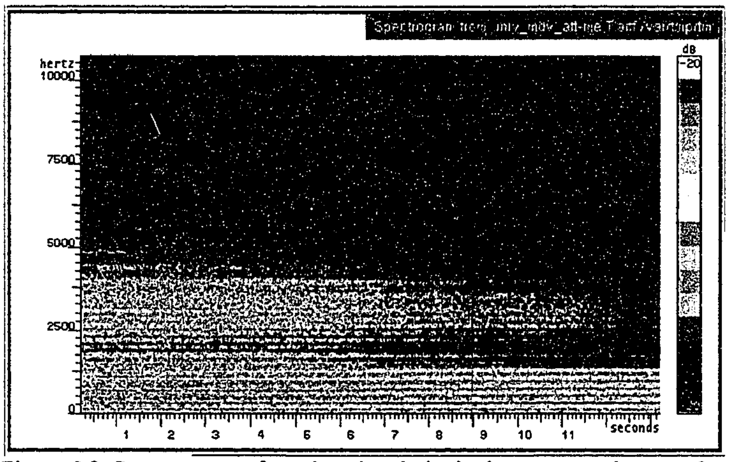

Figure 5.8. Spectrogram of a university choir singing a *messa di voce* ***after*** working *bel canto* technique. Compare to Figure 5.7.

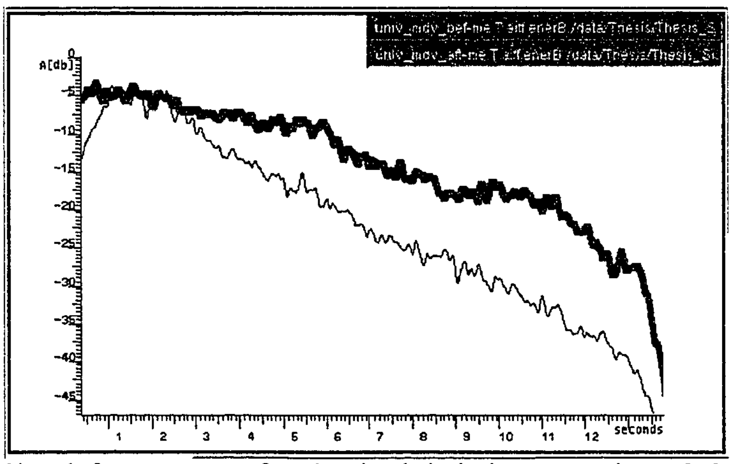

Figure 5.9. Singer's formant energy of a university choir singing a *messa di voce* ***before*** *and* ***after*** working *bel canto* technique. Grey line = before, Black = after.

For this page, recorded examples # 39 & 40 on accompanying CD

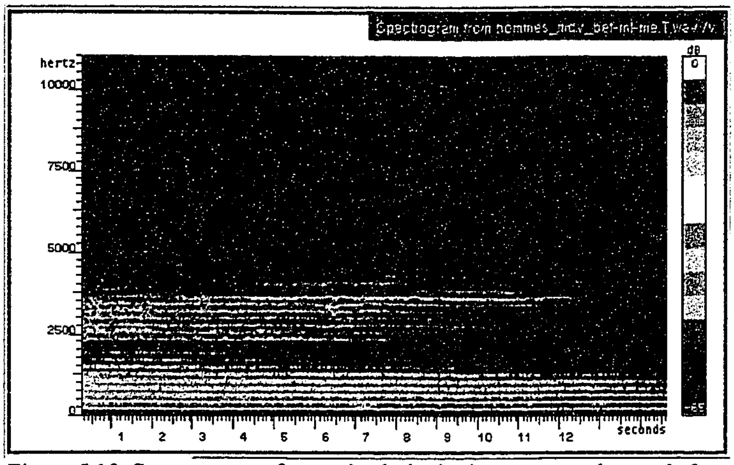

Figure 5.10. Spectrogram of a men's choir singing a *messa di voce* ***before*** working *bel canto* technique. Compare to Figure 5.11.

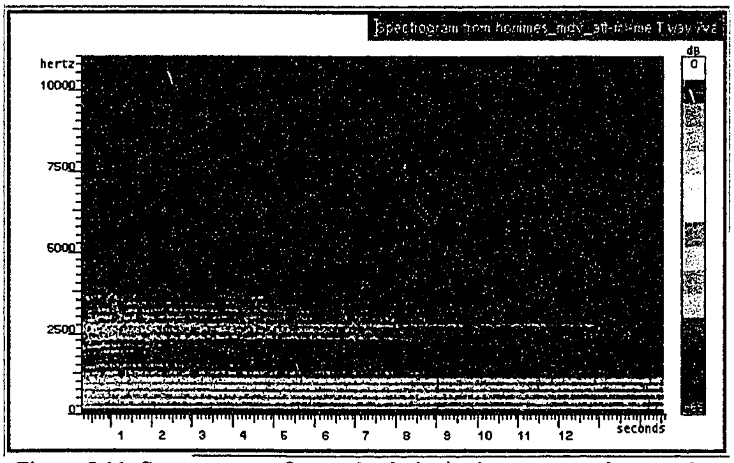

Figure 5.11. Spectrogram of a men's choir singing a *messa di voce* ***after*** working *bel canto* technique. Compare to Figure 5.10.

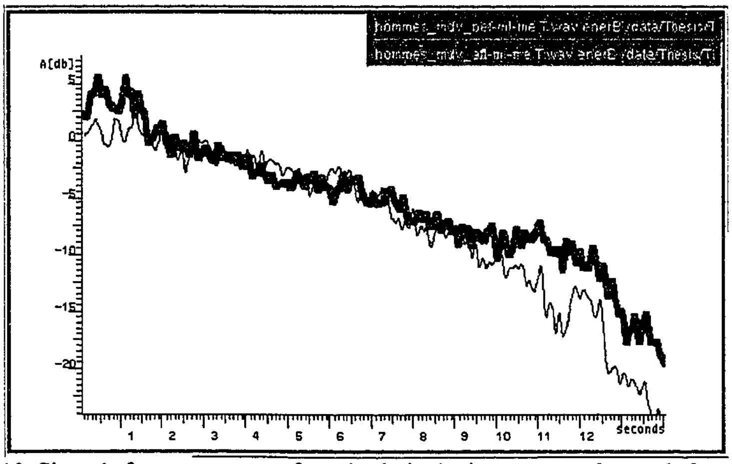

Figure 5.12. Singer's formant energy of men's choir singing a *messa di voce* ***before*** *and* ***after*** working *bel canto* technique. Grey line = before, Black = after.

For this page, recorded examples # 41 & 42 on accompanying CD

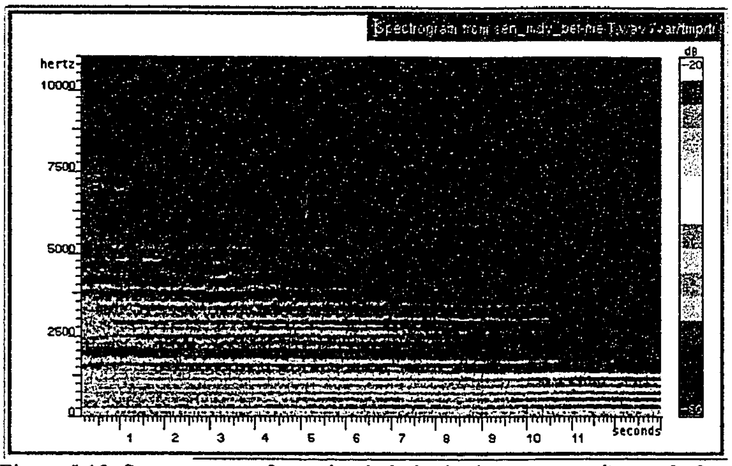

Figure 5.13. Spectrogram of a seniors' choir singing a *messa di voce* ***before*** working *bel canto* technique. Compare to Figure 5.14.

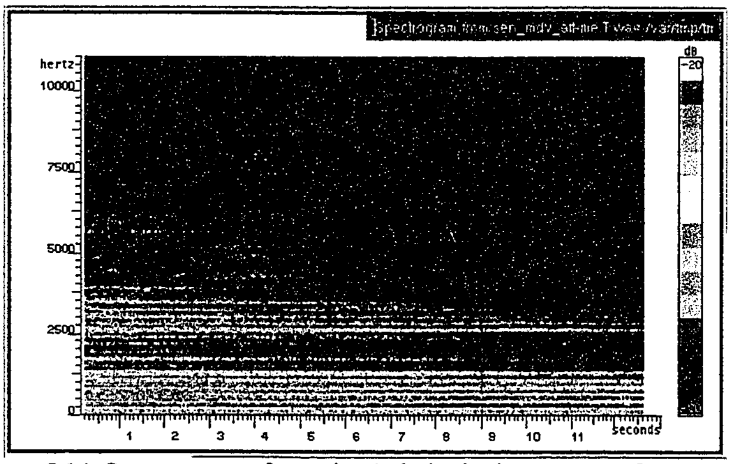

Figure 5.14. Spectrogram of a seniors' choir singing a *messa di voce* ***after*** working *bel canto* technique. Compare to Figure 5.13.

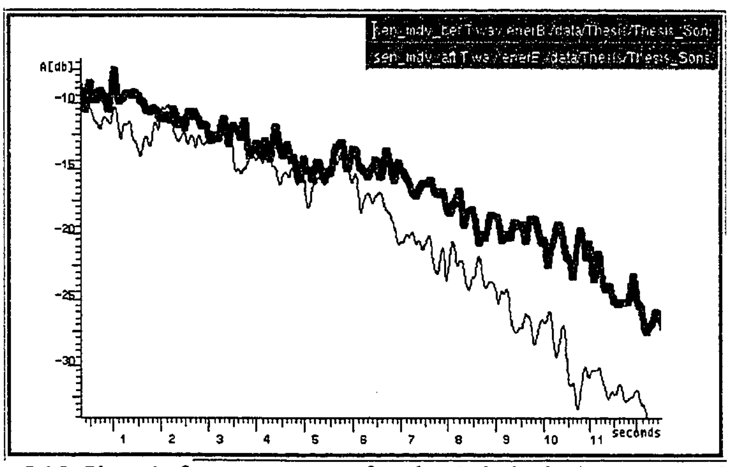

Figure 5.15. Singer's formant energy of seniors' choir singing a *messa di voce* ***before and after*** working *bel canto* technique. Grey line = before, Black = after.

For this page, recorded examples # 43 & 44 on accompanying CD

Comparison of Spectral Energy in *Forte-Piano* juxtapositions

The following analyses are a continuation of the previous section. The sound files associated with them were altered to more clearly show the disparity in spectral energy between *forte* and *piano* singing during choral experiments. The middle portion of the *messa di voce* (*mf* and *mp*) has been removed, leaving a sharp aural and visual juxtaposition between *forte* and *piano* singing. By removing the gradual surrendering of vocal energy, this acoustical 'cutting to the chase' lays bare the clear acoustical contrast between loud and soft modes of singing in the choral situation.

As with the full spectrograms above, the vertical axis represents frequency in Hertz while the horizontal axis displays time. The end of the *forte* section and the beginning of the *piano* section are clearly visible at approximately the 1.75 second mark for both the spectrograms and the *enerSimple* graphs. It is natural that the sharpest discrepancies in acoustic energy would manifest themselves at this point.

* *See next page for analyses*

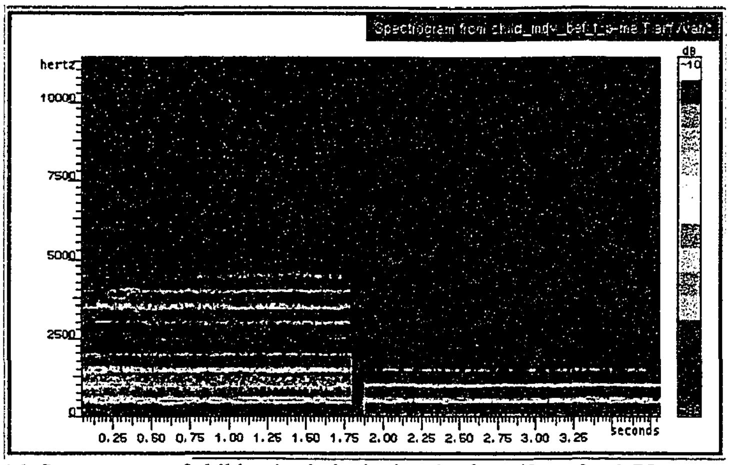

Figure 5.16. Spectrogram of children's choir singing the *forte* (from 0 – 1.75 secs) and *piano* (from 1.85-3.75 secs) sections of a *messa di voce* ***before*** working *bel canto* technique. Compare to Figure 5.17.

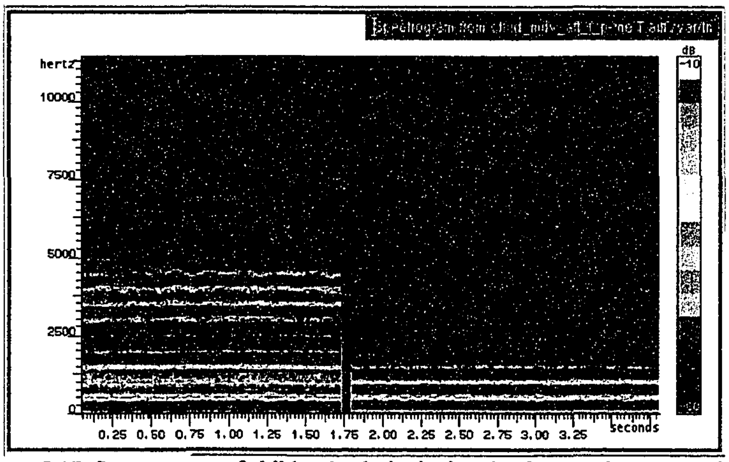

Figure 5.17. Spectrogram of children's choir singing the *forte* and *piano* sections of a *messa di voce* ***after*** working *bel canto* technique. Compare to Figure 5.16.

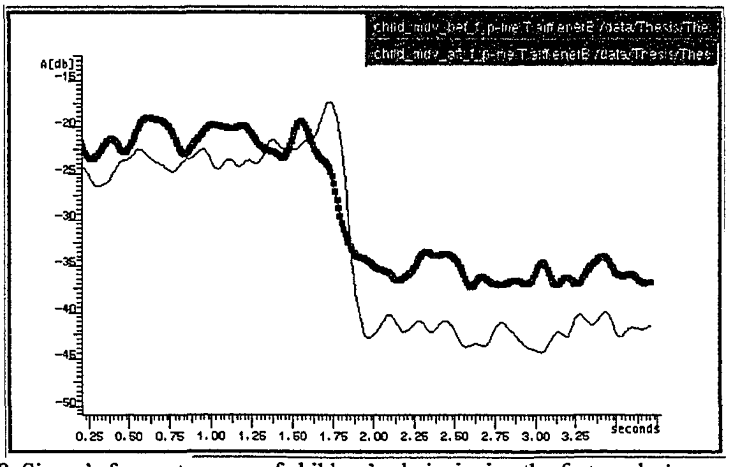

Figure 5.18. Singer's formant energy of children's choir singing the *forte* and *piano* sections of a *messa di voce* ***before and after*** working *bel canto* technique. Grey line = before, Black = after.

For this page, recorded examples # 45 & 46 on accompanying CD

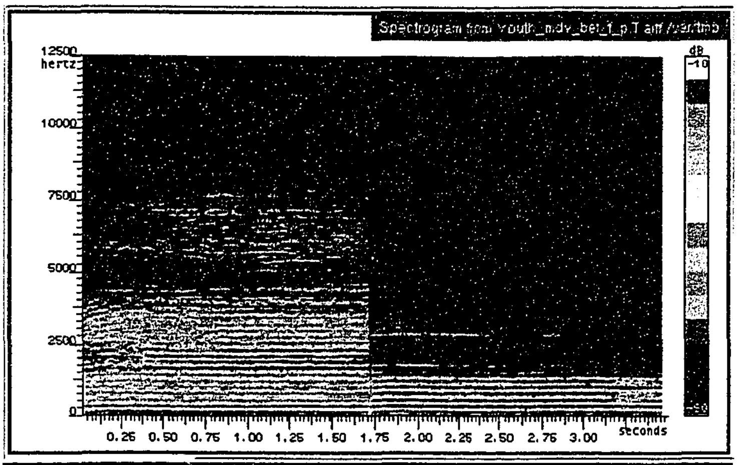

Figure 5.19. Spectrogram of youth choir singing the *forte* and *piano* sections of a *messa di voce* ***before*** working *bel canto* technique. Compare to Figure 5.20.

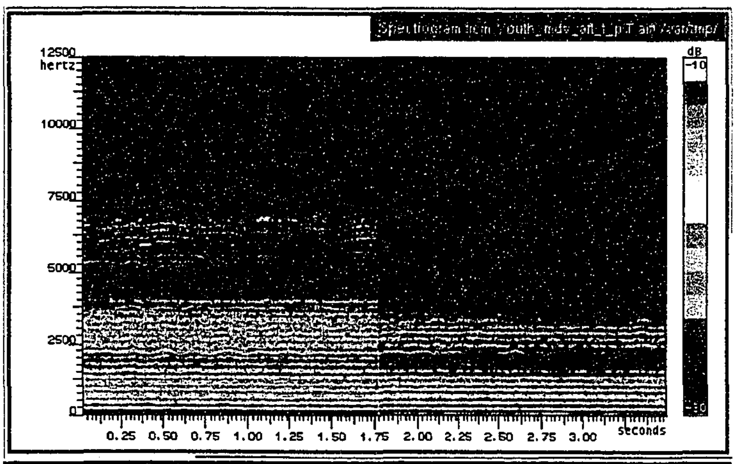

Figure 5.20. Spectrogram of youth choir singing the *forte* and *piano* sections of a *messa di voce* ***after*** working *bel canto* technique. Compare to Figure 5.19.

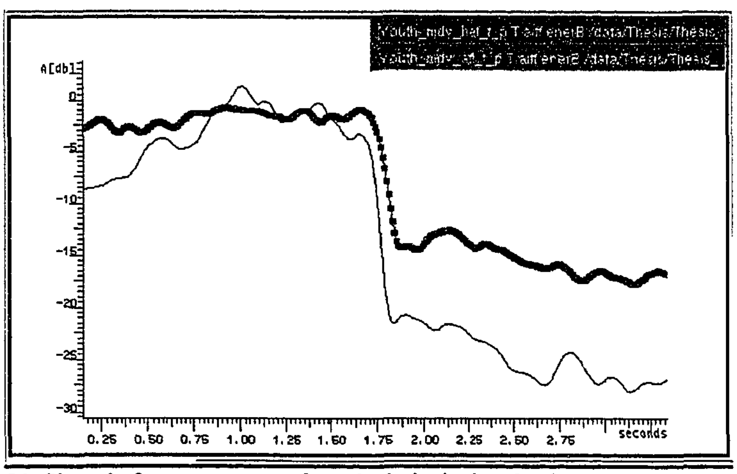

Figure 5.21. Singer's formant energy of youth choir singing the *forte* and *piano* sections of a *messa di voce* ***before and after*** working *bel canto* technique. Grey line = before. Black = after.

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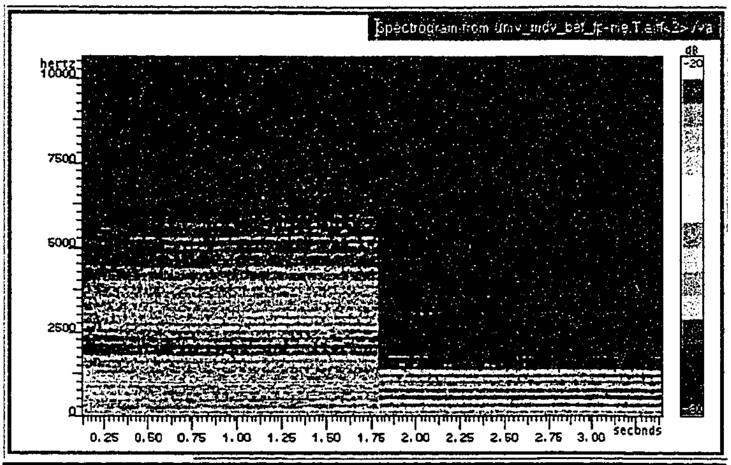

Figure 5.22. Spectrogram of university choir singing the *forte* and *piano* sections of a *messa di voce* ***before*** working *bel canto* technique. Compare to Figure 5.23.

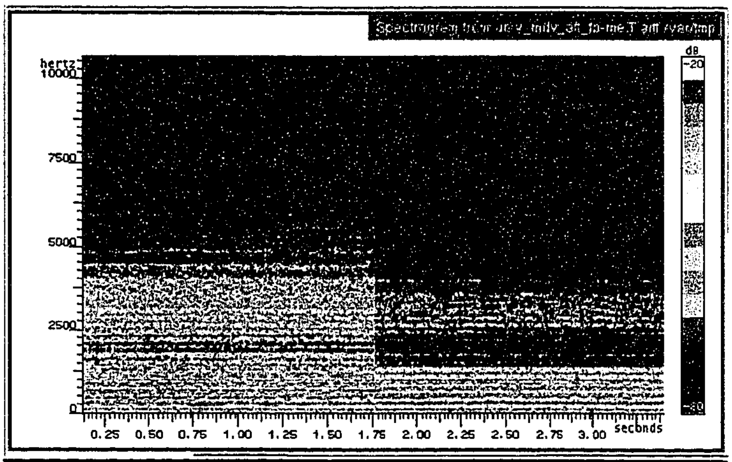

Figure 5.23. Spectrogram of university choir singing the *forte* and *piano* sections of a *messa di voce* ***after*** working *bel canto* technique. Compare to Figure 5.22.

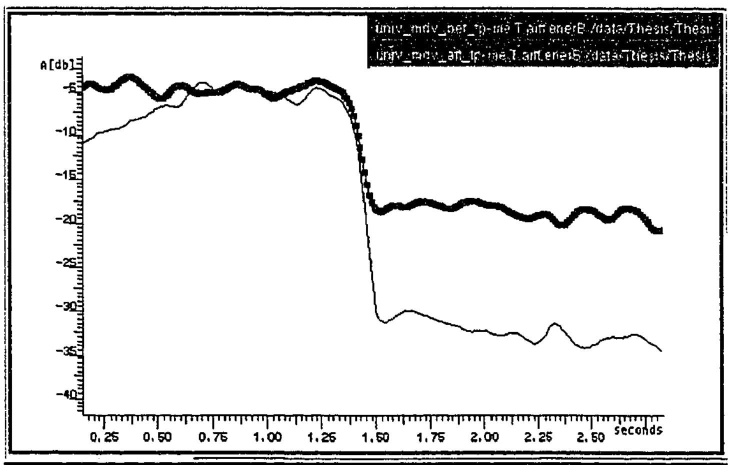

Figure 5.24. Singer's formant energy of university choir singing the *forte* and *piano* sections of a *messa di voce* ***before and after*** working *bel canto* technique. Grey line = before. Black = after.

For this page, recorded examples # 49 & 50 on accompanying CD

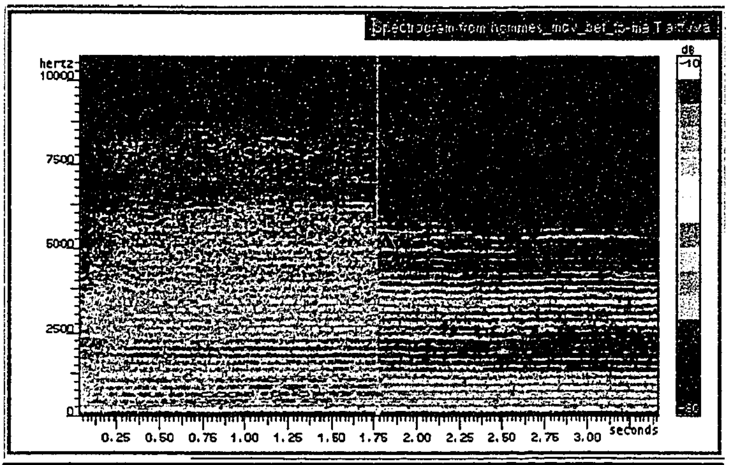

Figure 5.25. Spectrogram of men's choir singing the *forte* and *piano* sections of a *messa di voce* ***before*** working *bel canto* technique. Compare to Figure 5.26.

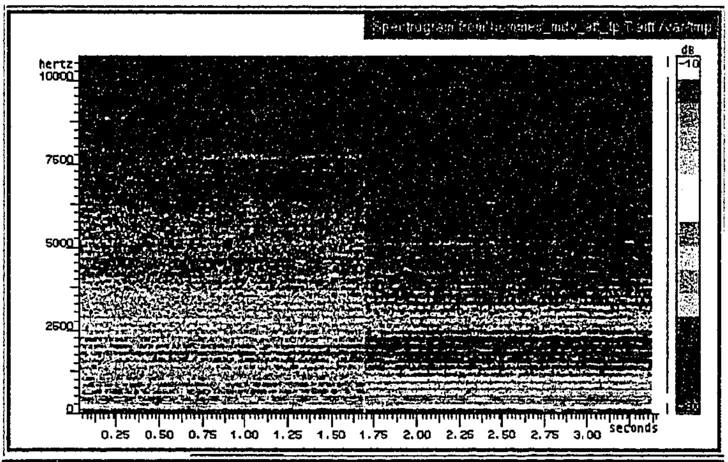

Figure 5.26. Spectrogram of men's choir singing the *forte* and *piano* sections of a *messa di voce* ***after*** working *bel canto* technique. Compare to Figure 5.25.

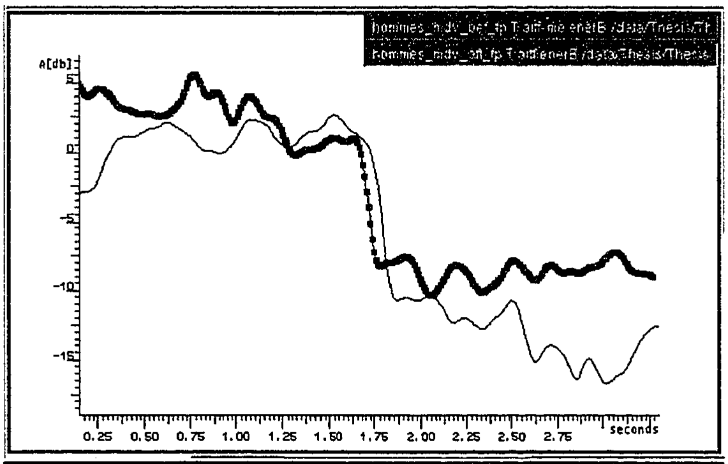

Figure 5.27. Singer's formant energy of men's choir singing the *forte* and *piano* sections of a *messa di voce* ***before and after*** working *bel canto* technique. Grey line = before. Black = after.

For this page, recorded examples # 51 & 52 on accompanying CD

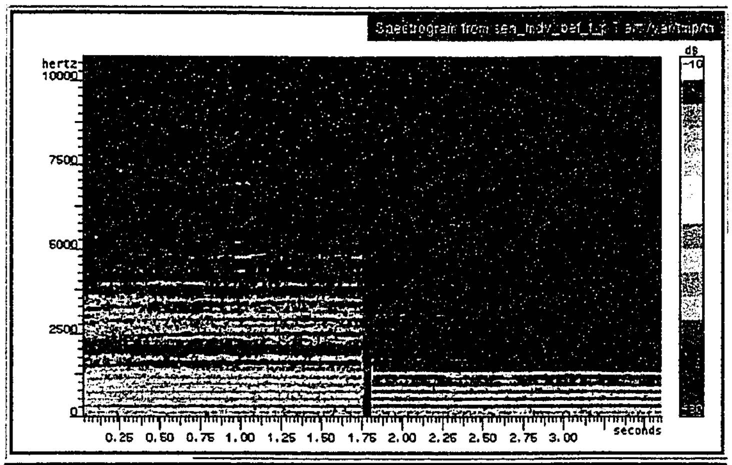

Figure 5.28. Spectrogram of seniors' choir singing the *forte* and *piano* sections of a *messa di voce* ***before*** working *bel canto* technique. Compare to Figure 5.29.

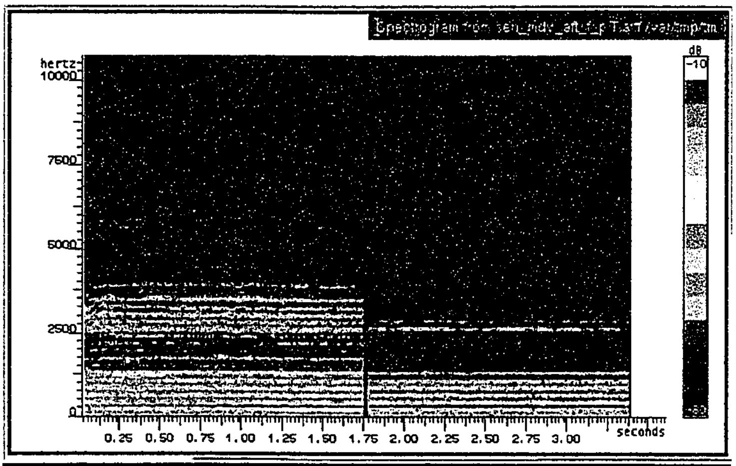

Figure 5.29. Spectrogram of seniors' choir singing the *forte* and *piano* sections of a *messa di voce* ***after*** working *bel canto* technique. Compare to Figure 5.28.

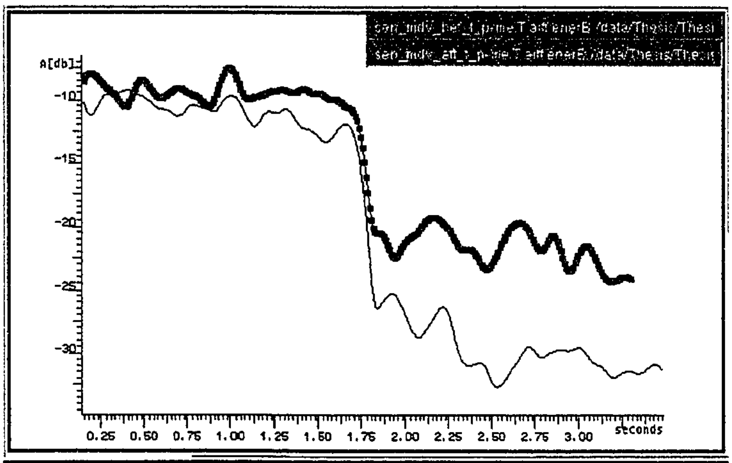

Figure 5.30. Singer's formant energy of seniors' choir singing the *forte* and *piano* sections of a *messa di voce* ***before and after*** working *bel canto* technique. Grey line = before. Black = after.

For this page, recorded examples # 53 & 54 on accompanying CD

General Observations and Conclusions

Choral groups in general exhibited distinct difficulty in maintaining vocal energy during the decrescendo process. The concept that they could (and should) retain the full character of the complete *chiaroscuro* vowel as well as a consistency of core vibration while keeping the breath at bay and therefore strive to sing the same quality of sound in their *piano* singing as in their *forte* singing seemed quite foreign to most groups.

During analyses of the *messa di* voce sound data it became obvious that a distinct acoustic weakness regularly set in when moving toward a *piano* dynamic, with most overtones in the upper spectrum becoming very faint or disappearing altogether at the softest points. As well, certain *before* graphs exhibit different acoustic properties in the softer portions than the corresponding *forte* section, a fact that cannot do otherwise but cause a difference in quality of sound.

For example, if we consider the men's choir in Figures 5.25 and 5.26, the central frequency of the singer's formant in the *before* portion of the *messa di voce* (5.25) is approximately 3 kHz. The ensuing *piano* portion shows little energy at this frequency, yet a very strong, single overtone at 3.6 kHz. Listening to the sound example (#51) reveals that there is indeed a distinct change in vocal quality with one or more voices assuming quite a metallic, edgy quality as the singer(s) attempt(s) to maintain tone by pressing the voice and singing with a resonance that is clearly marked by increased vocal tension. This sound can be heard to penetrate the sound of the ensemble. This effect is even more pronounced in listening to the complete *messa di voce* exercise in example #51. Although this approach may be technically in keeping with Lamperti's ideal of fairly firm glottal closure throughout this manoeuvre, he would never have advocated the type of pressed, unbalanced sound that emerges as singers press the voice to avoid the impending register change.[65]

In contrast to this, analyses of the *after* files show a definite similarity between loud and soft singing. An important acoustical consequence of the

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[65] Stark, *Bel Canto*, 246.

properly executed *messa di voce* seems to be a spectral consistency when moving from a *forte* to a *piano* dynamic. After having worked the *messa di voce* and the principles leading up to it, the central frequency of the singer's formant in *piano* sections remains virtually equivalent to corresponding *forte* sections. In comparing Figures 5.22 and 5.23 (University choir), it is evident that this ensemble must have enjoyed a very similar timbre when passing from *forte* to *piano* in the after example (5.23) as the spectra are exactly alike with intensity being the only variable. This is exactly what Lamperti intended when he remarked that "*piano* should in all respects, with the exception of intensity, resemble the *forte*" (see note 64). This similarity is immediately confirmed in listening to and comparing the two sound examples associated with these analyses (# 49 & 50) as well as other *before* and *after* comparisons in this section (# 47 & 48).

Another interesting aspect demonstrated by the spectrograms above is the balance that is maintained between the upper spectrum activity and the overtones lying between the fundamental frequency and the singer's formant. If we examine once again Figures 5.20 and 5.23, it is obvious that there is an even balance between the lower overtones where the first formant is located, and those of the upper spectrum in these *after* files. As Miller confirms, this is in keeping with the *chiaroscuro* tone that has been advocated in this study.

> This [first] formant is responsible for "depth" in the sound. In the trained singing voice, considerable acoustic strength is present in both upper and lower regions of the spectrum regardless of the vowel being sung... The combining of these formants produces the ideal "dark-light" tone of the historic *chiaroscuro* timbre. This presence of acoustic energy in the upper, middle, and lower portions of the spectrum ensures resonance balancing.[66]

It is apparent by these analyses that choirs were far more able to maintain the true *chiaroscuro* tone that they had been able to produce while singing *forte* when making the transition to *piano* *after* they had worked on the principle of *messa di voce*.

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[66] Richard Miller and Juan Carlos Franco, "Spectrographic Analysis of the Singing Voice," *The NATS Journal* 48, 1 (1991): 5.

In moving to the *enerSimple* analyses which here extract and display solely the singer's formant energy in the *forte-piano* sound files, the gap that exists in acoustic energy between the two dynamic extremes becomes even more apparent. Choirs seem to enjoy relatively even amounts of singer's formant energy in both *before* and *after* samples when singing at a *forte* dynamic level, even though it often takes them a certain amount of time to achieve this level after their primary attack in the *before* files.

However, the overall effectiveness of *bel canto* vocal-acoustic efficiency leading to a successfully performed *messa di voce* becomes very apparent as we compare the amount of energy lost between the *before* transition from *forte* to *piano* and the *after* versions. This is manifested in the vertical height of the black line over the grey line on the right side of each *enerSimple* graph compared to the same said distance on the left side of the graphs.

As can be observed from the graphs above, certain groups tended to exhibit greater energy in the region of the singer's formant than others. The analyses related to the children's choir's sound in particular display almost negligible amounts of vocal energy in this spectral band. The analyses illustrate this point in that the intensity values on the vertical axes of the graphs begin at much lower values for the children, and are highest for the men's choir. This is in keeping with research in vocal acoustics that has shown that higher female voices, and especially children's voices, typically possess very little singer's formant energy.[67] A partial explanation for this acoustic weakness is the fact that women and children sing at higher frequencies than do their male counterparts. As their fundamental frequencies are typically much higher, they have fewer partials to cluster in the upper spectrum than do their male counterparts. Despite this natural acoustical disadvantage, upper spectral energy was consistently augmented in this ensemble's *after* samples.

[67] Morris and Weiss, 22.

Further Conclusions and Observations

In his study which acoustically compares solo and choral singing modes, Rossing found that choirs and soloists exhibited very different acoustic behaviour when it came to upper spectral energy. He discovered that although there was a loss in singer's formant energy when experienced soloists passed from loud to soft singing, this loss was fairly slight. On the other hand, choirs consistently lost almost three times more of this energy than soloists when making the same dynamic transition.[68]

This sharp loss of energy is completely in keeping with the findings of this study in the *before* portions of experiments. In the *enerSimple* graphs in the first section of this chapter (Figures 5.3 – 5.15), the slope of loss in singer's formant energy is noticeably less steep in the *after* portions when compared to *before* portions.

When considering the *forte-piano* juxtapositions of the second section of this chapter (Figures 5.18 – 5.30), the *forte* portions of the exercise demonstrating only a modest advantage over before examples. However, any gap that existed between the *before* and *after* versions has widened remarkably at the beginning of the *piano* portions as the *bel canto messa di voce* begins to reveal its acoustic influence. We notice an average loss of 20 decibels of singer's formant energy in *before* analyses as compared to 13 decibels lost in the *after* examples. This accounts for an improvement of 7 decibels of increased energy in this very important spectral band in choral singing at a soft dynamic. When we consider the logarithmic nature of the decibel scale discussed in chapter two, this improvement becomes all the more significant. Graphs and sound files combine to confirm that choristers were consistently more able to sustain vocal energy into the softest portion of the exercise.

The *chorus effect* is an acoustical property that is unique to choral singing. This phenomenon that results when members of a group sing together, yet slightly asynchronously (pitch, vibrato, vowel) is one of the determining identifying

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[68] Thomas D. Rossing et al., "Acoustic Comparison of Voice Use in Solo and Choir Singing," *J. Acoust. Soc. Am.* 79, 6 (1986): 1976.

factors in choral singing, lending fullness and complexity to an ensemble's sound when the acoustical energy of individual voices is summed. Its effect can be compared to the difference between two guitars, one six-string and one twelve-string. The latter introduces no new notes as each of the added strings is an exact copy of one of the string on the original six-string guitar. Yet the effect of having these six extra strings gives a whole other 'chorus' or 'ensemble' sonority to the instrument. Ternström has casually referred to this effect, which he finds of the utmost importance in choral singing, "chorusness."[69] Although the positive aspects of this phenomenon can be taken to the extreme and thereby detract from the beauty of an ensemble's sound, it is usually viewed as a positive acoustical property of ensemble singing, one that is easily accepted by the ear.

During experiments with choirs, it was noticed that the chorus effect tended to almost disappear as dynamics diminished during the *before* portions of experiments. If one listens to the juxtaposed *forte* and *piano* portions of the *messa di voce* exercise of both the *before* and *after* versions associated with Figures 5.22 and 5.23 (#49 & 50), this difference is immediately apparent. In this *before* sound example, as well as the others in this section, choirs do not only sound as though they are singing more softly; often the ensemble also sounds as though it has fewer members as well as much less colour and vibrancy to the tone which seems quite 'white.' Vowel definition also suffers as the throat begins to close and free, self-sustaining vibration ceases. Choirs have diminished their *quality of tone* as much as they have diminished their *quantity of tone.*

However, in the *after* examples, especially in Figure 5.23, the *piano* portion sounds as though the chorus has as many choristers and the tone is as complex and colourful as it is in the *forte* portion. It is easy to imagine that this type of tone will carry much better in a large hall and fall upon the ears of an audience with much more appreciation.

One factor noticed during experiments which can be heard in certain *before* sound files (e.g. Youth mdv *before,* #37) is that choristers experienced

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[69] Sten Ternström, "Physical and Acoustic Factors that Interact with the Singer to Produce Choral Sound." *Journal of Voice* 5, 2 (1991): 134.

difficulty managing the transition to softer singing from the register point of view. Male voices especially can be heard 'cracking' as they attempt to decrescendo without having the necessary, efficient glottal closure to effect such a change. The *bel canto* masters knew that a voice must undergo a change in vocal register in order to successfully execute a smooth *messa di voce* without register break.

> In speaking of Mancini's use of the *messa di voce* to aide in register coordination, Taylor states: "Every student can hear for himself with perfect ease the difference between the two registers... For the blending of the registers, he advises the practice of the crescendo on single tones on the notes from G to D, starting the tone softly in head voice and swelling it gradually to chest voice."[70]

In fact, the *messa di* voce was commonly used as a pedagogical tool to repair breaks in vocal registers. Garcia also maintained that singers must adopt a slightly more sombre timbre when returning to a piano dynamic in order to avoid the 'hiccough which so disagreeably separated the one register from the other.'[71] Throughout this section of experiments, in keeping with Garcia's teaching, choristers were admonished to maintain the *oscuro* character to their resonance, especially as they moved toward the end of the decrescendo.

It is clear in listening to the *after* sound examples, that after having undergone some brief training in effective vibration and *chiaroscuro* resonance, singers found that they were able to perform a smoother transition to the softer dynamics without experiencing any cracking (with the exception of the ladies in the seniors' choir (#44 & #54). This seems to have been particularly helpful with the younger male voices that naturally tend to have difficulty with this vocal phenomenon.

Future Studies

There was not enough time in experiments with choral groups to test how this new knowledge and vocal ability would translate into improved quality of

[70] David C. Taylor, *New Light on the Old Italian Method: An Outline of the Historical System of Voice Culture, with a Pleading for its Revival* (New York: Novello, 1916), 52.
[71] Manuel Garcia, *A Complete Treatise on the Art of Singing: Part One* (New York: Da Capo Press, 1984), 135-36.

singing at lower dynamics in the performance of choral repertoire. Although the author's experience has shown that the transfer rate from exercise to repertoire is quite high, it would be important to have empirical data to substantiate this.

Another interesting study would involve the placing of microphones at ever-increasing distances from a choir in an attempt to ascertain how well an ensemble's sound carries and at what distance text is still intelligible when singing at softer dynamics. The hypothesis would be that choirs' sound would carry further and text would be intelligible at a greater distance when singing softly if ensembles apply the *bel canto* principles described in this chapter and study.

This chapter has examined the effect of core vibration and *chiaroscuro* resonance on soft singing within the choral context. These principles have shown that they are effective in helping to maximize spectral energy in choral singing, including that performed at softer dynamics. It would be important to carry this investigation further and analyze the *messa di voce*'s effect on the intonation during soft passages. As has been demonstrated in the previous chapter, *chiaroscuro* resonance, which is a pillar of the *messa di voce*, does indeed have a positive effect on intonation. It is therefore reasonable to hypothesize that choral groups would enjoy more precise intonation while singing softly when applying the principle of *messa di voce*.

The exercises in this chapter were sung in unison or in octaves. Further research in this area could seek to determine if this principle is easily applicable to multi-part singing. Whether or not all parts stay in tune or go out of tune in similar fashions while performing decrescendos would be valuable information for the choral director and the acoustician alike.

Chapter VI: Final Conclusions and Recommendations for Further Studies

Conclusions

Many conclusions have been drawn from the study of *bel canto* principles during the present study. In the author's experience, the acoustical benefits available to choral groups as outlined in these pages are reproducible and effectively applicable on a very regular basis with choral groups. After approximately three hundred workshops targeting the application of this material with vocal ensembles, it is rare that these principles have not had a remarkably positive effect in advancing the overall vocal technique of choirs. It is therefore expected that others who understand the substance and intention of these principles would also be able to improve the sound and vocal technique of the groups with which they work.

By studying the analyses and their interpretations as outlined in the present investigation, the following conclusions have been arrived at:

1. The application of Garcia's *coup de glotte* increases spectral energy in the singer's formant region (2.3 – 3.5 kHz) in a regular fashion and significant amount for choirs. The average increase in energy in this band was 4.08 dB for all choirs, a fact that will increase their carrying power and enable them to more effectively balance with the sound of an orchestral ensemble.
2. This same principle helps to decrease the amount of energy required in the region of the fundamental frequency while increasing its output in the region of the singer's formant, thereby rendering the vocal act more efficient.
3. The application of *chiaroscuro* resonance helps to consistently add and even out upper spectrum energy to a choir's harmonic spectrum. Combining efficient articulatory movements with this energy served to improve choirs' intonation significantly, by an average of 65% for the exercises in this study.

4. The result of the improvement in intonation experienced by choirs during this study as outlined in chapter 4 has been the correction of pitch errors to the point where they are probably no longer detectable according to research in perceptual acoustics (see note 54).
5. The application of proper *bel canto* vibration and resonance principles has shown that ensembles are much more successful in beginning phrases closer to the intended target pitch.
6. The attention paid to core vibration and *chiaroscuro* resonance during decrescendos has helped choirs to maintain a much more complete harmonic spectrum and, consequently, a much fuller sound, during periods of soft singing.
7. The increased spectral energy in soft singing is especially apparent in the area of the singer's formant, a fact that will enable a choir's tone to carry more efficiently and to be more successful in its acoustic competition with instrumental ensembles.
8. The application of the principles outlined in this study has enabled ensembles to continue enjoying that all-important acoustic marvel of the *chorus effect* which enables them to continue sounding very colourful, energetic and 'choristic' in their soft singing.

Recommendations for Further Studies

It is the author's belief that this study has but touched the surface of the many areas that lie open as meaningful research possibilities in the field of choral acoustics. The following questions are some that the current study has not ventured to answer, and may provide stimulus for further investigations in this area.

It has been shown that with increased attention to glottal closure and complete, *chiaroscuro* resonance, choirs can enjoy a higher level of vocal energy in the region of the singer's formant. However, one of the deciding factors behind this phenomenon that was not considered in this study was the common clustering effect of upper formants that is noticed in solo singing when there is a sharp increase in upper spectrum energy. In solo singing, formants 3, 4 and 5 typically approach each other, almost becoming one super-energized formant with much less distance between their frequencies. It would be interesting to determine whether or not this clustering trend also occurs in choral singing when energy in this spectral band is present at a significant level. Past studies have shown this *not* to be the case.[72] However, these studies have merely analyzed choirs' present state of singing and have not sought to increase an ensemble's vocal energy as has been done in this study. Therefore, the 'clustering' phenomenon of upper formants in choral singing according to *bel canto* principles of vibration and resonance remains to be studied.

Another related aspect that remains to be tested is the actual glottal behaviour of choristers who apply the principle of the *coup de* glotte and core vibration in choral singing. This type of singing has often been reproached for using too little glottal closure resulting in a type of flow phonation that yields lower upper harmonic-energy.[73] Although this low-energy production is often encouraged by choir directors, it does little for the power, colour and intelligibility of their ensembles. Investigations in the future could measure changes in glottal closure quotients during experiments if multiple electroglottographs were available. This would give more specific information into the separate contributions of the laryngeal-glottal source and the resonance-filter components of the voice in choral singing.

Although *chiaroscuro* resonance balancing was presented after work on vibration and the *coup de* glotte had already been done and its effect was therefore a cumulative one, it would be interesting to measure the effects of this principle on group intonation and spectral energy without the application of any principle other than *chiaroscuro* resonance.

Also, the effect of this complete, bright-warm resonance on ensemble blend was presented but not tested in this study. It was *hypothesized* that the increased homogeneity of spectral energy that was a marked feature of the *after*

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[72] Thomas D. Rossing et al., "Acoustic Comparison of Voice Use in Solo and Choir Singing," *J. Acoust. Soc. Am* 79, 6 (1986): 1978.
[73] Rossing et al., "Acoustic Comparison," 1979.

files would have a beneficial effect on a choir's blended tone, but this effect remains to be tested with a qualified listening panel.

Testing how *bel canto* principles of vibration and resonance affect the number of choristers needed to accomplish certain performance requirements would also be an interesting study. For instance, let us hypothesize that it normally takes a choir of at least 100 singers to perform the Verdi *Requiem* with full symphonic orchestra in order to be effectively heard, understood and have dramatic impact. Would it be possible to take the same choristers, teach them the *bel canto* principles outlined in this paper, and then reduce their number to 75 and test if their effectiveness in the aforementioned areas has declined, remained the same or improved. This would possibly be a very effective, contextualized scenario for testing the acoustic effect of these principles.

Although the majority of exercises tested for this study were performed either in unison (for the children's and men's choir) or in octaves (for the mixed choirs), it is anticipated that the vocal and acoustical benefits presented in this paper would naturally carry over into full four-part or even eight-part singing. It is reasonable to expect that if the unison tuning of the fundamental frequency has improved, and if upper spectrum energy has been increased and somewhat standardized within the choral context employed in this study, that all vocal parts would also enjoy similar benefits in a mixed-voice, multi-part context. This hypothesis, however, remains to be tested.

Further work needs to be done testing other seminal *bel canto* principles such as *la nota mentale* (creating the mental and acoustic energy needed for a phrase *before* you begin to sing) and *aggiustamento* (vowel modification in the ascending scale) in the choral setting.

How effectively these principles can be transferred into the singing of choral repertoire remains to be tested. Because of the limited time spent with each choir, this was not done. There was, however, time to briefly apply the *bel canto* principles to one piece with the university choir. This example (#55, *before*, and 56, *after*) clearly shows that the fuller sound espoused by the *bel canto* masters through these principles can bring a choir's beauty of tone and level of interpretation to another level.

It is the author's intention to use the findings of this study as the basis for a systematic pedagogical tool in the advancement of vocal technique for choirs according to *bel canto* principles. Although possibly detracting from the choral idiom when taken to the extreme, these techniques cannot help but improve the quality of an ensemble's sound and, consequently, the quality of their interpretations, when applied with taste and discretion.

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Appendix A

Chiaroscuro Results for University Choir

As stated in chapter IV, the university choir that participated in this study was the first ensemble to go through the experimental process with the author. At the time of their experiment, Ternström's article on the F_0 Perturbations had not yet been studied and analyzed. As a result, the exercises that were inspired from that study and subsequently used for testing *chiaroscuro's* effect on intonation in this study were not employed for this first experiment. Rather, the following exercises were used to test this principle in the same manner as discussed in Chapter IV. The graphs and tables begin on the next page.

1. The phrase *Et Spiritu Sancto,* sung in unison octaves at G3 for men and G4 for women,
2. The vowel series [i-e-ɑ-o-u] sung at A3 for men and A4 for women.

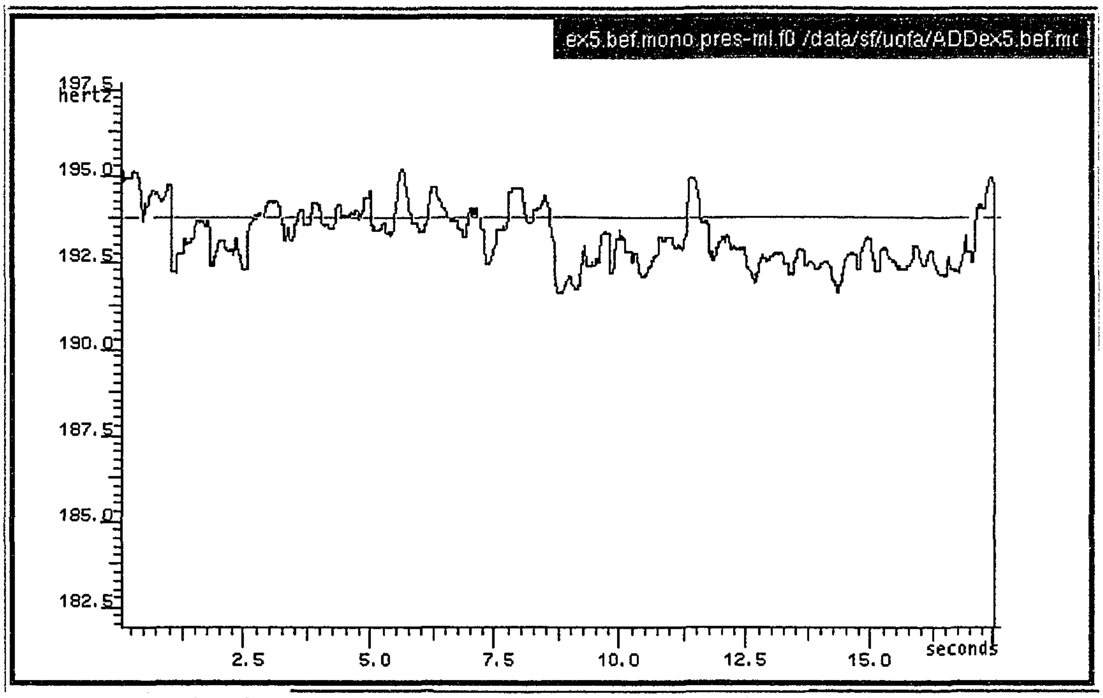

Figure 6.1. University choir singing *Et Spiritu Sancto* (men's note) at G3, *before chiaroscuro* (compare with Figure 6.2)

Recorded Example #57 on accompanying CD

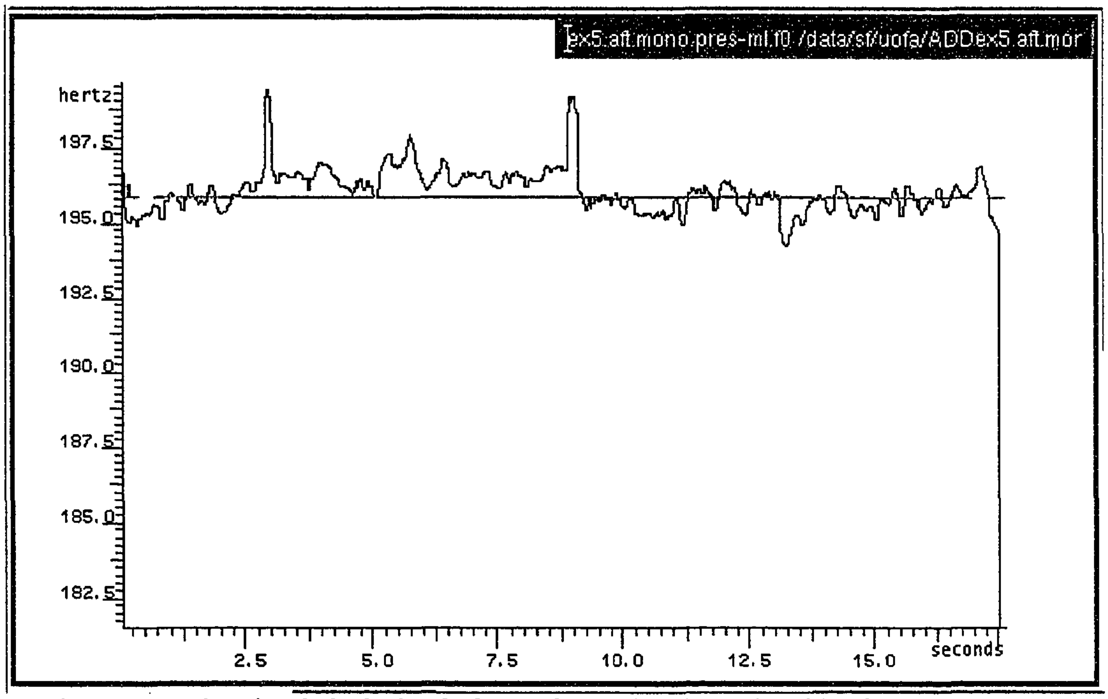

Figure 6.2. University choir singing *Et Spiritu Sancto* (men's note) at G3, *after chiaroscuro* (compare with Figure 6.1)

Recorded Example #58 on accompanying CD

Table 6.1. Frequencies sung by University Choir for *Et Spiritu Sancto* exercise

		University Mixed Choir
Fundamental Frequency Comparison before/after *Chiaroscuro* work	**1. Bef.F0 – [ɛ]**	**193.65 Hz**
	2. Bef.F0 – [i]	193.85 Hz
	3. Bef.F0 – [u]	193.74 Hz
	4. Bef.F0 – [ɑ]	192.62 Hz
	5. Bef. F0 - [o]	192.52 Hz
	6. Aft. F0 – [ɛ]	**195.67 Hz**
	7. Aft. F0 – [i]	196.53 Hz
	8. Aft. F0 – [u]	196.54 Hz
	9. Aft. F0 – [ɑ]	195.63 Hz
	10. Aft. F0 - [o]	195.68 Hz
	11. Beginning to end ***before*** deviation (1 minus 5)	- 1.13 Hz
	12. Beginning to end ***after*** deviation (1 minus 5)	+ .01 Hz
	13. Improvement (+) or deterioration (-) over amount of total pitch deviation from beginning to end -Percentage of improvement	+1.12 Hz / 1.13 Hz = 99%

There is a marked improvement in intonation if we consider the matching of pitch from the beginning to the end of the phrase: 99%. There is, however, considerable fluctuation in F_0 when the inner vowels of the phrase are examined (see Figure 6.2). As was found in most exercises with the other ensembles in chapter IV, [i] and [u] are found to have a raising effect on fundamental frequency, whereas [ɑ] and [o] tend to lower it. However, if we examine table 6.1, the [ɛ], [ɑ] and [o] are all remarkably close in pitch in the *after* version, but the *before* version has less deviation between the 'high' and 'low' vowels.

Fullness of spectral energy and fullness of tone usually accompany the improved intonation that results from *chiaroscuro* singing. The spectrograms below are generated from the opening and closing vowels of the phrase *Et Spiritu*

Sancto. The middle section of the phrase has been removed in order to highlight the spectral similarities and differences that exist from the beginning to the end of a long phrase that ends on a different vowel from that on which it began. The accompanying sound examples also clearly show how both the tone and the pitch at the end of the phrase are better matched to the beginning of the phrase when *chiaroscuro* resonance is applied.

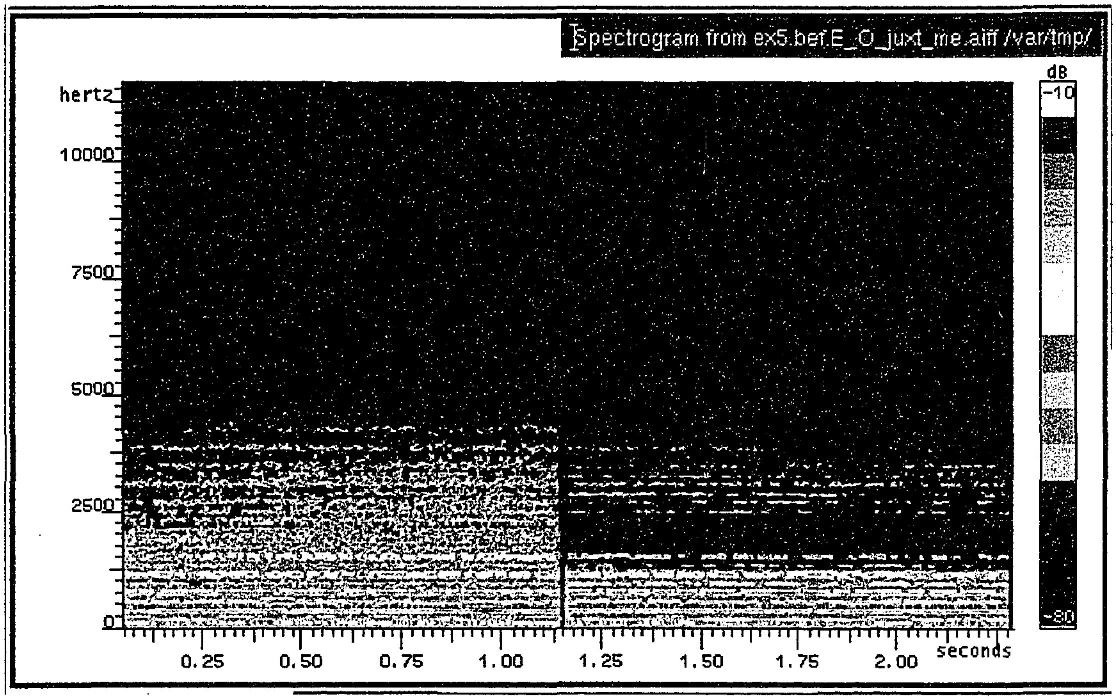

Figure 6.3. Spectrogram of University choir singing [ɛ-o] (first and last vowels of *Et Spiritu Sancto* exercise with middle section removed) at G3, *before chiaroscuro* (compare with Figure 6.4)

Recorded Example #59 on accompanying CD

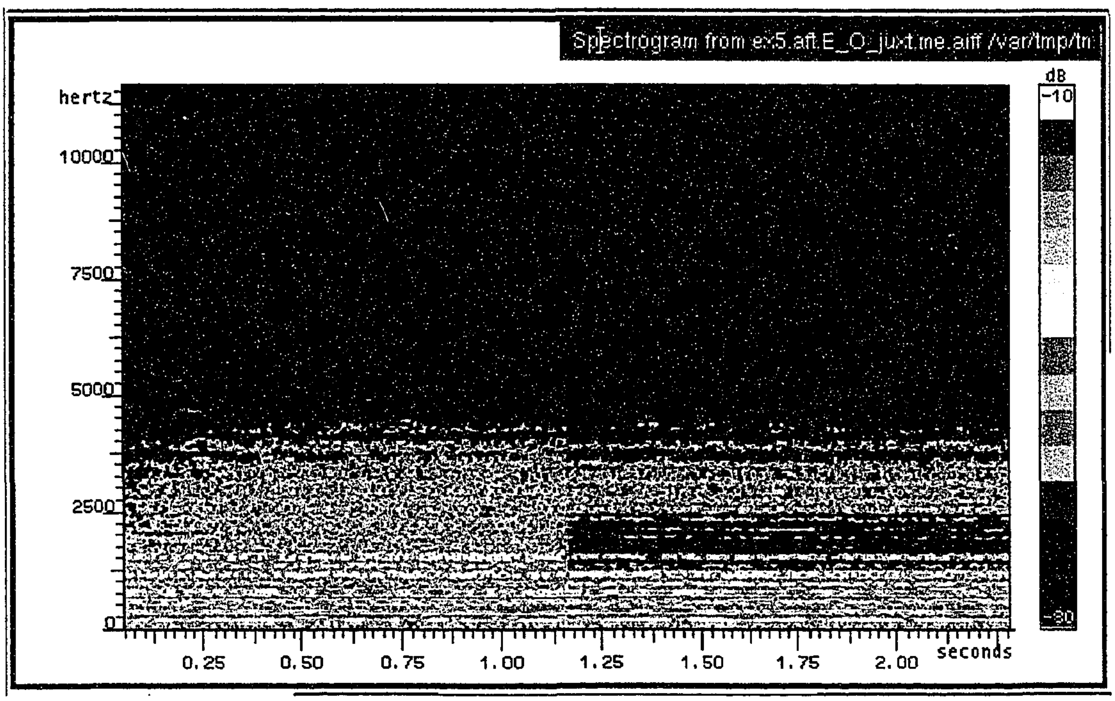

Figure 6.4. Spectrogram of University choir singing [ɛ-o] (first and last vowels of *Et Spiritu Sancto* exercise with middle section removed) at G3, *after chiaroscuro* (compare with Figure 6.3)

Recorded Example #60 on accompanying CD

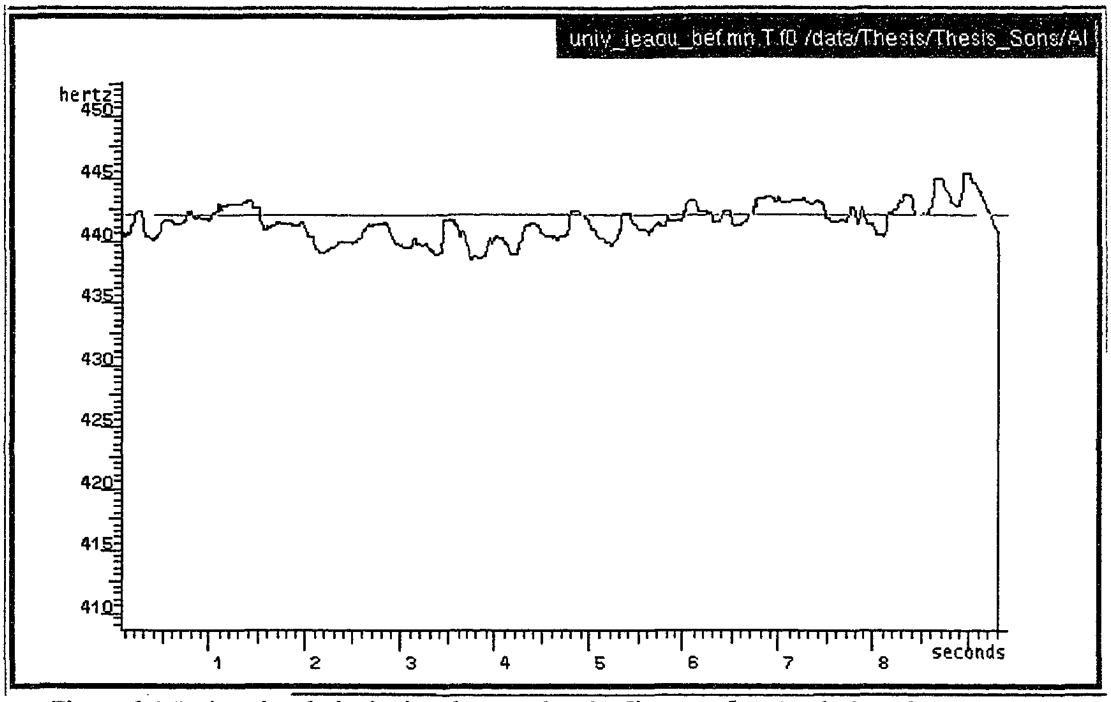

Figure 6.5. University choir singing the vowel series [i-e-ɑ-o-u] at A4, *before chiaroscuro* (compare with Figure 6.6)

Recorded Example #61 on accompanying CD

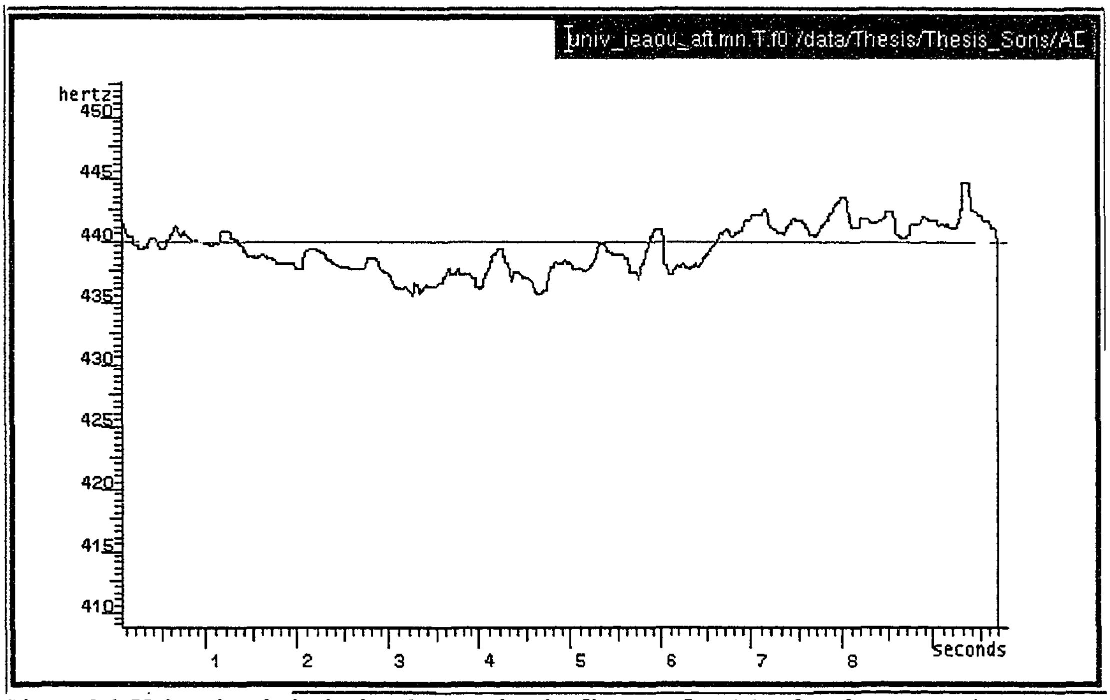

Figure 6.6. University choir singing the vowel series [i-e-ɑ-o-u] at A4, *after chiaroscuro* (compare with Figure 6.5)

Recorded Example #62 on accompanying CD

Table 6.2. Frequencies sung by University Choir for [i-e-ɑ-o-u] exercise

		University Mixed Choir
Fundamental Frequency Comparison before/after *Chiaroscuro* work	**1. Bef.F0 – [i]**	**441.88 Hz**
	2. Bef.F0 – [e]	440.27 Hz
	3. Bef.F0 – [ɑ]	440.33 Hz
	4. Bef.F0 – [o]	441.47 Hz
	5. Bef. F0 - [u]	442.50 Hz
	6. Aft. F0 – [i]	**439.79 Hz**
	7. Aft. F0 – [e]	438.15 Hz
	8. Aft. F0 – [ɑ]	437.14 Hz
	9. Aft. F0 – [o]	438.44 Hz
	10. Aft. F0 - [u]	441.20 Hz
	11. Beginning to end ***before*** deviation (1 minus 5)	-0.62 Hz
	12. Beginning to end ***after*** deviation (1 minus 5)	+ 1.41 Hz
	13. Improvement (+) or deterioration (-) over amount of total pitch deviation from beginning to end -Percentage of deterioration	+1.41 Hz (-0.79) / 0.62 Hz **= -43%**

Clearly, the university choir was not successful in correcting its pitch deviations in this exercise according to Figures 6.5 and 6.6 and the above table. However, it is interesting that despite greater deviations in pitch in the *after* version of the exercise, it would *seem*, according to the sound examples, that the choir sings almost more in tune in the *after* sound example (author's opinion only). This is possibly due to the increased and consistent acoustic energy in the upper spectrum that detracts the listener's ear from the fact that the fundamental frequency is 'slipping' with the vowel transitions (see Figures 6.7 and 6.8 below). Even if the pitch drops, the consistency of the tone quality and spectral energy may be able to compensate somewhat for this acoustic fault. This could point to the possibility that a tone that is alive with the full spectral energy characteristic of *chiaroscuro* resonance may help ensembles to *sound* as thought they are singing more in tune, even when they are not. The spectrograms below illustrate the increased amount of upper spectral energy throughout the exercise in the *after* version.

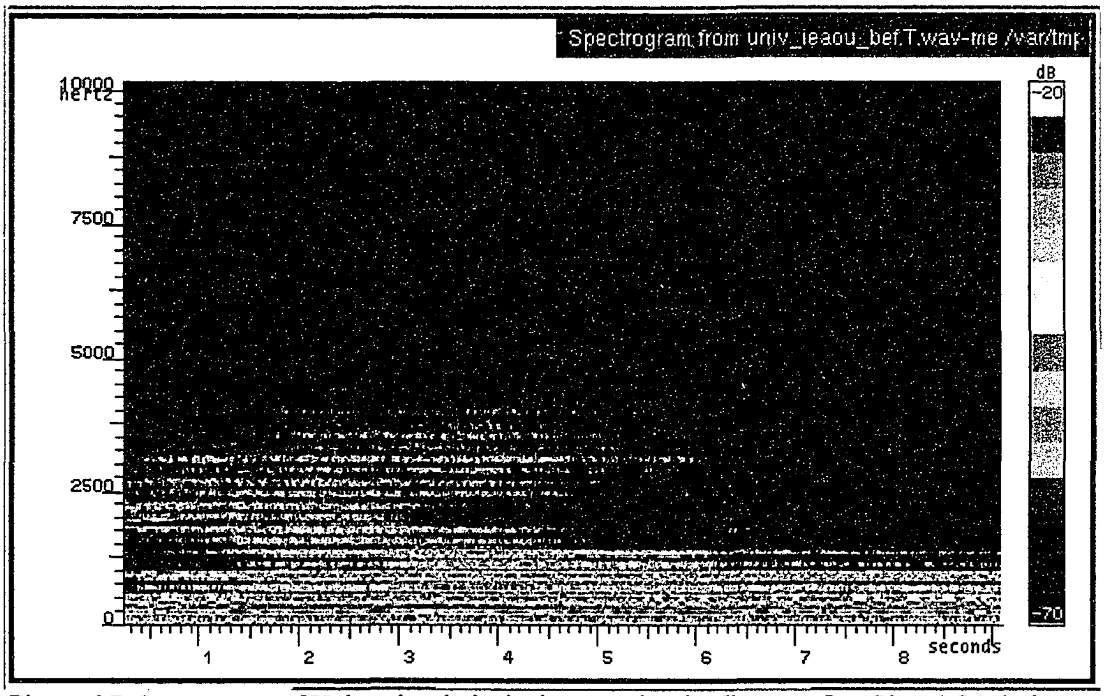

Figure 6.7. Spectrogram of University choir singing vowel series [i-e-ɑ-o-u] at G3 and G4, *before chiaroscuro* (compare with Figure 6.8)

Recorded Example #61 on accompanying CD

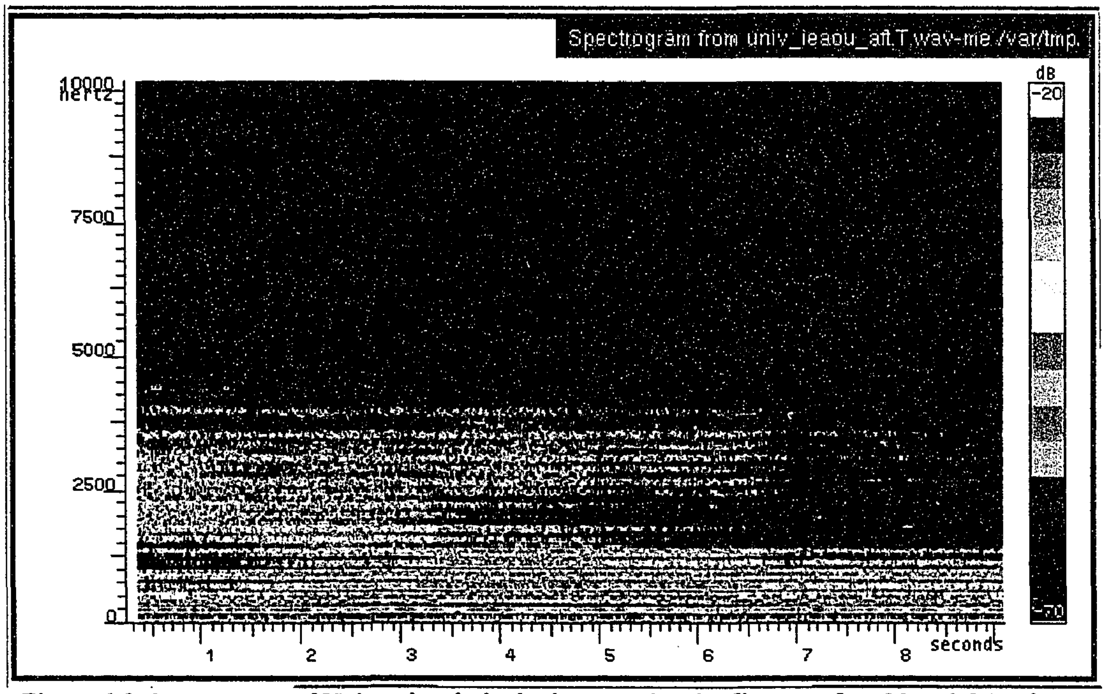

Figure 6.8. Spectrogram of University choir singing vowel series [i-e-ɑ-o-u] at G3 and G4, *after chiaroscuro* (compare with Figure 6.9)

Recorded Example #62 on accompanying CD

Appendix B

Bel Canto Choral Exercises