SINGING TECHNIQUES AND VOCAL PEDAGOGY

"Sine scientia ars nihil est"

BRIAN DAVID WHITE

Department of Music, University of Surrey

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VOLUME ONE
ABSTRACT

Some aspects of singing techniques and the teaching of singing are reviewed in the context of their historical origins, and in relation to basic scientific principles. The reasons for the success of some ideas and techniques are explained; others are shown to be false because they lack any scientific basis. Certain misconceptions have been explained: for example, those related to vocal resonance. Some important historical facts have been identified which may not have been commented upon elsewhere.

A survey of British singing teachers has served to demonstrate the diversity of opinions which exists, and the lack of standardization in teachers' methods.

The practical work which was carried out involved an experiment on chest resonance; the analysis of the voices of some singers who claimed to be using particular techniques; and the analysis of the voices of some famous singers. An unique approach was used to establish whether a singer's voice has a characteristic "sound spectrum pattern", and many specific suggestions on a variety of phenomena are presented. Sufficient details of vocal acoustics are provided to explain the practical work and the many other ideas which are discussed.

Some specific ideas have arisen from the evidence presented. These include: an "ideal singing posture"; a detailed explanation of high male voices; the nature of "white" voices; some important conclusions about partials and formants in the singing voice; also the suggestion that the vocal folds may not have to vibrate with the fundamental frequency of a low-pitched sound.
Some ideas about the effects of the environment upon the respiratory systems of singers are also presented; so too are comments regarding the validity of using gramophone recordings when studying voices.
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PREFATORY NOTES

1) It will be evident that the chapters and sections vary in length. This is because the subject matter has been compiled in what seems to be a sensible sequence; therefore balance in terms of length has been sacrificed to logical presentation.

2) A large amount of background information has been provided in some of the Appendices; these have been printed separately, as Volume Two. This information is intended primarily to help readers who are unfamiliar with some of the major topics which are dealt with in this thesis. For example, it would be unrealistic to expect a musician to be wholly conversant with the anatomy and physiology of the respiratory system, so these matters are covered in Appendix C. On the other hand, a medical reader might find this Appendix superfluous.

3) Section headings are printed in upper case letters, and sub-section headings in lower case letters. (All sections whose numbers begin with capital letters appear in the relevant Appendices.)

4) I have adopted the convention of underlining foreign words or phrases which have not been "anglicized" by common usage. For example, "bel canto" is underlined, but "crescendo" is not.

5) As this work is lengthy, I have tried to adopt an economy of writing style in order to avoid greater proliferation. The text may, therefore, not "flow" in the most desirable manner,
but I think that this is an essential measure.

6) As references to other works play an important part in this study, I have taken a great deal of care in checking the details of publications. I have received advice from professional librarians which has proved to be invaluable. However, despite their best endeavours, some works could not be tracked down in this country, and I have been able to quote from them only via secondary sources. Several potentially useful items proved to be so elusive that I have not mentioned them at all for fear of quoting inaccurate information.

7) It is not the aim of this work to quote all relevant authorities (that would be a virtually impossible task), but to help the reader to identify useful information when reading the works of other authors.

8) In nearly every case, all works are referred to in the text by the author's or editor's name. This avoids the use of cumbersome footnotes or lengthy titles, but may be held to be inappropriate in certain cases. For example, The New Grove... is referred to as Sadie (1980,...), although Sadie probably did not write the articles referred to in each case. Nevertheless, it seems unnecessary to quote the names of individual writers from a work like this, and I have maintained this procedure throughout.

9) The date which is given against a work is that of the edition which I have referred to in the text. This may not be the first edition in all cases, but I have tried to also give
the date of the first edition where desirable for historical, or other, reasons.

10) It is always difficult to decide whether to quote an author as having written in the past or present tense; to avoid this problem, I have adopted a simple convention. All authors who wrote before 1900 are referred to in the past tense; those writing from 1900 onwards are referred to in the present tense.

11) Where other works are quoted verbatim, any explanatory words which I have added are indicated thus: "...[the]...", etc.

12) All musical pitches have been named according to the convention shown in Tab. E1.
There are many diverse factors which affect the ability to sing. I investigated some of these factors during a research project which led to the writing of my M.Phil. thesis (White, 1980, upon which White, 1982B is based). The course of development of 15 singers was studied during their vocal training, and 13 non-singers were used as "controls". It became obvious during my work that there is a plethora of books on the subject of voice production; many of these are based upon "scientific" studies, but are often confusing and inaccurate.

The present work is intended to examine the scientific basis of techniques used by singers and singing teachers. I shall achieve this end by the following means:

1) By giving an historical account to show how singing teaching has been influenced by scientific discoveries about the voice.

2) By providing a clear description of the anatomy, physiology and acoustics of the vocal organs, in relation to the singing voice, so far as these are known at present.

3) By reviewing many aspects of vocal pedagogy, with criticisms based upon a strictly scientific approach. This review is founded partly upon the results of a questionnaire sent to singing teachers in the United Kingdom.
4) By the analysis of the recorded voices of some famous singers, with attempts to clarify some fundamental scientific aspects of voice production.

I have been able also to assess the usefulness of gramophone recordings in the study of singing techniques.

Needless to say, many will disagree with my opinions and conclusions; this is inevitable when one considers this basic truth:

"...even in the most rigidly controlled scientific investigations on vocal function, most conclusions must ultimately be based upon subjective evaluation of the 'quality' of the sound..." (Miller, 1977, xvi.)

It is impossible to avoid being side-tracked in this kind of work. There are so many factors which may be important: where can one draw the line? Nevertheless, I have tried to bear in mind this valuable comment:

"Hypotheses tend to limit one's aspect of a study, whereas asking a question leaves one free to observe side issues." (Lombard, 1975.)

Furthermore, in this kind of work, one must be careful to avoid post hoc ergo propter hoc reasoning: "after it, therefore, because of it".

In general, I have been concerned primarily with the fundamental principles relating to how the singing voice is produced. I have not dealt with skills such as
sight-singing; neither have I considered interpretation. I have also not suggested in most instances how teachers should instruct pupils, but have sought to clarify areas of confusion. The following topics are therefore not covered in the present work, although they may be mentioned in passing:

1) Song literature.
2) Vocal exercises.
3) Interpretation.
4) General musicianship and musical theory.
5) Training of singing teachers.
6) Singing in schools.
7) Pathology of voice and vocal health and hygiene.
8) Speech.
9) Diction.

I have endeavoured to avoid the simple repetition of other work for its own sake, using only information relevant to the matters in hand. Much earlier scientific work on the voice has now been superseded, but wherever possible, I have quoted what I believe to be important, even if at times outdated, sources of information, so that the interested scholar may be led to other lines of inquiry.
A chronological account of important voice scientists, singing teachers and their works is given in Appendix A. I have excluded from this chapter and Appendix A purely medical works which deal mainly with treatment, and also works on speech; these topics are outside the scope of this study.

Important detailed sources which furnish information on the scientific study of the voice are Holmes (1885) and Moore (1937). The latter work contains a very detailed account of all the techniques used to investigate the larynx up to 1937. The following are important sources on the history of singing and vocal pedagogy: Duey (1951), who covers the period up to 1777; Monahan (1978), who covers 1777 - 1927; Fields (1947), who covers 1928 - 1942, and Burgin (1973), who covers 1943 - 1971.

I am indebted to these books for valuable summaries and references, but with Duey's and Monahan's works, it is useful if one is already familiar with the literature and understands the historical perspectives: otherwise, the detail is bewildering. Monahan also creates confusion about the dates of some publications. As Monahan says:

"No attempts have been made to assess the validity or to evaluate the opinions of those authors selected for this study... Many opinions presented in this work are
In other words, there is no criticism in Monahan's work, merely a presentation of selected quotations. In the present work, I have attempted to provide scientific criticism wherever possible. Fields provides detailed summaries of controversial points, and of the numbers of writers supporting or condemning them (pp 247-249).

Duey considers that:

"The not inconsiderable vocal art and virtuosity of later antiquity passed into limbo and withered for nearly 1000 years until about 1100." (pp 30-31.)

He also says that there was a considerable degree of vocal pedagogy in the sixteenth century, when singers were told when and where to breathe, but not how to breathe. (p 42.) At the same time, there was an increasing interest in the anatomy and physiology of the larynx, with works by Vesalius (1543), Codronchi (1597), and others. (See Appendix A.)

Between about 1575 and 1623, there were two important developments in singing. Firstly the rise of the castrati, and secondly, the invention of opera. Ornamentation increased from the mid-sixteenth century (see for example the work by Caccini, 1602), and also the use of early styles of recitative came into being in the last decades of the sixteenth century.

Bel canto singing is believed to have originated with the
Renaissance, influenced by the Camerata in Florence in particular. (Troup, 1982, 1.) The castrato voice was probably the most important element in its development. (Duey, 1951, 44.)

Taylor (1908, chapter VII) summarizes the later situation well when he says that there were three periods of voice culture:

1) 1600 - 1741: empirical techniques were used: the so-called bel canto period. (See below.)

2) 1741 - 1854: a transitional period brought about by the experiments of Ferrein (see section A4). An enlightened work, according to Taylor and many other writers, was written in 1803 under the influence of Cherubini (Anon., 1803). This showed that in this transitional period, there was little attention to mechanical rules and breathing.

3) 1855 onwards: the invention of the laryngoscope lead to mechanical methods of instruction, which have tended to continue since. (Monahan, 1978, 226, dates the era of scientific voice training from Garcia's work of 1840: see Garcia, 1840.)

The term bel canto deserves special consideration, as it is so widely used and abused. Duey (1951) is probably the key writer on this subject. He says that the term did not acquire a special meaning in Italy until the 1860's, but it "...denotes the Italian vocal technique of the eighteenth century with its emphasis on beauty of tone
and brilliant virtuosity, rather than dramatic expression or romantic emotion." (Apel, 1944, quoted in Duey, 1951, 3.)

It is easy to assume that bel canto techniques spread throughout Europe. However, the term should be limited to Italian methods as there were distinct regional differences. For example, there was a quite separate French style of singing:

"The Italian manner of singing is refined and full of art; it moves us and at the same time excites our admiration, it has the spirit of music, it is pleasant, charming, expressive, rich in taste and feeling, and it carries the hearer agreeably from one passion to another. The French manner of singing is more plain than full of art, more speaking than singing; the expression of the passions and voice is more strange than natural." (Quanz, 1752, quoted in Sadie, 1980, 17, 342.)

Duey himself limits the term bel canto to the Italian methods of the seventeenth and eighteenth centuries (p 11), and says that its conflict with German Sprechgesang in the nineteenth century was an important factor in the etymology of bel canto. A valuable book on the vocal technique of the seventeenth century is that by Goldschmidt (1890).

The four bel canto skills to be mastered were, in order:

1) the ability to sing intervals correctly;
2) ornamentation;
3) elegance, charm and decorum;
4) sweetness of voice. (d'Avella, 1657, 112.)

As Duey says (p 154), there is little agreement on techniques today, and it is difficult to set standards. In the bel canto period, there was a general agreement on standards, although teachers did not, in general, write detailed accounts of their methods. Writers such as Tosi (1723) lay much emphasis upon the style of performance: vocal technique was acquired simply by long practise and careful attention to the quality of tone. (White, 1982D.)

Although not stated above, it was taken for granted that a good legato style was a fundamental necessity for bel canto, as it is for all good singing. Another important fundamental was messa di voce: a crescendo and diminuendo on one note. Manén (1979, 41) even says that this was the main feature of the classical school of singing (or bel canto). From a work by Agricola (1757), Duey (1951, 153) derives this opinion:

"Therefore it may be safely assumed that physiological knowledge had little or nothing to do with the vocal technique of the bel canto period."

Henderson (1909, 8) says that beautiful tone was cultivated to the detriment of the text, and he considers this to have been a "radical error". I think that he misses an important point, which is that the very nature of the music sung in the bel canto period made the text subordinate. One must
always look at singing styles in the context of the historical period. Further, as Sadie says (1980, 17, 342), vocal techniques have always influenced the composition of music.

Because of the vague nature of bel canto teaching, anyone who today sets himself up as a bel canto teacher can teach virtually anything, without much fear of informed criticism! Even in 1906, Henderson wrote:

"To hear the singing teachers talk, one would think that every one and no one possessed the true Italian school. Each teacher claims it, and vehemently denies that any one else knows anything about it."

An important point which is often forgotten is that the great exponents of bel canto were the castrati (evirati or musici). As I have pointed out elsewhere:

"...much confusion appears to have arisen because later writers forgot, or ignored, the fact that works such as those of Tosi [himself a castrato] often referred in large part to castrati singers. The old Italian techniques might not be very suitable for the kinds of voices which we hear today." (White, 1982D.)

An example of a book which contains erroneous reasoning as a result of this very mistake, is that by Husler & Rodd-Marling (1976, 84).

(See also section D2, which deals with castrati voices.)

The seventeenth and eighteenth centuries saw the rise of the
professional opera stars, many of them being castrati.

As mentioned above, bel canto involved empirical techniques: the teachers listened to their pupils and adjusted their teaching to suit each voice. Wright (1955, 7) expresses similar sentiments, when he says that a singer must be taught

"...to register for himself the sensation of what is good, so that he can reproduce it at will."

Negus (1929, 434) makes a strong plea for the use of empirical teaching techniques,

"...because it is impossible [for students] to acquire any knowledge of the anatomy and physiology of the vocal mechanism except with the expenditure of some years of study."

The following quotation sums up what happens in many cases today:

"Teachers fall down when they try to force pupils into the rigid straitjackets of their favourite methods of voice production, and lay too much emphasis on anatomical and physiological principles which the pupils, and probably they themselves, do not fully understand." (White, 1982D.)

Brodnitz (1953, 40) agrees broadly with this statement, and criticisms along similar lines are made by Brown & Brown (1913, 21).
During the eighteenth century there was a trend towards extremes of pitch in vocal and instrumental music, and this continued with a rise in concert pitch in the nineteenth and early twentieth centuries. The rise of Romantic opera in the nineteenth century, together with the building of larger opera houses, led to the idea of "resonance", intended to increase vocal power. This was something neglected by the bel canto methods.

Vocal Science has blossomed during the last one hundred years, stimulated by the scientific discoveries of the nineteenth century, and especially by Garcia's laryngoscope. (See details in section A6.) The development of this instrument was arguably the single most important event in the whole history of the scientific study of the voice. But has Vocal Science produced singers better than their predecessors? Possibly not:

"The art of singing is an aesthetic art, not an anatomical study." (Henderson, 1938, 51.)

"Is a knowledge of anatomy of any assistance in the acquirement of skill in performing complex muscular actions? Not in the least." (Taylor, 1908, 145.)

This last comment is probably a reaction to a strong argument for the need for a physiological method which was put forward by Browne & Behnke (1890, 1):

"Some have ridiculed the idea that an acquaintance with this subject [vocal physiology] is of any more use to the vocalist than is the anatomy of the hand to
the pianist. But the examples are not analogous, inasmuch as the pianist obtains his instrument ready made for him, and if he wear it out or injure it he can purchase another, while the vocalist has to form his voice, and if he wrongly use it, it may be gone for ever."

I am not sure of the validity of this statement. After all, it might be argued that the pianist's hand is equivalent to the singer's voice, and what does a pianist need to know of the hand muscles? As Monahan (1978, 226) says, the inclusion of minute anatomical and physiological material in works on singing was "obligatory" around the end of the nineteenth century. Also, as Arnold (1973, 141) says, in the second part of the nineteenth century, laryngology expanded into voice science, or "phoniatics", a term coined by Mackenzie, the great medical authority on the voice.

I think that Mackenzie summarizes succinctly the late-nineteenth-century attitude towards the teaching of singing:

"...a new school has arisen of late years, which demands that an exact and profound acquaintance with the anatomy and physiology of the vocal organs gained by dissection of the dead, and laryngoscopic examination of the living body, familiarity with the mysteries of acoustics, pneumatics, and hydrostatics, together with some added tincture of metaphysical lore, shall form part of the equipment of the unhappy wight who wishes to take up the profession of a
singing master." (Mackenzie, 1890, 73.)

A further trend in late Victorian and Edwardian times was a development of interest in phonetics. This is illustrated by works written by Bell (1867), Ellis (1878) and Mott (1910).

Taylor (1917, 97) lists three distinct types of vocal instruction:

1) empirical;

2) mechanical;

3) attempts to interpret empirical doctrines in the light of scientific analysis.

There is a further category, represented by Greene (1912) and Marafioti (1922 and 1925), who was Caruso's physician. These writers show a strong reaction to scientific methodologies, particularly on the question of breathing, and call for a return to "natural" breathing. Monahan (1978, 227) dates 1896 as the beginning of this "natural school", and he gives Arlberg (see Arlberg 1896 and 1899), Thorp & Nicoll (see Thorp & Nicoll 1896, and Thorp 1896A and B), and Botume (see Botume 1885 and 1897) as leading members. According to Fields (1947, 243), their slogan was:

"Train the mind, train the ear, but let the vocal organs alone."

Monahan (1978, 228) lists Botume (1885 and 1897), Parisotti (1911), Shakespeare (1899 and 1924), Shaw (1914) and Taylor
(1916) as trying to recapture the "old Italian school", whilst Henderson (1906), Klein (1923), Myer (1883) and Taylor (1908) offer useful surveys of the work of others. However,

"Much of the information offered by authors would be of considerably greater value if they had taken the trouble to define their terms." (Monahan, 1978, 228.)

Many people now feel that there has been too much emphasis upon the scientific aspects when teaching singing. Henderson (1938) in particular, is very critical of the standard of singing in the first part of this century. He had heard many of the great late-nineteenth-century singers, and was in a good position to judge whether the general standard of singing had degenerated as Vocal Science came to the fore. He is adamant that it had declined, and he blames a change in teaching and study techniques; in particular the lack of time involved is criticized heavily.

Henderson is cutting in his references to many famous singers, which makes one wonder just how good they really were. I have commented on this elsewhere, when I pointed out that each generation has tended to denigrate its own singers, and lament those of bygone "golden ages" of singing. (White, 1982D.) For example, Garcia said that the artists of the 1870's were "unquestionably" poorer that those of 50 years before (Klein, 1923, 12), and The New Grove... refers to the "golden age" of Wagnerian singers in the 1920's and 1930's. (Sadie, 1980, 17, 344.) (Many other similar examples could be quoted.) On the other hand, Henderson's enormous reputation as a critic adds credence to
his views. (Henderson was critic of the New York Times from 1887 - 1902, and of the New York Sun from 1902. He died in 1937.)

More recent books which show a reaction against the scientific approach to voice training are those by Field-Hyde (1950) and Litante (1962). Field-Hyde's book is based upon great practical experience and contains strong support for empirical teaching methods.

During the twentieth century, scientific research on the voice has escalated, and there is a multitude of publications. Many aspects of voice production have been elucidated, and these are discussed in the relevant sections of this work. Also, a list of important selected twentieth-century publications is given in section A7. Despite all this activity, many would question whether the teaching of singing has been much enhanced by increasing scientific knowledge.
CHAPTER 3: POSTURE AND BREATHING IN RELATION TO SINGING

Further details of the Alexander Technique and related ideas may be found in Appendix B.

3.1: POSTURE AND SINGING

"Perhaps the richest comedy presented by the evolutionary process is that the creatures nature designed to have perfect posture and vision should to-day present a picture of bespectacled decrepitude."

(Dart, 1947, 90.)

Most singing teachers are aware that posture is of great importance to the singing process, but how many realize that correct posture is of immense significance to every aspect of life? The posture of most people is appalling:

"...the 5 per cent. or 10 per cent. of human beings who exhibit poise are...dancers, jugglers, tight-rope artists, skating enthusiasts, top-line sportsmen and the like..." (Dart, 1947, 78.)

And again:

"Amongst diseases there is, therefore, no condition more entitled to the term pandemic than malposture."

(Dart, 1947, 78.)

It seems that the position of the head in relation to the body is a key factor in singing. F. Matthias Alexander suffered hoarseness as a young actor:

"I considered that the source of my trouble lay in the
use of my vocal organs." (Alexander, 1932, and Alexander Journal, 1972.)
"...his voice problems cleared up when he had learned how to stop pulling his head back and down." (Barlow, 1973, 20.)

This lead to Alexander's basic premise: Use affects functioning.

The correct position of the head is thus Alexander's Primary Control (see Fig 3.1), and Alexander himself wrote a paper on vocal problems. (Alexander, 1906.) Duarte (1981) has also described how the Alexander Technique may be applied directly to singers. (Section B1 contains further comments about the correct positioning of the head.)

FIG. 3.1: CORRECT AND FAULTY HEAD POSITIONS (Adapted from Barlow, 1973)

Manén (1974, 16) seems to go against Alexander's basic idea, when she writes that when singing, the neck should be straightened and extended and then moved backwards.
The idea of **lengthening** is very important to Alexander; so too to some singing teachers who encourage the pupil to feel that his body is suspended from the head, which in turn is suspended from above. Dart makes an excellent summary:

"The head, somewhat forwardly inclined, pivots freely on the vertebral column, and the musculature of the neck, without displaying any stiffness, pain or tension, freely suspends the jaws, tongue and laryngeal apparatus, so that unimpeded chewing, swallowing, breathing or speech can occur concurrently."

The Alexander Technique is now widely-accepted by singing teachers, singers and actors, and I found it prominent in exercise classes (with Noelle Barker, for example) which I attended at the Britten-Pears School for Advanced Musical Studies in 1977, 1978 and 1979. Duarte (1981, 3) says that in America it is taught at the Julliard School, the Eastman School and Indiana University, and in this country at the Guildhall School of Music (where Noelle Barker teaches) and the Royal College of Music. The Ernest George White Society also appears to endorse the Alexander Technique. (E. G. White Society, 1982, 15.) (See sections 4.4 and 9.2.)

Another technique which has proved valuable to singers is Tai Chi, the Chinese movement method which instils excellent co-ordination, balance, and what Dart would call poise. I attended such classes with a group of singers in 1979. Again, an expert teacher is needed.
Dart (1947, 82) believes that the fact that many sports and other activities encourage right- or left-handed asymmetries leads to postural torque, in other words, a twisting of part of the body. This twisting is easy to see in singers, who often stand with one shoulder higher than the other; my own left shoulder used to be noticeably higher than the right when singing. The well-known teacher Nancy Evans told me that in her experience, most singers tend to lift one shoulder, usually the left one. I postulate that this is because most are right-handed, and tension whilst singing tends to make them grip down involuntarily with the right hand.

This brings me to an interesting concept put forward by Lucie Manén. She derives her so-called "startled" technique from a book by Wilson (1918), and this assumes that the feeling of being startled is the correct preparation for running, dancing, intense listening or classical singing:

"The person draws instantly a sharp hollow breath popularly called a gasp or snap breath - the chest is lifted - and the costal margins are pulled apart - the abdominal muscles are tautened, the abdomen is flattened - the larynx closes, breath is held - the jaws open abruptly and are kept half an inch apart in a parallel position - the eyes open - the facial muscles are lifted - the muscles of the back of the leg are tautened." (Manén, 1979, 36.)

Duarte (1981, 8) says that it has been shown that a slamming door produced a "startle pattern" in a singer. This led to bad posture, with the head and neck muscles shortened, the
head pushed forward and the shoulders lifted. How can such a "startled" posture lead to what Barlow (1973, 51) has called "postural homeostasis", or the "relaxed tension" of Wright (1955, 8)? In other words, a perfectly relaxed and balanced system. Manén's term is anathema to anyone familiar with the Alexander Technique, because it seems to imply "alarm". I discussed this in 1983 with a very experienced Alexander teacher (Johnston, 1983), who agreed that the concept was quite incorrect for preparing posture when singing. She pointed out that the "startled" pattern is constantly being triggered by the bustle of cities, and suggested that perhaps we should used the word "surprised" if we wish to describe correct posture succinctly.

In fact, I believe that Manén confuses the words "startled" and "surprised" in view of some of her comments (Manén, 1974, 18). In the latter work, she describes her "startled" technique in detail, but seems to be describing what I would call a "surprised" technique; in other words, a pleasant, uplifting sensation. So in fact, Manén may have a valid hypothesis, but she uses misleading terminology. I was taught Manén's technique by Sir Peter Pears, and he certainly used the sensation of a pleasant surprise to elicit the desired response.

I will mention one further point at this stage which has interested me, and which I have not been able to investigate. Manén (1979, 42) says that the trigeminal region of the upper part of the skin of the face has an important effect upon the larynx. (She is really indicating that facial expressions are very important in affecting the
voice.) I had thought that this idea was speculative, despite the fact that the trigeminal nerve is extensive, until I read the following in Dart (1947, 86):

"The importance of muscular mass-reflexes of trigeminal origin have been brought to light in a dramatic way by the study of foetal reflexes."

Trigeminal stimulation in the foetus leads to strong contralateral bending of the trunk and rotation of the pelvis. (Dart, 1947, 87.) The trigeminal innervates the anterior end of the body in general and the respiratory tract in particular, and there may well be some truth in Manén's idea. This is certainly a topic which warrants further study.

From a consideration of the evidence presented, and from practical experience, I suggest the following as an "ideal singing posture". (This accords well with the Delsarte exercise described in section B2.)

A singer should have his feet spaced apart comfortably, with one foot slightly in front of the other. (Probably the right foot if right-handed.) The weight of the body should be taken on the balls of the feet, the knees flexed slightly, and the buttocks pulled in to move the pelvis forward. (Caruso is said to have mentioned pulling in his buttocks when singing - one of his few references to posture.) Manén (1974, 15) agrees that the pelvis should be tilted forwards when singing. The back should be lengthened and widened, with the head lifted forward and kept level.
The upper chest will probably rise to the correct level of its own accord, and the singer then concentrates on breathing with the back and sides of the upper abdomen. The ribs will then rise slightly as air moves into the lungs, without further conscious effort. The lower abdominal muscles are kept in a slight degree of contraction even when breathing in; this contraction increases with expiration, especially when high notes are sung. For example, Tetrazzini says:

"...no singer can really get the high notes or vocal flexibility or strength of tone without the attack coming from this seat of respiration." (Caruso & Tetrazzini, 1909, 16.)

The latter point has no substitute, but Mancini (1774, 95f, quoted by D'ley, 1951, 63) noted a method still attempted by some singers today:

"...singers, who in reaching a high tone stand on their toes, thinking this will help them."

3.2: BREATHING AND SINGING

"Chi sa respirare sa cantare."

The anatomy and physiology of the respiratory system are discussed in Appendix C.

3.2.1: Breathing techniques

There is no doubt that posture has a profound effect upon breathing patterns. But how should one breathe in order to sing? As Fields (1947, 93-94) says, with reference to writers on breathing and singing:
...author opinion on this subject is diversified and fragmentary.

There seems to be a consensus of opinion amongst those who are well-informed about physiology that breathing should be as low as possible when singing. Barlow (1973, 124) says that breathing must not start by a raising of the upper chest and sternum, which do become raised at the end of the breath. (He is not referring specifically to singers.)

This runs counter to the idea that a singer must thrust his chest forward and upward at the outset: this is tiring and actually restrictive during breathing. (For example, see Mackworth-Young, 1953, 37.) In fact, if the "ideal singing posture" suggested in section 3.1 is adopted, with a lengthening upwards towards the head, the upper chest rises automatically to a comfortable level. Personal experience shows that a higher chest position adds no benefit when singing, such as a greater lung capacity; indeed, such a position makes singing a tiring process.

This fact is borne out by comments in the literature which are far too numerous to list, and clavicular breathing, which is the ultimate in high chest breathing, is condemned by most authorities on singing. However, Jenny Lind found clavicular breathing "indispensable" as a means of quick replenishment of the lungs. (Rockstro, 1894, 15.) It is significant that Garcia, who taught Lind, also mentioned the use of this technique (e.g. Garcia, 1894, 4).

Barlow (1973, 124) says that breathing should be an activity
of the middle of the back, and of the back and sides of the abdomen; in other words, the common idea that a singer should simply push down his diaphragm, thus displacing his upper abdominal contents forwards, is really wrong. Many singing teachers recognize this fact, and try to develop the back muscles. For example, in 1896, Thorp (1896, 11) described how to acquire backward expansion of the ribs by leaning forwards when breathing in, with the hands on the back, in order to feel the expansion. I was taught this technique by Noelle Barker, and it is certainly valuable. Other teachers use different techniques to achieve the same end: for example, they may suggest that the pupil should feel that the air passes into his lungs through his back. This is a powerful concept and usually has the desired effect. The Alexander idea of widening the back and pulling the shoulder-blades apart encourages the use of the back muscles when singing.

"Expiration is assisted during vigorous breathing by contraction of the abdominal muscles. (Cotes, 1968.) The abdominal musculature supports the weight of the viscera, thereby relieving the ribcage of an appreciable gravitational load. According to some authorities, the abdominal wall and diaphragm form a stable platform during the act of singing; the ribcage contributes actively to breath control, but its large surface area means that its apparent motion may appear small. (Sears, in Critchley & Henson, 1977.)" (White, 1982B, 146.)
I quote this summary from my previous work as it is succinct, but it must be made clear that the diaphragm cannot contribute actively to expiration. (See section Cl.) This fact is not understood by a large number of singing teachers and singers. The abdominal musculature contracts against the abdominal contents during expiration, thus pushing up the diaphragm. de Bacilly (1668, 28) said that a singer must sing as much as possible from the diaphragm; this kind of statement is ambiguous, and leads to much confusion.

Singers talk frequently of "support" (appoggio); this has been defined as:

"The resistance that the inspiratory musculature offers to oppose the expiratory collapse of the breathing organ." (Winckel, 1952, quoted in Luchsinger & Arnold, 1965.)

It is true that there is even an "abdominal breathing" school which believes in a gross exaggeration of abdominal movements: this is quite ridiculous on postural and physiological grounds. Indeed, Manén (1979, 38) says that some singers tend to contract the abdomen too much, thus compressing the lungs, causing a sensation of not having enough air. I consider that Manén is really describing what a chest physician might call air-trapping; I have suggested in another work that this might occur in athletes. (White, 1980, 99.)
3.2.2: The nervous control of respiration

This is a complex topic, and there would be little virtue in exploring this in detail in the present work. (See also sub-section C3.2.) However, some interesting points are made by Butenschön and Borchgrevink (1982) which have a direct relevance to singers. They point out (p 53) that many writers stress the need to maintain the inspiratory position ("yawn") when singing. This is because the larynx is then lowered, as discussed in sub-section 3.3.2, and because activation of the upper pharynx leads, by reflex action, to tensing of the inhalatory muscles, and expansion of bronchi. This allows controlled expiration and fits in well with the definition of appoggio given in sub-section 3.2.1. On the other hand, activation of the lower pharynx and larynx (as in the cough reflex) leads to tensing of the abdominal wall (for forced expiration), and constriction of the bronchi.

Much of Butenschön's & Borchgrevinck's book is devoted to the "dorsal method" of singing, whereby singing is supposedly brought about by the conscious use of the back muscles. The writers suggest (p 9) that every pitch has a "place of origin" in the vertebral column: the higher the note, the lower the level of this place of origin. They obviously have a great belief in their method, but many of their explanations are extremely confusing. (See section A7 for an example of a ridiculous exercise suggested in this book.)
3.2.3: Breath pressure and flow rates

(Details of units of pressure are given in Table C1.)

Proctor (1980, 106) says that at full lung volume, the elastic forces of the chest and lungs, with the muscles relaxed, produce about 18 – 22 mm Hg (above atmospheric pressure) against the closed glottis. Only about 7 mm Hg is needed in singing; this can be demonstrated by the famous candle experiment: a lighted candle held in front of the mouth only flickers if a note is sung correctly. (See White, 1982D.) (Wyke, in Bless & Abbs, 1983, 74, suggests that 7 – 14 mm Hg is needed in mf singing, but that peak values reach 37 – 51 mm Hg at ff. However, he does not say whether he is referring to trained singers.)

I have explained in another work (White, 1982D) that although it may be thought that a great deal of force is exerted upon the vocal cords when the chest and abdominal muscles are compressing the thorax, this is not the case. Taylor (1908, 115ff) likens the whole system to a hydraulic press. Fig. 3.2 illustrates Taylor's theory. Although the force exerted on the larynx is smaller than might be supposed, the breath flow through the larynx can be fast if unrestricted by the vocal cords or by control of the muscles of expiration. A small movement of the thorax produces a much larger movement of air through the larynx. (I also built a piece of apparatus suggested by Taylor which displays his ideas clearly. This is illustrated in White (1982D).)
FIG. 3.2: THE PROCESS OF EXPIRATION LIKENED TO A HYDRAULIC PRESS (Adapted from White, 1982D, after an idea by Taylor, 1908)

\[ \text{\textit{A}} \]

(\textit{\textup{A}}} \text{ chest and abdominal muscles})

\[ \text{\textit{R}} \]

(\textit{\textup{R}}} \text{ larynx})

A movement at \textit{A} produces a movement 1,000 times greater at \textit{R}.
Thorp (1896A, 29) laid stress upon the importance of the density of the air in the lungs, which, he said, is altered by the action of the relevant muscles. He pointed out that an electric bell in a bell jar cannot be heard if the air is evacuated. The sound returns as air is allowed in, and becomes louder still if air is pumped in. Thorp believed that compressing the air in the lungs would increase the vocal intensity. (See sub-section 6.8.2.) He also believed (1896B, 50ff) that making the trachea shorter and wider would increase the vocal intensity; hence the use of an exercise described in sub-section 6.8.3. Thorp was certainly correct about the physical basis of his ideas, but whether they work in practice in voice production is open to question: could air be compressed sufficiently in the lungs under normal conditions to produce the results he suggested?

A widely-held view is that the subglottic air pressure increases with the pitch of the fundamental (see, for example, Hollien & Curtis in Large, 1973, 130). I have pointed out already in section 3.1 that contraction of the abdominal muscles must be increased when singing high notes, and it is generally believed that a lack of adequate muscular "support" leads to undue strain in the larynx. It is easy for the singer to feel this strain himself, and there is no doubt that the need for good abdominal support is very real.

Hollien & Curtis (in Large, 1973, 131) suggest that in modal registers, as the vocal folds are closed for a significant period of time, there is a build-up of subglottic pressure
which leads to a greater intensity of sound than is possible in the falsetto register. This is presumably because a greater pressure causes a greater amplitude of vibration in the vocal folds. (See section 4.3 for more details of vocal fold action.) Therefore, Thorp's theory about increased density leading to a greater sound intensity may simply be due to an increased pressure. Of course, the reverse may be the case: perhaps density is the key factor, rather than pressure. No doubt both are involved, but there is considerable doubt about the whole matter.

Some figures quoted by Manén (1979, 41) suggest that the air flow may decrease as a crescendo is made; these are shown in Table 3.1.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Sound</th>
<th>Loudness (dB)</th>
<th>Air-flow (litres/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>226 (c A3)</td>
<td>&quot;ee&quot;</td>
<td>74</td>
<td>8.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>79</td>
<td>7.1</td>
</tr>
<tr>
<td>222 (c A3)</td>
<td>&quot;ah&quot;</td>
<td>74</td>
<td>12.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>79</td>
<td>9.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>82</td>
<td>9.1</td>
</tr>
</tbody>
</table>

Hardy (1956, 131) says that breath consumption is least at mp and rises at pp and ff: from a singer's subjective point of view, I agree with Hardy's assertion. The measurement of
breath flow whilst singing is difficult: any mask which is used inevitably interferes with the act of phonation, and I think that figures such as those in Table 3.1 should be treated with caution.

Hardy (1956, 135) suggests that the overall range of breath flow is from 2.4 - 13.2 litres/min, being least in sopranos and tenors and highest in contraltos and basses. Common sense suggests that this statement is probably true. (See also sub-section 5.3.2 for further comments about the breath consumption in modal registers.)

3.2.4: Methods of breathing advocated by singers and teachers

Taylor (1908, 21) suggests that there are two main systems of breathing used by singers:

1) Abdomen protruded, upper chest held firm, greatest expansion at the base of the lungs.

2) Abdomen drawn in slightly, chest expanded upwards, laterally, forward and backward, upper chest held in a fixed and high position.

Neither of these schemes corresponds exactly to that which I have suggested as "ideal" in section 3.1, but scheme 2) is the nearest. I think that scheme 1), which many would refer to as "abdominal breathing", stems from work by Mandl (1876 and 1885). Mandl said that the abdominal wall should be flaccid, a view opposed by many writers, such as Garcia and
Mackenzie (1890, 88):
"...in consequence of Mandl's teaching...singers are often taught to breathe by pushing down the diaphragm and protruding the stomach."

Lunn (1900, 28-29) also disagreed with Mandl's ideas. Lunn, Garcia, Klein (1923, 22) and many other authorities state that the abdomen must be drawn in when singing; the experiences of most singers confirm this fact. However, Miller (1977, 38) says that some German teachers still advocate Mandl's method.

One must be very careful when reading some books on singing, in view of the fact that certain powerful authorities have advocated idiosyncratic methods of breathing. A good example is Lehmann (1902), who had a strange (and confusing) technique which seems to have been due to her need to overcome childhood asthma. Writers such as Henderson (1938, 33) have remarked upon this fact. Furthermore, Proctor (1980, 143) has identified what he considers to be the most important teaching fault:

"...failure to use appropriate simple [postural and breathing] exercises to develop that correct use of the breath and breathing mechanism so absolutely essential to effective talking or singing."

3.2.5: Imagery used to help breath control

An idea used by many teachers is this:

"Breath control has been described as a column of air which supports the note above it; just as one sees in
.a tiny fountain the column of water supporting the ball on its jet." (Shakespeare, 1924, 4.)

Wright (1955, 8) suggests almost the same idea, and along similar lines, Jean de Reszke advocated that the voice 'in the mask' is united to breath control from the diaphragm. (Cooke, 1921, 146.)

Shakespeare (1924, 8) describes an idea used by many teachers:

"The act of breathing out slowly should be like warming, quite different from that of blowing."

Appoggio has been mentioned already in sub-section 3.2.1: a common idea is to imagine that one is actually inspiring when singing. This provides the necessary opposition to the expiratory muscles; comments on this may be found in Shakespeare (1924, 7) and Cooke (1921, 94). (It will be noted that the sensation of "yawning" whilst singing is similar: see also section 4.2 and sub-section 6.7.3.)

3.2.6: Singers with legendary breath control
As mentioned in section D2, the castrati like Farinelli were famous for their breath control: their physical abnormalities assisted this. Four other singers deserve special mention. It was said to be impossible to tell when Jenny Lind breathed, unless she did so for dramatic effect. Rockstro (1894, 9) said that she and Rubini were the supreme masters of breathing. Lablache once held Rubini's hand and watched his face whilst singing, for a period of four
minutes; he could not "detect the act of breathing in the least degree". (Rockstro, 1894, 9, and Mackenzie, 1890, 84.)

Lablache himself is the subject of a famous anecdote:
"At dinner one day this artist, full of fun, sang a long note from piano to forte, and back to piano; then drank a glass of wine, without having breathed; then sang a chromatic scale up the octave in trills, still in the same breath; and finally blew out a candle with his mouth open!" (Shakespeare, 1924, 114.)

One may be tempted to dismiss such stories, but the contemporary singer, Piero Cappuccilli, is also credited with phenomenal breath control. This is said to be due to his experience of sub-aqua diving, and is acknowledged by other great singers, such as Placido Domingo.

3.2.7: Environmental influences which affect the respiratory system
I propose to mention two phenomena which, I believe, have some historical significance in the context of the present work.

HAY FEVER
The term "allergy" was introduced in 1906, and the scientific study of allergies dates from the work of Charles Richet, (1850 - 1935), at the beginning of this century. (Asimov, 1975, 459.) Obviously, people had previously suffered from allergies, and no doubt hay fever was thought to be due to "summer colds" or the like. In 1937, Daniele
Bovet, (born 1907), discovered the first antihistamine compounds, which help to prevent allergic symptoms caused by the release of histamine in the body. (Asimov, 1975, 720.)

Hay fever is a serious problem for some singers, perhaps a relatively large number, as it is estimated that about 5% of the British population suffers from this complaint, and that about 1% of the population requires medical treatment. (Thomson, 1981, 428.)

One often sees mention in nineteenth century works of the fact that flowers in a concert hall are a danger to singers, and I believe that this idea may have arisen because some singers were allergic to the flowers' pollens. The superstition amongst stage performers that real flowers should not be used on stage could have arisen, at least partly, in a similar manner.

AIR-BORNE IONS

In fresh country air, there are usually 1,000 to 2,000 ions per cubic centimetre, with a positive - negative ratio of five to four. In cities, the number of ions can fall as low as 80 per cubic centimetre, with a positive - negative ratio of two to one. Positive ions increase in concentration before thunderstorms, contributing to the oppressive atmosphere; they also tend to build up on plastic surfaces, causing problems, for example, when playing gramophone records.

Man thrives in a negatively-charged atmosphere, and a high
proportion of positive ions can lead to insomnia, irritability, tiredness, exacerbation of allergic conditions such as hay fever, and allegedly, many other unpleasant symptoms. A great deal has been written about these effects in recent years, and there is a thriving market for ionizers which fill the atmosphere of a room with negative ions. I built such an ionizer (see Fig. F1), and found that it did help to relieve my hay fever symptoms; it was also used to help reduce static electricity on gramophone records. (See sub-section F1.1.) Such instruments could have a therapeutic effect in concert halls; this might help singers with hay fever and similar conditions.

I think that I have found an early comment upon the detrimental effects of positive ions on the singing voice:

"...I have a theory that the electricity in the air [of cities] is injurious [to the voice]." (Emilio de Gorgoza - baritone - in Cooke, 1921, 197.)

The effects of these ions upon the singing voice could be profound, and I believe that this subject warrants further detailed study. (See also White, 1982E, 9.)
CHAPTER 4: THE FUNCTIONING OF THE LARYNX IN RELATION TO SINGING

4.1: INTRODUCTION

(The anatomy and physiology of the larynx are discussed in detail in Appendix C.)

Many authorities point out that the larynges of great singers appear little different from those of others. An example is Corri (1811, 5), who concludes, as others have done, that the manner of use is more important than the structure. However, Luchsinger & Arnold (1965) list anatomical features which they say are characteristic of a "well-built vocal organ". One may summarize these by saying that the cavities from the nose and mouth downwards should be spacious; the soft tissues should be flexible; and structures such as those in the larynx should be symmetrical in appearance.

4.2: THE "SHOCK OF THE GLOTTIS"

The actual mechanisms of vocal fold movements are discussed in section 4.3, but it is worth considering the "attack" stage itself. It is generally held that the attack stems from the actions of the true vocal folds, but some authorities believe that the false folds are involved.

Much discussion has taken place over the last century about Garcia's use of the term coup de glotte (shock of the glottis). Many people have believed that Garcia advocated an
attack rather like a slight cough; in other words, a pronounced approximation and immediate release of the vocal cords, allowing a sudden flow of breath. Opponents of Garcia used this as ammunition, pointing out the possible dangers of such a technique, but Garcia appears to have been misinterpreted. At least, he implied this in his last major work (Garcia, 1894, 13), where he stated that the coup de glotte was more delicate than a cough. Garcia's editor and pupil, Hermann Klein, in a footnote to the same page, said that Garcia's term had been misinterpreted, and that the student should feel only a "mental cognizance", not an actual physical sensation in the throat. This may well have been an attempt to wriggle out of what was by then an embarrassing situation, but Klein confirms his point in a later work (Klein, 1923, 25).

Vennard (1968, 44) says that Garcia actually meant that an imaginary aspirate should be used, and points out (p 43) the obvious fact that a glottal plosive is damaging. In fact, it is difficult to believe that a teacher such as Garcia, steeped in traditional singing techniques, could have advocated the use of a glottal plosive. On the other hand, one wonders how he was influenced by his use of the laryngoscope. Did he gain a distorted view of laryngeal function which led him to the idea of the coup de glotte?

There are two extreme and undesirable forms of attack: a pronounced coup de glotte (the vocal cords meeting before air is expelled), producing a distinct "click"; and an aspirated "h" (the vocal cords meeting after air is
expelled). The latter may be heard in many unwieldy bass voices attempting rapid runs, where an aspirate on each note is a substitute for correct legato singing. The ideal attack lies somewhere between the two extremes, and was described by Browne and Behnke (1890, 28) as being when the vocal cords meet just at the moment when air strikes them. They said that this was the true *coup de glotte*, and it is considered by the majority of singers to be the most desirable form of attack.

It is important to realize that the form of attack may have to be modified according to the pitch. As Scholes (1955, 1093) says, on high notes the vocal folds are tighter, and therefore more force is required to set them into motion. Indeed, it is easy to detect the pronounced attack which many singers use on high notes.

Manén (1974 and 1979) has a rather different idea of the attack stage. She believes that before phonation, the larynx closes completely from the level of the true vocal cords upwards. There is good evidence for this, mainly from x-ray studies carried out by Manén and other workers. (See also Ardran, Kemp & Manén, 1953.) The same thing may happen during coughing (see sub-section C3.1).

Fig. 4.1 shows the supposed condition of the larynx immediately prior to phonation; Thorp & Nicholl (1899, 24) and Taylor (1908, 28) had similar ideas about the involvement of the false cords. The supposed valvular action of the latter is discussed in sub-section C3.1, and other ideas about their rôle in voice formation are mentioned in
section 5.4.

Manén suggests (1974, 28) that the larynx is closed partly by the backward movement of the epiglottis, which is in turn affected by structures such as the hyoid bone. When the larynx opens abruptly, the "click" produced is due to the separation of the moist membranes. Air then rushes into the glottis from below and above, the latter movement supposedly producing the sense of inspiration when singing (pp 22 and 38). An alternative explanation is that the sense of inspiration may be simply a method of obtaining the "yawn" position. (See sub-section 6.7.3.)

4.3: THE ACTION OF THE TRUE VOCAL FOLDS DURING PHONATION

I emphasize "during phonation", as it would be all to easy to digress in this sub-section. There is much controversy about the actions of the larynx during breathing, coughing, etc., but a discussion of these features would be inappropriate in the present work.
Ferrein (1741) thought that sound was produced directly by vibrations of the vocal folds, in the way that a violin string produces sound. In fact, over the centuries, the mechanism of the voice has been compared to the action of the flute, clarinet, oboe, violin, harp and drum (Nathan, 1836, 119). It is now certain that sound is actually produced by the puffs of air which are released as the vocal cords alternately meet and separate. (However, Hardy, 1956, dismisses evidence that the cords form vortex movements in the air and cause sound in this way.)

The **initial** closure of the larynx is discussed in section 4.2. The cords are separated initially by breath pressure from the lungs, and then come together again because of three factors (van ben Berg, 1958, 240; and Levinson & Liberman, 1981):

1) A decrease in subglottic pressure. (Garcia, 1855, 409, said that this depends not only upon the lungs, but also upon adjustments in the shape of the trachea.)

2) The tension of the vocal folds.

3) The Bernouilli effect.

The Bernouilli effect is a suction effect which can be demonstrated by holding two sheets of paper vertically, one in each hand, in front of the face. When one blows between the sheets, they are drawn **together**, not pushed apart, as one might imagine. (The Bernouilli effect as related to the
vocal cords is explained by van den Berg, 1968, 42. This is now a widely-accepted principle.) It is known that the vocal cords separate with a vertical phase difference, the lower parts separating before the upper parts. (See in particular, Laver, 1980, 96, and van den Berg, 1968, 129.)

It is now believed by most scientists that van den Berg's myoelastic-aerodynamic theory of vocal fold movement is correct. (See van den Berg, 1958.) He says that the vocal folds are actuated by air from the lungs, and regulated in fine detail by nervous innervation of the intrinsic and extrinsic laryngeal muscles. The fundamental pitch of the sound depends upon the effective mass and stiffness of the cords, and it is influenced by the activities of the lungs and resonators.

To explain some of these points simply, one can use information in Backus (1969, 27):

Increasing the mass of an oscillating system lowers the frequency:

\[
\text{frequency} \propto \frac{1}{\sqrt{\text{mass}}}
\]

So, increasing the mass by four times halves the frequency. Increasing the stiffness of an oscillating system raises its frequency. If the force constant of a spring is increased by four times, its frequency is doubled.

(An interesting factor which affects the mass of the vocal folds is posture. In the morning, after lying horizontal,
they are charged with tissue fluid, as are other head and neck tissues. This means that most singers can sing lower pitches early in the morning until the tissues return to normal after about three hours. Troup, 1982, 13.)

The muco-undulatory theory, which has been put forward in various forms by many researchers, is complementary to the myoelastic-aerodynamic theory. This postulates that there is a wave motion in the wet mucosal layer covering the vocal folds. (See Smith, 1961 and Perellö, 1962.)

Another factor to be considered is the vibrating length of the vocal folds; this inevitably leads us to the question of vocal registers, which are considered in detail in Chapter 5. It is well-established that cord tension and length increase with rising pitch (Hardy, 1956, 13-15), but the vibrating length is shortened (Luchsinger & Arnold, 1965). The effective mass of the vocal folds will also be decreased as they lengthen. Because there can be infinite fine adjustments of the breath pressure and the tension of the vocal cords, it is possible to produce a fundamental pitch using different combinations of these factors. In Garcia's words (1855, 410):

"...different lengths of the glottis can, under different degrees of pressure, produce the same number of shocks, but at different degrees of intensity."

In other words, more than one register mechanism can be used to produce a particular pitch. This is the concept of voix mixte, which is discussed in section 5.2.
As a result of an experiment, the results of which I describe in sub-section 7.4.3, I postulate tentatively that in some cases the vocal folds may not have to vibrate with the fundamental frequency of a low-pitched sound. (I have no firm evidence for this, but it is known that the brain is capable of "filling in" missing harmonics, even the fundamental.) This is an idea which I have seen mentioned nowhere else.

The relationship between breath pressure and the tension of the vocal cords determines how much laryngeal strain is experienced; this is especially noticeable when singing high notes. Müller (1837) proposed his "law of compensation of forces" to explain this:

Decreasing intensity of sound and air pressure leads to increased laryngeal tension to maintain pitch.

Increasing intensity of sound and air pressure leads to decreased laryngeal tension to maintain pitch.

(See also section A5 for more information about Müller.)

As the pitch rises, the air-flow falls, but the subglottal pressure rises, because the glottis becomes smaller and the vocal cords more tense. (Troup, 1982, 11.)

Matters are never simple, and it is known that the vocal cords do not just open and close. Hardy (1956, 10) quotes much evidence to show that vocal cord movement is not just a simple parting and meeting process: a movement within the
cords is superimposed upon this. There is also evidence that they **vibrate** laterally as well (p 30). The motion of the cords is apparently complex at low pitch, but less so as the pitch rises (Fletcher, 1953, 20). (See the note above regarding the muco-undulatory theory.)

Hardy (1956, 23) says that there is no simple relationship between the amplitude of the vocal cords and the sound intensity. Garcia (1894, 7) said that sound intensity is not due to the amplitude of vocal cord movements, but to the quantity of air passing between them. For a given intensity of sound, the amplitude of vibrations is less for a trained voice than an untrained voice (Fletcher, 1953, 23). The closure time of the cords also varies: it is greater for trained voices (Troup, 1982, 13-14); this leads to a greater build-up of pressure and thus a greater sound intensity when the glottis opens. This is a well-known principle in sirens (Fletcher, 1953, 23).

Everything which has been said so far conforms to the modern theories of voice production. However, in the early 1950's, a quite different theory was developed which raised enormous controversies. Although this theory is now discredited, it is instructive to consider why this is so.

Husson's **neuro-chronaxic** theory (Husson, 1950) states that the vocal folds contract **actively** in order to open the cords, rather than being parted by breath pressure. Husson believes that nervous impulses can travel at far more than the usually-accepted 50 to 100 m/sec, and therefore induce vocal fold contractions which are related to the fundamental
pitch of the sound. Essentially, a tetanic contraction would be set up in the thyro-arytenoid muscles.

An important piece of evidence which seems to back up Husson's theory is the observation by Goerttler (1951) that the thyro-arytenoid muscles consist of two strands of fibres which originate at the thyroid and arytenoid cartilages respectively, and insert onto the vocal folds at different points. Thus, the vocal cords could be pulled sideways by these muscles. All modern writers who discuss Husson's theory seem to have overlooked the fact that Garcia (1855, 406) predated Goerttler's observation by nearly a century. Garcia, however, was not advocating Husson's interpretation of the use of these muscle fibres.

Other workers believe that Goerttler (and, by implication, Garcia) is mistaken, and that the fibres may not be fixed onto the vocal folds themselves, but into the tissues beneath them. (Weiss, 1959, 85; and van den Berg, 1958, 231.) There are many other objections to Husson's theory, some of which may be summarized as follows:

1) The theory requires unproven abilities of the nervous system. For example, Wyke (in Bless & Abbs, 1983, 73) says specifically that in no circumstances, even when singing, does the maximal motor unit frequency of laryngeal muscles ever exceed 50 Hz.

2) It contradicts the traditional view that phonation is a secondary use of structures, by implying that certain fundamental features in Man are designed for phonation.
alone. (Husson does not accept animal evidence, as he says that neurochronaxic production is unique to humans.)

3) "All known evidence contradicts the possibility of a vibration...of the vocal cords without airflow." (Weiss, 1959, 87.)

In general, Weiss (195) and Rubin (1960), amongst others, provide detailed discussions which effectively demolish Husson's theory. However, the influential teaching manual by Husler & Rodd-Marling (1976) perpetuates Husson's ideas.

4.4: SINUS TONE PRODUCTION

I feel that it is necessary to mention a theory of voice production which is in total conflict with what has been said in the previous section. This is the theory of "sinus tone production", as advocated by E. G. White (1931, 1938A and 1938B), and promoted by his pupil, A. D. Hewlett (1983). Four members of the Ernest George White Society replied to my questionnaire, as mentioned in section 9.2. White's thesis is that:

"...the vocal cords...are not the seat of sound...the whole compass of the human voice is divided between four sets of sinuses [in the head]..." (White, 1938A, 7.)

In his various books, White quotes a vast assemblage of "facts" to support his case. But alas, these are generally either incorrect, quoted out of context, or simply the rather elementary explanations of his earlier age. White attempts to prove that the vocal cords merely control the
flow of breath, and that sound is created in the sinuses. These are shown in Fig. 4.2 and Fig. 6.3, and their possible resonant properties are discussed in sub-section 6.8.8.

White admits that:

"...it is difficult to explain in so many words exactly how the sinuses are controlled..." (White, 1938A, 34.)

Difficult indeed!

There is overwhelming evidence to condemn White's ideas; apart from all else that is said in the present work, one may quote the following anecdote. Lindahl (1969, 593) mentions examining a person with a cut throat. His larynx protruded and he tried to speak. A "thin reedy squeak" was heard emanating from the vocal cords. One wonders how White
would have dealt with that fact alone! Paget (1930, 204-205) also provides conclusive experimental evidence against White's theories.

Nevertheless, White's adherents still form a small but significant school of thought amongst Britain's singing teachers. White certainly achieved success in improving the voice in patients with vocal problems. As with many other methods, White's ideas and techniques probably achieve satisfactory results quite by accident. In other words, they serve to elicit the correct responses from the singer, and may thus be valuable. Nevertheless, we cannot condone White's claims to scientific objectivity and accuracy.

White created a controversy akin to that started by Husson in 1950 (see section 4.3), and a lively and valuable debate was started which still continues. We must be grateful for White's dedication and perseverance.
5.1: INTRODUCTION

The term "register" was taken from organ terminology (Tosi, 1743, 22; footnote by Galliard), and has been in use since at least the thirteenth century, when John of Garland distinguished the "chest", "throat" and "head" voices. Unfortunately, there was considerable confusion amongst later writers over both the terminology and the number of registers. I have pointed out in Chapter 2 that some early writers like Tosi may have been referring specifically to castrati, which complicates the issue. (In fact, I think that Shakespeare, 1924, 76, may be confused because of this very point.) However, in a footnote to his translation of Tosi's famous work (see Tosi, 1723), Galliard said:

"Voce di Petto is a full Voice, which comes from the Breast by Strength, and is the most sonorous and expressive. Voce di Testa comes more from the Throat, than from the Breast, and is capable of more Volubility. Falsetto is a feigned Voice, which is entirely formed in the Throat, has more Volubility than any, but of no Substance." (p22.)

Others have also used the terms Voce di Petto and Voce di Testa (although it seems odd that Galliard should say that the latter, the "head" voice, comes from the "throat"), but not always in quite the same way. For example, Bacon (1824, 63) and Anon. (1870) said that Voce di testa is the head voice, and commonly called falsetto. They therefore admitted of only two registers. Sadie (1980, 17, 339) may clarify the situation when he says:
"Until the nineteenth century almost all mention of *vox capita* (later *voce di testa*) can be taken as referring to falsetto."

This implies that *voce di testa* came to mean "falsetto" only in the nineteenth century, and this would explain the discrepancies noted above. Yet other terms were used by early writers. Caccini (1602) used the terms *voce piena*, which is taken to mean "full" or "chest" voice, and *voce finta*, which is taken to mean "disguised" or "head" voice. Even if one thinks one knows what the falsetto voice is, the illusion is shattered by comments like this:

"Most scientists as well as musicians describe falsetto tones, which may occur in any voice in the highest and lowest tones." (Agricola, 1757, 34f.)

Furthermore, Garcia and others placed falsetto between the chest and head voices. This was apparently the custom amongst physiologists during the first three-quarters of the nineteenth century (Mackworth-Young, 1953), and the reason was explained by Hermann Klein, Garcia's pupil and editor of Garcia (1894), in a footnote. He said that the mechanism of the male medium register corresponds to the acute falsetto sounds of the female. (Garcia, 1894, 9.) Monahan (1978, 161) sums up the whole confusing picture well, when he says that in the *bel canto* era,

"Teachers learned to associate various vibratory sensations in the local areas of the chest, neck and head with different pitch levels in the singer's compass."
In other words, each teacher had his own concept of registers which was a useful rule of thumb and was applied subjectively and empirically. As Root (1894, 227) said, with regard to the different sensations taught by teachers:

"...all these sensations are helps, doubtless, to one or another among students; but one can hardly fail to see that they are all mere changing shadows of some strong, decided action elsewhere."

In addition, Taylor (1908) says that contemporary teachers handled registers purely empirically.

There is therefore probably little virtue in attempting, as some have done, to describe in detail, and reconcile, the ideas of different writers. Nevertheless, the great majority of teachers and singers believe that registers exist, and the best definition of a register is probably that of Garcia (1847), as modified by Large et al (1980):

"By the word 'register' we mean a series of succeeding sounds of equal quality on a scale from low to high produced by the application of the same mechanical principle, the nature of which differs basically from another series of succeeding sounds of equal quality produced by another mechanical principle. Mechanical principle is understood to include both myoelastic and acoustic determinants. (Underlined section added by Large, et al.)

An opposite view is well-illustrated by this statement made by Frieda Hempel:
"I prefer the word range to 'register'...because 'registers' are really only arbitrary divisions of a naturally occurring range." (Martens, 1923, 142.)

It is useful to list the different theories regarding the numbers of registers and their terminology, and this is done in Table 5.1.

### TABLE 5.1: A SUMMARY OF EARLY THEORIES OF REGISTERS

(These ideas were put forward up to the end of the nineteenth century; most modern theories are derived from them.) (Modified from Rowley, 1898, 50.)

1) No registers.

2) Two registers:
   - chest and head.
   - chest and falsetto.

3) Three registers:
   - chest, medium and head.
   (Most leading
   - chest, falsetto and head. (Inc. Garcia.)
   nineteenth-
   - thick, thin and small. (Inc. Behnke.)
   century
   - lower, medium and high.
   authorities.)

4) Four registers: strohbass*, chest, head and falsetto.

5) Five registers: lower thick, upper thick, lower thin, upper thin and small.

* The Russian church bass register.
There have been even six- and seven-register theories (Large, 1973, 9), and others attribute different numbers of registers to different types of voices (e.g. Rogers, 1895, 90). Others, notably Luchsinger and Arnold (1965) believe that the female voice has a high "flageolet" or "whistle" register, and one can find convincing examples of this.

Others have suggested that the basic pattern of registers is different in male and female voices, but Lunn (1900, 160) puts a clear-cut objection to this view. He says that the larynges of the two sexes must be basically the same in register action, as they differ only in size. (A similar feature is the so-called "octave phenomenon", whereby female voices lie about an octave higher than their male counterparts: see also sub-section E1.2.)

American speech scientists in particular tend to use the term "vocal fry" for low-pitched sounds which are sometimes categorized with hoarseness. (Colton & Hollien in Large, 1973, 117.)

I shall not list in detail which authors advocated the various theories and their terminologies, but this has been done by Rowley (1898, 50) and in very great detail by Large (1973, 14). Lunn (1900, 154) also produced a very confusing table of registers with differing terminologies. Readers should be especially wary of a book by Hoole (1902), entitled Physiology of Vocal Registers. Purporting to be "scientific", it contains a mass of inaccurate and speculative information. For example:

"[the diaphragm] is mostly passive, like the skin of a
Garcia's comments on registers seem somewhat ambiguous, although many other writers probably based their ideas on his. In 1861, he advocated a five-register theory (Garcia, 1861), and in 1894 a three-register theory (Garcia, 1894, 7); as Duey (1951, 162) has said, the majority of other writers' five-register and three-register theories appear to stem from Garcia's ideas:

"Many authors, no doubt, never used a laryngoscope, but relied on Garcia's findings to advance a theory for their own books."

Even if others had used the laryngoscope, it is likely that they would have arrived at different conclusions anyway:

"It is hardly too much to say that no two of them quite agree as to what is seen." (Mackenzie, 1886.)

In fact, it is well-known that it is impossible to phonate properly with a laryngoscope in position, and Garcia's reliance on this method of observation was a mistake, although modern methods of investigation were not available to him.

The terms "thick", "thin" and "small" which appear in Table 5.1 were first used by Curwen (1875), according to Large (1973, 11), and taken up by the influential teacher, Emil Behnke (see Behnke, 1882). Others also used these terms, notably the famous researcher Ellis (1878), and they refer to the supposed appearance of the vocal cords. Ellis also
tried to link vowel sounds to specific pitches and registers, as did Rogers (1895, 108-109). Although this rather difficult concept may not be useful in a practical sense for singers, there is good evidence to support it. (See also section 5.3, and sub-sections 6.7.2 and 6.7.5.)

Mackenzie suggested the terms "long-reed" and "short-reed" for "chest" and "head" (falsetto) registers respectively. (Mackenzie, 1890, 41.) Henderson (1938, 71) says that Mackenzie stated that all scientific investigators had found only two registers, but teachers had always held that there were at least three. (Henderson believed in the existence of only two registers, as did Caccini, 1602, over three centuries earlier.) This may have been true until the beginning of this century, but modern scientists seem to agree that there are at least three registers, as I shall explain.

5.2: MODERN SCIENTIFIC EVIDENCE FOR REGISTERS

Despite many statements to the contrary, there is now scientific evidence that registers are not merely psychological phenomena. It is also worth pointing out that some singers have distinct register breaks which are easy to hear. Many contraltos have a notable "chest-break", but perhaps the most extreme example was Maria Callas: "she has three voices" was a common criticism. (See also Appendix H.) Nevertheless, many eminent authorities have thought registers to be "unnatural" in some way, artefacts introduced or imagined by a singer. Examples are Lehmann (1902, 133), who also writes much contradictory nonsense about registers (p 45ff), and Henderson (1938, 69).
Fields (in Large, 1973, 29) points out that register breaks do not occur in speech. He suggests that this is because correct vocal reflexes are used as there is no self-consciousness. I think that these are sweeping statements, and I would argue that as the range of pitches used in speech is usually small, register transitions are not common anyway.

One of the most comprehensive studies of registers is that by Nadoleczny (1923), and much of the modern work quoted below stems originally from his ideas.

Data quoted by Large et al (1980) make no reference to a middle register, but it is not clear whether they deny its existence. However, Large (1973, 15) specifically supports the idea of a middle register with the following useful table:

<table>
<thead>
<tr>
<th>Voice type</th>
<th>Upper and lower limits of the middle voice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bass</td>
<td>D3 - D4</td>
</tr>
<tr>
<td>Baritone</td>
<td>E3 - E4</td>
</tr>
<tr>
<td>Tenor</td>
<td>F3 - F4</td>
</tr>
<tr>
<td>Contralto</td>
<td>D4 - D5</td>
</tr>
<tr>
<td>Mezzo-soprano</td>
<td>E4 - E5</td>
</tr>
<tr>
<td>Soprano</td>
<td>F4 - F5</td>
</tr>
</tbody>
</table>

TABLE 5.2: AVERAGE TRANSITION Pitches FOR REGISTERS. (Adapted from Preissler, 1939.)
It is important to note that these are "average" pitches. Many writers have stated dogmatically that register transitions occur at fairly precise pitches, but as each voice is unique, there seems to be no reason why this should be so. Furthermore, register transitions may vary with different vowel sounds: see sub-section 6.7.5. (Shakespeare, 1924, 38, makes the obvious suggestion that the pitches at which to change registers should be those allowing the singer to avoid strain.) There is the persistent idea of a series of 2 - 4 transitional notes between the middle and head voices which can be produced with either register mechanism, or, allegedly, with both mechanisms together. In the latter case, the sound produced is referred to as the "mixed voice" or voix mixte. For example, Garcia (1894, footnote p 21), Klein (1923, 29), Henderson (1938, 76) and Vennard (1968', 73) all mention this.

Arnold (in Large, 1973, 138) uses the terms "amphoteric" or "isoparametric" to describe these transitional notes. The former term is drawn from chemistry: the analogy is excellent to one who understands the chemical term, but I shall not attempt to explain it. I comment further on the voix mixte in sub-section 7.5.3.

It is worth pointing out that many singers use a similar idea to help them sing high notes. This involves singing the note before the high one with a similar mechanism. (At least, singers think that they are doing this!) For example:

"...I must attack the lowest note in such a way that I can easily reach the highest. I must, therefore, give
it much more head tone than the single note requires."  
(Lehmann, 1902, 55.)

Sir Peter Pears told me to
"leave part of the voice behind on the previous note."
(White, 1982A, 6.)

Large (1973, 12) says that there is remarkable agreement among European scientists in accepting "singer-sensation-based" terminology for the main registers, but Colton (1972, 337) explains how most definitions of registers fall into two categories:

1). Physiological variations. (Vibration patterns, vocal fold length and thickness patterns, and aerodynamic patterns.)

2). Voice quality characteristics.

It is the physiological concepts which can now be explained in reasonably accurate terms, and in sections 5.3 and 5.4, I discuss this in more detail.

A useful analogy made by various authorities, including Arnold (in Large, 1973, 138) and Ardran & Wulstan (1967) is that of "gearchanges" between registers. The basic idea is that a good voice has smooth changes which may be undetectable: this is like an automatic gearbox. A voice whose changes are just detectable is like a manual synchromesh gearbox, whereas distinct audible changes are like a crash gearbox. This is a simplistic idea, but I think...
it is useful as it gives a singer a definite idea of what is required in terms of equalizing registers. The care taken by some singers in this respect is well-illustrated by this comment:

"Marchesi is said to have devoted three entire years to equalising and perfecting two notes of his voice."

(Bacon, 1824, footnote p 77.) (Luigi Marchesi, 1754 - 1829, was a castrato soprano.)

5.3: MODAL REGISTERS

5.3.1: Introduction

The usually-accepted modal registers are the chest, medium and head, although the terminology and number vary. (See Table 5.1 and section 5.2.) Many writers have stated that these registers are caused by resonances in different parts of the body (this is a common belief amongst singers and teachers), but it can now be said with some certainty that the sensations in the chest, head, etc. are subjective. They are important as sources of proprioceptive "feedback", as mentioned in sub-section 6.8.1. Indeed, Ardran & Wulstan (1967) point out that the term "head voice" implies a condition of the vocal folds, not necessarily resonance in the head.

Oncley (in Large, 1973, 39) suggests that the sensations felt by singers are due to the shifting of formant frequencies to achieve maximum sonority (see also sub-section 6.7.5). Oncley also believes (p.43) that changes in resonance are reflected as changes in the loading on the vocal cords. This would affect the working of the muscular
mechanism of the larynx, and is discussed in another context in sub-section 6.7.4.

There is no doubt that the psychological aspects of register sensations are very important. I agree wholeheartedly with the view of Henderson (1938, 77) that chest notes should be "placed" at the front of the hard palate, and head notes in the soft palate. These sensations produce the desired effects; the latter presumably helping the singer to lift the soft palate, a manoeuvre important when singing high pitches. Other writers are a little less precise: Shakespeare (1924, 37) says that head notes reverberate towards the back of the head. (See also the comments by Tetrazzini and Caruso, mentioned in sub-section 6.8.1.) In this connection, Agricola (1757, 34f, quoted by Duey, 1951, 120) makes a statement about the falsetto register which is undoubtedly true if one thinks in terms of resonance rather than air-flow:

"...and it will be noticed that the air escaping from the glottis strikes further back in the roof of the mouth."

It cannot be disputed that it is possible to use different register mechanisms to produce a particular note, but only notes sung with specific mechanisms in each case are usually acceptable to an audience. For example, Large et al (1980, 31) point out that chest production of high notes sounds like shouting. Further,

"Performers, pedagogues, intendants, audiences and critics prefer the 'operatic head' [on high notes]." (p 27.)
5.3.2: Anatomical and physiological considerations

Hardy (1956, 12-13) points out that the change of pitch of the voice cannot be explained entirely by changes in cord motion, as the larynx rises with pitch. Indeed, Butenschohn and Borchgrevink (1982, 32) make the interesting observation that if the larynx moves above the fourth cervical vertebra, the falsetto mechanism comes into play automatically. They say that this may happen accidentally on soft notes, and personal experience confirms this. The raising of the larynx with register changes was noted long ago; for example, by Rogers (1895, 91).

Butenschohn & Borchgrevink (1982, 27) say specifically that in the low laryngeal position, the vocal cords and muscles are short, thick and relaxed; in the high position the vocal cords are lengthened and the vibrating mass of the muscles is reduced. (See sub-section C3.2 for a brief description of the extrinsic laryngeal muscles which control the position of the larynx.) The vocal cords will obviously be at their shortest in the chest register, and Vennard (1968, 66-73) explains that this is due partly to the thyroarytenoid muscles being active and shortened. The cords come into contact fully in the chest register, a fact noted by many writers, including Hardy (1956, 17) and even Garcia (1894, 8), who observed this with the laryngoscope.

However, I fail to understand Garcia's (1894, 9) assertion that the chest register causes a smaller loss of breath than the middle register. Although the cords do not meet in the latter (Hardy, 1956, 17), or meet only at the edges (Garcia, 1894, 8), it is difficult to sustain a very low note for a
long period. I postulate that although the cords are more closely approximated in the chest register during the closure phase, this condition results in a high breath flow because low frequency vibrations cause the cords to be apart for comparatively long periods. A good deal of energy will also be used up in moving the \( \text{thickened} \) cords. These points are confirmed by Hardy (1956, 135), who also mentions (p 147) that it is difficult to sing a low note loudly: this is undoubtedly true.

A further relevant point is made by Hardy (1956, 20), when he says that in the chest register, the cords are pressed more firmly together when singing forte, and the closure phase is longer, than when singing piano. Thus it will be noticed that a lot of breath is used when singing low notes quietly.

Many writers agree that in the head register, only the edges of the cords oscillate (e.g. Luchsinger, 1950), and that the vibrations are limited to the front of the cords. Hardy (1956, 16) makes the latter point, and says that there is little change in the thickness of the cords from the medium register. On the other hand, Fields (in Large, 1973, 26) makes the general point that thinning the vibrating margins of the cords raises the pitch, whilst thickening the margins lowers the pitch.

Butenschön & Borchgrevink (1982, 42) obviously agree with Vennard's (1968) statement that in the head register, a proportion of the muscles of the vocal folds participate actively in the vibrations of the glottis.
A further point which should be made here is that the epiglottis is elevated on high head notes, whereas it is lowered on low chest notes. Thus laryngologists ask patients to phonate a high-pitched "ee" when using a laryngoscope. (Arnold, in Large, 1973, 141.)

5.3.3: Acoustic considerations

The chest register is rich in high harmonics, whereas in the falsetto register, the energy is mainly around the fundamental. (Arnold, in Large, 1973, 146, and Colton, 1972, 339.) In the head register, there is an increase in sound energy around the singing formant. (Large et al, 1980, 29.)

5.4: THE FALSETTO REGISTER

5.4.1: Introduction

I believe that a disproportionate effort has been made by authors over the last 100 years to explain the falsetto mechanism. Many writers seem to have been preoccupied with it, whilst condemning it at the same time as unnatural or undesirable! Rowley is a good example:

"It is, therefore, an abnormal voice, and, like most things abnormal, is more or less objectionable."

(Rowley, 1898, 64.)

However, he summed up the late-nineteenth-century view very clearly:

"Messrs. Marcet, Guttmann, Lunn and Segend say that falsetto is produced by the vocal cords vibrating only on the outer rim; Messrs. Le Pileur and the author of "Advice to Singers" say it depends on the position of
the larynx; and Dr. Champneys says it arises from nodes. Mr. Lunn says that the vocal cords in the use of falsetto are insufficiently approximated; whilst Dr. Morrell Mackenzie says falsetto occurs through the edge of one cord overlapping the other, or by both cords being forced against each other... Dr. Reimann, Dr. Champneys and Dr. Lennox Browne agree that it is a problem not yet cleared up... nearly all the authorities jumble up the head voice with the falsetto..." (Rowley, 1898, 62-64.)

The confusion was illustrated further when Mackenzie (1890, 49) said that the rim of the larynx is constricted during falsetto, leading to the common sense of fatigue. He admitted that Garcia said that the rim is dilated. No two views could be more diverse! van Deinse (1982, 34) believes that in the falsetto all muscles are relaxed: this might be in accord with Garcia's idea. (Some of van Deinse's other comments appear to be rather unconventional, however.)

Over the years, there seem to have been three main groups of theories about the falsetto register:

1). A mechanism involving the false vocal cords and/or the laryngeal ventricles.

2). A mechanism involving the vocal cords alone.

3) A mechanism involving elements of 1) and 2).

I shall attempt to explain these in turn.
5.4.2: Production of the falsetto register by the false vocal cords and/or the laryngeal ventricles.

Illingworth (1876 and 1882) thought that the falsetto was produced by the false cords and the ventricle acting in the same way as a hazel nut can be used as a whistle. This was an idea taken up by several authors, including Lunn (1900), who further explained that the air in the ventricles was equivalent to the air in a trumpet player's cheeks. (pp 116-117.) He quoted Semple (1884/1886), for further evidence of this. Vennard (1968, 15-16) does not believe that the falsetto can be produced by "overblowing" the voice. I consider that by "overblowing" he refers to the whistle idea.

At the other extreme, Hardy (1956, 6), in an excellent scientific review, says that no definite rôle in singing has been established for the false cords or ventricles. Garcia (1855, 402/405) said that the false cords cannot contribute to voice formation because their muscles are too frail. (However, see below, and sub-section C3.1.)

Hodgkinson (1895) was supposed to have discovered the "true" function of the ventricles as receptacles for dust and mucus which then passed into the pharynx for swallowing. It is interesting in this connection that Vennard (1968, 57) says that the ventricular glands sometimes lubricate the vocal cords excessively. Also, Ardran & Wulstan (1967) point out that mucus irritation is a problem in altos because of the shorter vibrating length of the vocal cords, which are thus easily interfered with. (I can confirm from personal knowledge of inexperienced male altos that this is a real
5.4.3: Production of the falsetto register by the vocal cords alone

Marcet (1869) said that falsetto was due to vibrations at the edges of the cords. Rowley (1898, 64) mentioned Hodgkinson's experiments (see sub-section 5.4.2), where indigo powder was sprayed onto the cords as they were observed with a laryngoscope. The whole length of the cords was seen to vibrate, but I have already pointed out that the use of a laryngoscope introduces distortions. (This point is made with specific reference to the falsetto voice by Ardran & Wulstan, 1967.) Fletcher (1953, 20) says that only the front edges of the cords vibrate, and Vennard (1968, 73) implies that the glottis is not fully opened during falsetto singing. (As Vennard sometimes uses "falsetto" to mean "head" register, some of his comments tend to be confusing.) Oncley (in Large, 1973, 37) agrees, and likens this to the stopping of a violin string, an idea developed by Ardran & Wulstan (see below).

The partially-opened glottis of the falsetto register is generally referred to as "spindle-shaped" (e.g. see Vennard & Hirano in Large, 1973, 144). Large et al (1980, 28) make the interesting point that there will be less efficient conversion of airflow into sound than in other registers, because the glottis does not close firmly. Other registers will therefore tend to put more energy into the higher partials. (See the results of my experiments in Chapter 8.)
5.4.4: Production of the falsetto register by the false vocal cords and/or the laryngeal ventricles, and the vocal cords

In my opinion, one of the most useful recent scientific papers on the falsetto register is that by Ardran & Wulstan (1967). They investigated five male subjects using various techniques, and found that all showed prominent air-filled ventricles in the chest register, but these were reduced in the falsetto register. (This is in direct conflict with the theory put forward by Illingworth and Lunn: see sub-section 5.4.2.) They point out that the vocal folds cannot vibrate unless associated with an air-filled ventricle. (This fact is also stated by Manén, 1974, 22.)

Ardran & Wulstan found that the backward movement of the hyoid bone in turn moved the epiglottis, thus altering the tension on the false vocal folds. They in turn could then bulge inwards onto the true vocal folds, damping them in the process. The effective vibrating length was thus reduced by about 25% to 33%, and this was analogous to stopping strings on a violin. A reduction in the tension of the vocal folds allowed the pitch to remain the same, despite the shortening of the folds. It will be noted that these findings accord with the comments of Fletcher, Vennard and Oncley, mentioned in sub-section 5.4.3.

Ardran & Wulstan do not mention an interesting fact quoted by Mackenzie (1890, 47-48): Mandl said that the false vocal folds help in the formation of the falsetto by pressing on the upper surface of the vocal folds. Gouguenheim and Lermoyez (1885, 142) claimed to have observed this in a bass
using falsetto. This predates Ardran's & Wulstan's work by almost a century, but it must have been fortuitous that these early observers saw this mechanism by using a laryngoscope.

Table 5.3 gives an interesting summary of the supposed differences between the chest and falsetto registers. However, the comments regarding the ventricles and supraglottic space are at odds with the findings of Ardran & Wulstan.
**TABLE 5.3: DIFFERENCES OF LARYNGEAL FUNCTION IN CHEST AND FALSETTO REGISTERS OF THE MALE.**

(Adapted from Arnold, in Large, 1973, 149.)

<table>
<thead>
<tr>
<th></th>
<th>Chest register</th>
<th>Falsetto</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape of cords</td>
<td>rounded, full</td>
<td>sharp-edged, thin</td>
</tr>
<tr>
<td>Length of cords</td>
<td>short</td>
<td>elongated</td>
</tr>
<tr>
<td>Tension of cords</td>
<td>low isotonic inner</td>
<td>great isometric tension</td>
</tr>
<tr>
<td></td>
<td>tension</td>
<td>outer tension</td>
</tr>
<tr>
<td>Ventricular folds</td>
<td>adducted</td>
<td>abducted</td>
</tr>
<tr>
<td>Ventricles</td>
<td>narrow</td>
<td>wide</td>
</tr>
<tr>
<td>Glottal closure</td>
<td>complete in each cycle</td>
<td>open oval slit</td>
</tr>
<tr>
<td>Length of glottis</td>
<td>full length of cords</td>
<td>short, anterior</td>
</tr>
<tr>
<td>Vibrations</td>
<td>broad, entire surface</td>
<td>narrow, marginal</td>
</tr>
<tr>
<td>Amplitude</td>
<td>wide</td>
<td>small</td>
</tr>
<tr>
<td>Frequency</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>Epiglottis</td>
<td>lowered</td>
<td>elevated</td>
</tr>
<tr>
<td>Supraglottic space</td>
<td>narrow</td>
<td>widened</td>
</tr>
<tr>
<td>Thyroarytenoid</td>
<td>very active</td>
<td>inactive</td>
</tr>
<tr>
<td>Cricothyroid</td>
<td>inactive below 150 Hz</td>
<td>very active</td>
</tr>
<tr>
<td>Harmonics</td>
<td>prominent higher</td>
<td>fundamental almost</td>
</tr>
<tr>
<td></td>
<td>harmonics</td>
<td>sinusoidal</td>
</tr>
</tbody>
</table>
5.5: HIGH ADULT MALE VOICES

5.5.1: Introduction

This is perhaps the most problematical group of voices from the point of view of categorization, and the one which usually excites the strongest views on vocal quality. It is fruitful to consider these voices in the light of the previous discussion on registers. In fact, if one makes allowances for differences in terminology, there is much common ground between the leading authorities. I have seen no clear explanations of the whole subject, although certain books and papers are excellent in limited respects. I suggest that the following principal categories should be used:

1). Natural male soprano. (Stubbs, 1908, 19.)

These are individuals who retain an unbroken voice, probably for hormonal reasons. (These are the eunuchoids of Ardrañ & Wulstan, 1967.) I have known one singer who may have been of this type; he called himself a "sopranist", and sounded like a boy, although he was in his late 20's. These singers were apparently in demand in Italy between 1550 and 1590 (Stubbs, 1908, 19), but are not to be confused with castrati singers.

2). Falsetto male soprano. (Stubbs, 1908, 21.)

This type of singer uses the falsetto register, but sings higher than a countertenor.

3). Falsetto male alto or countertenor, type A.

These singers use only the falsetto register when singing. (Stubbs, 1908, 14-15.) This voice corresponds to the high
countertenor of Ardran & Wulstan (1967).

4). Falsetto male alto or countertenor, type B.

These singers use both the chest and falsetto registers when singing, in order to increase the vocal range. (Stubbs, 1908, 14-15.) This voice would be the low countertenor, referred to by Ardran & Wulstan (1967). Henry Purcell was presumably a low countertenor; this can be inferred from what is known of the parts he sang.

5). Natural countertenor.

In this type, the singing and speaking ranges agree (Stubbs, 1908, 14-15). This is essentially a high tenor voice (Hardwick & Hardwick, 1980, 147, and Oberlin, 1980). Russell Oberlin, the American singer, is of this type, and he often sounds exactly like a young female soprano. I have known personally one singer of this type; he told me that his voice had never really broken, although hormonally he appeared normal, with a family to prove it! This type of singer may have a "chest break" which sounds like that of a female contralto.

The great countertenor Alfred Deller agreed with the idea that there are falsetto countertenors (like himself) and natural countertenors (like Oberlin). (Hardwick & Hardwick, 1980, 78-79.) Stubbs (1908, 50) says that this voice was neglected and supposedly rare at the time of writing because it was practically unsought by choirmasters. Oberlin (1980) says that natural high voices are available today, but their possessors may not realize the possibilities afforded them by Baroque music.
6). Castrati singers, or eunuchs.

These are dealt with in section D2.

There are numerous pathological or freak voices which I shall not discuss here. McWhirter (1983, 21-22) gives examples of freak voices, and Brodnitz (1953, 177-179) deals with the pathological examples. Stubbs (1908, 16) makes this interesting point:

"Hundreds of men's voices never undergo mutation, and women's voices of tenor and baritone range are not as rare as they are supposed to be. [He names celebrated female 'tenorists'.] The fact that they are not, as a rule, cultivated for singing purposes, proves nothing whatever but the force of custom."

The terminology used for all these voices is a problem, and I do not intend to discuss the voice part terminology used in early ecclesiastical music, which often had no bearing upon the voice type.

5.5.2: Altos and countertenors

Most reliable authorities say that these terms are interchangeable. (See Stubbs, 1908, 11; Whitworth, 1965; Ardran & Wulstan, 1967; and Hardwick & Hardwick, 1980, 75.) Hodgson (1965) and Tatnell (1965) try to imply that the terms refer to different voices, but Ardran & Wulstan (1967), in their excellent paper, demolish this argument effectively. There are always those who try to cloud the issue. van Deinse (1982, 42) calls Deller a "male contralto" and a "countertenor", and Oberlin a "male mezzo-soprano" and a "countertenor"!
The falsetto countertenors (types A and B) are the commonest; natural countertenors like Oberlin are a rarity. In fact, I do not know of another with a good reputation. We can therefore confine ourselves at this point to the falsetto singers. (The mechanism of the falsetto register is dealt with in section 5.4.)

Historically, the terms "alto" and "countertenor" were used in England at different times. The difference between the "hooting" church alto ("owl-to") and the refined countertenor like Deller may be simply a difference in ability and training, rather than a difference in voice type. (Ardran & Wulstan, 1967.) Hardwick & Hardwick (1980, 75) agree with this conclusion, and their statement which follows is supported by Sir Michael Tippett:

"...we suggest that a countertenor is, quite simply, a male alto of exceptional brilliance and flexibility."

The male falsetto singer has existed for many centuries, but became prominent in England after the Restoration of Charles II, when church choirs had been disbanded and no trained boys were available. (Stubbs, 1908, 8, and many other sources.) Similar situations may have arisen in other countries, according to sources quoted by Duey (1951). It is notable that Purcell usually used countertenor, tenor and bass soloists, and not boy soloists, for the same reason.

Purcell is believed to have been an accomplished low falsetto countertenor (type B) (see Salter), and England produced others at the end of the seventeenth century such as John Abell (or Abel) and Francis Hughes (or Hughes).
The voice declined in England towards the end of the eighteenth century (Hardwick & Hardwick, 1980, 92) in all but church and cathedral choirs, until the advent of Alfred Deller in the 1940's. (See Appendix H.) The reason for the decline was the increasing use of female singers. The first women altos in oratorio in England were used in Judith by Arne, in its first performance at Covent Garden on 26th February, 1773. Stubbs (1908, 12) makes this point, and goes on to say:

"The novelty was then the 'female alto', and not the counter-tenor."

Stubbs (1908, 12) also points out that Handel probably never heard women contraltos singing in any of his oratorio choruses. (Bach is also known to have used high male voices in some choruses.)

Falsetto countertenors (types A and B) have a natural bass or baritone range; they seem never to have a natural tenor range. Stubbs (1908, 68) says that this is because only singers with large laryngeal pockets (ventricles) can achieve a full falsetto tone. (See section 5.4.) Alfred Deller was naturally a baritone (Hardwick & Hardwick, 1980, 76); he was self-taught, and he had a wide falsetto range, from G3 to Gb5. (Hardwick & Hardwick, 1980, 48.)

5.5.3: The use of falsetto by other singers

Many early writers referred to the fact that the falsetto should be cultivated. For example, Petri (1761), quoted by Duey (1951, 120), said:

"Any singer should learn to use the falsetto..."
According to Hardwick & Hardwick (1980, 79), in an illuminating section on high male voices, the castrati used falsetto to increase their ranges; Farinelli's was about three octaves! Tenors used the falsetto register for high notes until about the time of Duprez in 1836 (see sub-section 6.7.3), and Stubbs (1908, 35) says that Meyerbeer indicated "pp" where he wanted the falsetto tenor range to be used. Interestingly, Large, Baird & Jenkins (1980, 27), with reference to a musical example for baritone in the text of their paper, say:

"To elicit 'falsetto' production, it is more appropriate to show 'pp' in the score."

Even baritones and basses sometimes use falsetto production. It is essential in works like Orff's Carmina Burana, although accomplished singers like Fischer-Dieskau can blend the falsetto indistinguishably with the normal voice. I postulate that the famous bass, the Rev. John Gostling (1650-1723), may have used falsetto to produce his supposed three-octave range. (Purcell is said to have composed his great anthem They That Go Down To The Sea In Ships for Gostling. There is evidence that Purcell himself may have sung as a bass, in addition to his work as a countertenor: see Salter.)

Many authors have lamented the loss of falsetto usage by tenors, including Lehmann (1902, 156-157). She also says that basses and baritones should not neglect the use of this register (p 165). Much earlier, Tosi (1723, 23) said that a soprano (presumably a male castrato) should be taught the use of the falsetto to increase the vocal range. On the
other hand, Playford (1694, 95) appeared to denigrate the use of falsetto.

Vennard (1968, 76) says that development of the falsetto voice is good, because it builds strength in muscles which are not usually used. However, the experienced laryngologist, Proctor (1980, 129), believes that its use involves that risk of injury to the larynx. Mackenzie (1890, 59) believed that exclusive use of the falsetto voice destroys the natural register; if both are used, no harm is done.
CHAPTER 6: VOCAL ACOUSTICS

"The medium of musical art lies primarily in artistic deviation from the fixed and regular; such as rigid pitch, uniform intensity, fixed rhythm or pure tone."

(Seashore, 1930, 75.)

Appendix E contains information on aspects of acoustics which is provided for reference purposes. Details of vibrato are given there: this is a topic which was not investigated practically during this study, for reasons given in section 7.2.

Reference should be made to Table E1, which shows the frequencies of notes in the tempered scale.

6.1: INTRODUCTION

When one is considering musical instruments, (including the human voice), pure notes, i.e. those consisting of sounds of a single pitch, are rarely encountered. Complex notes are produced by such instruments.

A complex note consists of a number of sounds of different pitches which are called partials. Partials related to the partial having the fundamental frequency by multiples of 1, 2, 3, 4, etc., are called harmonic partials, and others which are not integral multiples, inharmonic partials. (Backus, 1970, chap. 6.) The following system is adopted herein for numbering harmonic partials:

F1 (fundamental = first harmonic partial); F2 (second harmonic partial); F3; F4, etc. (Backus, 1970, 96.)
6.2: PERIODICITY

Individual notes produced by an instrument are periodic. The pattern for one cycle is called a waveform. (See Fig. 6.1.)

The relative amplitudes and phases of the various harmonic partials determine the waveform.

"...the quality of a periodic complex tone [produced by a musical instrument] depends mainly on the relative amplitudes of the harmonics [harmonic partials] and very little on their relative phase."

(Backus, 1970, 100.)

Fletcher (1953, 32) and Levinson & Liberman (1981, 59) agree with this, and so did Helmholtz and Ohm, although there are some conditions under which the ear can hear changes in the...
phase of the harmonic partials. This does not seem to be the case in general, however. (Backus, 1970, 100 and Vennard, 1968, 8.) This has important implications for the present study, and phase differences are considered again in sub-section 8.4.9, where the waveforms produced by the Nova 4 computer analyses are discussed.

Little mention will be made of consonants in this work, as they do not really contribute to beautiful tone, although they are important in diction, of course:

"...it is necessary in singing to lengthen the vowels and to shorten and give less emphasis to the stop and fricative consonants. [In order to facilitate good qualities of tone and legato singing.] It is for this reason that it is more difficult to understand song than speech." (Fletcher, 1953, 55-56.)

(Further mention of unintelligible singers is made in sub-section 6.7.5.)

Fricative consonants such as "f" are created by aperiodic noise. However, a combination of the noise source of "f" and vocal fold vibration creates "v".

Paget (1930, 182) points out an important distinction between the pitch of the voice and articulation, which is worth quoting at this juncture:

"It is the rising and falling of the pitch of the speaking voice which carries the emotional message, while the movements of articulation...carry the intentional message which accompanies it."
This is equally true of singing, although the singer is restricted by a composer's ability to use the "rising and falling of the pitch" to the best advantage.

6.3: "WHITE" VOICES

"All recognized professional singers sing with a pitch vibrato in about 95% or more of their tones."
(Seashore, 1936, 48.)

This may have been generally true in the 1930's, but the modern revival of early music has brought about an increase in "white" voices, which may be deficient in vibrato and lack a complex vocal spectrum. There has been a trend to recapture early singing styles, exemplified by recordings made in the 1930's by Yves Tinayre and Hughes Cuenod. The rise in popularity of the countertenor voice is another interesting phenomenon, started by Alfred Deller in the 1940's. (See also section 5.5.) I have said the following elsewhere, (White, 1982D):

"The smaller [vocal folds] of women and boys can more easily vibrate without vibrato than those of men, but the resulting 'white' voice...is unpleasant to many ears...It does not matter too much if an operatic voice is slightly out of tune, as the vibrato allows some leeway without the audience noticing this too much...A 'white' voice presumably sounds so awful when even slightly out of tune as there is no room for error before the hearer is aware of the incorrect pitch."

Sundberg (1982, 15) agrees that vibrato may be relevant
where the singer's accuracy in tuning is uncertain. He says that vibrato may hide beats between mistuned sounds when accompanied by instruments. Troup (1982, 21) says that the pleasing quality of ensemble singing may depend upon whether the singers' vibratos synchronize, but that this has not been investigated.

So, the less massive vocal folds of women and boys probably vibrate more "cleanly" than those of men. This reduces vibrato and the number of inharmonic partials which add "richness" to voices. (See also sub-sections 1.2.3 and 8.4.10.) I believe, therefore, that there are three main factors which are involved in making a voice sound "white":

1) A reduced vibrato.

2) A relatively low number of strong inharmonic partials.

3) A lower number of harmonic partials than is found in most adult male voices. (See also sub-section 8.4.10 and section J3.)

Seashore (1936) often states that singers can be taught to use vibrato (Wagner, 1930, carried out a detailed study of this phenomenon), and some singing teachers mention this specifically. For example, they often refer to listening for "beats" in the voice. (White, 1982C, 19-20.)

6.4: THE TRILL

This can be defined as differing from vibrato in having a clear interval concept and being a multiple of the time
designated by the tempo. (Seashore, 1936, 153-154.) It is probably quite wrong to assume that frequency modulation of this kind can be controlled by the larynx alone; certainly, many singers use rapid movements of the abdominal muscles and diaphragm to produce a trill.

6.5: THE "WOBBLE"

This is often caused by poor breath control, which in turn leads to low breath pressure, insufficient to support a relatively steady tone. It is, in effect, an uncontrolled vibrato, often with a fairly wide pitch variation. Its rate is slower than the optimum for pitch vibrato (see sub-section E1.3), and can almost produce the illusion that the singer is trilling on each note!

6.6: THE TREMOLO

This is a vibrato with a rate greater than the optimum range for pitch vibrato (see sub-section E1.3), and many listeners find this as unpleasant as a "wobble". It is invariably found in poorly-trained or untrained singers; I have found few specific suggestions regarding its cause, but I postulate that it may be due to excessive muscular tension within the larynx. (Taylor, 1908, 265; and Stanley & Maxfield, 1933, are in agreement with this suggestion.) Sacerdote (1957, 65) believes that periodical variations of the mouth cavities are also involved.
6.7: SOUND SPECTRA

6.7.1: Introduction

The source spectrum of the larynx alone shows that the amplitudes of partials decrease uniformly with frequency at the rate of about 12 dB/octave. (Sundberg, 1977, 82: see Fig. 6.2.) Most spectral components of the singing voice have been shown to be harmonics of F1, others are related to 0.5 F1, or are non-harmonic. The latter are probably due to random or "noise" components of the glottal source. (Seymour, 1971, chap. 5.) Seymour found also that at the 1%

![Fig. 6.2: The Modification of the Voice Source Spectrum by Formants](image)

The voice source has a spectrum containing a large number of harmonic partials, the amplitudes of which decrease uniformly with frequency. As the voice source moves through the vocal tract each partial is attenuated in proportion to its distance from the formant nearest to it in frequency.
level of significance, the voices of internationally-known male singers contained more non-harmonic components than those of less experienced singers. This relationship was not seen in female voices.

6.7.2: Formants

The resonances of the vocal tract enhance certain partials of the sound source, creating formants. These are peaks in the sound spectrum which include one or more harmonic partials. They are independent of laryngeal tone (Luchsinger & Arnold, 1965, chap. 3), but are related partly to the vowel being sung. Fig. 6.2 illustrates how the voice source spectrum may be modified by formants.

Hardy (1956, 87) makes the interesting suggestion that:

"...the' first formant fixes the broad pronunciation of the vowel, while the remaining formants refine this pronunciation and perhaps even give an indication of voice quality."

This idea appears to attempt to explain why such varying formant values are seen in different individuals. (Hardy, 1956, 84.) Hardy (1956, 120) also quotes Essner (1947), who believes that the ratio of the amplitudes of the first two vowel formants is important in defining a vowel. For example, he says that the French "oeuf" and the American "men" have the same two first formants.

Formants are modified because the back of the tongue, the hump of the tongue, the middle of the tongue and the lips, may variously constrict the vocal tract, creating resonance
cavities which enhance certain partials. For an average male tract of 17.5 cm, the first four formants would be at about 500 Hz, 1500 Hz, 2500 Hz and 3500 Hz. (Sundberg, 1977, 83.) Expansion or constriction of the vocal tract at the points mentioned may raise (expansion) or lower (constriction) the formant frequencies. (This is confirmed by McGinnis & Albert, 1952, quoted by Hardy, 1956, 114.) In particular, jaw movement affects the first formant; the back of the tongue the second formant, and the middle to front of the tongue the third and fourth formants. (Based upon Sundberg, 1977, 83-84). (See Fig. 6.3, Fig. 6.4 and section 6.8.) The formant frequencies are shifted when different vowels are formed, and thus a listener can identify a vowel sound.
FIG. 6.3: SECTION THROUGH THE HEAD SHOWING THE VOCAL ORGANS AND DETAILS OF

FORMANT PRODUCTION (See also Fig. 6.4.)

Sensations here may not be important to sound output, but give useful "feedback" to the singer.

Sphenoidal sinus

3rd formant*

Nasal cavity

2nd formant*

Frontal sinus

Nasal pharynx

1st formant*

Epiglottis

4th formant*

Soft palate (velum)

Lips

Oral pharynx

Tongue

Larynx

Pharynx

Singing formant*

False vocal fold

Laryngeal vestibule

Vocal fold

Oesophagus

Sensations in the chest may not be important to sound output, but give useful "feedback" to the singer.

*These formants are affected by constriction and expansion at the points indicated.
FIG. 6.4: POINTS OF CONSTRICION IN THE VOCAL TRACT WHICH MODIFY FORMANT FREQUENCIES
(Adapted from Sundberg, 1977, p. 86)
(Patterns of air pressure oscillations in the vocal tract are shown)

First formant
\[ \frac{1}{2} \text{ wavelength: } 500 \text{ Hz} \]

Lips \[ \downarrow \]

Second formant
\[ \frac{2}{3} \text{ wavelength: } 1,500 \text{ Hz} \]

Back of tongue \[ \downarrow \]

Lips

Third formant
\[ \frac{5}{4} \text{ wavelength: } 2,500 \text{ Hz} \]

Back of tongue \[ \downarrow \]

"Hump" of tongue \[ \downarrow \]

Lips

Fourth formant
\[ \frac{7}{4} \text{ wavelength: } 3,500 \text{ Hz} \]

Back of tongue \[ \downarrow \]

"Hump" of tongue \[ \downarrow \]

Middle of tongue \[ \downarrow \]

Lips
Table 6.1 shows the frequencies of the first two formants, as spoken by an average male. It would be fruitless to quote the many variations on these figures which have been produced by other authorities. Suffice it to say that singers shift formant frequencies for reasons which are explained in sub-section 6.7.5.

<table>
<thead>
<tr>
<th>Vowel sound</th>
<th>First formant</th>
<th>Second formant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heed</td>
<td>260 Hz</td>
<td>2300 Hz</td>
</tr>
<tr>
<td>Head</td>
<td>500</td>
<td>1880</td>
</tr>
<tr>
<td>Heard</td>
<td>500</td>
<td>1350</td>
</tr>
<tr>
<td>Hard</td>
<td>580</td>
<td>900</td>
</tr>
<tr>
<td>Hawed</td>
<td>580</td>
<td>800</td>
</tr>
<tr>
<td>Who'd</td>
<td>300</td>
<td>850</td>
</tr>
<tr>
<td>Had</td>
<td>650</td>
<td>1700</td>
</tr>
<tr>
<td>Hod</td>
<td>730</td>
<td>1100</td>
</tr>
</tbody>
</table>

The arrangement of vowel formants has lead to onomatopoeic words in languages - e.g. from low to high pitch: moan, groan, shout, yell, scream, shriek. (Vennard, 1968, 128).

The variations in vowel formants were recognized even during the nineteenth century:

"Helmholtz and a number of distinguished German physicists and physiologists have analysed the vowel sounds in the whispering voice and obtained very different results. If their experiments show nothing else, they certainly indicate that there are no
universally fixed resonances for any particular vowel sound." (Mott, 1910, 45.)

Fig 6.5 shows the maximum limits of the first formant in relation to the harmonic partials of the notes D3, D4 and D5. The exact position of the intensity maximum within a formant area depends on the pitch of the fundamental harmonic partial.
FIG. 6.5: THE POSITION OF THE FIRST FORMANT OF "AH" AND THE SINGING FORMANT IN RELATION TO THE HARMONIC PARTIALS OF D₃, D₄ AND D₅

The theory of vowel production which has been described is the harmonic or steady state theory proposed by Wheatstone in 1837. (Wheatstone, 1837, referred to by Fletcher, 1953, 49.) An alternative theory is the inharmonic or transient theory of Willis (1829) and Herman and Scripture. (See Scripture, 1921.) In this latter theory:

"...the vocal cords act only as an agent for exciting the transient frequencies which are characteristic of the vocal cavities. A puff of air from the glottis sets the air in these cavities into vibration... According to this theory, the puffs do not necessarily follow each other periodically and hence the name 'inharmonic'." (Fletcher, 1953, 49.)

McGinnis et al (1951) established that the harmonic theory is correct. The result of each theory is basically the same, but the inharmonic theory may have lead to the idea of sinus tone production, which was advocated by Ernest George White. (See section 4.4.)

A further theory relating to vowel production is that of vocal timbres, put forward by Lucie Manén. This theory is discussed in sub-section 6.7.4.

6.7.3: Covering

In 1836, the tenor Gilbert Dupréz used his newly-acquired Italian singing technique in Paris. This probably involved singing high notes (up to C5) in a modal register, rather than in falsetto, which had been the previous practice. van Deinse (1982) is probably correct when he says that this technique originated in Italy between 1800 and 1830. Its use
was certainly frowned upon by some mid-nineteenth-century writers, who considered it tasteless. It was, of course, symptomatic of changing musical styles.

Diday & Pétrequin (1840) thought that Dupréz was using a dropped larynx, and called the technique voix sombrée, voix fermée or voix couverte. This led to the term "covered voice" in English. Covering tends to produce a darker sound which probably helps to equalize register transitions. For example, "ee" moves towards "u", and "e" ("head"), moves towards "er" ("heard"). The larynx is lowered and the lowest parts of the pharynx and laryngeal ventricles are expanded. (Sundberg, 1977, 84.) This position is also the optimum for the production of the singing formant, which is discussed in sub-section 6.7.6.

Adjustments of the vocal tract are similar to those involved in yawning, i.e. a lowering of the larynx and expansion of the pharynx. (Singing teachers often encourage pupils to imagine that they are yawning when singing. The commonly-heard phrases such as "open the throat" and "drop the larynx" obviously derive from this phenomenon.)

In his survey of works written between 1777 and 1927, Monahan (1978, 85 and 87) states that 32 authors from the large number he investigated supported the idea of a raised soft palate when singing, and nine opposed it. However, eleven authors advocated using the sensation of yawning; as a raised soft palate is a result of yawning, we can say that it will be raised during covered singing. It is not clear from Monahan's work if the latter eleven authors were
included in the 32 advocating a raised soft palate. The numbers should have been the same if the writers understood what they were saying!

It is also interesting that Monahan (p 85) found only two authors who declared palate position to be related to pitch. As the pitch rises, the jaw tends to drop, especially in women (see sub-section 6.7.5), and the palate tends to rise. Why did so few writers mention this fact? (Luchsinger & Arnold, 1965, 449, make the important point that the soft palate is the anterior portion of the velopharyngeal valve, which functions not as a hinged trap door, but as a circular spincter.)

Monahan (p 89) also found many varying ideas on the position of the larynx when singing. He quotes Myer (1891, 115-116):

"Nature never intended that man should manage the position and movements of the larynx by a direct control effort..."

However, as Nature never intended that man should sing operatic arias, I fail to see the relevance of this statement!

Pielke (1910), quoted in Luchsinger & Arnold (1965, chap.6), observed a strong fundamental, a weak second harmonic and rich harmonics generally in covered singing. There was a prominent second harmonic in "open" singing. I have investigated these, and related ideas, in the present work and in a previous study, and my findings are discussed in sub-sections 8.4.2 and 8.4.3, and section J3. Winckel (1952
and 1954), quoted in Hardy (1956, 94), corroborates one of Pielke's statements by saying that when a singer changes from an open to a covered tone, there is generally an increase in the intensities of the upper partials. However, Hardy (1956, 95) tends to discount this idea.

Sundberg (1977, 87) makes the very sensible suggestion that the lowering of the larynx during covering shifts down all formant frequencies except the singing formant, and that this accounts for the darkening of the sound.

Some singers cultivate a more "open", or "brighter", sound than usual, and amongst contemporary British singers in this category, one may mention the tenors Sir Peter Pears, Robert Tear and Nigel Rogers. I noticed during my studies with Sir Peter Pears that he encouraged an "ee" sound throughout the spectrum of sung vowels. (White, 1982A.) Admittedly, my voice was probably too "dark" at the time, partly because of a displaced nasal septum which produced a rather muffled sound.

Professor Richard Miller (see Miller, 1977) heard me sing in 1978, and suggested that I might have a nasal deformity. This was confirmed by a surgeon who corrected the defect by septoplasty, producing a marked improvement in singing quality.

Sir Peter Pears's singing voice is certainly bright, and this confirms his insistence upon an "ee" sound. Interestingly, "ee" has a strong second formant between 2 KHz and 3 KHz (confirmed by Fletcher, 1953, 52), which is
in a region including the singing formant. Therefore, using an "ee" sound would be an alternative, or additional method of producing a penetrating tone. (See sub-section 6.7.6.) This point is confirmed by Vennard (1968, 128.)

At the other extreme are the voices which are heard often in choirs. A soloist "sticks out like a sore thumb" in a choir, as I found when I sang as a cathedral lay-clerk for two years. I was told constantly that I was singing too loudly; I was not, but merely using the powers of resonance which I had been taught to use as a soloist. Many lay-clerks have a muffled or "introverted" sound which is particularly evident in tenor and bass voices. My own work as a soloist suffered because of my cathedral singing: when I left the choir there was an immediate improvement in vocal quality.

Choir singing can lead to over-singing, because one's own voice is probably damped by the middle ear in ensemble work. I have discussed this phenomenon in other works: see White (1980, 114, and 1982B, 152):

"There is the tendency to shout louder than your neighbour, to use yourself to the bad habits of those on each side of you." (Crowest, 1900, quoted by Monahan, 1978, 21.)

It would be interesting to analyze the sound spectra of lay-clerks' voices, in order to identify the reasons for the muffled quality.
6.7.4: Vocal timbres

Lucie Manén suggests in a recent paper (1979, 38) that:

"...the prime vowels a, i, and u are generated within the ventricles above the vocal cords ...they are vocal timbres...articulated vowels are grafted upon the varying vocal timbres...I call the mechanism to produce the vocal timbres 'Ventricular Mechanism'."

Bennati (1833) said that there were two mechanisms for voice production: voix ordinaire ("natural" singing, explained along conventional lines), and voix orotunde. The latter was supposedly superior, and used by the famous singers of the time. Manén (1979) makes great play on voix orotunde to bolster her theory of vocal timbres, and says that Ferrein (1741) made a tantalizing reference to the same phenomenon. I think it likely that voix orotunde was simply "covered" singing, which was coming into vogue at this time, as explained in sub-section 6.7.3.

However, Manén mentions only briefly that Gemelli has some experimental evidence for these facts. The fact that the vocal cords and epiglottis have a particular disposition for a, e, i, o, and u has apparently been borne out by the latest fibre optic techniques. (Miller quoted in Troup, 1982, 22). (Similar ideas to those of Manén were expressed by Rogers, 1895, 115. Garcia, 1894, preface, seemed to imply a similar belief.) Previous work has generally indicated that all modifications of the basic laryngeal tone are carried out by the organs mentioned in sub-section 6.7.2. To quote Fletcher (1953, 16):
"Experience with persons who have had their larynx removed by a surgical operation has emphasized the fact that the differentiation of the speech sounds is practically all accomplished by the mouth and lip positions and that the sounds from the vocal cords act only as a carrier for these variations."

An opposing view is given by Bosma & Fletcher (1962, quoted by Butenschön & Borchgrevink, 1982, 54), who say that as people without tongues can talk and produce vowels, the latter must be produced in the upper pharynx. This is one of the tenets of the so-called "dorsal method" of singing.

We must take note of Paget's authoritative comments on this subject. He says (1930, 182) that because all the essentials of speech can be rendered in a whisper, which does not require voiced sounds from the larynx,

"...the sounds which we make by the vibration of our vocal cords are a separate language altogether from that which we make by the movements of our tongue, lips and other organs of articulation."

However, he then makes a comment which sheds new light on the whole problem (1930, 208):

"It is indeed quite conceivable that the vocal cords may adjust themselves so as to give a note rich in the particular overtones which are required to energize the resonators which the tongue and lips have prepared for them."

In my opinion, Manén is saying something very similar; she confuses the issue by looking at it from the wrong
viewpoint. If Paget's theories on the evolution of languages are correct, then articulated vowels will not be "grafted upon the varying vocal timbres", but rather, the exact opposite is true.

An interesting paper by Honda (in Bless & Abbs, 1983, 286-297) deals with the possibility of a relationship between articulatory movements of the tongue and pitch control in the larynx. There is a connection between these two organs, in the form of the hyoid bone and its associated musculature, and this concept may well complement ideas such as those of Paget and Manén. (See also the notes to Fig. C4.)

There is obviously considerable doubt about this matter, and furthermore, Hardy (1956, 35, 43 and 97) suggests that if the larynx does behave differently for different vowels, these differences may be due to the "reactions" of the oral cavities on the vocal folds. He comes to this conclusion as a result of work done by a number of people which showed that singing into an open tube produced strange sensations in the larynx, or difficulties in singing, at critical frequencies. The latter were always partials of the tube's resonant frequency. Scholes (1955, 1094) also mentions the effects on the vocal folds of acoustic loading. (See also sub-section 5.3.1.)

I would add that my own experience is that some auditoria, and some specific locations within other auditoria, do produce a sensation of difficulty when singing. This may be due solely, or partly, to the reverberation time, but could
the difficulties created by singing into a tube provide a clue that singing into any chamber causes a "reaction" on the vocal folds? The reaction might be adverse only in certain cases, depending upon the resonant frequencies of the chambers.

Husson (1952), quoted in Hardy (1956, 142), says that when reverberation time is less than two seconds, singing is tiring and difficult. I have sung in the Snape Maltings concert hall on several occasions and found it to be perfect from a singer's point of view. However, its reverberation time is apparently 1.9 seconds. (Servaes, quoted in White, 1982A.) Backus (1970, 151) suggests that:

"...the best reverberation time for the average fair-sized auditorium will be between 1.5 and 2 seconds."

Furthermore:

"...the audience subconsciously needs to hear the sound created by reflections which persist for between 1.5 seconds for chamber music and 2.5 seconds for a large symphony orchestra." (New Scientist, 1984, 28.)

Hardy (1956) suggests that fatigue in the larynx in some auditoria could be due to an unconscious effort on the part of the singer to improve the sound he hears. (The quality of what he hears will to some extent depend upon the reverberation time.) I agree with this as any tendency to over-sing, in an acoustically "dead" room or in ensemble, can be overcome by cupping a hand over an ear. This amplifies the singer's own voice, improves the apparent
quality, and one sings more quietly and with less strain. Singers often adopt this technique in rehearsal. (I have discussed this in other works: see White, 1980, 114, and White, 1982B, 152.)

6.7.5: The shifting of vowel formants

It will be observed from Fig. 6.4 that in female voices, F1 is likely to be the strongest harmonic, or next strongest after F2, because it is nearer the first formant range than is F1 in male voices. In the latter, F1 is likely to be perhaps third or even lower in the rank order of amplitudes. Harmonics from higher formant ranges may also be stronger than F1, including those of the singing formant range. (See sub-section 6.7.6.)

A soprano may sing a note with a fundamental frequency higher than that of the first formant area (over 1 KHz in some cases), and needs to raise the first formant frequency in order to match the frequency of the fundamental and thus amplify the latter. (No extra vocal effort is needed to achieve this). Opening the jaw wide has such an effect, so too does drawing back the corners of the mouth; hence the use by singing teachers of phrases such as "lower the jaw", "smile", "hear the tone before you sing it" (this prepares the jaw position), and so on. (Sundberg, 1977, 90.) Tetrazzini, in Caruso & Tetrazzini (1909, 30) says that it is necessary to smile for upper notes. Contraltos, tenors, and occasionally baritones, may also revert to this technique. (Sundberg, 1977, 90.)

The quality of a sung vowel tends to deteriorate as the
pitch is raised, because the harmonics are not within the required formant frequencies, and adjustments are made which alter the vowel sound. Thus all notes in a soprano's voice tend to sound like "ah". (Sundberg, 1977, 90.) I have already pointed out that this is one of the reasons which leads to the frequent assertion that it is not possible to understand what is being sung by many opera singers. This comment is made most frequently about high female voices, that of Joan Sutherland being a prime example. (White, 1980, 125). Hardy (1956, 75) agrees with this view, and Field-Hyde (1950, 161-162) mentions an interesting comment which was made to him by another musician:

"I prefer to hear Opera in a language that I don't understand, as it saves me the continual strain of trying to catch the words."

(See also section 6.2 for other comments about intelligibility). Earlier attempts to explain this phenomenon were hopelessly wrong:

"...the great breath pressure needed to energize high notes and words closes up the voice." (Scott, 1933, 53.)

In a generally excellent book, Miller (1977, 55) makes this very inaccurate statement regarding vowels:

"...For increased power and for rising pitch, the mouth opens wider, yet each vowel retains its own posture in relation to its companion vowels. Vowel differentiation remains at any pitch or dynamic level."
As Vennard (1968, 27) says, more correctly:

"...the typical modification of vowel quality in singing, the vowel definition being weakened or even sacrificed so that 'tone' may be enlarged."

Table 6.2, which follows, shows the pitches suggested by Large et al (1980, 30) at which each male vowel sound tends to "flip over" into what they call the "operatic head" register. It follows that it should be easiest to sing a vowel in the head register at its transition pitch or above.

<table>
<thead>
<tr>
<th></th>
<th>Bass</th>
<th>Baritone</th>
<th>Tenor</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;ah&quot;</td>
<td>D4/D♯4</td>
<td>D♯4/E4</td>
<td>F♯4/G4</td>
</tr>
<tr>
<td>&quot;eh&quot;/&quot;oh&quot;</td>
<td>C♯4/D4</td>
<td>D4/D♯4</td>
<td>D♯4/E4</td>
</tr>
<tr>
<td>&quot;ee&quot;/&quot;oo&quot;</td>
<td>B3/C4</td>
<td>C4/C♯4</td>
<td>D4</td>
</tr>
</tbody>
</table>

* p: semitone lower; f: semitone higher.

In other words, the loud phonation of any vowel, at the mf transition pitch, shifts it to the lower register. Arnold (in Large, 1973, 139) says that this holds true for changes between the falsetto/head and middle/chest registers. Luchsinger & Arnold (1965) also agree with this basic idea, and say that this is how well-trained singers produce the
voix mixte. (See sections 5.2 and 7.5.3.)

6.7.6: The singing formant
In general, lower voices, e.g. those of basses, tend to have lower formant frequencies than higher voices, e.g. those of tenors. Sundberg (1977, 91) says that a panel of teachers classified voices as tenor, baritone or bass according to how low the formant frequencies were, rather than by the actual ranges. (See also Appendix D, which deals with voice types.)

It has been noted often that professional male opera singers produce a peak, or singing formant, in the sound spectrum at between 2.5 KHz and 3 KHz, the figure of 2.8 KHz being sometimes quoted. This is apparently a necessary technique to enable male voices to "carry" over the sound of an orchestra. The orchestra's highest level of sound is in the region of 450 Hz, which approximates to the normal speech level, and the singing formant reinforces frequencies in a region where orchestral sound is rather weak. (Sundberg, 1977, 88.) I know from personal experience of singing with orchestras, that one may feel that one is swamped by the orchestral sound, when in fact the voice can be heard clearly by the audience. (I produce a marked singing formant: see section 7.4.3.) Female voices do not have the same need for a singing formant, as their fundamental frequencies are relatively higher than those of male voices. However, Troup (1982, 7) states that both male and female singers produce this singing formant. This has not been widely noted by other writers. Bartholomew (1934, 32) suggests that female voices may have a high formant at about
3.2 KHz because of their smaller larynges. The singing formant is indicated in Fig. 6.5.

Stout (1938), quoted in Troup (1982, 8), says that males produce another singing formant at about 500 Hz. This is apparently variable, and depends upon the frequency of the first vowel formant. In view of what has been said above, it is difficult to see why this lower singing formant should be produced; however, it is also mentioned by Bartholomew (1934, 27, and 1940, 447).

The singing formant at about 2.8 KHz is apparently produced by resonance in the top part of the larynx, including the sinus Morgagni. (Sundberg, 1977, 89.) Also, Bartholomew (1934, 29, and 1940, 447) reasons that the singing formant is produced in the larynx. This needs no extra vocal effort, but requires the larynx to be lowered and the pharynx widened, a situation which arises during "covering". (See sub-section 6.7.3.) The resonant frequency of the larynx is thus prevented from being altered by articulatory movements. (Sundberg, 1974, 843.)

It is known that the maximum sensitivity of the human ear lies between 3 KHz and 4 KHz, partly because the auditory canal which terminates with the eardrum is a closed tube with a resonance frequency in this region. (Backus, 1970, quoted in White, 1980, 115.) I suggested in another work (White, 1982D) that this might have a connection with the presence of the singing formant at approximately 2.8 KHz. This idea is confirmed by Bartholomew (1940, 447) and Sundberg (1982, 4).
Although it has been stated often that great singers show no unusual anatomical features of the larynx, Sundberg (1974, 839) says that singers with good voices tend to have a large sinus Morgagni (laryngeal ventricle) and a wide pharynx. This is logical, as it would obviously assist the production of the singing formant. The large pharynges and mouths of great singers have been remarked upon: Caruso, amongst others, is said to have been able to hold an egg inside his closed mouth without breaking it. Photographs showing close views of his face when singing give credence to this statement.

6.8: THE RESONANCE PROPERTIES OF BODY CAVITIES

6.8.1: Introduction

As mentioned already in sub-section 6.7.2, resonance cavities are created by constrictions in the vocal tract. Of course, without resonances of any kind, the primary sounds produced by the larynx would be negligible in volume. Attempts have been made to describe the vocal tract as a series of Helmholtz resonators coupled together, and two typical examples are shown in Fig. 6.6. Many variations of such schemes have been published, but their value is open to question in view of the fact that the vocal tract is a dynamic system. It is unlikely that any one scheme could represent the overall situation satisfactorily.
In fact, there are two types of resonance. Normally, one thinks of air being in stationary vibration, with sound waves running back and forth. However, in a Helmholtz resonator, the air expands and contracts uniformly. The latter may account for much of the resonance in the human voice. (Hickworth-Young, 1953, p. 72.) Benton (1930) provides a detailed mathematical treatment of resonance and the voice.
The materials of which the body cavities are constructed affect their resonance properties. Most early theories dealt with rigid-walled cavities (Hardy, 1956, 126), which are unrealistic. Cotton (1934), used models made of various materials, and found that soft walls inhibit the radiation of sound energy by resonators.

There is a serious misconception about resonance which is held by many writers, especially those with little scientific knowledge. This involves a failure to appreciate the fact that resonance in the various cavities of the vocal tract depends upon what may be called "sympathetic" vibrations. There is no need to assume that the breath flow must be directed into a cavity by some mechanical means, but this is exactly what is suggested in many cases. For example, the influential book by the celebrated singer Lilli Lehmann (1902) perpetuates this myth. She also makes some other quite ridiculous statements, for example:

"The palate must remain elastic from the front teeth to its hindmost part, mobile and susceptible, though imperceptibly, to all changes."

This represents a failure to separate subjective sensations and actual physiological facts.

Taylor, (1908, 70), says:

"How can the 'column of vocalized breath' be voluntarily directed in its passage through the pharynx and mouth?"

Mackworth-Young agrees with this; so did Rowley (1898, 5),
and Garcia said:

"All control of the breath is lost the moment it is turned into vibrations." (Root, 1894, 229.)

Paget (1930, 211-212) provides further evidence to demolish the idea of sound being directed inside the mouth.

Eighteenth century, and earlier, Italian sources said little about resonance in the cavities. (Duey, 1951, 102.) Mention of resonance certainly increased throughout the nineteenth century, in line with the rapid development of vocal science. No doubt the work of Helmholtz (1821-1894), was a major stimulus in this case. Monahan (1978, 116) says that the mouth and pharynx were usually mentioned in passing as resonators by writers in the period 1777 - 1927. However, "...in the last three decades [to 1978] intensive investigation has been placed on the oral-pharyngeal cavity system, using techniques unavailable to vocal scientists and pedagogues of earlier eras." (p 127.)

It is now realized that the mouth and pharynx are probably the most important resonating cavities. (See below, and also sub-section 6.7.2.) Sundberg (1977, 91) says that resonances in the head [i.e. the sinuses and cranium] and chest are not important to output, because of the attenuation of the tissues, but that they may be important as cues for a singer. Such terms as "chest resonance", "head resonance", and "singing in the mask (face)" probably describe patterns of vibration sensations which appear only when the tone is properly produced, and thus provide a proprioceptive "feedback" mechanism for the singer. (Bartholomew, 1940,
Mullendore (1949, 176) says that the contribution of bone vibration to air conduction is unresolved, but that some contribution "appears probable".

Root (1894, 227), in an interesting article, made the following perceptive point:

"All these sensations are helps, doubtless, to one or another among students; but one can hardly fail to see that they are all mere changing shadows of some strong, decided action elsewhere."

An opposing view of the resonance phenomenon is illustrated by Caruso's claim that his whole body resonated when he sang. He advised singers to:

"Feel the tones all through your whole body, otherwise your singing will possess no sentiment, emotion or authority." (Caruso & Tetrazzini, 1909.)

This statement gives the clue that this is a psychological phenomenon, and a further clue that many of these sensations are purely subjective is the assertion by Tetrazzini that high notes feel as though they go out through the crown of the head. (Caruso & Tetrazzini, 1909, p 26.) Lehmann (1902, 109) says the same thing, and Caruso made similar comments, and also said that it sometimes seemed as though his voice came from behind him.

6.8.2: The chest

It has long been thought by some authorities that resonance in the chest might be equated with the "chest register".
(See Chapter 5.) However, the lungs are obviously too spongy to act as resonators (this is noted by Taylor, 1908, 127), but there is some evidence that in low male tones there may be oscillations of the sternum and thorax walls. For example, see Ellis (1878, 15). Also:

"Perhaps all parts of the thoracic wall and particularly the sternum act as sounding boards."

(Kambata, 1977.)

Mullendore (1949) suggests that chest resonance was shown by experiment to be important to vocal output. Further, he postulates that forced vibration of the thoracic framework is more important than resonance of the underlying cavities. High notes alone would be damped out before they reached the walls. (Hardy, 1956, 99.) Troup (1982, 4-5) does not agree:

"Hence, 'to a good approximation, we can ignore the resonant behaviour of the power source [thorax] below the vibrator [larynx]."

However, Scholes (1955, 1094), in a very useful and comprehensive section on the voice, quotes the idea that the air passages in the lungs and the framework of the thorax contribute to resonance. The "drumming" of apes is given as evidence of this. Fletcher (1953, 7) states that chest resonance must contribute to speech, because a bather's voice changes according to whether he is standing in knee-high or neck-high water. This suggested to me a series of experiments on chest resonance; these are discussed in section 7.4.

Thorp & Nicholl (1896) and Thorp (1896) made an unusual
suggestion, which, they claimed, stemmed from an estimate by Hutchinson that "pressure" in the lungs may reach 1000 lb (454 Kg). (This was presumably during the act of singing. "Pressure" is here used incorrectly, as no indication of area is given.) Because air would be compressed and its density increased, the tone would be reinforced. (See also sub-section 3.2.3.) Field-Hyde (1950, 126) supports this idea. Rubini is said to have exerted himself for a high note, and,

"...breath pressure broke his collar-bone." (Thorp, 1896, 32.)

6.8.3: The trachea

Hardy (1956, 99) suggests that as basses tend to have long thin necks (see section D1), this may improve the transmission of vibrations from the trachea to the open air through the walls of the neck. There is apparently some evidence that the trachea has a resonant frequency of about 85 Hz. Hardy (1956, 110) implies that the fundamental frequency of such a cavity could be found by tapping and recording the sound. This could be done with the glottis open or closed, as one can sense these two conditions. Hardy (p98) also points out that the matter is complicated by the fact that the trachea would resemble a pipe closed at one end in the closure phase of the vocal folds, and a pipe open at both ends in the opening phase.

Another unique suggestion made by Thorp (1896, 40) is one which I have seen nowhere else during my extensive review of the literature on singing. This is that the trachea should
be developed by compressing the

"...air in it daily and continue the practice for
weeks."

This is done by taking a full breath, closing the throat as
for "K", and then pressing the breath upwards until the
lower part of the neck is well expanded. He implied that
this, coupled with a low position of the larynx when
singing, would make the trachea shorter and wider. This
would tend to amplify sounds, he said, in the way that
holding a tuning fork over a wide-necked jar produces a
louder sound than holding it over a narrow-necked jar.
Support for Thorp's ideas comes from Field-Hyde (1950, 117),
who says that the throat in general increases in size as a
result of singing, especially in young people. He quotes a
specific example of this happening in one of his pupils.

6.8.4: The larynx

Mention has been made already of the theory that basic
"vocal timbres" are produced within the larynx (see
sub-section 6.7.4), and also that there is good evidence
that the singing formant is produced there. (See sub-section
6.7.6.) It is obviously difficult to study the larynx during
the act of phonation, and some theories of its function have
been based almost wholly on observations made with the
laryngoscope or on excised larynges. There is still no
complete theory of how the larynx functions, but details of
its anatomy and physiology are discussed in section C3, the
functioning of the larynx in Chapter 4, and artificial
models of the larynx in section E3. One constantly meets
ridiculous statements regarding the larynx, and to quote
again from Lehmann (1902, 252):

"The breath vibrates above the larynx, but does not stick in it, consequently, this is not dangerous."

6.8.5: The pharynx

This is acknowledged by most writers to be of great importance in adding resonance to the voice, but there appear to be few precise statements other than the frequent mention of the fact that lowering the larynx during covered singing helps to create more space in the pharynx. However, we now know that vowel formants are created in the pharynx and mouth. (See sub-section 6.7.2.) Although any sensations may be subjective as far as the singer is concerned, there is no doubt that these cavities are of vital importance, and their manipulation will have a marked effect upon the resulting sound. It is to be hoped that the good singing teacher will, probably by trial and error, teach a pupil to recognize sensations which by chance coincide with acoustically desirable positions of the tongue, soft palate, etc.

6.8.6: The mouth

Many references to the mouth concern the "placement" of sounds. Usually this can be taken to mean the pattern of vibration sensations which are felt when notes are produced correctly. Again, this provides a useful feedback system for the singer, but may have little acoustical relevance. In general, most writers on singing say that chest notes (low notes) should be "placed" at the front of the hard palate, and head notes (high notes) in the soft palate. This observation is corroborated by Henderson (1938, 77). (See
I agree, from personal experience, that this pattern of sensations is correct. Part of the reason for the backward shift as the pitch rises may be that in order to sing high notes successfully, extra space has to be created in the pharynx by raising the soft palate. (Lowering of the jaw usually accompanies this action.) Attention will therefore be focussed on the soft palate whilst singing high notes. Sir Peter Pears has described this as a feeling of "post-nasality". (White, 1982A, 6.) (See also sub-section 6.7.3.)

I have noted in another work (White, 1980, 188) that I could find no evidence that the teeth act as "sounding boards", and Punt (1952, 81) agrees. Indeed one cannot see why they should, but despite this, the myth is perpetuated by many writers. A good example is Anon. (1870, 34):

"[the teeth]...increase the volume and resonance of the voice."

Paget (1930, 211-212) destroys such ideas by devastating scientific reasoning regarding the necessary effective sizes of such "sounding boards".

6.8.7: The nasal cavities

Hardy (1956, 44) says that as the nasal cavities are more rigid than the oral cavities, and their volume and shape are unchangeable, they must resonate on narrow frequency ranges, and hence would only rarely be excited by laryngeal tone. He says that there are inconclusive results about this from
various experiments (p 47), but that they may reinforce a frequency of about 3.3 KHz (p 93).

Certainly, many singers and singing teachers ascribe great importance to nasal resonance, and this derives from the strong sensations experienced in this region. This is probably not a purely subjective sensation, as a distinct nasality can be produced by conscious effort; probably by lowering the soft palate. (Mott, 1910, 53.) This can produce a penetrating tone, which may be too "bright" and unpleasant to some listeners. Sir Peter Pears certainly emphasizes nasal resonance in his teaching, (see sub-section 6.7.3), and lays stress upon the idea of imposto. This is significant, as Lucie Manén is an advocate of imposto, and Pears was her pupil for some years.

It is difficult to explain imposto simply, as the technique must be practised in order that one may appreciate what it involves. Basically, as described by Manén (1974, 27ff) one must adopt the "opening" sensation of sniffing. This, it is claimed, allows resonance in certain of the nasal cavities. To quote Manén:

"On the start of the note the singer should sense an abrupt opening of the entrance of the olfactory region, which closes again on the rest before the next note." (1974, 28).

Miller (1977, 79) gives an interesting description of what is obviously imposto. He says that the idea of "inhalation of the fragrance of the rose" is a common one in Italian
studios.

Bearing in mind Hardy's very logical ideas which were quoted above, it is difficult to see how the imposto technique could be used over a wide range of frequencies. It may simply be yet another example of a feedback mechanism which helps a singer, but one must admit that the imposto sensation is very real, and widely accepted by singers, even though it may appear under other names. For example, Tetrazzini (Caruso & Tetrazzini, 1909, 19) says that she starts her upper register tones in the "head cavity". This sort of description is probably synonymous with imposto technique. (More is said in section 3.1 about Manén's associated "startled" technique.)

The term "singing in the mask", or to use the original French term, dans la masque, describes a similar technique which cultivates nasal resonance. Henderson (1938, 60-61) says that the over-use of this by French masters results from the nasality of the language. (Taylor, 1908, 81, agrees that this concept is of French origin.) It must be noted that the nasality heard when someone has bad nasal congestion may be due to changes in the person's proprioceptive feedback, because of blockage of the eustachian tubes, rather than to a simple alteration of resonance properties. (Young, 1977.) Troup (1982, 7) says that the nose and sinuses give sensations of correct tone, but do not help in its formation. Laver (1980) quotes information to support the idea that nasality may be caused by resonance as low as the larynx.
6.8.8: The sinuses

These include the frontal, ethmoidal, sphenoidal and maxillary paranasal sinuses. (See Fig. 4.2 and Fig. 6.2.)

"In spite of the frequently mentioned term 'sinus tone' amongst singers and vocal teachers, the paranasal sinuses do not appreciably alter the resonance of the voice." (Kambata, 1977.)

"The frontal sinuses are frequently vestigial, and apparently not associated with any particular vocal characteristic." (Young, 1977.)

"Thus the aborigines of New Zealand, in whom the...sinuses are very ill developed, have voices remarkably deficient in resonance." (Mackenzie, 1890, 29.)

These apparently contradictory statements show the general divergence of opinion regarding the functions of the sinuses. Many singers claim to use the sinuses in voice production, and one may quote possessors of such widely differing voices as Alfred Deller, the countertenor (Hardwick & Hardwick, 1980, 28), and Lilli Lehmann (Lehmann, 1902, 37, 45, 46, and 51). The laryngologists Proctor (1980, 20) and Brodnitz (1953, 16) disagree about this matter. The former says that the sinuses act as resonators, but the latter says that this is unlikely.

The famous theories of George Ernest White must be mentioned
here, although they are discussed more fully in section 4.4. Troup (1982, 6) says:

"The major thesis of White's book, [White, 1938], that the voice is formed by the sinuses and not by the vocal cords, is not tenable today."

Monahan (1978, 113) says:

"Few authors [in the period 1777 - 1927] consider the sinuses worthy of mention in connection with cavities of resonance."

Overall scientific opinion now denies that the sinuses can possibly act as resonators. Bearing this in mind, why is the idea of resonance in the sinuses perpetuated in such an august publication as Gray's Anatomy? To quote this work,

"The function of the sinuses is doubtful. They lighten the skull and add resonance to the voice..." (Warwick & Williams, 1973, 1092).

6.8.9: Conclusion

Many authorities try to pinpoint precisely where certain notes should be sensed. A typical example is that of Lehmann (1902, 37):

"cavity of the forehead [sinus] - high range
nasal cavity - middle range
palatal resonance - low range"

One sees endless amplifications and variations of such schemes, which indicates that such sensations are very personal. As no two individuals are alike in anatomical and
physiological details, it may be fruitless to try to produce a system suitable for every singer. Moreover, can we really expect a bass and soprano to experience similar sensations? Many authors make no allowance for sexual or other differences and try to reduce all singing technique to a set of simple rules which should be followed by everyone. With regard to the positions of the larynx, tongue and soft palate in great singers, Taylor (1908, 49) says:

"It would be hard to find a greater diversity of opinion on any topic connected with the voice than is encountered here..."

A great many books about voice production and elocution give detailed instructions about how the tongue, for example, should be positioned for different vowel sounds. (Fletcher, 1953, and Ellis, 1878, may be quoted as examples.) The points of sensation within the mouth are given for the various vowels, but these should not be confused with the vibration sensations discussed above, which relate to pitch. Although different vowels are used when singing, they are often much modified (see sub-section 6.7.5), and so the situation is extremely complex. There seems to be little virtue in trying to lay down detailed rules about patterns of pitch and vowel vibrations for singers to follow. As has been stated by many observers (e.g. White, 1982D), an empirical approach is necessary. Singers should be told by their teachers when their production is correct, and taught to correct faults by imitation. Henderson (1938, 51) makes the very succinct statement that:

"Great masters of the early period reasoned from the
tone [meaning sound] to the operation, modern theorists tend to reason from the operation to the tone."

Finally, Field-Hyde (1950, 23), in discussing this topic, says that he has never seen a definition of "voice placing." He offers this eminently sensible definition of his own:

"Voice placing is the art of so adjusting the vocal resonators as to provide on all vowels, in the most natural way, the ideal tone of each individual voice."
CHAPTER 7: THE ANALYSIS OF RECORDED VOICES (1)

7.1: INTRODUCTION

This chapter describes how voices were analyzed, but technical details of the equipment used and the problems encountered are discussed in Appendix F.

The object of analyzing recorded voices was to gather data which might clarify some fundamental scientific aspects of voice production. In this chapter, I deal with the results of an experiment on chest resonance, and the analysis of some recordings produced under the direction of Lucie Manén. The voices of a group of famous singers are analyzed and discussed in Chapter 8.

I have discussed already the problems and results of a previous survey of singing voices. (White, 1980 & White, 1982B.) Material from that study is summarized in Appendix J, and incorporated in the present work, where appropriate. The present study concentrated on recordings of singers taken from gramophone recordings, whereas previously, "live" recordings were used. As I intended to investigate the voices of great singers, it would have been impossible to have made "live" recordings.

An important note of caution should be sounded at this point. Earlier authorities, far too numerous to mention individually, have made extravagant claims about the analysis of vocal waveforms and spectra. The equipment used was often primitive by modern standards, and it seems likely
that many statements have been far too speculative. I do not intend to try to dismiss other work out of hand, but several writers have commented upon the dubious results obtained by some voice researchers. Even in 1956, Hardy, in an excellent survey of the work carried out on vocal acoustics, made many criticisms of previous experimental work. A recurring feature was the lack of details regarding apparatus and experimental techniques, which made it impossible in some cases to establish exactly what had been done; far less could any satisfactory appraisal be made of the results obtained.

7.2: EXPLANATIONS OF THE WAVEFORM DIAGRAMS

A typical waveform is shown in Fig. 7.1 (actual size). Four blocks are printed, and each block represents 0.00512 seconds.

The pitch can be checked against the result from the Brüel & Kjaer Analyzer, and against the pitch estimated by a listener. Care must be taken because of the effects of vibrato, but the best guide to the overall true pitch of a sung note is the trained ear of the listener. The Nova 4 computer gives the exact pitch at one moment, and the Brüel & Kjaer Analyzer an "average" estimate of pitch. Thus, where waveforms appear in this chapter, the "expected" pitch as heard is given in Hz and octave notation, together with the actual pitch at the moment of sampling. Thus the true overall pitch of the note whose waveform appears in Fig. 7.1 is B4, although it is approximately C5 at the moment of sampling. (All notes are shown as sharps, where appropriate, rather than as flats.)
FIG. 7.1: AN EXAMPLE OF A WAVEFORM PRODUCED BY THE B PLOT PROGRAM ON THE NOVA 4 COMPUTER
(See sub-section A.4.4)

Total length of plot = 246 mm.
Total time interval represented = 0.02048 seconds.
Time interval represented by 1 mm = 0.0000832 seconds.
The arrow represents one complete cycle, and this measures 23.5 mm, which represents a time interval
of 0.0019552 seconds.
Frequency = 1/0.0019552 = 511.46 Hz (c C5). (Overall pitch = 494 Hz/B4).
When a waveform was displayed on the oscilloscope screen using the program S PLOT, it was examined over much of its extent in order to ensure that a fairly representative section was chosen for sampling. ("Representative" here means in terms of the pattern, rather than frequency.) However, this selection was a subjective process.

The vowels being sung, (according to the musical scores consulted) are also shown in each case, simplified to the nearest sound where necessary. (It was generally not possible to identify vowels in the instances where no scores were available.) Vowel formants may play an important part in determining the shape of a waveform and the pattern of the sound spectrum. However, vowels are modified as the pitch is raised, especially in high voices. (See sub-section 6.7.5.) This may therefore be no simple matter. In general, only one cycle is shown in each case, indicated by an arrow, and it must be made clear that the scales of different waveforms vary. This was caused partly by the need to avoid overloading the plotter which was used; also, the waveforms were enlarged or reduced for the convenience of printing in this work, after all calculations had been made. The shapes of the waveforms are of interest in this study, but careful judgement was exercised when they were examined.

The problems of vibrato are discussed in section E1 and sub-section F1.3, and it is possible to see why vibrato cannot be studied easily with this apparatus. Assuming that a singer's rate of vibrato was 6 "beats" per second, one "vibrato cycle" would occupy about 0.167 seconds. This would require about 33 blocks of the display, and the printing of
such long sections would be tedious and probably not very useful. In other words, the technique used in this study is really too detailed for this purpose.

"Noise" peaks produced by the apparatus must have affected the waveforms, but this problem is difficult to assess. "Noise" is discussed in section 7.3 and sub-section 8.4.9.

7.3: EXPLANATIONS OF THE SOUND SPECTRA DIAGRAMS

Fig. 7.2 shows a blank grid on which the Brüel & Kjaer sound spectrum is drawn. The intensity is shown in dB on the vertical linear axis, and the frequency in Hz on the horizontal logarithmic scale. Where the vertical axis is labelled with two sets of figures, the left-hand set, i.e. 0 - 50 dB, applies. It should be noted that the pen baseline of the 2305 Level Recorder is sometimes below the 0 dB line. (See section F7 for details of the 30 third-octave filters used in this apparatus.)

FIG. 7.2: BLANK GRID ON WHICH THE BRÜEL & KJÆR 2305 LEVEL RECORDER DR Naz SPECTRA

---

\[ \text{Fig. 7.2 shows a blank grid on which the Brüel & Kjaer sound spectrum is drawn. The intensity is shown in dB on the vertical linear axis, and the frequency in Hz on the horizontal logarithmic scale. Where the vertical axis is labelled with two sets of figures, the left-hand set, i.e. 0 - 50 dB, applies. It should be noted that the pen baseline of the 2305 Level Recorder is sometimes below the 0 dB line. (See section F7 for details of the 30 third-octave filters used in this apparatus.)} \]
Fig. 7.3 shows the "background noise" levels produced by the Brüel & Kjaer apparatus. These levels varied on the three occasions when the equipment was used, and so the spectra are designated "1", "2", or "3" accordingly. One must check the relevant noise levels when looking at a spectrum, as otherwise a peak may be wrongly attributed to the sound source being analyzed. In addition, on the spectra of the RR1 notes which were taken from gramophone recordings, there are peaks at 50 Hz and 100 Hz which were probably due to turntable rumble. In effect, peaks at 100 Hz or below can be ignored, as none of the fundamentals was at such a low pitch.

Level Recorders of the type used tend to be inconsistent in their plotting, in relation to the horizontal frequency scale. Some spectra are therefore too far to the left or right. In these cases, an arrow and two lines indicate the amount of error which must be taken into account when reading the graph: e.g.

It will thus be seen that no inaccuracies of frequency have been introduced.
7.4: THE CHEST RESONANCE EXPERIMENT

7.4.1: Introduction

There has always been much controversy about the resonance properties of body cavities. (See Chapter 5 on registers, and section 6.8.) A comment by Fletcher (1953, 7) (see sub-section 6.8.2) suggested an experiment which might shed some light upon the subject. Thus, I decided to record my voice (bass-baritone) whilst standing in air, and then when immersed in water. Ideally, this would have been done in a swimming pool, where I could have remained standing, but no pool would normally have an environment quiet enough for this purpose. I therefore recorded my voice whilst:

FIG. 7.3: BACKGROUND NOISE PRODUCED BY THE BRÜEL & KJAER APPARATUS

1. "Background noise" peaks when analyses indicated as were produced
2. "Background noise" peaks when analyses indicated as were produced
3. "Background noise" peaks when analyses indicated as were produced

19 20 50 100 200 500 1000 2000 5000 100 200
1) standing naked beside a bath full of water;

2) lying naked in an empty bath; My head was raised slightly from the horizontal, in order to clear the water level

3) lying naked in a bath full of water.

I hoped that comparisons of the resulting sounds would allow me to eliminate the resonance effects of the room, and see whether my voice changed when my body was submerged. Any differences in the analyses might have indicated, for example, that chest resonance did occur in air, but was damped down by water. Standing and lying naked in air eliminated any damping effects caused by clothing, which would obviously not be worn in the water!

To allay the criticism that such an approach is invalid because a singer normally wears clothes, I repeated the recordings whilst standing clothed. There were no appreciable differences between the resulting recordings and those made when standing naked. The former results are not presented here, as they were almost identical to those shown as RR1/66, RR1/65 and RR1/67.

7.4.2: Expected results

Three media of sound conduction must be considered: air, water and steel (the material of which the bath was made).
TABLE 7.1: VELOCITY OF SOUND

<table>
<thead>
<tr>
<th>Material</th>
<th>Velocity (m/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>344</td>
</tr>
<tr>
<td>Water</td>
<td>1437</td>
</tr>
<tr>
<td>Steel</td>
<td>5000</td>
</tr>
</tbody>
</table>

Air: $c_{\text{Air}} = 344$ m/sec at 20 degrees C. (Backus, 1970, 43.)

Water: $c_{\text{Water}} = 1437$ m/sec at 15 degrees C. (Backus, 1970, 44.)

Steel: $c_{\text{Steel}} = 5000$ m/sec (Backus, 1970, 44.)

Sound losses by absorption in water are small compared with air, but there is more absorption at higher frequencies. (McGraw-Hill, 1960, 12, 107.) (One may mention here the long distances over which underwater sounds, especially low sounds produced by whales, can travel.)

As Fletcher (1953, 7) says that a bather's voice changes when water is neck-high, what causes the change? Are some vibrations from the chest damped down by water? (This might happen with a large volume of water, especially if the water did not re-radiate the sound into air.) Could the differential transmission of harmonics through the three media cause phase differences which would alter the waveforms of sounds? In the experiment described here, would the small volume of water have easily transmitted chest vibrations to the steel sides of the bath, which would then have re-radiated them into the air? Would my body, being in contact with the bottom of the bath, have transmitted vibrations directly into the steel?

Furthermore, could the standing waves in the air of the room have been altered by the volume of water in the bath, and thus have enhanced some harmonics? This question was tested
by standing and singing beside a bath full of water and an empty bath. The latter results are not shown here, as they were identical to the former, thus eliminating the possibility of significant changes in the standing waves.

Bearing in mind all the facts mentioned above, in this case I expected little change in vocal quality attributable solely to being immersed in water. The volume of water was too small to have been very significant, I thought. However, changes in the vocal quality did occur, as demonstrated below.

7.4.3: Observed results.
(Some relevant points are summarized in Table 8.1.)

I sang a number of notes in each situation, all to the vowel sound "ah", and selected those numbered as in Tab. 7.2.

<table>
<thead>
<tr>
<th>TABLE 7.2: DETAILS OF NOTES SUNG IN THE CHEST RESONANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXPERIMENT</td>
</tr>
<tr>
<td>1) Standing beside empty bath</td>
</tr>
<tr>
<td>pitch: A2 A3 E4</td>
</tr>
<tr>
<td>number: RR1/66 RR1/65 RR1/67</td>
</tr>
<tr>
<td>2) Lying in empty bath</td>
</tr>
<tr>
<td>pitch: A2 A3 E4</td>
</tr>
<tr>
<td>number: RR1/57 RR1/56 RR1/58</td>
</tr>
<tr>
<td>3) Lying in full bath</td>
</tr>
<tr>
<td>pitch: A2 A3 E4</td>
</tr>
<tr>
<td>number: RR1/75 RR1/74 RR1/76</td>
</tr>
</tbody>
</table>
Fig. 7.4 shows the results for A2, A3 and E4. It will be noted that only the middle, "steady-state" section of each note was analyzed for the purposes of this experiment.

(An interesting piece of work on this topic is described by Mullendore (1949), but his subjects all sang sounds at a fixed pitch of 128 Hz (c C3). His results, regarding the contribution of bone vibration to air conduction, are mentioned in sub-section 6.8.2.)
FIG. 7.4: CHEST RESONANCE EXPERIMENT, PITCH A2: WAVEFORMS AND SPECTROGRAPHS

Artist: WHITE No. RR1/66
Expected pitch: 110/112-
Actual pitch: 103/110 Vowel: AH

(Artist beside full bath)

Artist: WHITE No. RR1/57
Expected pitch: 110/112-
Actual pitch: 103/110 Vowel: AH

(Artist in empty bath)

Artist: WHITE No. RR1/75
Expected pitch: 110/112-
Actual pitch: 103/110 Vowel: AH

(Artist in full bath)
FIG. 7.4 (continued): PITCH A3

Artist: WHITE No. RRI/65
Expected pitch: 220/65
Actual pitch: 220/65 Vowel: AH

(Artist standing beside full bath)

Artist: WHITE No. RRI/56
Expected pitch: 220/65
Actual pitch: 220/65 Vowel: AH

(Artist lining with empty bath)

Artist: WHITE No. RRI/74
Expected pitch: 220/65
Actual pitch: 220/65 Vowel: AH

(Artist lining with full bath)
FIG. 7.4 (continued): PITCH E4

Artist: WHITE No. RR1/67
Expected pitch: 330/64
Actual pitch: 312/64 Vowel: AH

Artist: WHITE No. RR1/58
Expected pitch: 330/64
Actual pitch: 356/64 Vowel: AH

Artist: WHITE No. RR1/76
Expected pitch: 330/64
Actual pitch: 356/64 Vowel: AH

(LYING IN EMPTY BATH)

(LYING IN FULL BATH)
The main observations are as follows.

1) The overall spectral patterns for each group of three sounds at the same pitch look similar, apart from differences in the amplitudes of some harmonic partials.

2) For A2, the fundamental is very weak in each case. In fact, in RR1/66, the "fundamental" is due mainly to noise in the apparatus. (See Fig. 7.3.) This note is easily identifiable as A2 when listened to, which indicates that the brain is capable of "filling in" missing harmonic partials, even the fundamental. This subject is discussed fully by Schouten (1940) and Backus (1970, 105-106), and mentioned by Vennard (1968, 129). Also, Lewis (1983, 99), quoting Fletcher (1934), says:

"Whenever a complex tone is composed of frequencies differing by a constant amount of 100 cycles or more, the apparent pitch of the complex mass is not the mean of the component frequencies, but is that of a tone whose frequency is equal to the constant difference."

This phenomenon could easily explain the present situation, if we assume that the only strong partials present are the harmonic partials of the fundamental. However, we cannot ascertain this from the spectrographs, as the Brüel & Kjaer filters do not allow us to pinpoint the relevant frequencies. (See section F7.)

An interesting question is posed at this point. Do the vocal folds not have to vibrate with the fundamental frequency of a low-frequency sound? This could have important
implications for the functioning of the vocal folds. (See section 4.3 and sub-section 6.7.5.)

3) Peaks in the spectra between about 500 Hz and 1 KHz are probably due to the first, and second, formants of "ah". (See sub-section 6.7.2.) It is also possible that these could be affected by the supposed lower singing formant of about 500 Hz. (See sub-sections 6.7.6, 7.5.3, and 8.4.6.)

4) All the tones show a marked singing formant at about 2.5 KHz, but this is of a relatively lower amplitude for A2, which might be expected of a low frequency sound. (The nearest filter frequency centres to 2.8 KHz are 2.5 KHz and 3.15 KHz: see section F7.)

5) The waveforms for each group of three sounds at all pitches show some degree of similarity. Differences may be attributable to immersion/non-immersion, or to standing/lying down. (Waveforms are discussed in detail in sub-section 8.4.9.)

When the sounds are listened to carefully, the following observations can be made:

1) The sound becomes gradually "darker" from RR1/66 - RR1/57 - RR1/75 (A2). (The latter note is slightly lower in pitch than the other two, which would affect this phenomenon.)

2) There is a change of timbre from RR1/66 - RR1/57 - RR1/75 (A2), the second and third sounds being more resonant than the first.
3) The tone becomes progressively "darker" and more resonant from RR1/65 - RR1/56 - RR1/74 (A3).

4) RR1/58 and RR1/76 (E4) are not very good sounds, and a wobble is evident. This is due to the extreme difficulty of singing a high sound in a reclining position. (Differences in the waveforms and spectra may also be attributed to this problem.)

7.4.4: Conclusions

It is difficult to draw conclusions, but there is no doubt that there are differences between the sounds. However, were these due to:

1) Genuine effects upon chest resonance, caused by immersion in water?

2) Proprioceptive feedback altering my voice production? (Any vibrations in the chest might normally be felt by the singer or speaker, even if these do not contribute to what is heard. See, for example, Caruso's comments in sub-section 6.8.1).

3) The difficulties of singing when lying down? (The horizontal body position and the head angle were unnatural.)

Certainly, this topic warrants further investigation, and this immersion experiment could be improved. For example, a large tank is needed, in which the singer can stand. I think that this might well elicit some useful conclusions about the problematical question of chest resonance.

7.5.1: Introduction
There are very few gramophone recordings in which singers demonstrate precise vocal techniques in order to explain what they are doing, (or think they are doing). Lucie Manén's book, The Art of Singing (1974) is accompanied by a disc containing such recordings. These are used to illustrate points made in the book by this influential teacher. (See also sections 3.1 and 4.2, sub-section 6.7.4, and section 6.8.) The three singers, Elizabeth Harwood (soprano), Peter Pears (tenor), and Thomas Hemsley (baritone), were all pupils of Manén, although she now seems to disclaim the recordings, in view of what she told me personally (White, 1981). However, they certainly represent what she was teaching when the book was published in 1974.

I decided to analyze the sung sounds, in order to see whether any quantitative measurements could be related to the supposed or real qualitative differences produced by different techniques. These techniques were:

1) The mechanism of the larynx
Manén lays great stress upon the valvular function of the larynx. She believes that the "click" at the start of the note should be produced by an implosion of air from above and below the larynx as it opens, rather than by forcing air from below, as in Garcia's coup de glotte. She believes that a constant breath pressure from the chest should be regulated by the larynx. (Manén, 1974, 20-25.) (See also
section 4.2.)

2) The mechanism of the pharynx
Manén believes that the pharynx is the main vocal resonator, and that it should be opened widely when singing. (Manén, 1974, 20-25.)

One assumes that when the above techniques are demonstrated on the gramophone recording by Thomas Hemsley, he constricts his pharynx in order to reduce its resonance for 1), and dilates it for 2).

3) The start of the note from imposto
For details of imposto, see sub-section 6.8.7.

4) Adding the nasal resonators
This, in Manén's terms, consists of resonance in the naso-pharynx, but she distinguishes this from the nasality evident in French, American or Australian accents. (1974, 29.) Manén perpetuates the myth about resonance in the sinuses of the head. (1974, 31.)

5) The use of "normal" and "mixed" voice production
Manén describes "normal" voice production as being that of the middle register. "Mixed" voice production is described as the technique used to sing notes which are transitional between the middle register and the "head" register. (See also section 5.2 and sub-section 6.7.5.) She suggests that the mixed voice requires a laryngeal "oo" production and an emphasis on the imposto mechanism, which gives a brilliance to the sound. (1974, 36-39.)
It should be mentioned that Manén is guilty of grossly unscientific statements, such as:

"The nasal resonators are opened widely, the air in the nasal passages being felt to float in a backward direction." [When using the mixed voice] (1974, 39.)

7.5.2: Expected results
I anticipated two possible extreme results: either the singers would be making the changes they supposed (or similar ones), and there would be marked differences between the analyses of the different sounds; or the changes would be primarily subjective, and the differences would be few. Of course, there could be many stages between these two extreme situations.

7.5.3: Observed results (Some relevant points are summarized in Table 8.1.)
Fig. 7.5 shows a representative selection of the waveforms and spectral charts. There were actually many individual notes in the complete sequence of recordings, and it would be an almost impossible task to present and discuss them all.

Each mechanism (see sub-section 7.5.1) is represented by one or more notes. I was able to analyze both the beginning and middle sections of most notes, using the Nova 4 computer, and both waveforms are shown in each case, with the exception of note RR2/100: see below. (It was not possible to do this with the Brüel & Kjaer Analyzer, as the operator's reflexes would not have been fast enough to have isolated the two sections of a note. The spectrum shown in
each case is thus an overall spectrum, which is influenced overwhelmingly by the "steady-state" section of a note: see section F7.)

The two artists concerned are Elizabeth Harwood and Thomas Hemsley. Harwood's waveforms are noticeably less complex than those of Hemsley. This would be expected, as Harwood's voice is "whiter" than Hemsley's. (See section 6.3 and sub-section 8.4.9.)

An important point which should be noted is that all the notes in the Manén recordings were sung to the vowel sound "ah". This should make the analyses of the sounds more straightforward than if different vowels were involved.
FIG. 7.5: MANEN RECORDINGS: WAVEFORMS AND SPECTROGRAPHS

Artist: HEMLEY No. RR2/47
Expected pitch: 208/463
Actual pitch: [diagram showing waveform]
(LARYNX - BEGINNING)

Artist: HEMLEY No. RR2/47
Expected pitch: 208/463
Actual pitch: [diagram showing waveform]
(LARYNX - MIDDLE)

Artist: HEMLEY No. RR2/52
Expected pitch: 165/163
Actual pitch: [diagram showing waveform]
(PHARYNX - BEGINNING)

Artist: HEMLEY No. RR2/52
Expected pitch: 165/163
Actual pitch: [diagram showing waveform]
(PHARYNX - MIDDLE)
It will be noted that in most cases, the beginning of a note is lower in pitch than the middle "steady-state" section. This is particularly true of RR2/70 (Fig. 7.5), and is not a surprising finding, as it is generally accepted that singers tend to "scoop" up to a note. The scoop may be rapid and not detected by a listener, or it may be prolonged and objectionable. A scoop of some kind might be expected as man corrects the vocalized sound after it is produced, and the larynx cannot necessarily be accurately adjusted to a particular frequency before the sound is made. (Pye, 1974, quoted in White, 1980, 78.)

The notes are now considered in groups: the mechanism of the larynx and the mechanism of the pharynx; the start of the note from imposto and adding the nasal resonators; and the use of "normal" and "mixed" voice production.

A) The mechanism of the larynx (note RR2/47) and the mechanism of the pharynx (note RR2/52). (Hemsley.)

1) The overall spectral patterns look similar, apart from differences in the amplitudes of some harmonics, bearing in mind the fact that the two notes are not of the same pitch. There seem to be, in general, no dramatic differences between these spectra. Both notes sound "dark".

2) The fundamental is quite strong in both cases, and there is a steady increase in the amplitudes of the harmonic partials from F1 to F2 to F3.

3) There are peaks in the spectra between about 500 Hz and 1 KHz which may be due to the first and second formants of
"ah". (See sub-section 6.7.2.) However, they could provide tentative evidence for the supposed lower singing formant of about 500 Hz. (See sub-section 6.7.6.) It is interesting that similar peaks also occur in the spectra of the A3 and E4 notes, of the chest resonance experiment (Fig. 7.4) and in many of the spectra shown in Chapter 8. However, see sub-section 8.4.6.

4) There appears to be a strong singing formant at around 3.0 KHz in both spectra.

5) The waveforms at the beginnings of the two notes are very different, although the steady-state sections are similar. I suggest that this could be due to the use of a different attack at the beginning of the note. In fact, this may be the only real difference between these two sounds. A distinct difference between the two attacks can be heard. RR2/47 has a "clean" attack, but RR2/52 has an aspirate and "scoop".

B) The start of the note from imposto (notes RR2/61 and RR2/65), and adding the nasal resonators (notes RR2/70 and RR2/74). (Harwood.)

1) At the pitch of G4 (RR2/61) and F#4 (RR2/70), the spectral patterns are very similar, although there is possibly some emphasis of the higher harmonics, relative to the fundamental, with the nasal resonators.

At the pitch of D5 (RR2/65 and RR2/74) the spectral patterns are again similar to each other, and there is some emphasis of the higher harmonics at about 4 KHz with the nasal...
resonators. All notes sound "dark", and RR2/61 to RR2/65 sound progressively more brilliant. RR2/70 and RR2/74 are more "produced" sounds than the others.

2) The fundamental is the strongest harmonic in all cases.

3) The peaks between 500 Hz and 1 KHz may be partly due to the first and second formants of "ah", or to the lower singing formant, as suggested under A) above. However, peaks here are strong only when the fundamental is in the same region.

4) The higher singing formant is not as easy to identify as in male voices, but the peaks in its general area are relatively stronger at D5 than at F#/4/G4, with both vocal mechanisms. The highest peak tends to be nearer 2 KHz than 3 KHz.

5) The waveform becomes more complex for the imposto mechanism as the pitch rises; this is probably coupled with an increasing complexity of the spectrum. It was noted from the whole series of other notes, whose spectra and waveforms are not displayed here, that both singers' notes showed modifications and increasing complexity with rising pitch. It is interesting that the steady-state sections for the imposto mechanism are almost the same as the steady-state sections for the nasal mechanism at similar pitch. This must mean that there are no phase changes (see sub-section 8.4.9), and that the relative amplitudes of the harmonics remain similar. However, the beginning sections are very different in each case; this could be due to different
methods of attack being used. It should be noted, however, that the first note (RR2/61 - imposto) begins at almost the correct pitch, whereas its nasal mechanism counterpart (RR2/70) begins well below the final pitch and at a low amplitude. In fact, the overall amplitude provides the main difference between these two beginning sections in imposto and the nasal mechanism. There is a significant difference in the second pair of notes, where the nasal mechanism note has a much simpler waveform at its start.

Again, the use of different attacks may be the main difference between the imposto and nasal mechanisms. The imposto notes, such as RR2/61 and RR2/65 have pronounced "glottal stops" at the start, whereas the nasal notes have softer attacks.

C) "Normal" and "mixed" voice production (note RR2/100). (Hemsley.) (These two sounds were sung contiguously; hence there are no "beginning" sections.)

1) The overall spectral patterns are similar, but the "mixed" spectrum shows an extra high peak at about 1.2 KHz which is apparently F4. This peak is not seen in the larynx or pharynx mechanism spectra, although the latter are generally similar to the two spectra under discussion. This peak may therefore be a special feature of Hemsley's "mixed" voice production, but there are only two notes on the Manén recording where Hemsley demonstrates the change from "normal" to "mixed" voice production. I have therefore had limited scope to study this phenomenon. (The other note also shows this peak, although to a lesser extent. Both notes sound the same, and neither is "well-covered".)
It should be pointed out that wherever "double" peaks occur, as in RR2/100 "normal", where there is a small peak at 250 Hz and the true peak of Fl at 315 Hz, frequency vibrato is obviously to blame. (See section F7 for comments on frequency "shifting" from one filter band to another.) A distinct "wobble" can be heard in both notes.

2) The fundamental is not the strongest harmonic, and shows a similar relationship to the second harmonic as that seen in the larynx and pharynx spectra.

3) The strong peak at about 600 Hz could be due to a lower singing formant.

4) The singing formant is clearly seen in both cases at around 3 KHz.

5) The waveforms are both very erratic, but there does seem to be a difference between "normal" and "mixed" voice production. This would be expected in view of the changes in the spectra.

7.6: A COMPARISON OF THE RESULTS FROM THE CHEST RESONANCE EXPERIMENT WITH THOSE FROM THE ANALYSES OF THE MANÉN RECORDINGS

It is interesting to compare the note A3 (c 220 Hz), sung by myself (Fig. 7.4), with the note A3 sung by Thomas Hemsley (Fig. 7.5). Although not strictly comparable for many reasons, it can be seen that the formant areas are similar, although the relative amplitudes of the harmonics are different. Hemsley's fundamental is notably lower in
amplitude relative to other harmonics.

Comparing E4 (c 330 Hz), sung by myself (Fig. 7.4) with D4/D♯4 (c 301 Hz/311 Hz), sung by Hemsley (Fig. 7.5), similar comparisons can be made. In fact, each voice seems to have a characteristic "spectrum pattern", and this is probably true of many voices: a point which has been made by other writers. (See also sub-section 8.4.8.)

The waveforms for the two voices seem to be very different in general, which is hardly surprising, considering the great differences in the spectra.

7.7: OVERALL CONCLUSIONS WHICH MAY BE APPLICABLE TO THE ANALYSIS OF SINGERS' VOICES IN GENERAL

1) On low notes, the fundamental may be very weak, and possibly "filled in" by the brain of the listener.

2) A particular voice probably produces a characteristic "spectrum pattern" which will probably vary at different pitches.

3) The singing formant at approximately 2.8 KHz is clearly seen in trained voices.

4) Formants between 500 Hz and 1 KHz appear to be important in general, and there may be a lower singing formant at about 500 Hz or higher, especially in male voices.

5) Waveforms differ from one singer to another, and between different notes sung by one singer. This probably indicates
differences in the complexities of the sounds and the relative amplitudes of the harmonics.

6) Singers tend to "scoop" up to a note, so its beginning section is lower in pitch than the steady-state section. The waveforms at the beginnings of notes may vary according to the method of attack. (This could not be studied in the recordings discussed in Chapter 8, as most of the notes analyzed were within musical phrases and had no clean attack sections.)

7) "White" voices have the least complex waveforms and sound spectra. (See also section 6.3 and sub-section 8.4.10.) Female voices in general have less complex and more regular waveforms, and less complex sound spectra than male voices, although one would certainly not call all female voices "white". It is interesting that Hemsley's spectra show more, or stronger, high harmonics in some cases than do Harwood's. Harwood's fundamental tones were always higher than Hemsley's, despite this fact. (Both I and another author have noted this phenomenon previously: see section J3.)

8) The waveforms and sound spectra of sung tones tend to show modifications and increasing complexity with rising pitch. (This could be observed only in the recordings discussed in this chapter where a rising sequence of notes was sung.)

Of course, one would not, on the basis of these results, be able to look at the waveform and sound spectrum of any note
and say "this singer is using such-and-such a mechanism of voice production". Nevertheless, as far as is practicable, the points made above will be applied in Chapter 8 to the analyses made of recordings of famous singers.
CHAPTER 8: THE ANALYSIS OF
RECORDED VOICES (2)

8.1: INTRODUCTION

This chapter deals with the recorded notes sung by famous artists, all of which were taken from gramophone recordings. I cannot claim that I have chosen a representative sample of singers: tenors predominate for reasons discussed in section 8.2. It would be a mammoth task to extend this kind of work to a larger number of singers; not least because of the varying availability of suitable, undamaged, gramophone records. (Brief details of the singers and their voices are given in Appendix H.)

Many of the recordings analyzed were certainly acoustic: those of Caruso, for example. There were three important reasons for using such old recordings:

Firstly, Caruso was a giant amongst singers and a major factor in the rise in popularity of the gramophone. A consideration of his voice is vital in any survey.

Secondly, many of Caruso's 154 recordings have been re-issued many times. Thus it is possible to see how different transfers of a particular recording compare with one another. An assessment may be made of their consistency, which might give one encouragement to rely upon the accuracy of transfers in general. Few, if any, other singers have enjoyed such frequent releases of their recordings.

Thirdly, an interesting L.P. disc of computer-enhanced
Caruso recordings is available. Comparison of these recordings with the same, non-enhanced transfers might shed some light upon the value of such computer-enhancement.

8.2: THE CHOICE OF NOTES FOR ANALYSIS

In order to produce an accurate waveform or sound spectrum, a voice must be unaccompanied. This poses an immediate problem: how many singers have recorded unaccompanied songs? The solution is to extract notes from accompanied recordings, but this imposes some limitations. Firstly, singers usually sing unaccompanied notes only in operatic items, and these are often interpolated as "showpieces". This means that a Lieder singer's voice cannot usually be analyzed in this way.

Secondly, high voices sing unaccompanied notes more often than low voices, and these notes are usually high notes. Thus, for example, it is easy to find such notes on recordings of operatic tenors; less so on recordings of basses. It might be felt that these notes will be atypical of a singer's voice as a whole, but there is no alternative method which will produce accurate results.

In some of the many publications produced in the 1920's and 1930's by the University of Iowa Laboratory for the Psychology of Music, there are many references to the analysis of voices. For example, Seashore (1936) contains "pattern scores" which follow changes in pitch and intensity for the duration of certain songs. These were produced by a camera technique, but in only one paper have I found a clear reference to the fact that unaccompanied sounds were used.
A further point which should be mentioned here is that when an operatic singer sings an exposed unaccompanied note, he, or she, often uses a portamento from the previous note. Thus one cannot identify a true attack at the beginning of the note. In most of the recordings analyzed (with the exception of the Manén recordings discussed in Chapter 7), it was possible to deal with only the "steady state" section of a sung tone.

8.3: DETAILS RELATING TO THE RECORDINGS, WAVEFORMS AND SOUND SPECTROGRAPHS

The sources of all recordings are detailed in Appendix G. The data may seem exhaustive, but I think it is important that other workers should be enabled to repeat my analyses. I have not been able to specify the exact position of a note in its original recording. I could have done this only by specifying the bar numbers of the musical works; it is no easy matter to establish bar numbers when an aria is continuous with the music which precedes it. However, there are usually only one or two sustained unaccompanied notes in an aria, and so each is relatively easy to locate. (I can supply the exact locations of notes.)

The waveforms and spectrographs are printed as in the preceding chapter, and are shown in Fig. 8.1. They are grouped in a logical manner, which will become obvious upon inspection. With Caruso's recordings, some notes are from the same original matrix number which has been transferred onto different L.P. discs. In other cases, two notes are
from the same location in a particular aria, but come from
two different original matrix numbers. Three symbols are
therefore used between some of the waveforms and
spectrographs:

- Notes from the identical position in an aria; original matrix number the same,
  but transferred onto different L.P. discs.

- Notes from the identical position in an aria, but from two different original matrix numbers.

- Original matrix number the same; transferred from the same L.P. disc, but
  at two different recording sessions (RR1 and RR2). (See sub-section 8.4.1 and section F3.)

The information from Fig. 7.4, 7.5 and 8.1 is summarized in Table 8.1.
Fig. 8.1: Waveforms and Spectrograms of Famous Singers

Artist: Caruso No. ZZ/11
Expected pitch: 440/A4
Actual pitch: 444/A4 Vowel: ?

Artist: Caruso No. ZZ/16
Expected pitch: 440/A4
Actual pitch: 444/A4 Vowel: EE

Artist: Caruso No. ZZ/27
Expected pitch: 440/A4
Actual pitch: 444/A4 Vowel: EH
FIG. 6.1 (continued)

Artist: CARUSO No. RR2/11
Expected pitch: 494/164
Actual pitch: 500/14, Vowel: AH

Artist: CARUSO No. RR2/16
Expected pitch: 496/164
Actual pitch: 511/14, Vowel: AH

Artist: CARUSO No. RR2/19
Expected pitch: 496/164
Actual pitch: 498/16, Vowel: AH
FIG. 6.1 (continued)

Artist: Caruso  No. RR2/6
Expected pitch: 441/13 Hertz
Actual pitch: 443 Hertz  Vowel: oo

Artist: Caruso  No. RR1/46
Expected pitch: 446 Hertz
Actual pitch: 445 Hertz  Vowel: oo

COMPUTERIZED
FIG. 8.1 (continued)

Artist: Caruso
No. RR18
Expected pitch: 543/65
Actual pitch: 541/65
Vowel: EE

Artist: Caruso
No. RR118
Expected pitch: 494/64
Actual pitch: 500/64
Vowel: EE

Artist: Caruso
No. RR148
Expected pitch: 494/64
Actual pitch: 500/64
Vowel: EE
FIG. 6.1 (continued)

Artist: Caruso No. RR2/12
Expected pitch: 4c/16th
Actual pitch: 4c/4th Vowel: AH

COMPUTERIZED

Artist: Caruso No. RR1/45
Expected pitch: 4c/8th
Actual pitch: 4c/4th Vowel: AH
FIG. 8.1 (continued)

Artist: Caruso No. R11/44
Expected pitch: 311/4
Actual pitch: 311/4; vowel: AH

COMPUTERIZED

Artist: Caruso No. R11/44
Expected pitch: 311/4
Actual pitch: 311/4; vowel: AH
FIG. 8.1 (continued)

Artist: Caruso No. RR1/15
Expected pitch: G4/G4
Actual pitch: G4 G4 Vowel: EH

Artist: Caruso No. RR1/40
Expected pitch: G4/G4
Actual pitch: E4 E4 Vowel: EH
FIG. 8.1 (continued)

Artist: CARUSO No. RR1/4
Expected pitch: 441/4
Actual pitch: 411/4 Vowel: EH

Artist: CARUSO No. RR1/16
Expected pitch: 361/4
Actual pitch: 461/4 Vowel: EH

COMPUTERIZED

Artist: CARUSO No. RR1/41
Expected pitch: 415/4
Actual pitch: 411/4 Vowel: EH
FIG. 6.1 (continued)

Artist: Caruso No. RR2/5
Expected pitch: 440/1/4
Actual pitch: 4/1/4 Vowel: EH

Artist: Caruso No. RR1/17
Expected pitch: 440/1/4
Actual pitch: 4/1/4 Vowel: EH

Artist: Caruso No. RR1/42
Expected pitch: 440/1/4
Actual pitch: 4/1/4 Vowel: EH

Computerized

Artist: Caruso No. RR1/17
Expected pitch: 440/1/4
Actual pitch: 4/1/4 Vowel: EH

Artist: Caruso No. RR1/42
Expected pitch: 440/1/4
Actual pitch: 4/1/4 Vowel: EH
FIG. 6.1 (continued)

Artist: Caruso No. RR2/17
Expected pitch: 466 hertz
Actual pitch: 466 hertz Vowel: AH

Artist: Caruso No. RR2/36
Expected pitch: 466 hertz
Actual pitch: 466 hertz Vowel: AH

Artist: Caruso No. RR1/47
Expected pitch: 466 hertz
Actual pitch: 466 hertz Vowel: AH

COMPUTERIZED
FIG. 6.1 (continued)

Artist: Caruso No. BRI/10
Expected pitch: 440/440
Actual pitch: 441/441 Vowel:

Artist: Caruso No. BRI/15
Expected pitch: 440/440
Actual pitch: 440/440 Vowel:

COMPUTERIZED

Artist: Caruso No. BRI/43
Expected pitch: 440/440
Actual pitch: 440/440 Vowel:
FIG. 6.1 (continued)

Artist: Caruso No. RR2/19
Expected pitch: 440/44
Actual pitch: 500/50 Vowel: EH

Artist: Caruso No. RR2/18
Expected pitch: 511/51
Actual pitch: 511/51 Vowel: EH

Artist: Caruso No. RR2/18
Expected pitch: 440/44
Actual pitch: 511/51 Vowel: EH

Artist: Caruso No. RR1/49
Expected pitch: 440/44
Actual pitch: 511/51 Vowel: EH
FIG. 6.1 (continued)

Artist: Caruso No. RRI 11
Expected pitch: 440/14
Actual pitch: 440/14 Vowel: AH

Artist: Caruso No. RRI 14
Expected pitch: 440/14
Actual pitch: 440/14 Vowel: AH

Artist: Caruso No. RRI 39
Expected pitch: 440/14
Actual pitch: 440/14 Vowel: AH
FIG. 6.1 (continued)

Artist: Tamagno No. R22/417
Expected pitch: 330 / 344.

Artist: Tamagno No. R22/22
Expected pitch: 44 / 64
FIG. 6.1 (continued)

Artist: ZENATELLO No. RR2/13
Expected pitch: 440/44
Actual pitch: 411/44 Vowel: EH

Expected pitch: 220/44 Vowel: OH
FIG. 6.1 (continued)

Artist: McCormack No. RE2/32
Expected pitch: 440/4
Actual pitch: 445/4 Vowel: ?

Artist: McCormack No. RE2/33
Expected pitch: 345/4
Actual pitch: 345/4 Vowel: ?

Artist: McCormack No. RE2/34
Expected pitch: 494/4
Actual pitch: 495/4 Vowel: ?

Artist: McCormack No. RE2/35
Expected pitch: 545/4
Actual pitch: 545/4 Vowel: ?
FIG. 6.1 (continued)

Artist: Schipa No. 882/38
Expected pitch: 3/4/6/8
Actual pitch: 1/2/6/8
Vowel: "?

Artist: Gigli No. 882/34
Expected pitch: 6/6/6/6
Actual pitch: 1/2/6/8
Vowel: "E,"

Artist: Gigli No. 881/19
Expected pitch: 4/4/6/6
Actual pitch: 1/2/6/8
Vowel: "?"
FIG. 6.1 (continued)

**Artist:** Pavarotti No. 3
Expected pitch: 440/1
Actual pitch: 440/1
Vowel: ?

**Artist:** Pavarotti No. 4
Expected pitch: 311/4#
Actual pitch: 311/4#
Vowel: ?

**Artist:** Pavarotti No. 5
Expected pitch: 310/1#
Actual pitch: 310/1#
Vowel: ?
FIG. 9.1 (continued)

**Artist:** Pavarotti No. ERI/6
Expected pitch: 370/FE-f
Actual pitch: 27e/fg. Vowel: RN

**Artist:** Pavarotti No. ERI/7
Expected pitch: 511/5
Actual pitch: 37e. Vowel:  ?
FIG. 8.1 (continued)

**Artist: Domingo No. RRI/8**
Expected pitch: 4% / 4%
Actual pitch: 4% / 4%
Vowel: ?

**Artist: Domingo No. RRI/9**
Expected pitch: 4% / 4%
Actual pitch: 4% / 4%
Vowel: ?

**Artist: Domingo No. RRI/10**
Expected pitch: 4% / 4%
Actual pitch: 4% / 4%
Vowel: ?
FIG. 6.1 (continued)

Artist: Nash No. RRI/21
Expected pitch: 440/44
Actual pitch: 445/44
Vowel: ?

Artist: Bjerling No. RRI/22
Expected pitch: 445/44
Actual pitch: 445/44
Vowel: ?

Artist: Thill No. RRI/23
Expected pitch: 445/44
Actual pitch: 445/44
Vowel: ?

Artist: Melchior No. RRI/31
Expected pitch: 445/44
Actual pitch: 445/44
Vowel: ?
FIG. 6.1 (continued)

Artist: Stracciari, No. 2222
Expected pitch: /g2/25
Actual pitch: /g2/25 Vowel: /EH/

Artist: Valdengo No. 4444
Expected pitch: /ae/cv
Actual pitch: /ae/cv Vowel: /ae/

Artist: Valdengo No. 5555
Expected pitch: /ae/cv
Actual pitch: /ae/cv Vowel: /ae/
FIG. 6.1 (continued)

Artist: Fischer-Dieskau
No. 36/36
Expected pitch: 220/1
Actual pitch: 220/1 Vowel: OH

Artist: Fischer-Dieskau
No. 36/37
Expected pitch: 244/1
Actual pitch: 244/1 Vowel: IH

Artist: Fischer-Dieskau
No. 36/38
Expected pitch: 144/1
Actual pitch: 144/1 Vowel: AH
FIG. 6.1 (continued)

Artist: Delma No. RR2/30
Expected pitch: 247/83
Actual pitch: 147/83 Vowel: ?

Artist: Delma No. RR2/31
Expected pitch: 123/82
Actual pitch: 135/83 Vowel: ?
FIG. 6.1 (continued)

Artist: ANZA No. R1/BE
Expected pitch: 147/B
Actual pitch: /5/4, vowel: OH

Artist: ANZA No. R1/FE
Expected pitch: 127/46
Actual pitch: /5/4, vowel: IH

Artist: ANZA No. R1/28
Expected pitch: 139/41
Actual pitch: /5/4, vowel: OH
FIG. 6.1 (continued)

Artist: Chaliapin No. 29/34
Expected pitch: 221/34
Actual pitch: 221/34

Expected pitch: 277/34
Actual pitch: 277/34
FIG. 6.1 (continued)

Artist: MILO No. RR1/24
Expected pitch: 330 Hz
Actual pitch: 330 Hz
Vowel: a

Artist: MILO No. RR1/25
Expected pitch: 1047 Hz
Actual pitch: 1047 Hz
Vowel: ?

Artist: MILO No. RR1/26
Expected pitch: 1047 Hz
Actual pitch: 1047 Hz
Vowel: ?
FIG. 6.1 (continued)

Artist: Del Monte
No. RRI/18
Expected pitch: 1104/c, lb
Actual pitch: [Data]

Vowel: [Data]

Artist: Callas
No. RRI/34
Expected pitch: 988/5s
Actual pitch: [Data]

Vowel: [Data]
TABLE 8.1

SUMMARY OF OBSERVATIONS FROM FIG. 7.4, 7.5, AND 8.1

Arrows are used to link notes so that comparisons may be indicated: 

\[ \uparrow \vee \quad \text{or} \quad \uparrow \times \]
<table>
<thead>
<tr>
<th>Note number</th>
<th>Artist</th>
<th>Sound quality</th>
<th>Pielke's scheme (1)</th>
<th>Pielke's scheme (2)</th>
<th>Fundamental weaker than at least one other harmonic</th>
<th>Evidence for singing formants: ( \sqrt{\text{= strong}} ) at about 500 Hz</th>
<th>Evidence for singing formants: ( \sqrt{\text{= strong}} ) at about 900 Hz</th>
<th>Evidence for singing formants: ( \sqrt{\text{= strong}} ) at about 2.8 KHz</th>
<th>Vocal spectra identical or very similar</th>
</tr>
</thead>
<tbody>
<tr>
<td>RR1/56</td>
<td>WHITE CROSS SEALS</td>
<td>DA</td>
<td>( \checkmark )</td>
<td>( \checkmark )</td>
<td>( \sqrt{\text{= strong}} )</td>
<td>( \sqrt{\text{= strong}} )</td>
<td>( \sqrt{\text{= strong}} )</td>
<td>( \sqrt{\text{= strong}} )</td>
<td>( \sqrt{\text{= strong}} )</td>
</tr>
<tr>
<td>RR1/57</td>
<td>DITTO</td>
<td>DA</td>
<td>( \checkmark )</td>
<td>( \times )</td>
<td>( \sqrt{\text{= strong}} )</td>
<td>( \sqrt{\text{= strong}} )</td>
<td>( \sqrt{\text{= strong}} )</td>
<td>( \sqrt{\text{= strong}} )</td>
<td>( \sqrt{\text{= strong}} )</td>
</tr>
<tr>
<td>RR1/58</td>
<td>DITTO</td>
<td>DA</td>
<td>( \checkmark )</td>
<td>( \times )</td>
<td>( \sqrt{\text{= strong}} )</td>
<td>( \sqrt{\text{= strong}} )</td>
<td>( \sqrt{\text{= strong}} )</td>
<td>( \sqrt{\text{= strong}} )</td>
<td>( \sqrt{\text{= strong}} )</td>
</tr>
<tr>
<td>RR1/59</td>
<td>DITTO</td>
<td>DA</td>
<td>( \checkmark )</td>
<td>( \times )</td>
<td>( \sqrt{\text{= strong}} )</td>
<td>( \sqrt{\text{= strong}} )</td>
<td>( \sqrt{\text{= strong}} )</td>
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**Table 8.1:** Summary of Observations from Fig. 7.4, 7.5, and 8.1.
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<th>Note number</th>
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<th>Sound quality</th>
<th>Pielke's scheme (1)</th>
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<th>Evidence for singing formants:</th>
<th>Vocal spectra similar</th>
<th>Vocal waveforms similar</th>
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<td>X</td>
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<td>DITTO</td>
<td>DA</td>
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TABLE 8.1: SUMMARY OF OBSERVATIONS (continued)
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<th>Pielke's scheme (1)</th>
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<th>Evidence for singing formants: √ = strong at about 500 Hz</th>
<th>at 600 - 900 Hz</th>
<th>at about 2.8 kHz</th>
<th>Vocal spectra identical or very similar</th>
<th>Vocal waveforms identical or very similar</th>
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<td>RR2/3</td>
<td>CARUSO (tenor)</td>
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<td>√</td>
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<td>×</td>
<td>×</td>
<td>√</td>
<td>×</td>
<td>√</td>
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<td>DITTO</td>
<td>DA</td>
<td>√</td>
<td></td>
<td></td>
<td>×</td>
<td>×</td>
<td>?</td>
<td>×</td>
<td>√</td>
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<td>DITTO</td>
<td>DA (slightly higher pitch)</td>
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<td></td>
<td>×</td>
<td>×</td>
<td>?</td>
<td>×</td>
<td>√</td>
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<td>RR2/6</td>
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<td>×</td>
<td>×</td>
<td>?</td>
<td>×</td>
<td>√</td>
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<tr>
<td>RR2/37</td>
<td>DITTO</td>
<td>DA (wobble)</td>
<td>√</td>
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<td></td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
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<tr>
<td>RR2/45</td>
<td>DITTO</td>
<td>DA (darker)</td>
<td>√</td>
<td></td>
<td></td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
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<tr>
<td>RR2/4</td>
<td>DITTO</td>
<td>DA (powerful note, lower pitch)</td>
<td>√</td>
<td></td>
<td></td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
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**Table 8.1: Summary of Observations (continued)**
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<th>Pielke's scheme (2)</th>
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<th>Evidence for singing formants:</th>
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<th>Vocal waveforms identical or very similar</th>
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<td>✓</td>
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TABLE 6.1: SUMMARY OF OBSERVATIONS (continued)
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Table 8.1: SUMMARY OF OBSERVATIONS (continued)
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<th>Pielke's scheme (1)</th>
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<td>at about 500 Hz</td>
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<td></td>
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<tr>
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</tr>
<tr>
<td>R22/19</td>
<td>DITTO</td>
<td>DA BRILLIANT</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Table 6.1: Summary of Observations (continued)
<table>
<thead>
<tr>
<th>Note number</th>
<th>Artist</th>
<th>Sound quality</th>
<th>Pielke's scheme (1)</th>
<th>Pielke's scheme (2)</th>
<th>Fundamental weaker than at least one other harmonic</th>
<th>Evidence for singing formants: ✓ = strong</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>DA = dark, L = light, DU = dull, SH = shrill, # = sharp</td>
<td>✓ = correct in relation to sound quality</td>
<td>✓ = correct in relation to sound quality</td>
<td></td>
<td>at about 500 Hz</td>
</tr>
<tr>
<td>RR2/40</td>
<td>TOWSER (TENOR)</td>
<td>DA</td>
<td>AN INSTANT RECOGNIZABLE</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>RR2/41</td>
<td>DITTO</td>
<td>DA</td>
<td>VOICE, EVEN FROM ONE</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>RR2/42</td>
<td>DITTO</td>
<td>DA</td>
<td>NOTE</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>RR1/3</td>
<td>PAVAROTTI (TENOR)</td>
<td>DA</td>
<td>BRILLIANT, BUT LYRICAL</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>RR1/4</td>
<td>DITTO</td>
<td>DA</td>
<td>LYRICAL</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>RR1/5</td>
<td>DITTO</td>
<td>DA</td>
<td>LYRICAL</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>RR1/6</td>
<td>DITTO</td>
<td>DA</td>
<td>BRILLIANT</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>RR1/7</td>
<td>DITTO</td>
<td>DA</td>
<td>BRILLIANT</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>RR1/8</td>
<td>DOMINGO (TENOR)</td>
<td>DA</td>
<td>BRILLIANT  (LESS)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>RR1/9</td>
<td>DITTO</td>
<td>DA</td>
<td>BRILLIANT (LYRICAL THAN PAVAROTTI)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>RR1/10</td>
<td>DITTO</td>
<td>DA</td>
<td>BRILLIANT</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>RR1/21</td>
<td>MASHEL (TENOR)</td>
<td>DU</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

**Table 8.1: Summary of Observations (continued)**
<table>
<thead>
<tr>
<th>Note number</th>
<th>Artist (Vocals)</th>
<th>Sound quality DA = dark L = light DU = dull SH = shrill  ≠ = sharp</th>
<th>Pielke's scheme (1) = correct in relation to sound quality</th>
<th>Pielke's scheme (2) = correct in relation to sound quality</th>
<th>Fundamental weaker than at least one other harmonic</th>
<th>Evidence for singing formants:  ✓ = strong at about 500 Hz ✓ = strong at 600 - 900 Hz ✓ = strong at about 2.8 KHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1/12</td>
<td>STIRLING (tenor)</td>
<td>DA</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
<td>✓ very strong</td>
</tr>
<tr>
<td>R1/13</td>
<td>THILL (tenor)</td>
<td>DA</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
<td>✓ very strong</td>
</tr>
<tr>
<td>R1/31</td>
<td>MELCHEK (tenor)</td>
<td>DA RECOGNIZING VOICE</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
<td>✓ higher pitch than initial</td>
</tr>
<tr>
<td>R2/25</td>
<td>STRUNKER (baritone)</td>
<td>DA/DU</td>
<td>✓</td>
<td>?</td>
<td>✓</td>
<td>✓ very strong</td>
</tr>
<tr>
<td>R1/32</td>
<td>VALDENO (baritone)</td>
<td>DA</td>
<td>✓</td>
<td>✓ very strong</td>
<td>✓</td>
<td>✓ very strong</td>
</tr>
<tr>
<td>R1/33</td>
<td>DITTO</td>
<td>DA</td>
<td>✓</td>
<td>✓ very strong</td>
<td>✓</td>
<td>✓ very strong</td>
</tr>
<tr>
<td>R1/36</td>
<td>FISCHER-DISCHON (baritone)</td>
<td>DA</td>
<td>✓</td>
<td>✓ very strong</td>
<td>✓</td>
<td>✓ very strong</td>
</tr>
<tr>
<td>R1/37</td>
<td>DITTO</td>
<td>DA</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
<td>✓ very strong</td>
</tr>
<tr>
<td>R1/38</td>
<td>DITTO</td>
<td>DA</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
<td>✓ very strong</td>
</tr>
<tr>
<td>R2/30</td>
<td>DECMA (bass)</td>
<td>DA/DU</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
<td>✓ strong higher pitch than initial</td>
</tr>
<tr>
<td>R2/31</td>
<td>DITTO</td>
<td>DA</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
<td>✓ weak</td>
</tr>
</tbody>
</table>

**TABLE 6.1: SUMMARY OF OBSERVATIONS (continued)**
<table>
<thead>
<tr>
<th>Note number</th>
<th>Artist</th>
<th>Sound quality</th>
<th>Pielke's scheme (1) = correct in relation to sound quality</th>
<th>Pielke's scheme (2) = correct in relation to sound quality</th>
<th>Fundamental weaker than at least one other harmonic</th>
<th>Evidence for singing formants: ✓ = strong at about 500 Hz</th>
<th>✓ = strong at 600 - 900 Hz</th>
<th>✓ = strong at about 2.8 KHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>RR1/26</td>
<td>PINZA (BASS)</td>
<td>DA</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>RR1/27</td>
<td>DITTO</td>
<td>DA</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>RR1/28</td>
<td>DITTO</td>
<td>DA</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>RR1/29</td>
<td>CHIKIWAN (BASS)</td>
<td>DA</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>RR1/20</td>
<td>DITTO</td>
<td>DA</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>RR1/21</td>
<td>DELLER (COUNTER- TENOR)</td>
<td>DA</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>RR1/22</td>
<td>DITTO</td>
<td>DA</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>RR1/23</td>
<td>LEBBMAN (SOPRANO)</td>
<td>SH</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>RR1/24</td>
<td>DITTO</td>
<td>DA</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>RR1/25</td>
<td>MELBA (SOPRANO)</td>
<td>DA</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

**TABLE 6.1: SUMMARY OF OBSERVATIONS** (continued)
<table>
<thead>
<tr>
<th>Note number</th>
<th>Artist</th>
<th>Sound quality</th>
<th>Pielke's scheme</th>
<th>Pielke's scheme</th>
<th>Fundamental weaker than</th>
<th>Evidence for singing formants:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>at least one other harmonic</td>
<td>at about 500 Hz</td>
<td>at 600 - 900 Hz</td>
</tr>
<tr>
<td>118/130</td>
<td>Dal</td>
<td>DA = dark</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Monte</td>
<td>L = light</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>DU = dull</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>SH = shrill</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td># = sharp</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>118/34</td>
<td>Callas</td>
<td>DA = sharp</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 8.1: SUMMARY OF OBSERVATIONS** (continued)
8.4: DISCUSSION OF THE OBSERVATIONS SUMMARIZED IN TABLE 8.1

I have used the conclusions of my M.Phil. thesis (see section J3) and conclusions drawn in the last chapter (see section 7.7), to compile a series of specific questions which help in the consideration of the data.

8.4.1: When identical notes were transferred at the two recording sessions, were differences produced in the waveforms or spectra?

All the notes discussed here are those of Caruso, and the pairs concerned are RR2/4 and RR1/16; RR2/5 and RR1/17; RR2/1 and RR1/14. Peaks at 100 Hz or below can be ignored, as discussed in section 7.3. It is not possible to say why the background noise levels were not identical, but some turntable rumble at the RR1 session was probably to blame.

RR2/4 and RR1/16

Waveforms: not really similar, even allowing for different settings of the plotter. (The sections may not be typical, of course.)

Spectra: similar above 500 Hz, but the fundamental appears to be strongly enhanced in RR1/16 (or depressed in RR2/4, of course). This is not quite the case, as the trough between the 400 Hz and 630 Hz filters has been filled in in RR1/16. There are also peaks below 400 Hz in RR1/16.

RR2/5 and RR1/17

Waveforms: these would probably have been similar if the plotter settings had been identical.
Spectra: fairly similar throughout. The 500 Hz filter peak is slightly higher in RR1/17.

RR2/1 and RR1/14

Waveforms: these would probably have been similar if the plotter settings had been identical.

Spectra: very similar at the 800 Hz filter peak and above, but the troughs are filled in down to 200 Hz in RR2/1.

The three RR1 notes do seem to show an enhancement at 200 Hz or 250 Hz which may have been due to "noise" in the apparatus. However, not all other RR1 notes show this. Bearing in mind the rather odd appearances of the peaks below 800 Hz in RR2/1, I do not think that we can conclude that one tape recording session consistently produced more inaccuracies or "noise" than the other.

It is heartening that each note sounds practically identical to its partner, and it will be noted that the main differences in the spectra seem to be at relatively low pitches. These probably have less effect on the sound quality, at least in a tenor voice, than would differences in the middle or upper frequency ranges.

8.4.2: Do the notes conform in any way to Pielke's scheme? (See also section J3.) This is referred to as "Pielke's scheme (1)" in Table 8.1.

"Dark" timbre, [i.e. "covered"]: low partials predominate.
"Light" timbre, [i.e. "open"]: higher partials predominate.

"Dull" timbre: too few higher harmonics.

"Shrill" timbre: too many higher harmonics.

"Sharp" timbre: emphasis of the 3 KHz to 4 KHz range.

(This scheme was investigated in my M.Phil. work, where I subjected the data to detailed statistical analyses. This was thought to be an unwieldy process, and not very practicable in the present case as so many data are involved.)

As shown in Table 8.1, there are some instances where the scheme definitely seems either to work or not to work. These instances are indicated by a √ or x respectively. In most cases, however, the evidence is not clear. As mentioned in sub-section 8.4.7, the singing formant at about 2.8 KHz is very important in "dark" or "covered" notes, and therefore it is difficult to see how low partials could predominate in dark notes, except perhaps with relatively low-pitched fundamentals, as in notes RR1/66, RR1/57, RR1/75; and RR1/65, RR1/56, RR1/74, (White).

I think that there is some evidence that "dull" notes have a relatively strong fundamental. A good example is RR1/2 (Deller), where the singer is producing a dull timbre.
deliberately, for effect. The fact that this note is sung by a counter-tenor may complicate the picture: see sub-section 5.5.3 and section 5.4. In my opinion, Deller's voice always sounds "darker" than those of other counter-tenors.

The listener's conception of what is meant by "dull" is important, of course, but some of the notes which sound dull to me do not show a strong fundamental. For example, see RR1/27 and RR1/28 (Pinza), and RR1/29 (Chaliapin).

Fundamentals of very low pitch seem to be accompanied by few peaks over about 3 KHz.

The only two "shrill" notes are RR1/11 (Lehmann) and RR1/25 (Melba). The second of these may sound shrill because the fundamental is of high pitch and much stronger than all other formants. RR1/11 has a lower-pitched fundamental, but this is still very strong. RR1/13 (Lehmann) may not sound shrill, despite having a very strong fundamental, simply because the fundamental is at a relatively low pitch. None of the notes studied is truly assessed as "sharp".

Two further categories are defined which were not mentioned in Pielke's scheme. Firstly, "strained": again, a subjective judgement, where the singer does not appear to be at ease. These "strained" notes are RR2/11, RR2/7, RR2/36, RR2/10 (Caruso) and RR2/24 (Zenatello). There is no obvious link between the waveforms or spectra of these notes. Secondly, ringing notes are referred to as "brilliant".
8.4.3: Is there any evidence for Pielke's suggestion that there is:

a) a weak second harmonic in "closed" (covered) singing?

b) a prominent second harmonic in "open" singing?

c) a strong fundamental and rich harmonics in "covered" singing?

This scheme is referred to as "Pielke's scheme (2)" in Table 8.1. (See also section J3.)

Again, this was investigated in my M.Phil. work. Points a) and b), which refer to the second harmonic in "closed" and "open" singing are not, in general, supported by the spectra. In fact, it seems unlikely that the second harmonic would be important, as the singing formants are probably more significant. (See sub-sections 8.4.7, 8.4.8 and 8.4.9.) Some "brilliant" notes do have a prominent second harmonic, for example, RR1/8 and RR1/9 (Domingo).

With regard to point c), the assertions here are certainly not always true. The fundamental may be very weak, as in the case of RR1/66, RR1/57, RR1/75 (White), but covered tones do seem generally to have rich harmonics. Some "light" or "dull" notes have relatively few high harmonics, e.g. RR1/29 (Chaliapin), RR1/2 (Deller), and RR1/13 (Lehmann). (Compare the spectrum of RR1/29 with that of RR1/56 (White), which is at the same pitch, but properly covered).
8.4.4: Is the fundamental weak or strong in relation to the other harmonic partials? (Does it have to be "filled in" by the brain of the listener?)

In most cases, the fundamental is weaker than at least one other harmonic, indicating that the brain must interpret what it hears to a large extent. (See also sub-section 7.4.3(2).) The fundamental may be enhanced if it is in the region of an important formant. For example, the tenor fundamentals are often near the supposed singing formant at about 500 Hz (see sub-sections 8.4.7 and 8.4.8). In Caruso's case, the situation appears to have been complicated in the computer-enhanced recordings: see sub-section 8.4.13.

Female fundamentals are often in the first formant region of "ah" (see sub-section 6.7.5), and this is probably the reason for the strong fundamentals in female notes such as those of Lehmann (RR1/11, RR1/12, RR1/13).

8.4.5: Do males show higher numbers of harmonic components than females? Is there much evidence of non-harmonic components?

It is difficult to count harmonic and non-harmonic components in the spectra, as the filter bands of the Brüel & Kjaer Analyzer are wide. (See section F7.) Nevertheless, it is possible to detect vibrato, where a "double" peak occurs around the fundamental. (See also sub-sections 7.5.3(c) and 8.4.10.)
8.4.6: Are vowel formants as suggested in Table 6.1, or are they much modified? Is there evidence for a singing formant between about 500 Hz and 1 KHz?

N.B. In Table 8.1, where formants are indicated, I have used "?" where a possible formant area is obscured by other peaks, and "weak" if the formant area is generally of a lower amplitude than other harmonics.

Although the vowels are indicated for some notes, these were mostly identified from scores, when they were available. However, there is no guarantee that a singer sings the vowel he or she is supposed to sing. Vowels are often modified, (see sub-section 6.7.5), and it is usually impossible, especially on high notes, to identify exactly the vowel being sung by listening alone. Certainly, the notes analyzed in this study do not seem to show distinctly different vowel formants. For example, notes RR1/46 and RR1/48 (Caruso), are sung to totally different vowels, but their waveforms and spectra are remarkably similar. However, both these notes are computer-enhanced, which may be significant. (See sub-section 8.4.13.) Certainly, the fundamentals in Caruso's notes are often very strong, especially when near 500 Hz. Is it because this region is just at the bottom end of the first formant range of many vowels, or because it is near a lower singing formant? Could this be a factor contributing to the well-known "baritonal" quality of Caruso's voice?

The most important harmonic partials for many of the male singers appear to be F1, F2 and F3. These tend to appear as distinct peaks, with the singing formant at about 2.8 KHz
appearing as a fourth main peak. (See, for example, RR2/24, Zenatello.) In Table 8.1, I have headed two columns "Evidence for singing formants at 500 Hz and 600-900 Hz". I here indicate whether distinct peaks are evident in these regions; they could easily be vowel formants alone, and that is my overall opinion. In fact, Bartholomew, who is an advocate of the lower singing formant, says:

"This low formant [near 500 Hz] may in some cases be the lower of the two vowel formants which contribute the particular vowel quality of the tone."

(Bartholomew, 1934, 27.)

It is difficult to assess the precise vowels being sung, as mentioned above, and only recordings where controlled pronunciation is used can elucidate this matter.

The female singers do not seem to conform to the same scheme, but the sample is small, and the fundamental pitch is often very high, so no firm conclusions can be drawn.

An important point should be made here. When speaking, a precise pitch is not maintained. Therefore, slightly varying fundamental pitches are used which will generate varying harmonic partials. These may then fit precisely into the required vowel formant regions. When singing, on the other hand, frequency is more strictly controlled, and the harmonic partials produced may not fit the required vowel formant regions. The peaks seen will be the harmonic partials of Fl, which are approximately within the vowel formant regions. Let us imagine that a particular singer sings the vowels "eh" ("head") and "a" ("had"), with a
fundamental frequency of B3 (c 250 Hz). Using the information in Table 6.1, the result should be as in Table 8.2, all other factors, apart from the vowel, being equal:

| TABLE 8.2: SUPPOSED FORMANT AREAS OF "EH" AND "A" WHEN SUNG WITH A FUNDAMENTAL OF 250 Hz |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| F1  | F2  | F3  | F4  | F5  | F6  | F7  | F8  |
| 250 | 500 | 750 | 1000| 1250| 1500| 1750| 2000|
| Head √(F1) | √(A) | √(B) or √(B) |
| Had √(F1) | √(A) or √(A) | √(B) |

√ = harmonic partials enhanced.

F1 = fundamental
A = first formant area
B = second formant area

This is a very simple example, but shows that two different vowels sung at the same pitch could produce almost identical spectra. These may be made even more similar because of the relatively wide filter bands of an analyzer like the Brüel & Kjaer machine. The notes may also sound the same. A speaker might generate a variable fundamental or enough acoustic "noise" to allow exact fits between harmonics and formant areas.

Miller (1934, 244ff) makes the very interesting point that certain vowels are easier to sing if they are on notes which
agree harmonically with their formants. This is an important factor when translating vocal works into another language. He says (p 262):

"It has been suggested that certain songs and choruses which are especially effective owe this quality to the proper relation of vowel sounds to melody notes, and the Hallelujah Chorus from the 'Messiah' has been cited as an instance."

8.4.7: Is there evidence for a singing formant at about 2.8 KHz?

N.B. See the note at the beginning of sub-section 8.4.6.

The data presented leave no doubt about this matter. This formant seems to fall generally within the 2.5 KHz filter band of the Brüel & Kjaer Analyzer, and is evident in almost all "dark" notes. The following simple rules can be derived for male voices. (Although this formant may be evident in female voices, it is not as important as in male voices, as discussed in sub-section 6.7.6.) I have not quoted examples for all of the following, as details are given in Table 8.1.

a) This formant is generally weak in "dull" notes.

b) It is quite prominent in "dark" notes.

c) It is very strong in notes of "brilliant" or "ringing" quality.
d) Lyrical tenors do not produce a pronounced formant at this pitch. For example, see the spectra of McCormack, Schipa and Tauber. It is interesting that the counter-tenor Deller produces a strong singing formant in note RR1/1. This has a relatively low-pitched fundamental, and so this singing formant may be needed, even in a high voice.

8.4.8: Does each singer's voice have a characteristic "spectrum pattern"? Does each voice type produce a characteristic "spectrum pattern"?

I decided to approach this problem by producing some "average" spectra for different singers. This could probably be done using a computer program to compare, for example, all the spectra of Caruso. However, I do not think that this would be very useful, as such a mechanical method would allow little subjective judgement to be exercised. There are so many variables involved, such as the fundamental pitch, the stage of development of the singer, and so on. One would probably be led to apparently conclusive, but in fact wholly erroneous, results.

I therefore looked for spectra produced by a singer which had similar fundamentals and overall shapes. The amplitudes of the peaks were calculated for each spectrum and averaged with those of the other spectra in the group. The results were plotted by hand. The amplitudes and averaged results are shown in Table 8.3, and the plotted average spectra in Fig. 8.2.

I could identify only eleven groups of spectra from eight singers which I felt could be averaged. This was no easy
task, as it was difficult to identify the true fundamental of each note, as discussed in section 7.2. As the Brüel & Kjaer analyzer had quite wide filter bands, I could see whether a particular band contained the fundamental, and groups of notes for averaging were chosen with this in mind. The pair of notes RR1/5, RR1/6 (Pavarotti) is the most suspect in this respect, and the peaks do not match as well as those of other groups. The pitches quoted in Table 8.3 are the "expected" pitches which are shown in Fig. 8.1. Although the vowel sounds differ, I do not consider that this is of great importance, for reasons discussed in sub-section 8.4.6.
<table>
<thead>
<tr>
<th>Note number</th>
<th>Artist</th>
<th>Sound quality</th>
<th>Pitch</th>
<th>Vowel</th>
<th>Source of recording</th>
<th>Centre frequencies of the Brüel &amp; Kjaer 30 third octave filters (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BR2/57</td>
<td>Caruso</td>
<td>DA</td>
<td>ee</td>
<td>GTC 12</td>
<td></td>
<td>25 - 75 64 20 63 80 100 115 160 220 240 315 420 560 630 800 1000 1250 1600 2000 2500 3150 4000 5000</td>
</tr>
<tr>
<td>BR2/56</td>
<td>Caruso</td>
<td>DA</td>
<td>ah</td>
<td>GTC 12</td>
<td></td>
<td>25 - 75 64 20 63 80 100 115 160 220 240 315 420 560 630 800 1000 1250 1600 2000 2500 3150 4000 5000</td>
</tr>
<tr>
<td>BR2/15</td>
<td>Caruso</td>
<td>?</td>
<td></td>
<td>GTC 12</td>
<td></td>
<td>25 - 75 64 20 63 80 100 115 160 220 240 315 420 560 630 800 1000 1250 1600 2000 2500 3150 4000 5000</td>
</tr>
<tr>
<td>BR1/48</td>
<td>Caruso</td>
<td>DA</td>
<td>ee</td>
<td>RL 11749</td>
<td></td>
<td>25 - 75 64 20 63 80 100 115 160 220 240 315 420 560 630 800 1000 1250 1600 2000 2500 3150 4000 5000</td>
</tr>
<tr>
<td>BR1/47</td>
<td>Caruso</td>
<td>DA</td>
<td>ah</td>
<td>RL 11749</td>
<td></td>
<td>25 - 75 64 20 63 80 100 115 160 220 240 315 420 560 630 800 1000 1250 1600 2000 2500 3150 4000 5000</td>
</tr>
<tr>
<td>BR1/43</td>
<td>Caruso</td>
<td>?</td>
<td></td>
<td>RL 11749</td>
<td></td>
<td>25 - 75 64 20 63 80 100 115 160 220 240 315 420 560 630 800 1000 1250 1600 2000 2500 3150 4000 5000</td>
</tr>
<tr>
<td>BR1/35</td>
<td>Caruso</td>
<td>DA</td>
<td>eh</td>
<td>4072</td>
<td></td>
<td>25 - 75 64 20 63 80 100 115 160 220 240 315 420 560 630 800 1000 1250 1600 2000 2500 3150 4000 5000</td>
</tr>
<tr>
<td>BR1/17</td>
<td>Caruso</td>
<td>DA</td>
<td>eh</td>
<td>4072</td>
<td></td>
<td>25 - 75 64 20 63 80 100 115 160 220 240 315 420 560 630 800 1000 1250 1600 2000 2500 3150 4000 5000</td>
</tr>
<tr>
<td>BR1/40</td>
<td>Caruso</td>
<td>DA</td>
<td>eh</td>
<td>RL 11749</td>
<td></td>
<td>25 - 75 64 20 63 80 100 115 160 220 240 315 420 560 630 800 1000 1250 1600 2000 2500 3150 4000 5000</td>
</tr>
<tr>
<td>BR1/42</td>
<td>Caruso</td>
<td>DA</td>
<td>eh</td>
<td>RL 11749</td>
<td></td>
<td>25 - 75 64 20 63 80 100 115 160 220 240 315 420 560 630 800 1000 1250 1600 2000 2500 3150 4000 5000</td>
</tr>
<tr>
<td>BR2/41</td>
<td>Tausch</td>
<td>DA</td>
<td>?</td>
<td>HLM 7004</td>
<td></td>
<td>25 - 75 64 20 63 80 100 115 160 220 240 315 420 560 630 800 1000 1250 1600 2000 2500 3150 4000 5000</td>
</tr>
<tr>
<td>BR2/42</td>
<td>Tausch</td>
<td>DA</td>
<td></td>
<td>HLM 7004</td>
<td></td>
<td>25 - 75 64 20 63 80 100 115 160 220 240 315 420 560 630 800 1000 1250 1600 2000 2500 3150 4000 5000</td>
</tr>
<tr>
<td>BR1/5</td>
<td>Pavar-</td>
<td>DA</td>
<td>370</td>
<td></td>
<td>SXL 6377</td>
<td>25 - 75 64 20 63 80 100 115 160 220 240 315 420 560 630 800 1000 1250 1600 2000 2500 3150 4000 5000</td>
</tr>
<tr>
<td>BR1/6</td>
<td>otti</td>
<td>DA</td>
<td>370</td>
<td></td>
<td>SXL 6377</td>
<td>25 - 75 64 20 63 80 100 115 160 220 240 315 420 560 630 800 1000 1250 1600 2000 2500 3150 4000 5000</td>
</tr>
<tr>
<td>BR1/8</td>
<td>Dom-</td>
<td>DA</td>
<td>494</td>
<td></td>
<td>SCE 973</td>
<td>25 - 75 64 20 63 80 100 115 160 220 240 315 420 560 630 800 1000 1250 1600 2000 2500 3150 4000 5000</td>
</tr>
<tr>
<td>BR1/9</td>
<td>ingo</td>
<td>DA</td>
<td>494</td>
<td></td>
<td>SCE 973</td>
<td>25 - 75 64 20 63 80 100 115 160 220 240 315 420 560 630 800 1000 1250 1600 2000 2500 3150 4000 5000</td>
</tr>
</tbody>
</table>

"Average" of above spectra

* The pitches quoted are the overall "expected" pitches, shown in Fig. 6.1 and discussed in sub-sections 5.0.1 and 6.2.8.

See also Appendix B.
Although there are differences between the spectra produced by different singers, it is difficult to say whether any of these are significant. Nevertheless, one interesting point did emerge. The "averaged" spectrum B is a computer-enhanced equivalent of A; similarly, D is an equivalent of C. The computer-enhanced spectra are very different from their partners, especially in the case of A and B. B shows a considerable resemblance to G (Domingo), and I discuss this matter further in sub-section 8.4.13.

Now to the matter of whether each voice type shows a characteristic spectral pattern. Why should this be the case? It might be true if voices fell naturally into distinct categories, but they do not. The categories of soprano, bass, etc. are convenient for practical purposes, but:

"Voice types illustrate continuous variation in the statistical sense..." (White, 1982B, 143).

I think it would be a mistake to assume that all tenors, for example, should show similar acoustic characteristics. Certainly, there are similarities between some types of voices: see, for example, the comments in sub-section 8.4.7. Sacerdote (1957) analyzed recordings of the same piece of music made by six celebrated sopranos. He found wide differences, which he attributed to "individual sensitivity".
8.4.9 Do notes with similar vocal spectra show very different waveforms, thus indicating phase, or other, differences?

A partial may be prominent and impress its effect on a waveform, producing sub-peaks, or ripples. The order of the partial can be determined by counting the ripples. (Miller, 1934, 137.) For example, Fig. 8.3(a) shows six sub-peaks, and so F6 is prominent. Fig. 8.3(b) shows a waveform with one inharmonic partial. There are twenty-five ripples to four large waves. \( \frac{25}{4} = 6.25 \), and so the partial is about 6.25 times the fundamental.

In fact, a vocal waveform may be complicated by a number of partials. Fig. 8.3(c) shows a waveform of a bass intoning "ah" at 92 Hz, (F1). The loud partials are of a high order, as there are many "kinks" in one wavelength. On the other hand, Fig. 8.3(d) shows the waveform of a soprano intoning "ah" at 233 Hz, (Bb3). This is a simpler curve than the bass one, and there is only one strong partial, which is F2.

The waveform of a complex note depends upon the relative phases of the harmonics as well as their amplitudes. Fig. 8.4 shows a series of quite simple situations, where a waveform is affected by changing the relative phase of the second harmonic. As mentioned in section 6.2, phase differences do not appear to have much effect on what is heard, but they will affect the visual shape of a waveform.
a) "Ah" intoned at 159 Hz, (c D#/3). Six sub-peaks: F6 prominent, (954 Hz).

b) Clang-tone from a tuning fork. 25 ripples to four large waves: inharmonic partial = 25/4 = 6.25 times fundamental.

c) Bass intoning "ah" at 92 Hz, (F#1). Many "kinks": loud partials of a high order.

d) Soprano intoning "ah" at 233 Hz, (Bb3). Simple curve with one strong partial, i.e. F2

FIG 6.3: WAVEFORMS ADAPTED FROM MILLER (1934)
FIG. 6.4: EFFECT ON THE RESULTANT WAVEFORM OF CHANGING THE RELATIVE PHASE OF THE SECOND HARMONIC. (ADAPTED FROM BACKUS, 1970)
The basic principles relating to the effects of the amplitudes of partials, which are outlined above, can be seen quite easily in many of the waveforms in Fig. 8.1. For example, the waveform of RR2/26 (Caruso) shows six main sub-peaks, indicating that F6 should be prominent in the spectrum, which is indeed the case. Also, the waveform of RR2/27 (Caruso) shows five main sub-peaks, indicating that F5 should be prominent, as it is.

One important question is this: could phase differences have been introduced between identical original notes which were transferred onto different L.P. discs? In particular, the computer-enhancement technique might have introduced such differences. In some cases, the computer-enhancement has altered the spectrum dramatically, and so we would expect the waveforms to be very different. This is the case with RR2/37 and RR1/48 (Caruso), for example. On the other hand, the spectra of RR2/14 and RR1/44 (Caruso) are relatively similar, but the waveforms are not. Is this an instance where there are phase differences?

There are other possibilities which could explain such differences:

1) The amplitude settings of the plotter varied, as explained in section 7.2, and this could have been sufficient to alter the waveforms significantly. This is probably the case with RR2/5 and RR1/17, (Caruso), where the spectra are quite similar.

2) Even slight differences in the amplitudes of the harmonics may produce profound changes in the waveforms. If
many harmonics vary only slightly, there will be a cumulative effect.

3) "Noise" may be an important factor. This was discussed in section 7.3, but it is difficult to assess. The main harmonic peaks are easy to identify, but the large amount of background noise on many old recordings accounts for the "filling in" of a spectrum between the main peaks. This is no easy matter to study, but must affect the waveforms. My own spectra, shown in Fig. 7.4, seem to be quite distinctive, with well-defined "troughs". This may be because these notes were recorded "live", directly onto tape, avoiding much of the background noise which is present on virtually any gramophone record. Alternatively, of course, my voice may have fewer inharmonic partials than "richer" voices. (See section J3(5).)

4) The sections of waveforms which we are comparing may be atypical of the note as a whole, even though they were chosen carefully. (See section 7.2.)

I cannot see why phase differences should occur with different transfer processes, but without knowing exactly how the transfers were carried out, no firm conclusions can be drawn.

The waveforms of RR1/16 and RR1/41 look rather similar, but I think that this is quite fortuitous, as the spectra are so different! One has to exercise great care when examining these results.
Waveforms should be affected by vowel sounds because of changing formant areas. However, I do not think that this is evident in the case of the notes shown in Fig. 8.1. I have already discussed the reasons for this in sub-section 8.4.6, and noted the similarity between the waveforms and the spectra of RR1/46 and RR1/48 (Caruso), which are sung to different vowels.

8.4.10: Do "white" voices, or less "rich" voices, have less complex waveforms and spectra than rich operatic voices? First of all, I must state a point made in section J3(3). Males seem to show a higher number of harmonic components than females, probably because male fundamentals are of lower pitch, and there are more harmonic partials in the range analyzed. Also, females do not tend to show higher maximum partials than males when singing similar notes.

Certainly, many female waveforms and spectra do appear simpler than those of males. For example, see Harwood's waveforms and spectra in Fig. 7.5. Harwood has a "whiter", less operatic voice than Lehmann, Melba, dal Monte and Callas, and their spectra, shown in Fig. 8.1, are certainly more complex than Harwood's, although their waveforms are not. This complexity could be due partly to background noise, as some of the latter recordings are very old: Harwood shows distinct harmonic peaks; the troughs are not filled in by either background noise or the increased inharmonic partials present in a "richer" voice. (See section J3(5).)

Why should all women's waveforms appear to be simple,
however? The answer seems to be straightforward. Although inharmonic components may affect the hearer's appreciation of any voice, male or female, and its richness, their amplitudes are relatively low. Also, the less massive vocal folds of women probably vibrate more "cleanly" than those of men, thus producing fewer inharmonic partials. I believe that this, coupled with the smaller numbers of harmonic partials, is an important reason why some women's voices and those of children are "white". (See also section 6.3.) A few harmonic partials provide the main peaks in any voice. These tend to be fewer in a female's voice.

There is another important factor, I think. The fundamental tone is often strong in females because it is usually associated with the first vowel formant area. (See sub-section 6.7.5.) This imposes a strong basic waveform pattern. For example, see the waveforms and spectra of RR1/11 (Lehmann) and RR1/25 (Melba). Three of McCormack's waveforms seem much simpler than those of most other tenors, viz. RR2/33, RR2/34 and RR1/20. RR2/38 (Schipa) is similar. This seems to be because the second harmonic is very strong in these notes. These lyrical voices may also have fewer inharmonic components than dramatic tenor voices. (See also sub-section 8.4.7(d).)

With a low bass note, there are many "kinks" in the waveform because there are so many harmonic partials in the spectrum. For example, RR1/26 (Pinza) probably has about twelve harmonic partials which have a significant effect upon the waveform and spectrum.
I should point out that RR1/2 (Deller) shows a much less well-defined waveform than I would have expected from a note with such a strong fundamental. I think this is due to the low gain setting of the plotter when the waveform was drawn.

In conclusion, the waveforms served two other very useful functions: they allowed a precise calculation of the pitch at a given instant, and showed the attack sections of some of the notes analyzed in Chapter 7.

8.4.11: Does each voice have a characteristic waveform pattern?
In view of my discussion in sub-section 8.4.10, I think that it is very unlikely that this would be the case. So many variables affect the waveforms that they vary enormously. Those of quite different voices may even appear similar by pure chance.

8.4.12: In Caruso's case, are the spectra from notes of the same original matrix number, but transferred onto different L.P. discs, identical?
Aside from the computer-enhanced recordings, there are three groups of note to be considered. These are shown in Tab. 8.4.
TABLE 8.4: NOTES SUNG BY CARUSO

<table>
<thead>
<tr>
<th>Note number</th>
<th>L.P. discs</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>RR2/3</td>
<td>Boulevard 4072</td>
<td>very similar</td>
</tr>
<tr>
<td>RR2/16</td>
<td>GVC 12</td>
<td></td>
</tr>
<tr>
<td>RR2/29</td>
<td>FID 2139</td>
<td>a lot of &quot;noise&quot; at lower frequencies</td>
</tr>
<tr>
<td>RR2/10</td>
<td>Boulevard 4072</td>
<td>very similar</td>
</tr>
<tr>
<td>RR2/15</td>
<td>GVC 12</td>
<td></td>
</tr>
<tr>
<td>RR2/9</td>
<td>Boulevard 4072</td>
<td>very similar</td>
</tr>
<tr>
<td>RR2/28</td>
<td>Fid 2139</td>
<td></td>
</tr>
<tr>
<td>RR2/13</td>
<td>GVC 13</td>
<td>rather different</td>
</tr>
</tbody>
</table>

There is a good deal of similarity between some of these notes, which gives one confidence in the engineers who effected the transfers. No one L.P. disc appears to be significantly different from the others - at least there are not enough data to draw firm conclusions. Where there are differences, one of the engineers is wrong, but which one? The rather tenuous evidence suggests that RR2/29 and RR2/13 are suspect.
8.4.13: In Caruso's case, has the computer-enhancement process altered the relative amplitudes of harmonics to an extent which might seem unacceptable?

(See also White, 1984A.)

The computer-enhanced recordings were produced by the Soundstream process. (All details of this process are taken from Stockham, 1976?)

This is a digital process, and relies upon the fact that the computer can distinguish resonances and reverberations of the acoustic recording horn from those of the voice. (The former remain fixed throughout performance, the latter change constantly.) The tones in the original recording are compared with those in a "similar modern recording". The computer then alters the volumes of the tones in the original to match the modern recording. I suspect that this may have resulted in Caruso's voice being manipulated to resemble that of a modern singer, which is a very dangerous manoeuvre. For example, compare the "averaged " spectra A (non-enhanced), B (computer-enhanced), and G (Domingo), shown in Fig. 8.2.

"After processing, the resulting sound retains some [my emphasis] of the original flavor, but the clarity of expression, the texture of the voice, the artistic interest and the impact of the accompaniment are dramatically changed."

They are changed for the better in the sense of quality, but
is this accurate? I think that it is not.

Apparently, modern recordings were degraded deliberately and then processed by the Soundstream method. The results were "remarkably correct replicas". Also, old recordings of singers who recorded both acoustically and electrically were restored; the acoustic recordings then came very close to the electrical ones. But should they have done? If a singer made an acoustic recording early in his career, why should it resemble a later electrical recording, made after greater experience?.

I am rather dubious about the accuracy of the whole process. However, I must make one point in its favour. Consideration of the spectra in Fig. 8.1 and Fig. 8.2 shows that the computer-enhancement seems to emphasize the lower harmonics at about 200 Hz, and the fundamental. This gives a stronger "baritonal" quality which Caruso was supposed to have. (Note that many tenors have begun their careers as baritones. For example, see the references to Domingo and Melchior in Appendix H.) The singing formant may be over-emphasized on acoustic recordings, for reasons discussed in sub-section F1.1, and so the Soundstream method may correct this fault.

There are two facts which I find strange about the note RR1/49. This note, which is computer-enhanced, has more background noise than the other three equivalent non-enhanced notes. It is also not as brilliant as RR2/9 and RR2/28. This lack of brilliance may be justifiable, in view of my comments about acoustic recordings over-emphasizing the singing formant, but the extra background noise on such
an "improved" recording is very puzzling.

To summarize, I am doubtful about the accuracy of the Soundstream process, and it is a topic which needs further analysis. But who is to say if it is accurate or not? We really have no yardstick in this instance.

8.4.14: In Caruso's case, do notes from the identical position in an aria, but from two different original matrix numbers, have similar waveforms and spectra? In other words, was his vocal technique consistent?

The pairs of notes to be considered are RR2/6, and RR1/46, RR2/8 and RR2/37, RR2/7 and RR2/36. The members of the three pairs of waveforms do not really match each other, but the spectra have general similarities. However, the information is far too scanty for any firm conclusions to be drawn.
CHAPTER 9: THE RESULTS OF A SURVEY OF BRITISH SINGING TEACHERS

9.1: INTRODUCTION

I decided to collect information about contemporary singing teaching by distributing a questionnaire and then analyzing the results in the light of the scientific discussions presented in this work.

Henderson (1938, 10) is scathing about singing teachers:

"There are many teachers of singing in these days who know as much about the right schooling of the voice as they do about the establishment of secondary meridians or about suggestive therapeutics."

This statement holds true today, as there is no doubt that there are many charlatans posing as singing teachers. I include as charlatans those who have had no formal musical training or experience, and at the other end of the scale, those who may be highly qualified musicians but know little about singing. There is a belief in some quarters that anyone who can play the piano can teach singing: it is only necessary for a singer to "learn the correct notes". This is patently untrue, as I think I have demonstrated by my discussions of the complexities of the singing process.

On the other hand, there is a view that singing teachers use ridiculous terminology because they do not understand what they are talking about. (I have commented on this elsewhere.
see White, 1982D and 1984B.) This may be true of some teachers, but in my experience, even the best and most famous teachers use very personal concepts; they do this precisely because they do understand the subject, but recognize the need to explain complex ideas in simple terms. To a certain extent, "the end justifies the means"; if a teacher can make a student perform a task correctly, then does it matter how this is done? Surely this is the empirical approach used in the bel canto era? (See Chapter 2.)

There is a certain danger in this approach, however, as Monahan (1978, pp 123 and 127) has pointed out. For example, he says that a major objection to teaching voice placement [and many methods are used] is that students often confuse resonance sensations with the idea of a directed airflow. (The latter is an impossible concept, as pointed out in sub-section 6.8.1.) This can lead to over-exertion on the part of the pupil.

9.2: VOCAL SCIENCE QUESTIONNAIRE
The editor of the journal Singing agreed to print my questionnaire, and it must have been seen by a very large number of singing teachers. (I could not discover the exact number of recipients of the journal, despite several approaches to the publishers.) The questionnaire had to be produced in a manner suitable for publication; this involved saving as much space as possible, and the questions were reduced in comparison to what I would have preferred. Nevertheless, I could not lose the opportunity of reaching so many teachers, and I designed the questions very
The questionnaire appeared exactly as follows (White, 1982F):

"I am researching into singing techniques and the methods of training used by singing teachers. I have been given the opportunity to print some questions below, and would be grateful for replies from any readers of this magazine. It is not possible for me to pay for postage, I am afraid, but your help would be much appreciated.

"I have provided questions to act as guidelines, but any other comments about your opinions or methods would be welcomed. You may make your reply anonymous if you wish, and omit any other facts which you feel unable to provide. However, all replies will be treated confidentially, and compiled into a report which will mention no names: an overall assessment of singing tuition is desired. I hope that the results may be summarized in a future edition of this magazine.

[Address follows]

"1) Name.
2) Address.
3) Sex.
4) Age.
5) Qualifications.
6) Teaching experience.
7) Where or with whom did you train?
8) Singing experience.
9) Present employment."
10) Would you say that you teach any particular school of singing?

11) Do you teach a specific method of breathing? If so, what is it?

12) Do you teach a specific method of voice placement? If so, what is it?

13) Do you advocate any particular position of the larynx when singing? If so, what is it?

14) Do you use an empirical method when teaching students? For example, do you gear your methods to a particular pupil, or do you use the same method for all pupils?

15) Do you believe that singing teachers and students should know much about vocal anatomy and physiology?

16) Have you been particularly influenced by a particular authority?

17) Would you recommend any books which offer useful insights into the art of singing?

18) Which singers, living or dead, do you admire?

19) Have you any well-known pupils?

20) Any other facts, opinions or comments.

"Thank you in advance for your co-operation."

The questions were designed to encourage as many replies as possible: hence the contents of the second paragraph.

In addition to publication of the questionnaire, I mailed copies to at least 70 universities, colleges and schools of
music which may have singing teachers. Many were sent directly to singing teachers known to me. Despite this great effort, many promises to send replies, and the fact that a large percentage of British teachers must have seen my questionnaire, I received only 15 replies!

This poor response may be interpreted in a number of ways.

Firstly, a relatively small number of teachers may have seen the questionnaire, but this is unlikely. Secondly, the effort required and the need to pay postage may have deterred some people. Thirdly, one can take the cynical view that many singing teachers are either unable to explain their methods because they do not know what they are doing, or they may be unwilling to divulge their "secrets".

Elements of all these factors must be involved, but I received only one reply from someone giving me reasons for not answering the questionnaire. These were that:

"... the questions were open to misinterpretation and, some of them, only possible to answer in a 200 word essay."

(This comment was from an eminent singing teacher at one of the London Music Colleges.)

I have summarized the replies I received in Table 9.1. The order of the vertical columns coincides with the question order as shown above, and the teachers are designated A to O. I have retained the respondents' own words as far as possible, but as many replied in letter form, they could not
be quoted verbatim.

I shall analyze the results below, but firstly I wish to discuss the appearance of four advocates of the sinus control theories of Ernest George White. (See section 4.4.) These teachers are all full members of the Ernest George White Society, and registered teachers of The School of Sinus Tone. The Society had 30 full members and 42 associate members in 1982 (White, E. G. Society, 1982, 15-16), and the School had 17 registered teachers in 1981 (White, E. G. Society, 1981, 11-12.)

The Society promotes the teaching of the methods of White (1863-1940), and is keen to acquire new members. I suspect that an enthusiastic member may have seen my questionnaire and encouraged the other three to reply. These teachers are really on the defensive in view of White's discredited ideas; nevertheless, I have been grateful for their replies, and for literature which the Society provided at my request.
TABLE 9.1: REPLIES TO THE VOCAL SCIENCE QUESTIONNAIRE
A

* A Thinks that there is no special technique for singing early music, such as the use of "white" voices. Is concerned about the view that vibrato is undesirable, especially in choirs.

* F Believes that singing training can begin at a very young age, as long as the voice is not forced.

N.B. A blank box indicates that no answer was given.

I Relaxation important. Over-singing is dangerous, and encouraged by local operatic societies.

M Thinks that "back door" singing teachers are ruining young voices by method teaching.
9.3: DISCUSSION OF RESULTS

There is a wide age-range in both males and females, and a wide range of qualifications. Although G has no formal qualifications, she is a well-known and very successful teacher. Twelve teachers have specific musical qualifications, but some seem poorly-prepared for the teaching of singing in view of their lack of experience as singers. In particular, B, E, H, K; N and O seem to have done little singing as soloists. This may be compensated for by training and subsequent teaching experience, but I would loathe personally to go to a teacher who had not at some time been a good singer. de Bacilly had similar reservations in the seventeenth century:

"It is necessary, however, to avoid sinking into an error which is so widespread as to be nearly universal. This is the concept that a person can pass as a singer not only through skill in vocal performance, but also through the ability to teach others in the art, provided, of course, that he has learned to sing one or two tunes pleasantly enough, even though he knows nothing at all about music and has never heard any mention of the precepts of singing." (de Bacilly, 1668, 8.)

Further,

"It is, therefore, a grave error to say that a person isn't a good singer, but that he is a good voice teacher." (de Bacilly, 1668, 16.)

All except O have had some training from at least one other singing teacher. O is a fairly august individual, and if it
were not for this fact, I would be tempted to class him as a "charlatan" as far as the teaching of singing is concerned. He is elderly (I do not know his age), and he may have forgotten to include some relevant facts.

As far as employment is concerned, this ranges from those who are full-time singing teachers and singers (C, G, J, L and M) to those who have a few private pupils, but whose main employment is, or was, outside music. (A, B, I and N.)

Four teachers mention "sinus control", as discussed above, but only one mentions bel canto. However, I suspect, from my wide knowledge of teachers, that others would claim to teach bel canto if pressed on this point. C mentions the Italian School, and this may be synonymous with bel canto in her mind.

The ideas about breathing are interesting, as several misconceptions are implied. D mentions the use of a flexible rib-cage; everyone's rib-cage must be flexible in order to allow breathing to occur. She probably means that she does not encourage the use of the chest in an exaggerated raised position (see also G and J), although people who do advocate this seem to forget that the ribs must fall to a certain extent during expiration. (See Chapter 3.)

E uses "exercises to strengthen diaphragm and intercostals". This probably means that she believes that the diaphragm contributes actively to expiration: a commonly-held fallacy. (See sub-section 3.2.1 and section C1.)
G mentions "no unnatural raising of chest...", but this is probably done by most great singers, who often appear to have large chests because of their habit of "keeping the upper chest in the inspiratory position when singing". (White, 1982B, 146.) (But see my comments in section 3.1.)

The ideas of I appear to be disastrously vague: perhaps a reflection of his relative inexperience as a singer and teacher. J's "flexible diaphragm" is a nonsense, but again, it is probably an idea which conveys to pupils the idea of diaphragmatic breathing. It is not clear what K means by "abdominal breathing".

L is perhaps the only teacher who understands fully the basics of respiration. I interviewed him personally and found his knowledge to be profound; his Phonetics degree plays a large part in this.

M's "empirical" is hopelessly vague, and I have yet to discover what is meant by N's "spontaneous action". O perpetuates White's ridiculous theory; one wonders how a pupil can learn to breathe properly if he is told that the sinuses are involved.

Several teachers in addition to the "sinus tone" school believe that the voice should be directed into the sinuses, or at least the front of the face. This concept is discussed in sub-sections 6.8.7 and 6.8.8. Again, probably only L realizes that sinus placement is an impossibility. G is a devotee of more esoteric ideas, but this is not uncommon. (See comments about Tetrazzini and Caruso in sub-section
H adheres to Herbert-Caesari's highly subjective ideas, and those of Arthur D. Hewlett, who is General Secretary of the Ernest George White Society: I need not describe his ideas!

Only C mentions placement "in the mask", which is in fact a widespread term. (See sub-sections 6.8.7 and 6.8.9.) K's vague comment about using an "oo" sound is not very helpful.

The larynx position is either ignored (probably the safest course), or encouraged to be low, which is good acoustically. As described in sub-section 6.7.3, the larynx will fall anyway if other procedures are followed; thus the pupil does not have to think about his larynx at all.

Compare this fact with Herbert-Caesari's idea: he tries to describe how one should imagine that the larynx is being viewed from above when singing. (Herbert-Caesari, 1965.) I think that this leads to concern on the part of the pupil: it certainly did not help me when I tried the procedure. One must also mention teachers who force down pupils' tongues with spoons in order to lower the larynx, a procedure advocated by Garcia (1894, 17). (See also White, 1982D.)

Brodnitz (1953, 193) points out that one should not assume that flattening the tongue, dropping the jaw, etc. are normal for all singers.

All but five teachers admit to using some kinds of empirical techniques. (F, K and N are not clear on this point).

However, whether these are totally empirical or based upon
slight modifications of basic ideas was not really evident from the answers I received. One teacher's idea of "empirical" would be different from another's. It is again fruitful to quote de Bacilly (1668, 35):

"It might be seen that if a teacher makes use of a certain idiosyncratic approach in relation to one student and a differing approach for another student, the use of both is justified by whatever progress the two students may make."

All teachers apart from N and O agreee that some degree of knowledge of anatomy and physiology is needed by teachers. However, several feel that pupils need less knowledge of these subjects. It is interesting to speculate about the quality of these teachers' knowledge. In my personal experience, many singing teachers think that they understand vocal anatomy in particular, but in fact their knowledge is rudimentary, and positively dangerous when erroneous advice is given on vocal health.

The many books for singing teachers which describe vocal anatomy and physiology are of little use unless one is in a position to understand the basic facts. The whole subject is so complex that it is unlikely that anyone without medical or similar training could understand it to a satisfactory degree. Successful teachers probably manage to elicit good results from pupils because they teach procedures which are correct, even though they do not really understand why they work. They have evolved these procedures by trial and error, have been shown them by their own teachers, or have learnt them from books. They are lucky if they choose books which
are sound; as I have shown throughout this work, many incorrect ideas appear in print. (Some teachers are well-versed in anatomy and physiology, of course. A good example is Lucie Manen, who was trained in physiotherapy and related disciplines.)

The diversity of authorities who have influenced these teachers is shown in columns 15 and 16. Certain authors appear a number of times, and one would have expected B, H, N and O to have mentioned Hewlett or White. Manen appears a number of times, indicating her great influence in recent years.

Other interesting points are the mention of "original sources" by A - an indication of her interest in early music - and D's comments. I have discussed already the relevance to singing of Alexander Technique and related disciplines (see section 3.1 and Appendix B); D mentions this technique, Yoga and Noelle Barker. Barker is interested in preparing the body for singing by undertaking physical exercises, and I have participated in some of her classes. As D studied with Barker, the latter probably instilled the importance of these techniques.

The lists of singers admired by teachers obviously reflect their vocal preferences. This is probably an important factor in the teaching of singing, as it is inevitable that pupils will try to imitate singers they admire, even if this is done subconsciously. A teacher's preferences will therefore be transmitted to his pupils and may affect them
profoundly. I can draw no detailed conclusions about this matter, except to point out that some teachers quote a narrow range, for example A, B (Deller lived near this teacher!), and C (English singers only), whilst others' tastes are certainly catholic.

I thought that asking about well-known pupils might be one way of gauging the success of a teacher previously unknown to me. On reflection, I do not think that this information is very useful, as in no case did a teacher say for how long a well-known pupil had studied with him.

9.4: CONCLUSIONS
Despite the limited number of teachers who replied to my questionnaire, the information gathered does illustrate the diversity of ideas prevalent amongst British singing teachers; the varying backgrounds of teachers are also evident. It is clear that the lack of standardization is great: greater, perhaps, than in virtually any other area of pedagogy.
CHAPTER 10: SUMMARY AND GENERAL CONCLUSIONS

10.1: INTRODUCTION

In view of the enormously complicated nature of the subject matter, it has not been possible to provide a simple layout for this work, with topics dealt with concisely in separate chapters. There is, therefore, a great number of cross-references. Nevertheless, it is possible to review the major aims which were stated in Chapter 1, to establish whether they have been met successfully in the work as a whole.

The principal aim was to examine the scientific basis of techniques used by singers and singing teachers. This was to be achieved by four means; each of these is discussed in the following sections. I have been able to provide only brief summaries of the main points, as there are so many which must be included. In each case, however, references are made to the relevant sections in this work.

10.2: AIM: TO PROVIDE AN HISTORICAL ACCOUNT TO SHOW HOW SINGING TEACHING HAS BEEN INFLUENCED BY SCIENTIFIC DISCOVERIES ABOUT THE VOICE

1) In the Prefatory Notes, I stated that:

"It is not the aim of this work to quote all relevant authorities (that would be a virtually impossible task), but to help the reader to identify useful information when reading the works of other authors."

I hope that this aim has been realized, at least to a certain extent: I have pointed out many erroneous ideas, and
corroborated others. In addition, certain important historical facts have been identified, some of which do not seem to have been commented upon elsewhere.

2) A brief, but accurate, account has been given of the history of the scientific study of the voice and of vocal pedagogy. I have indicated clearly the main phases of vocal pedagogy, putting these into historical perspective. (Chapter 2.)

3) I have noted that Garcia (1855) predated Goerttler's (1951) observations on the insertions of the thyro-arytenoid muscles by almost a century. (Section 4.3.)

4) I have also noted the Gouguenheim and Lermoyez (1855) predated Ardran's and Wulstan's (1967) observations on the damping of the vocal cords in the falsetto register, by over a century. (Sub-section 5.4.4.)

5) I have identified a statement of great interest, made by Bacon (1824). This may pre-empt some later ideas about partials, and is mentioned even though it is peripheral to the main body of this thesis. (Section A5.)
10.3: AIM: A CLEAR DESCRIPTION OF THE ANATOMY, PHYSIOLOGY AND ACOUSTICS OF THE VOCAL ORGANS, IN RELATION TO THE SINGING VOICE, SO FAR AS THESE ARE KNOWN AT PRESENT

10.3.1: Investigations of the work of others and general discussions

1) Posture in relation to singing has been studied in detail, with many observations and clarifications. (Section 3.1.) An "ideal singing posture" has been suggested, based upon reasoning and practical experience. (Section 3.1.)

2) The details of breathing in singers have been examined (section 3.2), and anatomical and physiological facts have been linked to the methods used by singers and teachers.

3) The terminology of high male voices has been clarified. (Sub-sections 5.5.1 and 5.5.2.)

4) Aspects of vibrato, the trill, "tremolo" and "wobble" have been clarified. (Sections 6.3, 6.4, 6.5 and 6.6.)

5) The theory of vocal timbres has been explained, together with my own observations. (Sub-section 6.7.4.)

6) Certain misconceptions about vocal resonance have been explained. (Section 6.8.)
10.3.2.: New observations and hypotheses

1) A suggestion has been made about the possibility of the historical fear of flowers in concert halls and on stages being related to allergies. (Sub-section 3.2.7.)

2) Certain suggestions have been made about the adverse and beneficial effects on singers of air-borne ions. (Sub-section 3.2.7.)

3) The nature of "white" voices has been discussed, and some suggestions made about them. (Sections 6.3 and 7.7.)

4) I postulate that the region of maximum sensitivity of the human ear is connected with the frequency of the singing formant. (Sub-section 6.7.6.)

5) I suggest that the supposed lower singing formant may really be a vowel formant. (Sub-section 8.4.6.)

6) The suggestion is made that singing an "ee" sound has a similar effect to producing the singing formant. (Sub-section 6.7.3.)

7) Certain misconceptions about vocal resonance have been elucidated. (Section 6.8.)

8) The chest resonance experiment is a novel approach to a controversial issue. (Section 7.4.)

9) I hypothesize tentatively that the vocal folds may not have to vibrate with the fundamental frequency of a
low-pitched sound. (Section 4.3 and sub-sections 6.7.5 and 7.4.3.)

10.4: AIM: A REVIEW OF MANY ASPECTS OF VOCAL PEDAGOGY, WITH CRITICISMS BASED UPON A STRICTLY SCIENTIFIC APPROACH

1) I have emphasized the importance of empirical techniques in the teaching of singing. (Chapter 2.)

2) I have described some of the methods used by singing teachers when teaching singers to breathe. (Section 3.1 and sub-sections 3.2.1 and 3.2.5.)

3) It has been emphasized that, contrary to widespread beliefs, resonance sensations are probably not the same for all singers. (Sub-section 6.8.1.)

4) I have discussed many of Lucie Manén's ideas, particularly those on posture (section 3.1.); the possible importance of the trigeminal nerve in singing (section 3.1), and the concept of imposto (sub-section 6.8.7.)

5) The vocal science questionnaire was less successful than I had anticipated. Although it is difficult to draw detailed conclusions, it showed the diversity of ideas held by singing teachers, and their widely-differing backgrounds. (Chapter 9.)
10.5: AIM: THE ANALYSIS OF THE RECORDED VOICES OF SOME FAMOUS SINGERS, WITH ATTEMPTS TO CLARIFY SOME FUNDAMENTAL SCIENTIFIC ASPECTS OF VOICE PRODUCTION

1) In general, my experimental results and conclusions have been used to confirm or dispute the ideas of other writers. This has been done by the use of extensive cross-references throughout this work.

2) Certain conclusions have been drawn from some of the experiments which I conducted, and I have tried to apply these conclusions to singers' voices in general. (Section 7.7.)

3) The examination of the Manén recordings is important, because the singers were intending to produce precise effects. The question of whether these effects are measurable has been investigated. (Section 7.5.)

4) Certain theories have been explored practically: for example, those of Pielke, regarding harmonic differences between "open" and covered singing. The results were inconclusive in this case, but on balance, his ideas have not been confirmed. (Sub-section 8.4.3.)

5) There are important conclusions about the differences between spoken and sung vowel sounds. (Sub-section 8.4.6.)

6) I have provided strong evidence to corroborate the existence of the singing formant at around 2.8 KHz. (Sub-section 8.4.7.)
7) A novel approach, using "average" sound spectra, was used to find if a singer's voice has a characteristic "spectrum pattern". (Sub-section 8.4.8.)

8) Waveforms of singers' voices have been discussed in detail, together with a consideration of possible phase problems with gramophone recordings. (Sub-section 8.4.9.)

9) Explanations have been offered of the relatively simple waveforms shown by women's voices. (Sub-section 8.4.10.)

10) I have discussed some of the problems involved in using gramophone recordings to study singing techniques. (Section 8.2 and sub-section 8.4.12. More technical matters are discussed in section Fl.)

11) I have expressed serious reservations about the value of the computer-enhancement process which was used to "improve" Caruso's recordings. (Sub-section 8.4.13.)

10.6: EPILOGUE
Generally, I have tried to indicate areas which warrant further study, and as in all work of this kind, I have probably raised as many new questions as those which I have attempted to answer. Nevertheless, I believe that this concluding chapter demonstrates that my thesis is a definite contribution to knowledge. In some instances, it breaks new ground in the study of the complex art of singing.
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