Distinguishing Characteristics of Vocal Techniques in the Specialist Performance of Early Music

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Abstract

The early music singer became established within classical singing over the last forty years and is now accepted in the mainstream performance of music written into the nineteenth century, being identified by specific stylistic features and vocal qualities.

This thesis presents a multidisciplinary study to assess the distinguishing characteristics of this specialist group of singers. An experiment case-studied eight early music singers and eight opera singers to identify the vocal characteristics that made them suited to their specialty. Quantifiable aspects of vocal technique which have previously been associated with opera singing were analysed including, larynx closed quotient, vibrato, vertical larynx position, loudness, the singers' formant and other acoustic resonance strategies. Alongside the results of this study research exploring the emergence of the early music singer is reviewed together with modern theories of historical vocal techniques and the primary literature from which these theories are constructed.

Although classified as having a characteristically distinct sound from opera singers, early music singers were found to utilise methods of vocal production strongly representative of a modern operatic technique. Differences that were identified between early music and opera singers seem to represent the individual vocal backgrounds of the singers rather than any scholarly revival of historical vocal techniques. The training of the singers and particularly their choral background seemed to be a major determining factor of the singers' specialty. In spite of a scholarly interest in historical vocal techniques infiltrating performance institutions to various extents in recent years, the central objective of the singers appears to remain the need to conform to conventional aesthetic of a 'classical' voice.

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List of abbreviations

F0	Fundamental frequency
SPR	Singing Power Ratio
EnR	Energy Ratio
EGG	Electroglottograph
Lx	Laryngograph
CQ	Closed Quotient
Qx	Histogram of Closed Quotient Values
LH	Larynx Height
L_{SF}	Level of Singer's Formant

List of Accompanying Material

Audio CD

Track list

1	Subject 1	Handel Extract
2	Subject 1	Puccini Extract
3	Subject 2	Handel Extract
4	Subject 2	Puccini Extract
5	Subject 3	Handel Extract
6	Subject 3	Puccini Extract
7	Subject 4	Handel Extract
8	Subject 4	Puccini Extract
9	Subject 5	Handel Extract
10	Subject 5	Puccini Extract
11	Subject 6	Handel Extract
12	Subject 6	Puccini Extract
13	Subject 7	Handel Extract
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15	Subject 8	Handel Extract
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17	Subject 9	Handel Extract
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32	Subject 16	Puccini Extract

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Declaration

I hereby declare that this thesis is entirely my own work and all contributions from outside sources have been explicitly stated and referenced. I also declare that parts of this research have previously been presented at a conference, the details of which are listed below.

- **Singing Early Music,** Helena Daffern and David Howard, oral paper presentation at the 7^{th} *Pan European Voice Conference.* Groningen, Holland, August 2007.

Chapter 1

Introduction

This study considers the current trends of the specialist vocal performance of early music and grand opera, looking specifically at vocal techniques and the resulting sound produced by female voices. The nature of the thesis is intrinsically multidisciplinary, combining musicology, scholarship in performance as well as the science of singing to explore new avenues of performance research. Musicological studies of performance practices are considered alongside contemporary knowledge of the science of the singing voice, employing modern technological advances to obtain and examine quantifiable aspects of the voice to further the musicological discussion of modern performance practices. The presentation of this cross-disciplinary study between scientific and artistic fields intends to pave the way for musicians and particularly singers to introduce voice science as a tool in performance research in the future. The thesis is intentionally structured to remain accessible to both scientists and musicians, hopefully introducing new perspectives into both disciplines.

The core of the thesis is an experiment based on previous scientific studies in the singing voice, which was devised to analyse specific quantifiable aspects of vocal techniques. The investigation case-studied sixteen professional female singers, eight of whom specialised in the performance of early music repertoire and eight performed mainstream opera. The findings of this study are considered alongside modern perceptions of the two specialties and musicological theories of historical vocal techniques. The main objectives of this research are to determine the actual and perceived differences between the two groups, and to assess the extent to which any differences reflect theories on historical singing practices.

The present chapter introduces the current performing conventions of early music and grand opera, outlining the origins of the present performance culture and the scholarly investigations into historical vocal practices which have taken place to date. The tradition of performance in England is the primary focus of this thesis because the distinctive practices of the performance of early music originated in England and retain specific connections to English traditions: 'The phenomenon was particularly British, but found, as we know, imitators and admirers throughout Europe and America' (Wistreich, 2002: 21).

1.1Background

Fashions of performance are constantly changing. Particularly concerning singers, the apparent suitability of certain voices to specific genres of music is often high on the agenda of critics and vocal teachers: 'she has a splendid sense of rhythm for the baroque; her voice is not entirely to my taste in this music, however' (McHugh, musical criticism website 2007). Although perceptions of like and dislike ultimately decide the professional success or failure of a voice, there are distinctly traceable trends of preference in certain vocal qualities throughout the history of music as audience tastes have changed.

Within the domain of Classical Music a number of different categories of singer are now established. Aside from categorisation of range into soprano, mezzo-soprano, *etc.*, distinctions are now drawn between oratorio singers and opera singers, choral singers, ensemble singers and solo singers, *etc.* Within such categories, singers now further identify themselves; for example, opera singers will be defined as Wagnerian, Coloratura, Lyric, Dramatic, Bravura, *etc.*, (Mitchells, 1970-1971). Whilst it is now common and often expected of a singer, the trend to categorise and further sub-categorise voice types, and music in general, is quite recent. Potter comments that the term 'classical' in connection with music has only been in use in its common form since the nineteenth century and explains that 'its current status is the result of historical processes that have formed and re-formed over many hundreds of years' (Potter, 1998: 1). As a result of the early music revival, over the last 30 years a new genus of singer has evolved specialising in early repertoire composed from pre-1600 to the nineteenth century. 'One of the consequences of the stylistic fragmentation of classical music has been the proliferation of singing styles associated with early music' (Potter, 2000: 3).

The period of composition encompassed by this new genus of singer expanded from the Renaissance into repertoire of the nineteenth century, embracing both ensemble and solo repertoire of sacred and secular origins. Performance conventions currently practised in the musical canon therefore involve a cross-over of repertoire between this new specialising group of early music singers and the conventional opera singer: operas written before the late eighteenth, even the nineteenth century, now lie within the repertoire of the early music singer but are still also performed in the grand opera houses by more conventional operatic voices.

Due in part to this cross-over and in part to the divergent origins of the two groups, singers specialising in early music have had a 'sometimes fraught relationship with so-called "mainstream classical vocal practice"' (Wistreich, 2002: 17). Potter articulates a common attitude that divides the two performance genres in a book review: 'brighter performers tend to go into early music rather than submit their voices and their intellects to the coaching provided by opera houses' (Potter, 2000: 342). This divide and the stereotyped perception explained above is largely the result of the divergent backgrounds of the singers of the two genres, particularly considering the training and emergence of the early music singer from academic institutions.

The background to the establishment of the early music singer is particularly important to this study as it provides a base on which to form an investigation into the distinguishing characteristics of this specialising group from the conventional opera singer. The following sections therefore consider the origins of the modern early music singer, including their objectives, techniques and motives.

1.2 The Rise of the Early Music Singer

In order to begin a comprehensive study of the modern 'early music voice', it is necessary to retrace its development within the 'classical voice' drawing on the extensive range of research and resources which is now available. The early music revival which took hold in the 1950s and 1960s was the primary component which triggered the foundation of the specialist performance of early music, although the introduction of the new vocal sound of the early music singer did not become established until the 1970s (Wistreich, 2002: 20-21). Below is a brief review of the various aspects of the development of the early music revival which contributed to the impact of the phenomenon on current singing styles.

1.2.1 The Early Music Revival

A renewed interest in historical sound-worlds in the early twentieth century is thought to have been born out of a reaction against the 'romanticism' which had long reigned in performance conventions: 'we were in flight from elements of the then current musical aesthetic that we didn't like' (Potter, 2002: 9). This became expressed in a desire to identify and reconstruct the intentions of composers and performance practices of historical repertoire. Once the academic mission of those musicians was established and audiences warmed to a new style of performance, this period of change in the conventional playing of renaissance and baroque repertoire became known as the early music revival (Haskell, 1988).

Academic musicians began their re-discovery of old performance styles through the scholarly exploration of literary evidence such as historical treatises that provide an insight into attitudes towards performance and various rules of specific and informed practices such as ornamentation, as well as instructing technical methods of playing on specific instruments. Combined with the academic study of original manuscripts, Urtext editions of the compositions began to be produced and new manuals and texts became available informing the twentieth century performer how to interpret the information in the score based on the primary sources. As a result of these scholarly explorations and the subsequent implementation of their findings through performance, an abundance of literature has been produced since the early music revival, cataloguing and evaluating primary sources as well as discussing and instructing ways to perform music written before the nineteenth century (*e.g.* Newman, 1985; Bianconi, 1987; Donington, 1989; Brown and Sadie, 1989; Strunk, 1998; Somerset-Ward, 2004; Boorman, 2005; Foreman, 2006).

Since this retrospective approach to performance took hold, the scholarly world has been thronged with arguments concerning the relevance of performance practice as a concept and the different theories presented within it (see for example; Kenyon, 1988; Kivy, 1995; Leech-Wilkinson, 2002). The further research into historical performing conventions develops, the wider the period of music that is examined and therefore encompassed by early music performers and their styles of playing: notions of historically informed performance now affect the performance of music written into the late nineteenth and early twentieth centuries (Brown and Sadie, 1989b). Research into the historical performance of music continues to be important whether viewed as an essential conformist mode of performance, or simply an academic, musicological or historical exploration.

Resultant fashions of different playing styles have in turn impacted on the styles and techniques of singing music from the relevant period. Until recently, however, the voice was passively led by this fast-growing trend of historically informed performance in instrumental playing, applying, at most, the appropriate theoretical musical styles, but with no specific interest in investigating historical vocal techniques. This resulted in a peculiar blend of musical performance which could only in part lay claim to any scholarly rediscovery due to 'the strange coupling of highly researched instrumental playing with academically under-nourished singers' (Potter, 2000: 3).

The objectives and consequent practices of the singers involved in the beginnings of the early music movement inevitably impacted upon contemporary perceptions of early performing practices due to the 'authenticity' label under which they performed. However, the influences of these singers have a further residual effect on the re-examination of historical vocal techniques: once a style has been established, even if that style has no dependable historical grounding, it will influence the subsequent decisions made as the result of reliable research. Kivy philosophises, 'now evangelism is over, and the good news is established doctrine. In such a stage foundations cease to be argued for and harden into faith' (Kivy, 1995: 2).

Certain aspects of research into historically informed performance have become depended upon since the academic assessment of historical vocal techniques began. Investigations into historical vocal practices began to progress beyond the misconceived trends that became established as a results of the original sound-worlds associated with the start of the revival, however they remained embedded in modern traditions. For instance, whilst the playing techniques of historical instruments have been thoughtfully considered, applied, and reconsidered, the technical use of the voice in historically informed performances remains, on the whole, based upon reactions to instrumental findings and techniques. This oversight is enhanced in the musicological study of manuscripts, as, whilst vocal scores have been heavily scrutinised alongside instrumental music, the consideration of vocal performance remains, on the whole, a secondary element to instrumental music within a highly generalised umbrella.

> The early music movement has encouraged many excellent singers to cultivate various types of 'anti-romantic' vocal production, but we still fashion our 'Renaissance' voices after criteria that are really less secure than those by which the instruments of the period are reconstructed.
>
> Uberti, 1981: 486

1.2.2 Historical Instruments

It is unsurprising that instrumental music took the lead in historical performance techniques when the surviving evidence available for musicians and musicologists is examined. A renewed interest in historical instruments led to developments in the contemporary perception of the music of the past. New playing techniques and styles of performance emerged, and as a result the sound-worlds associated with pre-baroque to classical music changed:

> German scholars used to wonder how Bach could have seen anything of value in the *pièces de clavecin* of François Couperin. But now the harpsichord revival has proceeded beyond the Taskin model of the 1950s to include reconstructions of late 17th- and early 18th-century French models.
>
> Lindley 1977: 285

The attempted reconstruction of historical playing styles relies heavily on period instruments as the physical characteristics of the instruments are indicative of specific techniques. As with any historical evidence, whilst the existence of such instruments is of vast importance, there are vulnerabilities in their reliability as factual historical sources that need to be considered. The aging of surviving historical instruments is likely to have affected their sound quality and therefore cannot be relied upon as aural evidence. Also, most original instruments have been restored in some way, often presenting further issues of authenticity, as Lindley highlights; 'Misguided restorations often entail adding or removing major structural pieces or making critical changes in the acoustical apparatus' (Lindley, 1977: 288).

Further issues arise when the significant role of the instrumental players in the physical reconstruction of instruments is considered. In restoration, it is often on the advice of the instrumentalists after playing the original instruments that conclusions are drawn concerning physical characteristics of historical instruments, the twentieth century performer deciding which combination of instrument physiology and playing techniques produces the most popular effect. Lindley explains that 'in this sense authentic restoration depends on authentic playing' and recognises, 'Of course, using taste to decide points of fact is a nice paradox in itself and is bound to complicate matters.'

(Lindley, 1977: 188). This was almost entirely the method used in the vocal performance of historical music in that the music was performed in the manner which proved most appropriate and successful to modern vocal techniques.

Playing techniques (whether historically informed or otherwise) are bound to differ from original styles, resulting in a different sound from that made on the same instrument by the original players. Reproductions created from scrutinising surviving instruments, the study of detailed instructions on how they were constructed, iconography, literary descriptions, and evidence of sound quality, must also be used with a degree of caution, because any or all of the factors mentioned may be slightly changed or misunderstood. Most importantly, and a factor over which there is no control, human perception of sound is continuously changing; perceptions of music have been, and will continue to be affected by all subsequent musical influences. When used as reliable historical evidence, the above mentioned margins for error must be kept in consideration, especially when that knowledge is then used to inform another aspect of performance such as the voice; however, the combination of existing historical instruments with modern reproductions does provide beneficial evidence of a historical sound-world.

The lack of physical or audible evidence of a historical voice is, therefore, a significant disadvantage to any considerations of historical vocal practices. Instruments are still of utmost importance when making any investigations into the history of music, whether considering compositional style, performance practices, musicology or any other aspect of musical academia or performance. The dedication of the instrumentalists in their studies not being matched by singers also destabilises the academic integrity of the voices that went with them: 'Their readiness to take the major step of committing themselves fully to historically informed practice enabled the founding of the first successful professional period instrument ensembles' (Wistreich, 2002: 18). The use of this evidence is therefore essential for investigations into the voice; however, the limitations mentioned above are particularly important when using their evidence as a pathway towards historical techniques. In spite of the issues of 'authenticity' and the path of historically informed performance which are now well documented, there is now a wealth of established professional ensembles using historical instruments with playing styles that are currently conceived as appropriate.

1.2.3 Commercial Market

The founding of the scholarly rediscovery of historical instruments and playing styles led to the creation of the early music singer. However, this novel group of singers was not based, like the instrumentalists, on an academic study of their instrument, rather on the exploitation of an opportunity created by the scholarly performing historians. The historically informed instrumentalists, or rather their conductors, found they had a 'want or need for an "historically informed vocal performance" to go with their period instrumentalists' (Wistrich, 2002: 19). Wistreich identifies that this, alongside a number of other agendas, and hidden agendas, sparked the formation of a select group of singers specialising in early music. The key to their pursuit of such a voice lay in the outsiders' perception of the early music movement: that it was something new. 'In the early 1970s, clearing a fresh and separate space in the forest and announcing something "new" was an important part of the process of establishing a significant presence in a fiercely self-protective environment' (Wistreich, 2002: 20). This is also true of the profitable market, in that record companies needed a new angle allowing them to re-record and re-sell existing repertoire (Wistreich, 2002; Potter, 2002).

1.2.4 English Choral Roots

The early music movement found its new singers by turning to academic institutions, particularly the Oxbridge colleges, rather than performing establishments. The vocal traditions of these institutions have always been rooted in choral rather than solo music (Day, in Potter ed., 2000: 123 – 132). The quality of the choral music at these institutions is famed for its characteristic sound and the singers of these choirs are carefully selected for the desired timbral blend that has become the customary sound of the English choral tradition. It is mainly singers from these choirs, certainly in England, that became the specialists in early music singing, first exploring secular and sacred music (including madrigal and monody repertoire from the Renaissance), then moving into solo and ensemble baroque music and eventually classical repertoire (Wistreich, 2002). Due to the traditions from which they came, the sound which became established as the early music voice retained distinguishing characteristics largely identical to those of their origins.

As the musical environment of these singers was removed from the performing colleges in stylistic and technical conventions, the practices of the conservatoires were unlikely to infiltrate the techniques of the Oxbridge choral scholar, especially considering that the opposing schools strived for contrasting sounds, and to begin with performed different repertoire. Potter explains: 'In effect, singers from the two universities have been able to establish a dominant style of their own in parallel with the main classical style' (Potter, 1998 :116). However, in order to be accepted into the mainstream for later repertoire they had to correspond to the traditions which could be identified as 'classical singing' 'from this point on, the singing was to conform firmly to the same characteristics demanded by the received tradition, nuanced with certain stylistic gestures' (Wistreich, 2002: 22).

This new breed of early music solo singer lifted from a choral environment, politically and commercially adhered to the criteria of the early music revival – to provide the listener / conductor / record company / early instrumentalists with a new vocal sound to comply with their new performance ideals. Their voices appear lighter and quieter than those of modern day opera singers which suited the baroque instruments with their gut strings, lighter bowing techniques, and smaller orchestral ensembles. They 'answered the immediate demand for "otherness", but although that sound may have been quantitatively lighter (originally, perhaps because it was simply "younger") and more homogenous (and anonymous?) than the mainstream, it was still intimately linked to the same highly developed received tradition of western classical vocal production that it purported to displace' (Wistreich, 2002: 21). Although the new sound of early music singers was different enough from opera singing, the fundamental characteristics of the sound which the audience could associate with 'classical singing' remained.

The fact that the roots of the original early music singer lay in traditional academic institutions only strengthened their cause, as it provided an impression of further scholarly contributions towards the reclaiming of old performance practices. However, as explained above, when these singers were first introduced to the movement there was little or no scholarly impetus behind their objectives. In spite of this the characteristics of these singers' techniques that Wistreich identifies above, besides setting them apart from 'conventional classical singing', were still rooted in western conventions of classical singing and continued to represent early music, even once the academic investigations that followed began to disseminate through performance literature.

1.3 Theories of Historical Singing Techniques

The academic origins of the early music singer are a further advantage to the early music movement, in that once these singers had found their niche in the market genuine scholarly interest evolved. As Wistreich recollects above, whilst the musicological investigation into historical vocal techniques was not an original objective, it became so to many of those involved in the beginnings of the revival, and continues to inform singing practices today. This could also explain the continued function of academic institutions as a primary base for singers specialising in early music, as the subject has remained an area of academic interest. The exploration of historical vocal techniques to date employs the use of current understandings of intended performance styles, particularly since the sixteenth century, combined with the study and interpretation of historical treatises written on singing and vocal pedagogy.

Scholarly investigations draw on many of the resources utilised by the instrumentalists in their quest for knowledge of historical playing techniques, including treatises, original manuscripts, forewords, and contemporary descriptions of music, as well as historical instruments, the music and application of that music, and, more recently and less exhaustively, the consideration of scientific principles of the singing voice. Each of these resources has positive and negative attributes that need to be considered throughout the research process, as they can be manipulated individually and as collective resources by hidden agenda or misunderstanding.

Many aspects of performance style for the modern early music singer, in terms of the notes to be played or sung, approximate speeds and articulations, have often been deduced in relation to instrumental music and the findings of instrumentalists during the beginning of the early music revival. This is in part because instrumental music was 'revived' first, and also because instrumental music remains the area in which the majority of research has been focused to date, and where the majority of reliable sources can be found. Potter explains: 'There has been no revolution in singing techniques to compare with the reconstruction of historical instruments, but singers and conductors involved in early music are much more familiar with written sources than they used to be' (Potter, 2006: 523). As a result scholars have based many arguments on vocal techniques upon the conclusions drawn on instrumental music. The details of historically informed performance practices have been essential in research into the historical voice, in terms of gaining an understanding of the notational and musical demands on the singing voice in order to speculate on technical methods of performance. Whilst the specific theories of historically informed performance in singing are too vast to detail in this study, a brief outline of some of the attitudes and processes which contribute to the academic pursuit of the historical voice are outlined below.

1.3.1 Primary Sources

Primary source material in the form of letters, diaries, treatises and other literature commenting on the voice are invaluable to musicologists interested in historical techniques. Without any physical evidence in the form of recordings documenting voices before the 1900s, the study of historical texts has necessarily been relied upon. However, being graphic and prose descriptions of aural traditions, they are unavoidably exposed to interpretation and bias. Historical treatises have been utilised as reliable historical accounts of vocal techniques since interest in the field of historical vocal techniques began (See for example, Zacconi, 1592 facs., 1987; Caccini, 1602 ed. Tr. Hitchcock, 1970; Tosi, 1743 in ed. tr., Galliard, 1967; Mancini, 1774 ed. tr. Foreman, 1967; Hiller, 1780; Lanza, 1813; Garcia, 1841 / 1872 in tr. Paschke, 1984: Corri, 1810). When dealing directly with the voice and vocal techniques rather than descriptions of performances, as in the case of vocal tutors, the apparent significance and relevance to the matter of interest can lead to conclusions that appear more accurate but that are still based on interpretation. Wistreich highlights this in the case of the trillo, which in Caccini's treatise is demonstrated visually through the repetition of the same note gradually speeding up from crotchet length notes to demi-semiquavers:

> This has led to generations of 'Baroque' singers reproducing this exercise as it stands, in the belief that this *is* the *trillo.* If they read a little further into the treatise, they would see that Caccini explains: 'The *trillo* written by me on a single note is demonstrated in this way for no other reason than that, in teaching it to my first wife and now to the [other] one...I observed no other rule than that which is written out: that is...to begin with the first crotchet and then restrike each note with the throat on the vowel *a*, up to the final breve.' In other words, it is an *exercise* in speeding up the repercussions of the glottis. The *trillo* itself is in fact the fastest possible repetition of the tone...
>
> Wistreich, 2000: 187

The extraction of specific passages of treatises as a means of obtaining information on precise aspects of technique, or the execution of particular ornaments as the case above demonstrates, is common to contemporary literature which deals with historical performance practices, often with the same passages being highlighted throughout the research. However, as Potter explains, there is an aspect of bias in the interpretation of sources and the implementation of various performance styles represented within them,

> the received idea of what 'early music' *should* sound like has been a major determining factor behind what is likely to be implemented from historical sources, and this has resulted in the actual disappearance of certain stylistic or technical traits that we have consciously or unconsciously decided to ignore
>
> Potter, 2006: 523

It is likely that the few treatises which survive today represent only a fraction of the number produced, others having been lost or destroyed. The lost information within them would have contributed to current perspectives on historical performance practices and perhaps have altered the significance of the evidence that is currently relied upon. Wistreich's opinion concerning the correct execution of the *trillo* cannot be proven or otherwise; it is a question of interpretation. Caccini's explanation of the execution of the *trillo* is unavoidably ambiguous. It is also important to remember that the above example is in translation from Caccini's original Italian manuscript. Language is always an obstructive factor increasing susceptibility for ambiguous interpretation, not just in the translation of texts into the native tongue of the reader, but also in the changing use of terminology over time. However, this does not suggest that utilising such texts for historical study is futile.

The information obtained from treatises is often combined with other historical resources which comment on the voice in order to assess the relevance and meaning behind the technical explanations in the tutors. Diaries and correspondence are often thoroughly combed for references to any aspect of performance to construct theories of historical sound-worlds and preferences. Modern texts which present an assessment of the authority and significance of these primary sources are now common (For primary literature see for example Burney, 1776; Evelyn, 1620-1706 ed. Bédoyère 1995, Mozart in ed. Anderson, 1985; For secondary literature see for example, Lockwood, 1932; Lockwood, 1934; Myers, 1946)

The vast majority of relevant information concerning the history of vocal technique has resulted from the combined examination of historical sources, particularly treatises, and the musical score. However, the theories compiled need to be challenged from new perspectives to maintain some objectivity with the interpretation of the primary sources, even if the only outcome is to consolidate the original theory. The importance of maintaining a connection with mainstream classical ideals, which is a recurring factor in the commercial success of the early music revival, highlights the importance of the re-analysis of the original sources. As theories are developed certain aspects of performance are often bypassed in order to comply with a modern ideal, 'the need that we all have to fit the past into our contemporary aesthetic is something that needs to be negotiated, or we risk mythologizing our source material' (Potter, 2002: 12).

1.3.2 Stylistic Implications

Once the early music revival had been established, singers began to implement the theories of historically informed performance that were originally constructed by instrumentalists, creating contemporary performance techniques for the voice through the application to the music itself. Speeds and ornaments for example, are often considered using the most essential tool at the singers' disposal – through singing. This process presumes that through experimenting with different performance styles it is possible to deduce those theories of performance practice that are realistic and those which could not and would not have been possible. This is based on the assumption that the physiology of the voice hasn't changed significantly over the last four hundred years.

The problem identified by Lindley in terms of instrumental techniques being shaped by modern performers, and Wistreich's comment on the fundamental similarities between the techniques of the new early music singers and opera singers are particularly significant to this process. The fact that the physiology of the instrument of the singer is thought to have changed relatively little over that time, apart from likely affects of differences in height, diet, environment, *etc.*, seems to provide the scholar with a highly reliable source with which to test theories; 'the human voice box is itself an unchanged and unchanging organ' (Wistreich, 2002: 19). However, the singers implementing the theoretical styles being proposed were 'classical singers' with a modern technique which does not necessarily represent the possibilities of a sixteenth or seventeenth century voice.

The presumption that the vocal organ itself hasn't altered dramatically doesn't provide any specific evidence as to how that instrument was used. 'I reject the notion that because our larynxes are identical to those of our forbearers, then the way we use them to perform repertoires of the past must therefore also have remained unchanged' (Wistreich, 2002: 25). The vast possibilities of the voice are illustrated through the varied vocal traditions and techniques practised throughout the different cultures of the world in, for instance, Tuvan throat singing, overtone singing, or Mongolian chant. To use modern classical principles of vocal techniques as a basis for historical methods is therefore not necessarily reliable.

1.4 Environmental Factors

Alongside the study of vocal tutors and other literary evidence of vocal techniques and typical vocal timbres of the past, scholars interested in historical singing practices also construct theories of vocal change through evaluation of the changing demands made on the singers. Not only did the style of the music and so the technical intentions of the singer change, the environments in which they were performing are also thought to dictate certain elements of the singers' techniques based on necessary changing objectives of performance. The development of opera from a courtly entertainment to a public pastime with the introduction of public opera houses in the seventeenth century marks a significant change in the expectations of singers both in terms of social and vocal standing.

> It was at this juncture that the voice teacher began to play a major part in the art of singing. In order for singers to meet the increasing vocal demands made by composers, the singer's technical facility had to increase. The voice needed to be freely produced in order to accomplish the new technical feats demanded of it and to project in public theatres.
>
> Miller, 1995: 125

It is thought that the continually increasing environmental demands on singers throughout the Baroque climaxed in the early to mid nineteenth century contributing to a significant change in vocal techniques which has been identified at this time.

1.4.1 Concert Halls

Room acoustics are known to have an effect on both vocal production and perception. 'The effect that the local environment can have on the transmission of the acoustic pressure wave from speaker to listener arises from the dimensions of its enclosing surfaces, how the surfaces lie relative to each other, and the materials from which they are composed' (Howard and Angus, 2001: 29). This understanding, which has been held by musicians based on performance experience rather than necessarily an understanding of the physics of sound, has been used to construct theories on historical sound-worlds and performing practices considering the variations in conventional performance spaces over a considerable period of time.

The first public opera houses were notably larger than the rooms which had previously staged the courtly opera of the first half of the seventeenth century, mainly because they could seat a larger audience and accommodate the impressive stage machinery (Potter, 1998: 50). The new performance spaces therefore placed different requirements on the same singers.

A significant factor facing the singer in larger concert halls and opera houses is audibility in terms of both overall sound and musical expression and conveying text. Celletti comments on the alternative positioning of the performers on stage in the first operas as opposed to today,

> As far as the performance of music was concerned, was that the orchestra, which in the earliest operatic performances had been placed on the stage behind the singers, was moved to the front of the proscenium on a level with the stalls. There is no reason to think that given the limited resources of the orchestras of the time and the sparseness of the instrumentation, that there would be a wall of sound between singers and audience.
>
> Celletti,1991: 21

This alternative positioning of the singers and orchestra in turn implies that issues of audibility were less problematic in very early opera, if only due to the reduced distance between the singer and the audience.

The changing role of opera in society with the introduction of new opera houses, besides the need to be sizable to fulfil profitable capacities of audience, also dictated other physical aspects of the buildings themselves: 'the need for separate furnished boxes for the noble families who subscribed to the theatre in Venice and Naples, caused multiplied tiers and considerable total height – *yet lined the whole building with sound absorbents*' (Bagenal, 1951-1952: 16). Bagenal, in his detailed reconstruction of the acoustics of historical concert halls transfers the implications of the acoustics of the space to the possible effects on musical performance. In terms of the execution of the florid passages and the speeds that are thought appropriate for late seventeenth and eighteenth century compositions Bagenal comments 'it is true to say that this technique both as to coloratura and rapidity of tempo was made possible by the short sharp acoustics of the well-draped wooden box free from echoes, and with the majority of listeners raised well above the sound source' (Bagenal, 1951-1952: 17).

Unfortunately due to the impractical financial viability of opera, and the tendency of eighteenth century opera houses to burn down, much of the current understanding of the acoustics of these buildings is based the descriptions and plans of the famous performance spaces which are no longer standing combined with a study of those still in existence. There is now a significant amount of research into the construction and workings of the opera houses and theatres which contributes to the knowledge of those seeking to assess the consequences of these spaces on historical singing styles (Lawrence: 1921: Dent, 1944 – 1945; Buelow, 1978; Hume, 1982; Price, 1989; Price *et al.*, 1991).

Historical literary sources also comment on the development of opera houses and concert halls throughout the Baroque and Classical periods remarking on their visual impact and observing the resultant changes on the performance experience. Alongside a number of other references to concert halls in Fubini's comprehensive collection of primary sources, he includes the letters of a Samuel Sharp conveying his experience of a performance at the King's Theatre in Naples in 1765,

> The voices are drowned in this immensity of space, and even the orchestra itself, though a numerous band, lies under a disadvantage: It is true, some of the first singers may be heard, yet, upon the whole, it must be admitted, that the house is better contrived to see, than to hear an opera.
>
> Sharp, 1765 in Fubini 1994: 209

Comments such as these support theories of a period of change in vocal techniques during this time based on a need to be heard over the growing orchestral forces and sizable performance spaces. Primary source evidence on this matter is particularly important as it supports the theories which are constructed based on the knowledge of the environment which is often also constructed through modern day research.

1.4.2 Orchestras and Instruments

The increased size of the concert hall was reflected in the growth of the orchestra, as both the number of players increased and the instruments themselves developed to meet the demands of the larger space. There is also evidence that as orchestral forces continued to grow and compositional textures became denser in their orchestration, problems of audibility facing singers continued to grow (Potter, 1989: 50-51). Henry Phillips explains in his autobiography that as a professional singer in England in the mid-nineteenth century he did not possess a very powerful voice and that this was occasionally detrimental to his career: when seeking employment he was faced with a retort, 'Why sir, you are not worth two shillings, they can't hear you over the third row of the pit' (Phillips, 1864: 48).

Phillips makes other observations in his biography which provide a perception of performance in the nineteenth century and the 'power' a singer needed to possess. Phillips praises the acclaimed soprano Catalani after seeing her perform in London for overcoming the environmental hazards facing singers at the time, 'the chorus, the orchestra, and the organ tried to overpower her voice, but through all, such was her prodigious power, she could be heard as distinctly as if she was singing alone' (Phillips, 1864: 76). However, Phillips also comments on the subsequent change in attitudes toward singing, with a new importance being placed on the 'loudness' of a voice as he explains, ' in consequence of her extraordinary stentorian powers, the public began to think that a great singer must shout tremendously...' (Philips, 18: 77).

This apparent change in the primary objectives of a singer in the mid-nineteenth century, with a new predominance of perceived volume often defining the quality of a voice, is echoed in the current theories of scholars theorising on historical techniques. The consensus amongst modern theorists that there was a significant change in technique at this time has been formed based on the result of a culmination of changing environmental factors facing the singers, including compositional styles and a new scientific approach to singing introducing a more comprehensive understanding of the workings of the voice (Potter,1998: 50 – 56).

1.4.3 Composition and Orchestration

Combined with the growth of the orchestra is the continuously evolving world of composition. This is particularly important as the compositional style, the notes for the performers to play and sing, are the starting point from which any speculation on the techniques of playing the music of the period can be formed. Particularly important to the development of modern vocal techniques is thought to be the changing role of the accompaniment, particularly in the case of the orchestra in operatic repertoire as its role became more complex and integral to the overall musical expression throughout the classical period (*e.g.* Celletti, 1991, Potter, 1998: 51). Celletti bases his exploration of the voice through the ages on the changing compositional demands on the singer, retracing the various aspects of vocal style that are commonly identified with certain periods to various pivotal composers. The introduction of more virtuosic vocal parts with the move away from passive accompaniments he attributes to the progressive works of relatively little-known composers,

> All in all, the singing in Legrenzi, Sartorio, Ziani, and Pollarolo does not attain a level of virtuosity to compete with that of later composers, but it lays the foundations for them, above all by introducing figurations for trumpet and violin, and discourse between the voices and these instruments.
>
> Celletti, 1991: 52

The changing compositional style, combined with the new importance placed on voice training mentioned above, is thought therefore to suggest certain qualities were preferred in voices performing during this time. Miller deduces from these combining factors that music from this period necessarily requires an accomplished vocal technique, 'To conceive of early baroque solo music vocal literature as the domain of the vocal miniaturist is to ignore the internal evidence of what was demanded of the highly-trained professionals of the period' (Miller, 1995: 124).

Charles Burney in his comprehensive biographical records of performance in the eighteenth century, comments on the detrimental effect the increased orchestral numbers combined with a more involved compositional style had on the audibility of singers in 1770,

> In the opera house little else but the instruments can be heard through the noise; a delicate voice is suffocated: it seems to me as if the orchestra not only played too loud, but that it had too much to do.
>
> Burney, vol. 1 1770a: 77

Beyond the eighteenth century, composers began to react against the highly ornamental florid executions of the Baroque and Classical periods and began to claim an authority over their compositions which had previously been artistically shared with the singer. The result was thicker compositional and orchestral textures with longer, more sustained vocal lines, demanding a focus on the quality of sound produced by the singer and less virtuosity in terms of rolling coloratura phrases.

1.5 Scientific Revolution

The common theory that there was a significant change in vocal technique in the early to mid-nineteenth century from which a technique which we currently associate with modern 'classical singing' developed was mentioned above. Combined with the environmental factors also discussed, a principal change in the world of performance which contributes to this theory comes from the significant advancement in technology at that time and the new understanding of the voice which developed.

The leading figure in this scientific revolution of the singing voice was the singer, teacher and scientist Manuel Garcia (1805- 1906). His investigations into the voice led to a considerably increased understanding of the mechanisms of the larynx and the vocal tract in producing and shaping sound. One of the main characteristics of vocal technique which he identified and which modern theorists consider most significant in their theories of a new method of singing is the use of a lowered larynx to produce a dark quality which he defines as the '*voix sombre*'. This vocal timbre is identified in contrast to the light quality '*voix blanche*' which uses a higher larynx position and is thought to represent a sound and technique common before the nineteenth century (Potter, 1998: 55). Complementing this theory is the modern understanding that the use of a lowered larynx in singing, in addition to darkening the sound, introduces acoustic factors that increase the projection power of the voice over an orchestra by creating the singer's formant cluster, therefore satisfying the further environmental demands that were introduced to singers at this time (*e.g.* Potter, 1998; Wistreich, in ed Potter, 2000: Wistreich, 2002).

The new scientific age of the voice, which began with Garcia, took hold on the singing world and began quickly to infiltrate the common principles used in vocal tuition, with vocal treatises endorsing their methods with physiological principles and scientific jargon.

1.5.1 Teaching Styles

Historical sources that can be utilised in the pursuit of knowledge of historical singing techniques, due to the absence of any recording technology available, constitute the surviving literary evidence. Particularly useful are the treatises which provide information on the teaching methods used at certain periods and there have been a number of studies tracing the development of teaching methods over the last 400 years through the evaluation of treatises (Sands, 1943 – 1944; Foreman, 1967: Monohan, 1978). This information on teaching methods can yield certain speculative theories on the technique being employed by singers. After the dissemination of Garcia's discoveries through his own treatises published in the 1840s, vocal tutors undertook to include science in their teaching methods which had previously been less 'technical' in their explanations (Monohan, 1978). This dramatic change is thought to be the basis of the teaching methods used today, 'Eighteenth century singing-teaching was based on empiricism, whereas ours at any rate seeks to base itself on science' (Sands, 1943-1944).

Today an abundance of published vocal tutors are available for the classical singer, each promoting their own methods of vocal production through various holistic and scientific principles. However, all these techniques appear to be striving for the same result in terms of conforming to the modern ideal of the 'classically trained voice'. In turn, therefore, there remain common desirable aspects of the voice that are being strived for throughout the numerous genres that are incorporated into 'classical music'. This is particularly important to the current study considering the modern performance of early vocal music.

The theories which have been constructed concerning historical techniques are generally presented within academic literature rather than within modern teaching practices. The specialist music colleges have long had an interest in producing specifically opera singers which continues to contribute to the perception of all 'classical singing' today; 'opera increasingly became the flagship course, to the extent that all of the British conservatoires eventually became the opera singing factories that they are today' (Potter, 2002: 10). Without a training convention incorporating the scholarly findings of historical vocal techniques, the probability of these theories impacting on performance culture were very slight, unless the students were themselves interested in the scholarly investigations surrounding the music they performed.

It is only recently that conservatoires have begun to consider early music specialists. Wistreich explains that when he took responsibility for early music at a conservatoire he began to infuse his teaching with his academic understanding of historical techniques, 'Naturally I wanted to pass on the fruits of my haphazard studies and also infect my students with the same bug that infected me...' (Wistreich, 2002: 24). In spite of a change occurring in the teaching of singing to include a representation of the theories presented above, these continue to be applied to singers already trained to various extents in the modern tradition encompassing the concept of 'classical singing'. Wistreich also appreciated the need to satisfy the modern conventions of classical performance, going on to explain: 'I understand the need meanwhile to try to equip my students with the basic skills of received practice of vocal technique...' (Wistreich, 2002: 24). Potter explains that the need to comply with modern ideals, due to the audience preconceptions of classical music, and the wide range of repertoire performed by singers today can prevent a representation of historical ideals: 'We have to accept that singers today have to deal with a huge variety of music from many periods and need a good basic general technique, but they have to apply this judiciously: there is a tendency to teach way beyond the demands of the music so that everything comes out sounding the same' (Potter, 2002: 16).

1.6 Current Styles and Changing Fashions

Since the beginnings of the revival there has been a change in the various preferred traits in vocal performance of all 'classical music'. Desirable vocal qualities continue to change within the tradition of opera in addition to the specialist performance of early music which is a direct result of the revival. However, there is no doubt that the various stages of the revival discussed above effected a distinct change in voice-type expected to perform music of the Renaissance and Baroque periods. The introduction of an Oxbridge choral sound in solo repertoire was dramatically different to the operatic voices previously employed for that music; however, as discussed above, this originally had no foundation in an interest in historical performance techniques. A number of developments have occurred in the musical world since the inception of the early music singer which have contributed to the subsequent alteration of the early music voice.

The scholarly interest in historical vocal styles which emerged has begun to infiltrate those teaching establishments which previously focussed their attentions on grand opera singing. The repertoire encompassed by early music singers has also expanded to engulf much of the repertoire of the Classical period. In spite of the further interest in historical performance practice by singers, the 'classical' Western origins of the singers combined with the need to conform to acceptable sound worlds has resulted in a new sound that is not necessarily connected to a historical sound-world: 'what we in the so-called informed performance project have been up to for the last thirty years has nothing to do with the historical. It has to do with the modern: "it is the sound of now, not then"' (Wistreich, 2002: 24).

1.7 The Science of Singing

To establish a sound understanding of the vocal techniques employed by singers today requires a comprehensive knowledge of the workings of the voice. To consider in particular the viability of the techniques currently used by early music singers as reflecting conventions of the past, therefore necessarily involves the secondary assessment of descriptions of voices and vocal practices alongside the direct assessment of physical characteristics of modern performances. To date, research into vocal techniques has encompassed a wide variety of disciplines resulting in a certain amount of confusion. So that attitudes can progress through organised methodical research these complexities need first to be acknowledged and then re-examined. Awareness of the physiology of the voice has become far more specific and scientific to the point that there are now clear divides in the approaches used when investigating vocal techniques. Whilst previously, music and singing have been matters for musicologists and performers, the study of the singing voice is now as much a concern for acousticians and voice scientists as it is for the musical scholar (See, for example, Sundberg, 1987; Howard, 2006).

Significant progressions in voice science in recent years have the potential to provide musicologists with a vast new knowledge base, previously lacking in their resources, with which to take their investigations to a new level. However, currently these two researching disciplines remain, on the whole, self-contained. Uberti acknowledges that 'the time is ripe for an infusion of objective knowledge into this field of intuitive endeavours, and I think we can obtain it by reading the theorists of the day in the light of modern knowledge about the physiology of the voice' (Uberti, 1981: 486). Whilst Uberti recognises the potential of using voice science in a retrospective manner, the extent to which research to date actually uses such an approach is comparatively very small.

1.7.1 Advancement of knowledge

Voice science and its use in musical research are evidently extremely valuable to the advancement of research in singing:

> How the singing voice best functions, what constitutes its limitations, and how it should be trained to meet the performance demands placed on it, are interdisciplinary concerns in which experts must cooperate.
>
> Miller, 1995: 128

However, the novelty of such research also has the potential to cause complications in the pursuit of historical practices. Whilst scientific understanding of the singing voice has advanced significantly over the last fifty years, as a science it remains very young and general knowledge of the science of the singing voice amongst singers, voice teachers and theorists remains quite confused. There have been a number of scientific studies into the effects of training on the voice, the differences in vocal technique between musical genres, as well as much interest in the aspects of classical vocal technique that contribute to its distinguishing features (*e.g.* Sundberg, 1987). However, there is a danger of vocal coaches and musicologists working with only partial understanding of current scientific theories, or, a misconception that research in voice science is in itself complete. To combine such half-knowledge with theories and presumptions on the singing voice could contribute to an entirely misconceived concept of historical vocal techniques claiming to be rooted in scientific fact.

1.7.2 The Fusion of Science and Music

The progression of knowledge also causes further complications in the use of voice science in investigations into the historical voice. It was discussed above that the rapid development of the understanding of voice physiology in the early nineteenth century invited teachers, singers and musicians to discuss the voice in a new way, describing techniques and styles from a physiological and scientific rather than a metaphorical and descriptive perspective, although these explanations were often confused and misrepresentative of the techniques they were describing. It was explained previously that contemporary musicologists and performers constructing theories of historical vocal techniques have used such information, at least in part, to conclude that concurrent to the time of this changing outlook on the voice in the mid-nineteenth century there was a fundamental change in classical vocal technique.

Whilst philosophies such as these often provide logical solutions to questions of historical vocal techniques, notions based upon such evidence are deserving of closer scrutiny. It is often difficult to distinguish between those theories which are simply technical characteristics being explained in a scientific way for the first time, and those which were actually occurring for the first time. Careful selection and criticism of individual sources is therefore essential in the use of descriptive explanations, whether ostensibly scientific or otherwise.

1.7.3 Implementation of Knowledge

The relatively few musicologists who have drawn on the use of scientific knowledge of the singing voice to inform their theories of historical techniques, strengthen their theories based on the principles of voice science which are associated with classical singing today. Potter, for example, uses the modern understanding of vocal acoustics to explain the use of a lowered larynx technique in post-nineteenth century performance practices,

> Sundberg's (1977) researches imply that a modern opera singer is by definition one who sings with this technique, whether or not he or she is aware of it. A lower larynx undoubtedly became the norm during the later nineteenth and twentieth centuries, to the extent that in the twentieth century it is taken for granted.
>
> Potter, 1998: 55

The primary advantage of the singer's formant cluster in opera singing is deemed the ability for singers to be heard without needing to compete with the overall intensity of an orchestra (a physically impossible task). The basic understanding that lowering the larynx achieves this acoustic phenomenon complements the theory of a change in technique based on the changing environmental demands of the singer and supporting literary sources. Uberti places a strong emphasis on the science of singing, using a modern understanding of the voice to deconstruct a vocal technique in order to speculate on the preferred timbres and vocal qualities of Renaissance singing, 'When the jaw is held forward (as it is in Renaissance singing), the size of the throat cavity is slightly increased and thus stabilized, and so the vowels are somewhat 'rounded'' (Uberti, 1981: 490).

Stark's detailed research exhausts most aspects of vocal techniques and characteristics, actively incorporating modern knowledge of the singing voice and acoustics into his studies of historical techniques (Stark, 1999). Scientific studies applying his theories of historical vocal techniques by analysing himself singing were used to strengthen the technical and physiological aspects of his theories. As a result Stark goes beyond the application of modern acoustics to strengthen arguments of techniques, speculating on specific features of laryngeal activity and other physiological aspects of the voice,

> Dr Stark believes... that Caccini's singers, highly trained virtuosos, produced the ornaments with the more efficient anterior phonation, perhaps using a technique now lost to us.
>
> Robson, 1983:98

Caccini did not discuss or understand the role of the larynx in singing, and yet Stark here uses the information provided in the musical score and other literary information of voices to deduce finite detail of laryngeal behaviour in the techniques used by Caccini's singers.

1.8 Structure of the Thesis

The purpose of this thesis is to identify characteristics which distinguish modern performers of early music from modern performers of grand opera through the scientific study of various aspects of vocal technique. From this information it will be possible to ascertain the extent to which speculative theories on historical vocal techniques have infiltrated the modern performance of early music.

The aspects of vocal technique that are considered within the study have all been identified as having specific characteristics associated with modern opera singing, often known to be effected by classical training.

Chapters 3 – 6 of this thesis deal with specific aspects of technique and characteristics of the classical voice, drawing on the relevant results from the case-studies in detail, in light of both modern perceptions of early music singers and theories of historical techniques. The aspects of technique which are quantified and discussed in detail are: vocal fold contact area; vibrato; larynx position; timbre; loudness and intensity; and resonant strategies including the singer's formant cluster. These facets of the voice have been ordered and grouped as they function in the voice. For example, vocal fold contact area and vibrato are addressed in Chapter 3 under the heading 'vocal fold activity' because both aspects are connected with the voice source rather than, for example, the resonant frequencies of the vocal tract (which are addressed in Chapter 6 under the heading 'resonance strategies'). Each chapter explains the significance of the relevant vocal characteristic as it is currently understood in terms of contemporary scientific knowledge and musicological theories of contemporary techniques.

The following chapter explains the aspects of vocal technique that are measured in the study in terms of their role in voice production as it is currently understood.

Terminology is explained alongside the current methods available to measure various factors of voice production. The methodology of the study as well as an overview of the results is also provided within Chapter 2.

1.9 Hypothesis

New scientific understanding demonstrates that modern singers of early music exploit a technique which is founded on the same basic principles as modern singers of grand opera, which does not necessarily adhere to current theories of early singing practices.

Chapter 2

Experiment

This chapter explains the scientific element of the thesis presenting the methodology of the experiment. A background to the aspects of vocal technique that are analysed within the study is also provided, containing a review of methods currently available to assess these various qualities of voice. An overview of the results for all vocal facets which were assessed is also featured in this chapter detailing the methods used to analyse the data.

2.1 Background

Scientific investigation into the voice has identified various quantitative parameters of vocal production as being characteristic of classical singing and being effected by classical singing training (See, for example, Sundberg, 1987; Howard and Angus, 2006: 204-214). However, exploration of voice science tends to consider 'opera singers' as being representative of 'classical singing', without distinguishing any other areas of specialisation within classical vocal performance. Music theorists with interests in historical performance practices or historical vocal techniques tend to compare methods of singing early music with the modern practices of singing grand opera (Wistreich in Potter ed., 2000: 178 -191), partly because this is the conventional voice type employed to perform 'classical' music, and also as there is extensive scientific research in this area. Various parameters have been identified by voice scientists and acousticians as accounting for the typical acoustic characteristics of the 'operatic voice' and from these findings musicologists and performers have developed theories on historical vocal production and current vocal techniques used in modern performance practices of early music. However, to date very little specific research has been carried out to determine or confirm specific vocal differences.

This chapter outlines an experiment to investigate possible differences in vocal technique between modern singers specialising in early music compared with singers performing grand opera. Sixteen female singers were used as case-studies, eight from each genre and the study focussed on six parameters of voice production: vocal fold contact area, vibrato, larynx position, timbre, singer's formant cluster and other resonance strategies and intensity, and these are described below.

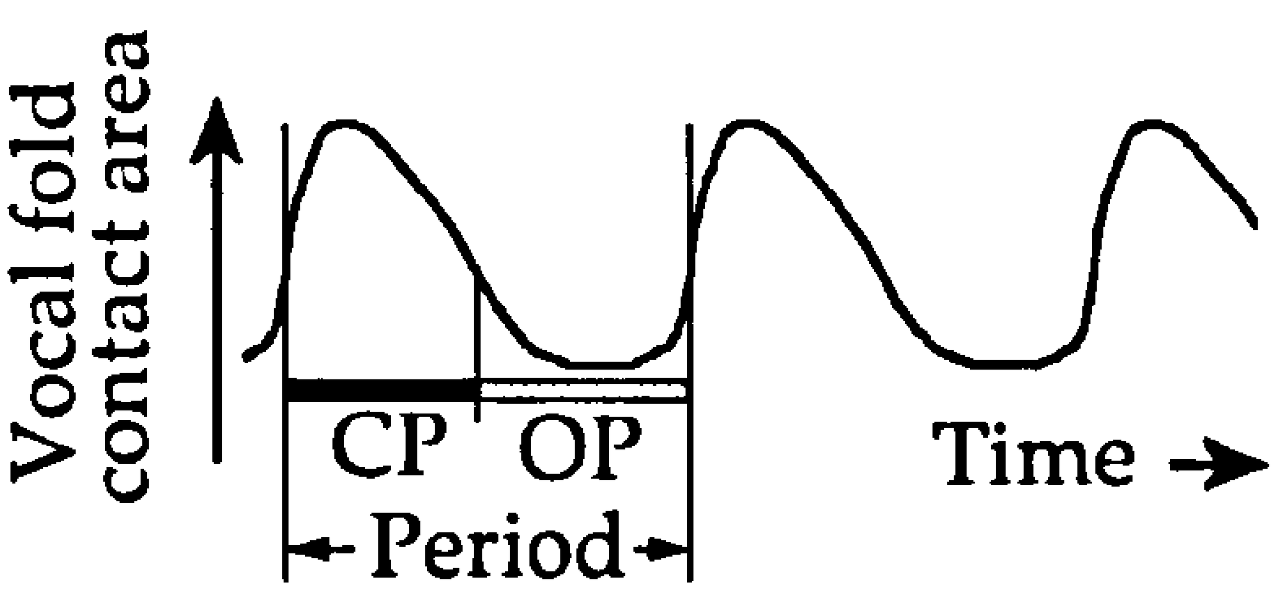
2.1.1 Voice Source Activity

With the invention of the laryngoscope at the beginning of the nineteenth century, an understanding of the working mechanisms of the larynx (and specifically the vocal folds) began to emerge. Whilst the larynx had previously been identified as an essential physical component of the voice, until recently theories of the role of the vocal folds remained confused. Although there were suggestions that the folds function as a type of reed mechanism, many incorrect assumptions were present, such as the idea that, rather than vibrating, the vocal folds actively open and close by a muscular action to create voiced sounds (Husler and Rodd-Marling, 1976: 55). The voice organ is composed of a complex system of muscles and tissue, the intricate workings of which are still not understood; however, the basic system of voice production is now more widely recognised.

Briefly, the vocal folds vibrate largely due to a force known as the Bernoulli effect as air is passed from the lungs through the glottis (Sundberg, 1987: 12). The vocal folds vibrate regularly producing a complex sound wave which is then 'shaped' by the acoustic properties of the vocal tract before it reaches the ear (Howard, 2007: 205-206). Sounds that can be made without the vocal folds vibrating are known as 'unvoiced' and include some consonants such as [s], [f]. For phonation to take place the vocal folds must be brought together, or adducted, by the muscles of the larynx. The adduction of the vocal folds is achieved by the actions of the arytenoid cartilages positioned at the posterior ends of the vocal folds controlled by the lateral cricoarytenoid and the interarytenoid muscles. Complex changes in the laryngeal musculature control the length, density and adduction of the vocal folds, changing the perceived pitch as well as spectrum of the sound wave being produced. For example, the contraction of the cricothyroid muscle causes a lengthening and thinning of the vocal folds, also increasing the tension, resulting in an increase in the fundamental frequency (Sundberg, 1987: 15 – 17). Investigations into the specific modes of vocal fold closure, or phonation type, are of particular interest to research into registers which are known to be connected with voice source changes (see for example Sundberg 1987: Miller, 2000). A complex discussion of the workings of the voice is not necessary here as publications dealing with the functioning of the voice are plentiful. For an introduction to the physiological workings of the voice see, for example, Sundberg, 1987: 6 – 25.

Whilst knowledge of the voice source is far from complete, it is rapidly improving as technology advances and new methods are implemented that progress our understanding. Endoscopic and stroboscopic imaging is now available allowing for high resolution pictures of the vocal folds as they vibrate, and electrolaryngographs and electroglottographs provide non-invasive methods for investigating aspects of voice source activity. In electroglottography or electrolaryngography, a pair of circular electrodes is placed on the neck either side of the thyroid cartilage and held in place using an elastic strap. A small high-frequency current is passed between the two electrodes. The conducting properties of human tissue mean that as the vocal folds come together the current flow increases, decreasing when they move apart. This is represented by the electrolaryngograph output waveform from which the vocal fold activity of each vocal fold cycle can be observed. Figure 1 shows an idealised output waveform from an electrolaryngograph and the way that each cycle can be divided to define the opening and closing phases. The amount of time the vocal folds spend in contact in each cycle, known as the closed quotient (CQ) can then be calculated. For more detailed descriptions of electrolaryngography and electroglottography see, for example, Baken, 1992; Rothenberg, 1992; Baken *et al.*, 2000; Herbst and Terström, 2006; Howard, 2008.

Figure 1 Idealised output waveform from the electrolaryngograph indicating Closing phase (CP), opening phase (OP) of one vocal fold cycle (Tx). (Howard and Murphy, 2007)



A key feature identified by voice scientists as being associated with classical singing is the amount of time the vocal folds spend closing and staying together and opening and staying apart in each vibratory cycle. Current research suggests that contact time or closed quotient increases with training (Howard *et al.*, 1990: 205-212). Increasing the contact time in each vocal fold vibratory cycle is thought to be beneficial to the classical singer for a number of reasons: the time that the folds spend apart is shortened reducing the time in which the sound can travel back down the glottis to be absorbed by the lungs; it increases the breathing capacity for phrases as 'less stored lung air being vented in each cycle with the reduced open phase'; and produces 'less breathiness of voice quality' (Howard *et al.*, 1990: 211). There is also evidence, based on research using electrolaryngograph derived data, that closed quotient also increases with fundamental frequency in trained female voices (Howard, 2003: 467-470).

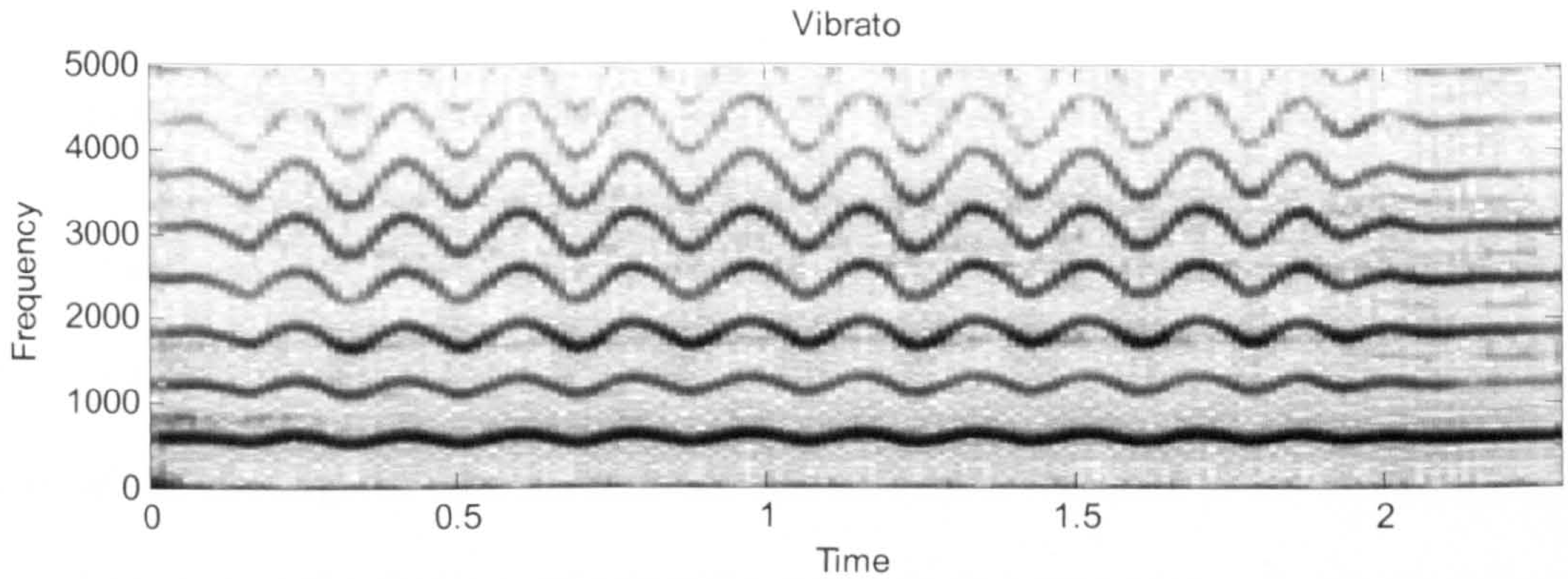
Research into the reliability of using electroglottography (EGG) to measure contact time suggests that when dealing with female voices closed quotient calculation can become inaccurate (Herbst and Ternström, 2006). Considerable discrepancies were identified between electroglottograph and videokymographic and videostroboscopic data in falsetto phonation which presents with little adduction, as compared with more reliable data for phonation in 'chest' register or high adduction falsetto phonation as employed by counter tenors (Herbst and Ternström, 2006: 126-138). Whilst this indicates limitations when dealing with female voices, the findings of Herbst and Ternström were based on 2 male voices, making relevance to female voices dependent on a number of factors, including the types of phonation being used by the singers presuming a likeness between the phonation type of female singing and male 'untrained' falsetto.

Factors of vocal fold closure in the present study will be investigated in terms of any consistent differences observed between the two groups and between individuals. The findings of Howard discussed above which connect increased closed quotient values with classical singing training are also of important consideration to this research. Therefore, particular focus will be given to the connection between any noteworthy findings and the training of the individual subjects in the current study.

2.1.2 Vibrato

Vibrato is perhaps the characteristic most typically associated with classical singing and corresponds to periodic modulations of the fundamental frequency which can be seen in figure 2. Stereotypically, it is often the singer's 'warble' that identifies them to the classical genre. Comprehensive research has been carried out in vibrato, beginning with Seashore in the 1930s, as to its perception and production in singing. In western classical singing it has been found that 'the regularity of this modulation is considered a sign of the singer's vocal skill: the more regular the vibrato, the more skilled the singer' (Sundberg, 1987: 163). The acceptable parameters of vibrato in terms of maximum rate and extent before becoming perceived as separate pitches have been explored and standardised at between 5.5 and 7.5 undulations per second with an extent of up to +/- one tone (Sundberg, 1987: 164; Hirano *et al.* in Sundberg, 1995: 50). Research suggests that vibrato is created by pulsations of the laryngeal muscles (Seashore, 1936 :196), although the physiology of vibrato is still not well understood (Dejonckere, in Sundberg, 1995: 4). It is thought that vibrato develops unconsciously in classical training (Bjorklund, 1961), although a study analysing changing vocal parameters with training across four semesters found no significant increases in vibrato (Mendes *et al.*, 2003:541).

Figure 2. Spectrogram showing vibrato in a sung tone. The oscillation in fundamental frequency is most easily viewed in the higher frequencies in the spectrum as the absolute frequency change is larger.



Although some scientific research suggests that vibrato is an integral element of classical singing, musicological literature suggests that vibrato would have been reduced in historical singing compared to modern standards, and that it would have been used as a musical ornament rather that as a standardised feature of vocal production (*e.g.* Wistreich in ed. Potter, 2000: 184-185). The use of vibrato by modern early music singers since the early music revival has also been reviewed (Potter, 2000:162). The literature presenting these theories along with the primary sources on which they are based are discussed in light of the current vocal practices explored in this study in chapter 3. The scientific findings presented by those such as Seashore on the physical production and perception of vibrato, and the theories of vocal performance practices presented by researchers such as Potter, provide an interesting foundation on which to consider any differences in vibrato usage between the singers specialising in early Music and grand opera. According to current theories of historical singing, the early music singers should present with less overall vibrato, consciously introducing it as a musical ornament. Depending upon their vocal training, according to scientific studies, this is less likely if they have been trained in a modern 'classical' style consistent with opera singing, as this promotes the 'natural' production of a constant vibrato.

2.1.3 Larynx Position

A significant amount of literature concerning the singing voice addresses larynx position. Chapter 4 explores some of this literature and the theories put forward in context of the findings of this experiment. Much of this material presents speculative theories based upon the findings of scientific research. In terms of the classically trained voice, there is an established theory of the use of a lowered larynx technique. Particularly considering the Singer's formant cluster (see below), physiological implications, such as necessary shapes of the sound modifiers (and specifically the lowering of the larynx) are often assumed to be based on acoustic understandings. Sundberg explains the likely association of larynx position with the singer's formant cluster, using the knowledge of the fourth formant and the non-intrusive nature of the singer's formant cluster on vowel production to presume its connection with the larynx tube (Sundberg, 1987: 115-124). In spite of the extensive discussion of larynx positions in singing, direct scientific and quantitative studies into larynx positions in singing are relatively scarce, in part due to the difficulties in obtaining and calibrating the data. Currently the most accessible means of measuring larynx position is by using a multi-channel electroglottograph with split electrodes, the details of the workings of which have been described in detail (Rothenburg, 1992: 36-43).

Measurement of larynx height using the dual-channel electroglottograph was found by Pabst to be valuable, particularly to allow measurements in females who tend not to have prominent thyroid cartilages (Pabst and Sundberg, 1992: 67-78). However, whilst Laukkanen also found it useful, when comparing results with simultaneous videofluorography there were discrepancies in the amount of movement made by the larynx, highlighting the limits of its accuracy (Laukkanen *et al.*, 1999: 60-71). Phonation is essential in order for a signal to be produced by the electroglottograph, and this poses a problem of calibration when using this method to measure larynx height as the resting position cannot be obtained through these means. In her study on 'Physiological Aspects of a Vocal Exercise' Elliot used a multi-channel electroglottograph to measure larynx height, calibrating the measurements by marking dots at the anterior gap between the cricoid and thyroid cartilage on the neck of the subjects in resting position and when deliberately phonating with a number of different fixed laryngeal positions (Elliot *et al.*, 1997: 172). If subjects could not consciously manipulate laryngeal positioning, Elliot used the reciprocal technique suggested by Rothenburg of moving the electrodes vertically as the subject sustained a vowel with a fixed larynx position (Rothenburg, 1992; Elliot *et al.*, 1997: 172).

The relatively small volume of research investigating the treatment of vertical larynx position in female singers compared to males is discussed in chapter 4 alongside a review of the overall findings of the studies using the techniques described above to discern larynx height behaviour in opera singers. There is clear evidence of a lowered larynx position being associated with opera singing in male voices which has come to dominate common opinion of larynx height behaviour in classical singers (*e.g.* Shipp and Izdebski, 1975; Sundberg, 1987: 113-115; Pabst and Sundberg, 1992), even though such secure conclusions have not been formed concerning the soprano voice (Johansson *et al.*, 1982). However, there are still indications of specific laryngeal height behaviours being employed in classically trained female singers (Johansson *et al.*, 1982; Pabst and Sundberg, 1992). In light of the research which does consider larynx height in female opera singers, the considerable attention given to vertical larynx position in theories of historical techniques and in the modern pedagogy of classical singing makes it of particular significance to the current study.

2.1.4 Timbre

Timbre plays a significant role in the speculations of historical vocal techniques, as well as in discussions of the modern performing cultures of early music and grand opera.

Considerations of tone quality in terms of historical ideals and modern practices are based largely on descriptive language, and, particularly in the musical literature of performers or musicologists, there is rarely an attempt to consolidate any timbral descriptors by means of acoustic analysis. When addressing the differences between early music singers and modern singers of grand opera, both as a historical ideal and a modern genre of singing, issues of tone quality and timbre often arise, labelling the early music sound as 'lighter', 'purer' or 'clearer' than that of opera singing (Wistreich in ed. Potter, 2000: 185; Wistreich, 2002). Chapter 6 explores issues of timbre, including theories presented in current literature on historical vocal sounds, modern day ideals and the origins of these theories.

There are now efficient methods of acoustic analysis available which allow the investigation of vocal timbres through a visual means, enabling the quantification of timbral aspects of the voice. Whilst these cannot be applied to voices of the past, such methods can provide another level of exploration for modern styles of singing, in order to clarify ambiguities caused by using timbral descriptors to define a sound, as well as providing new information on acoustic aspects which contribute to differences in perceived timbre.

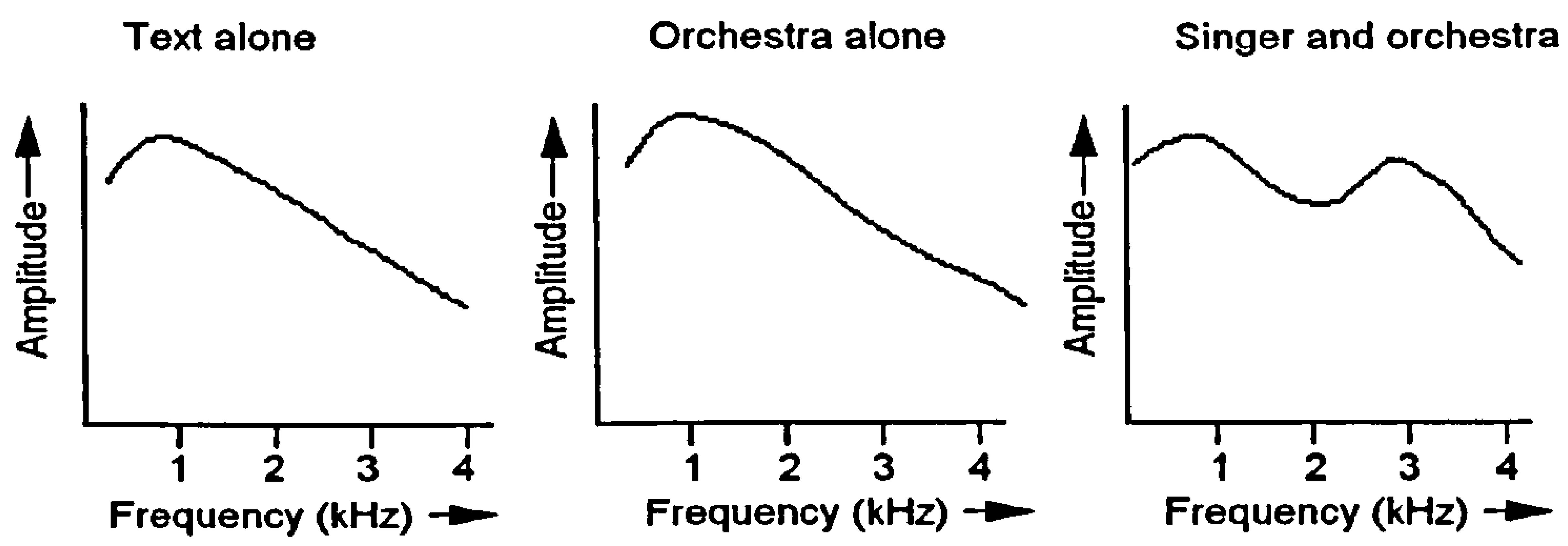
Spectrographic analysis to view and measure the quality of sound has become indispensable in the quest for knowledge on vocal physiology, singing techniques, and in gaining knowledge through listening tests in psychoacoustics. A spectrogram plots a pictorial image of the spectrum of a sound signal achieved by filtering the signal. This provides valuable information as the sound spectrum is the key information provided to the brain by each ear and is the basis for our perception of sound (for an understanding of psychoacoustics and its connection to spectrography see Howard and Tyrrell, 1997). Howard describes a filter as 'a device which separates out a portion of the frequency spectrum of a sound signal from the total' (Howard, 2007: 57). After filtering the signal, the spectrum can be viewed by a number of means. A spectrogram provides a pictorial representation of the sound spectrum over time by a process of narrow or broad band-pass filtering being applied to the sound signal. The spectrogram plots the signal as time along the x axis and frequency along the y axis. A grey scale is traditionally used to represent the amplitude of the signal; the darker the shade the higher the amplitude. Spectrograms can be used to quantify a number of acoustic factors of sound particularly in the voice, including formants, and overtone content in singing. There are an extensive number of studies on the voice which use and explain spectrograms (see for example, Fry, 1979; Baken, 1987; Howard, 2007: 62-63).

2.1.5 The Singer's Formant Cluster and other Resonance Strategies

The singer's formant cluster has long been discussed in scientific based literature on the voice, and has more recently become of interest to musicians exploring issues of vocal techniques. In 1934 Bartholomew comments on the presence of an extra formant in the region of 3 – 4 kHz (Bartholomew, 1934: 27-28). Whilst it is now understood that the phenomenon of the energy in this frequency region is not in fact an additional formant in the way that formants are defined in speech analysis, its presence continues to be of high importance in investigations of voice science and acoustics (see, for example

Sundberg, 1987 for a explanation of formants and their role in the identification of vowels). The band of high energy between 2 – 4 kHz, which remains labelled the singer's formant cluster, manifests as a peak in the output sound spectrum (see figure 3). This provides the singer with an acoustic advantage over the orchestra which has no such peak in this frequency region; the frequencies above a low frequency peak at 500Hz the harmonics gradually decay in amplitude. The frequency band of the singer's formant cluster also coincides with the most sensitive frequency range of human hearing, identified at around between 2.4 to 4 kHz (Howard, 2007: 80). One of the main effects of the singer's formant cluster has therefore been identified as allowing projection of the voice over the orchestra without needing huge sound pressure levels which could result in vocal strain.

Figure 3 Idealised spectral envelope for a singer speaking (left) an orchestra playing (middle) and a singer with an orchestra (right), the extra peak in this spectrum represents the singer's formant cluster. (Howard and Angus, 2006)



Whilst the singer's formant cluster has been identified as a defining characteristic of male opera singing, the effect of producing a peak in the spectral envelope is also employed by female opera singers. Weiss *et al.* (2001) found that trained female singers presented with a band of energy in the region of the singer's formant cluster when singing vowels at low and mid pitches in their range. This band of reinforcement was found to be wider in female singing than in male singing (Weiss *et al.*, 2001: 457). When singing at higher pitches, Weiss identified the production of a strong fundamental with a reinforcement of the first four or five harmonics in trained voices and the progressive deterioration of harmonics at higher frequencies in untrained voices. Weiss concludes that the methods of maximal projection used by sopranos are different to the singer's formant cluster phenomenon of male singers and suggests the introduction of EFR (extended frequency reinforcement) as a term to distinguish the two (Weiss *et al.*, 2001).

Mendes *et al.* (2003) reported a decrease in the presence of the singer's formant cluster in sopranos as the period of vocal training increased, and noted the raising of the first formant to approximate the fundamental causing an increase in SPL of the fundamental by up to 30 dB. These findings are supported by similar studies by such as Miller (Miller, 2000: 97-108). Mendes also noted a third formant located at approximately the same frequency as the singer's formant cluster, but agreed that vowel modification at higher pitches 'would cause the singers' formant to decrease in amplitude because there would be no harmonic energy in the area of a formant peak to be maximised' (Mendes at al., 2003: 542). Sundberg suggests that the singer's formant cluster is not necessary in the higher frequencies of females voices as 'the risk of masking is probably smaller in high-pitched singing female singing, as all partials are higher in frequency than the strongest sounds from the accompaniment' (Sundberg, 1974: 843).

Whilst there is evidence that the singer's formant cluster is not as relevant to female singing as male singing, research into the phenomenon of the singer's formant cluster and specifically the acoustic techniques of female opera singing remains inconclusive due to 'either insufficient evidence in the literature, or lack of consensus, or the results are inconclusive, nonexistent, or contradictory' (Weiss *et al.*, 2001: 458). Berndtsson and Sundberg (1995) found that the singer's formant cluster did influence voice classification when using singing synthesis. The perceived quality of soprano synthesis improved when increasing the centre frequency to 3.5kHz, except from the most high-pitched tones for which widely spread higher formants was preferred (Berndtsson and Sundberg, 1995). Due to this, even though the current study uses only female singers, the singer's formant band will be considered in terms of its acoustic significance particularly as a tool for projection. However taking into account current research into the specific devices used by females at high pitches, these alternative projection and resonance techniques will also be considered.

Projection techniques and acoustic trends known to be consistent with classical training are of utmost importance to this study, considering its comparison of two genres of 'classical' singing. Many of the arguments pertaining to the significance of acoustic features, such as the singer's formant cluster, are based upon the singer's environment, in terms of the large halls and substantial orchestral forces over which they need to project. Therefore, much of the research into the effects of classical training on the voice also considers the acoustic parameters being investigated in terms of presumed objectives of projection. Singers who specialise in the performance of early music are not faced with the same acoustic barriers, performing music written in a compositional style that provides more 'space', and usually performing with smaller orchestras in smaller concert halls. The training of these singers varies considerably, from the conventional training roots of opera singers through conservatoires to formal training through choirs. The standard performing environments and training of the individual singers are therefore of particular interest to the present study, especially when the extent to which the early music singers in the study present with similar acoustic tendencies to the 'opera singers'.

2.1.6 Intensity and Perceived Loudness

Whilst common perceptions of opera singing often include reference to the volume of the sound produced, in light of the strategies discussed above, and assuming that competing with overall sound pressure levels of an orchestra would be an impossible task for a singer, that overall intensity is not as significant a factor as it may seem.

As loudness is a perceptual measurement made by the human ear it is a very difficult parameter to measure. DB SPL meters are generally used to quantify intensity in voices, however the results do not necessarily represent the perceived loudness of the tone being analysed as the SPL meter may only be measuring the intensity of one or a few partials present in the sound (Sundberg, 1987: 32; Sundberg, 1994: 70). However, research does show that trained singers tend to produce higher overall intensity values than untrained singers, and that this effect is most noticeable in soprano voices (Sundberg, 1987: 116).

Research also shows that the steepness of the spectral slope has an effect on the perceived loudness of a tone as well as changing the projection qualities and timbre of the sound. Investigations into the effects of loudness on LTAS in speech suggest that the overall slope decreases if vocal loudness increases and is known to be connected to changes in subglottal pressure (Nordenberg, 2003; Sundberg, 2006).

Considering the importance placed on loudness in stereotypical perceptions of opera singing and the theories of historical techniques which suggest an increase in volume in classical singing over time, intensity is an important factor in the context of the present study. Current research relevant to intensity, particularly in sopranos, and the possible connections with this feature and other acoustic strategies is considered alongside the results in detail in chapter 6.

2.2 Methodology

2.2.1 Subjects

Sixteen subjects took part in the study, all professional female singers. Eight of the singers were employed on full time contracts by the Royal Opera House, Covent Garden in London as part of the opera chorus and formed the group named the 'opera group'. Four of these singers were sopranos and four were mezzo sopranos. The other eight singers who formed the 'early music group' had careers as freelance singers specialising in early music, often performing in professional early music vocal ensembles as well as regular solo engagements. Of these singers two were mezzo sopranos and six were sopranos. The age of the singers ranged from 29 – 54 years old in the opera group and from 28 – 59 years old in the early music group. All singers were British apart from subject 14 from the early music group who was Greek. Each subject provided information regarding their career and training which is summarised in table 1 and their own perceptions of current singing genres within classical music.

Table 1 The education and musical background of each subject

Subject	Age	Training	Choral Background	Career	Repertoire
1	28 Sop	Cambridge University	Choral scholar	Professional Early Music ensembles. Solo work (with early music string ensembles)	Mainly Renaissance and Baroque Some Classical
2	47. Sop	Birmingham University (BA Music) 2 yrs RAM	University Choirs	Professional Early Music ensembles Church choirs BBC singers	Mainly Early Music willing to sing music beyond Classical
3	36 Sop	University of York (BA Music) 2 yrs RCM	University Choirs	Early Music Ensembles Church choirs Solo work (oratorio)	Baroque and Classical some contemporary
4	38 Sop	Cambridge University 2 yrs GSMD (early music course)	University Choirs	Early Music Ensembles Solo work	Renaissance and Baroque
5	48	Music College Opera Course	Music College choir	ROH Chorus BBC Singers Glyndebourne Chorus	Anything

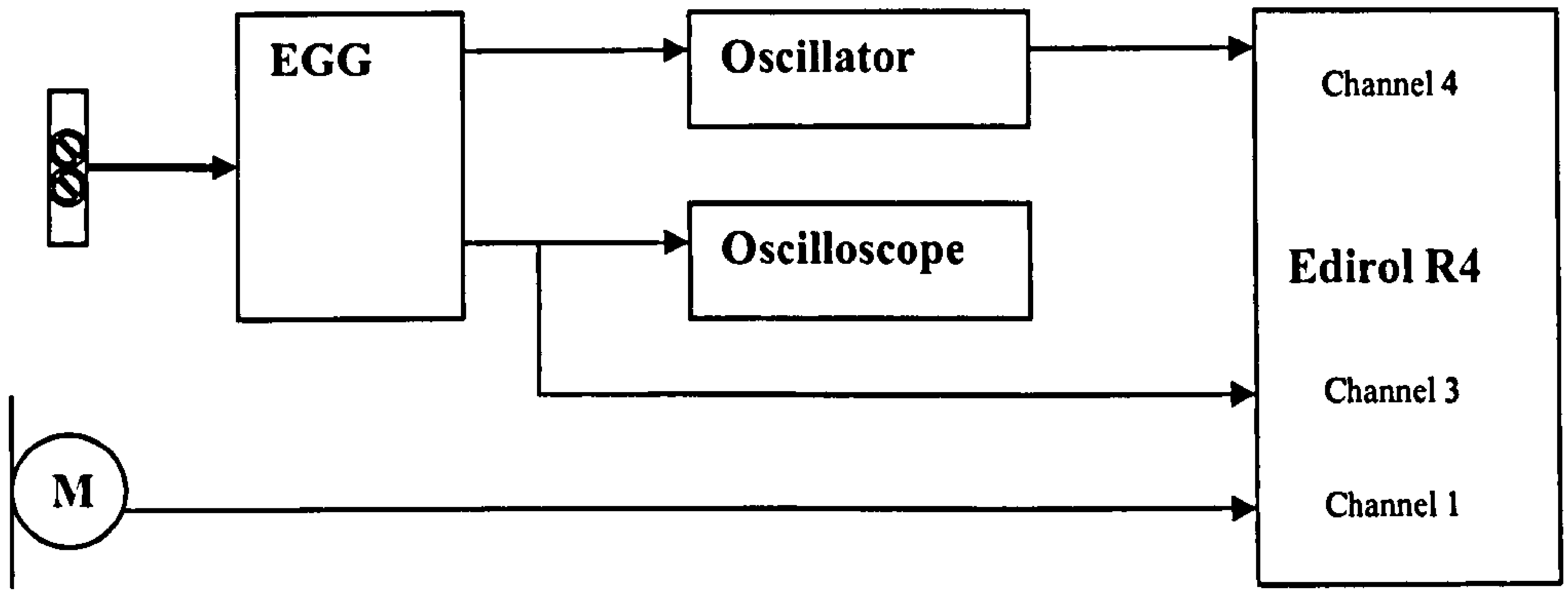
6	38	5 yrs Music College	Church Choir Music College choir	ROH chorus Glyndebourne Chorus	Anything except Bach or very early
7	54	Music College Opera Studio		ROH Chorus Buxton Opera chorus Scottich Opera chorus	Anything (avoids Verdi or Wagner)
8	29	Music College Opera Course	Girls' choir from 13 College choirs	ROH Chorus Glyndebourne chorus	All styles and eras 'Not so well suited to early music'
9	47	2yrs Copenhagen University RCM	Church choirs	ROH Chorus Glyndebourne Touring Opera - first career with early music ensembles	Anything Post-Mozart
10	37	4yrs Music College	Church choir	ROH Chorus	Mostly post-Mozart
11	54	Music college	School choirs Chamber choirs Church choirs	ROH Chorus	Anything
12	41	Music college	Choirs at college	ROH Chorus	Early to contemporary (not Wagner or Verdi)
13	58 Sop	GSMD	Choir at college	Mainly Oratorio	Mainly Early but to Puccini
14	37 M -S	Music School in Greece	Various choirs	Vocal ensembles in Europe Soloist, oratorio	Mainly Early Music but later opera as well (not Verdi or Wagner)
15	59 Sop	Oxford University	Choral Scholar	Early Music Ensembles Soloist	Renaissance and Baroque some Classical
16	27 Sop	Cambridge University 2yrs RAM	Choral Scholar	Early Music Ensembles	Mainly early music but no Wagner or Verdi

2.2.2 Dual-channel Electroglottograph (EGG)

During the experiment the singers wore an elastic neck collar to hold in place electroglotograph electrodes on either side of the thyroid cartilage. The electrodes were connected to a two-channel electroglottograph from which two outputs were recorded on an Edirol R4 4-channel hard disk recorder. To collect closed quotient data the glottal waveform was obtained using the average output of the electroglottograph.

To measure the larynx height of the subjects as they sang, the laryngeal tracking output from the electroglottograph was connected to a sinewave oscillator, the output of which was recorded on channel 3 of the Edirol. In order to calibrate this measurement, the procedure used by Elliot 1997 when using a multi-channel electroglottograph was adapted (Elliot *et al.*, 1997: 172). Before the electrodes were introduced, a strip of micro-porous tape was placed on the neck and a mark was made at the point of the centre of the thyroid cartilage with the larynx in rest position. The singer was then asked to sing three notes to the vowel [ɑ] these were A4 (440Hz), A5 (880Hz) and A3 (220Hz). The placement of the thyroid cartilage was marked for each note during phonation. When some of the subjects sang the upper note (A5), the larynx moved too high in the throat for the thyroid cartilage to be marked accurately. This exercise was then repeated with the electrodes placed at the marked resting position. If a good glottal signal (viewed on an oscilloscope) was not obtained by this placement, the electrodes were moved accordingly and their movement noted. The movements of the larynx were then obtained by viewing the frequency contour provided by the oscillator.

Figure 4. Box diagram of the recording set-up



The recordings took place at venues according to the suitability of the singers in rooms that were used for the practise of singing. All the subjects from the 'opera group' were recorded in the main rehearsal room at the Royal Opera House, Covent Garden. A CD quality recording (16 bit stereo at 44.1kHz sampling frequency) was made of each subject using a flat response omni-directional head-worn microphone and a 4-channel portable Edirol R4 Digital recorder. The microphone was positioned approximately 6cm from the subject's mouth at an angle to avoid popping due to plosives. Figure 4 shows the recording set-up represented as a block flow diagram.

2.2.3 Tasks

Once the recording was set up, the singer sustained a note while a sound pressure level was taken for purposes of calibration at the position of the microphone. The calibration measurements were then taken for larynx height investigation as the procedure is outlined above.

Wearing the electrodes, the first task assigned to the subjects was to read a passage of text aloud. Producing an 'ng' sound they were then asked to siren from the lowest part of their range to the top and then down again. A number of vocal exercises were then sung including two ascending two-octave Bb major scales, firstly to an [i] then to an [ɑ], followed by speaking and then singing the text 'bid, bead, bed, bard, bored' to each note of a D major arpeggio starting on D4 and ending on A5 (see appendix III). The final exercise was to sing an ascending F major scale of one octave as a coloratura scale.

To allow for consideration of stylistic changes all subjects were asked to sing a short extract from two songs, 'Ombra Mai Fu' from *Serse* by Handel (1685 – 1759) and 'O Mio Babbino Caro' from *Gianni Schicchi* by Puccini (1858 – 1924) which are shown in the appendix. The arias were taken from the Baroque and Romantic period respectively as these represent a period from within each specialism. This task is especially important to this experiment as specialist music performance employs specific performance practices depending on the compositional period, place of composition, nationality of the composer, the originally intended performers, venue and audience as well as modern expectations of style.

The songs that were chosen are currently popular in the musical canon and have been for some time. This was to avoid making subjects spend time learning new music or having to sight-read. Both songs chosen are idiomatic of their period; written in Italian (and to be sung in Italian by the subjects); have a range of a compound fourth; and are of a similar tempo. Whilst they have the same range, the tessitura of 'O Mio Babbino Caro' (Eb4 – Ab5) rests a minor 3rd higher than 'Ombra Mai Fu' (C4 – F5). All subjects were provided with the entire score for each aria so they could interpret the pieces as whole songs although they were only asked sing a short extract from each. They were informed of the composer, and the date of composition. Both songs were sung at modern pitch (A4=440Hz) in the original keys. The subjects sang the song related to their specialty first, all singers in the early music group first performing the Handel extract and the Puccini being performed first by singers in the opera group.

The subjects were asked to sing each extract in a style they considered appropriate in light of their knowledge of the music and were given a few minutes to look at the music and practice if they wished. This was to allow for the identification of any changes in technique caused by stylistic motives, and provide insight into the subjects' perceptions of differing styles and techniques across the periods.

2.3 Analysis Techniques

2.3.1 Speech Studio

The software 'Speech Studio' from Laryngograph Ltd. was used to extract quantitative closed quotient data from the electroglottograph waveform. This software estimates closed phase at 3:7 of the peak to peak amplitude of each vocal fold cycle. The waveform was inverted in 'Audacity' before it was analysed in speech studio to invert the electroglottograph waveform due to the necessary use of an electroglottograph rather than an electrolaryngograph to allow measurements of larynx height using split channel electrodes.

2.3.2 Inverse Filtering

Inverse filtering is another method that can be used to obtain closed quotient data and involves filtering the sound signal to remove the effects of the sound modifiers. To do this a filter that has a response curve exactly inverse to the sound modifiers needs to be used (Howard, 1998:373 - 375). Howard highlights the issue that in order for inverse filtering to be successful there must be an accurate presumed knowledge of either the formant frequencies or the nature of the excitation waveform itself, which makes inverse filtering an inappropriate method of analysis for this study. Whilst in the analysis of speech, the formants can be estimated with a high degree of accuracy, the possibilities of formant tuning being used by female singers at high pitches makes the identification of the formants very difficult and any results of inverse filtering are therefore likely to be unreliable.

2.3.3 Spectrographic Analysis (PRAAT)

Spectrographic analysis was carried out using the freeware voice analysis software PRAAT. This program allows the user to change many of the parameters of analysis including the time analysis window and frequency bandwidth. It also provides formant measurement, although this function can be inaccurate and so was not relied upon.

Spectrograms allow analysis of changes in acoustic energy over time which is particularly useful when considering timbre and the impact of consonant production on the spectrum.

2.3.4 Long Term Average Spectra (LTAS)

Long term average spectra (LTAS) analyses were performed on a number of the tasks to assess in particular resonance and singer's formant cluster characteristics as aspects of voice quality. LTAS plots provide a representation of the spectral energy in a sound sample averaged over time (Howard, 2006: 218) from which the spectral slope can be calculated and peaks in the spectral envelope can be observed and quantified (Sundberg, 2001; Kenny and Mitchell, 2004; Watts el al., 2005). The averaging process reduces the effects of short term variations in spectra caused by the production of different vowels and fundamental frequencies, the effects of which can be seen through spectrographic analysis. Sundberg encourages use of LTAS when analysing soprano voices as it is less dependent on fundamental frequency than other techniques which concentrate on specific vowels, and suggests a 20 – 30 second analysis to extract a 'stable and representative curve shape' (Sundberg, 2001: 181). A problem with using LTAS analysis to quantify aspects of voice is the effect of SPL on spectral slope. An increase in overall SPL yields a greater increase in energy in the frequencies above 2kHz in the spectrum: the greater the SPL the less steep the spectral slope (Bloothooft and Plomp, 1986; Sundberg, 2001). This is taken into consideration in the results.

2.3.5 Singing Power Ratio (SPR) and Energy Ratio (EnR)

Singing power ratio (SPR), first presented and defined by Omori *et al.* (1996) as 'the ratio between the highest intensity peak between 2 and 4 kHz and the highest intensity peak between 0 and 2kHz.' (Omori *et al.*, 2000: 490), has become a common quantitative measure of the resonant quality of the singing voice (Lundy *et al.*, 2000; Barnes *et al.*, 2004; Watts *et al.*, 2005; Kenny and Mitchell, 2006; Kenny and Mitchell, 2007). SPR within these studies was determined by calculating the difference between the highest energy peak in the 0 – 2 kHz frequency band and the highest energy peak in the 2kHz – 4kHz frequency band in the spectrum in dB SPL. SPR was therefore calculated from the LTAS plots to assess the significance of the peak in the 2kHz – 4kHz region of the spectrum.

Singing ratio (EnR) measures the difference between the overall energy in the 0 – 2kHz frequency region and the 2kHz – 4kHz energy region using the average energy of the two frequency bands (Thorpe *et al.*, 2001). This quantitative measure is often used in conjunction with SPR to obtain a representation of the significance of the overall energy in the spectrum compared to the two peaks identified by the SPR (Barnes *et al.*, 2004; Kenny and Mitchell, 2004; Kenny and Mitchell, 2007). To consider overall spectral energy this comparison was applied to the present study and EnR is calculated for all LTAS results for which SPR is obtained.

2.4 Results

The following section presents an overview of the data collected in the study for all of the factors assessed with any group effects identified. The subsequent chapters provide an in depth analysis and discussion of the relevant results with a commentary on the significance of specific findings within the present study. Subject 2 was ill with a cold on the day of the experiment, the possible effect on the findings for this singer is considered and for tasks in which she felt her illness affected her vocal production, the data is discarded.

2.4.1 Closed Quotient

A good electroglottograph signal could not be obtained for subjects 2 or subject 9, and so their data was discarded for this part of the study. This is most likely due to the incorrect placing of the electrodes on the neck particularly as the tendency for less prominent larynxes in females makes the successful positioning of the electrodes more difficult (Colton, 1990). Figure 5 shows the Lx waveform of subject 2 singing the two octave scale as viewed in speech studio, and illustrates the clipping of the signal due to large larynx movements and / or electrodes that are not making reliable skin contact which makes tracking of closed quotient unreliable.

For other subjects, certain exercises obtained a stronger electroglottograph signal than others, and so the reliability of the data was assessed for each exercise and subject. It was common in most subjects for the signal to weaken or disappear at the very highest pitches in their range, particularly A5 and Bb5. This was probably due to the larynx rising with fundamental frequency as supported by the results of the larynx height measurement which suggest considerable rising in larynx position at high fundamental frequencies. A raised larynx means that the electrodes are no longer on the thyroid cartilage and the electroglottograph signal will be greatly reduced in amplitude.

Figure 5 Lx signal of Subject 2 singing two octave ascending scale of Bb major analysed by speech studio by Laryngograph Ltd. Lower panel: Purple line represents the tracking of Qx and green line the tracking of the fundamental frequency. Middle panel: Lx Waveform

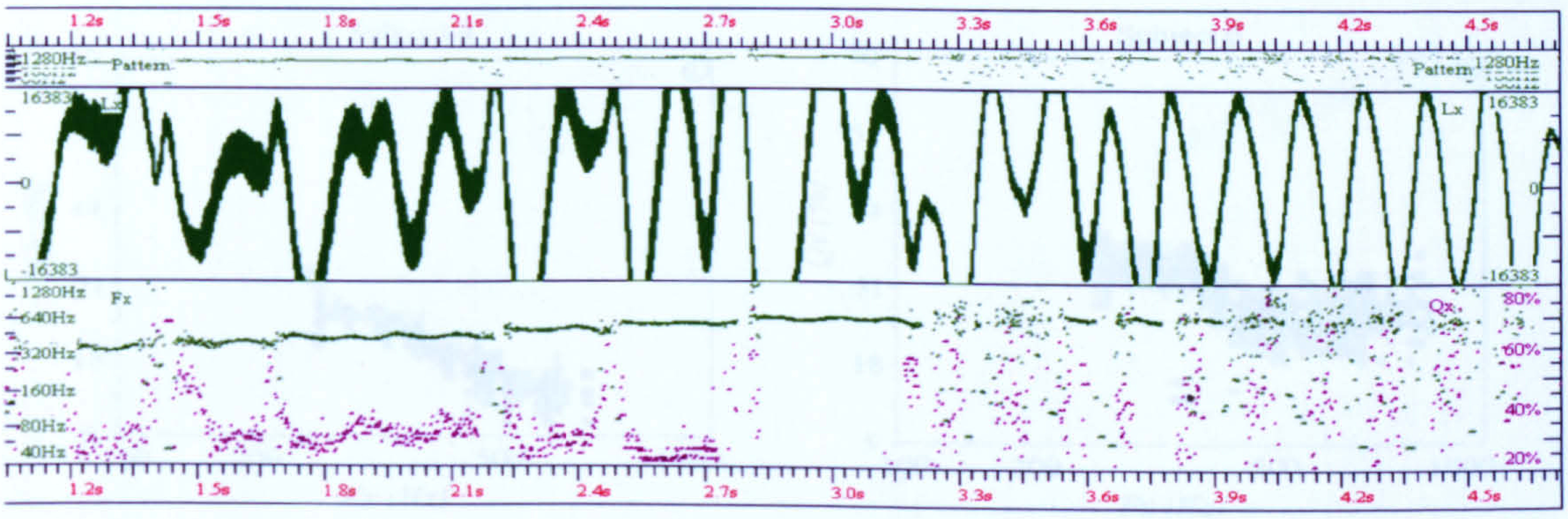
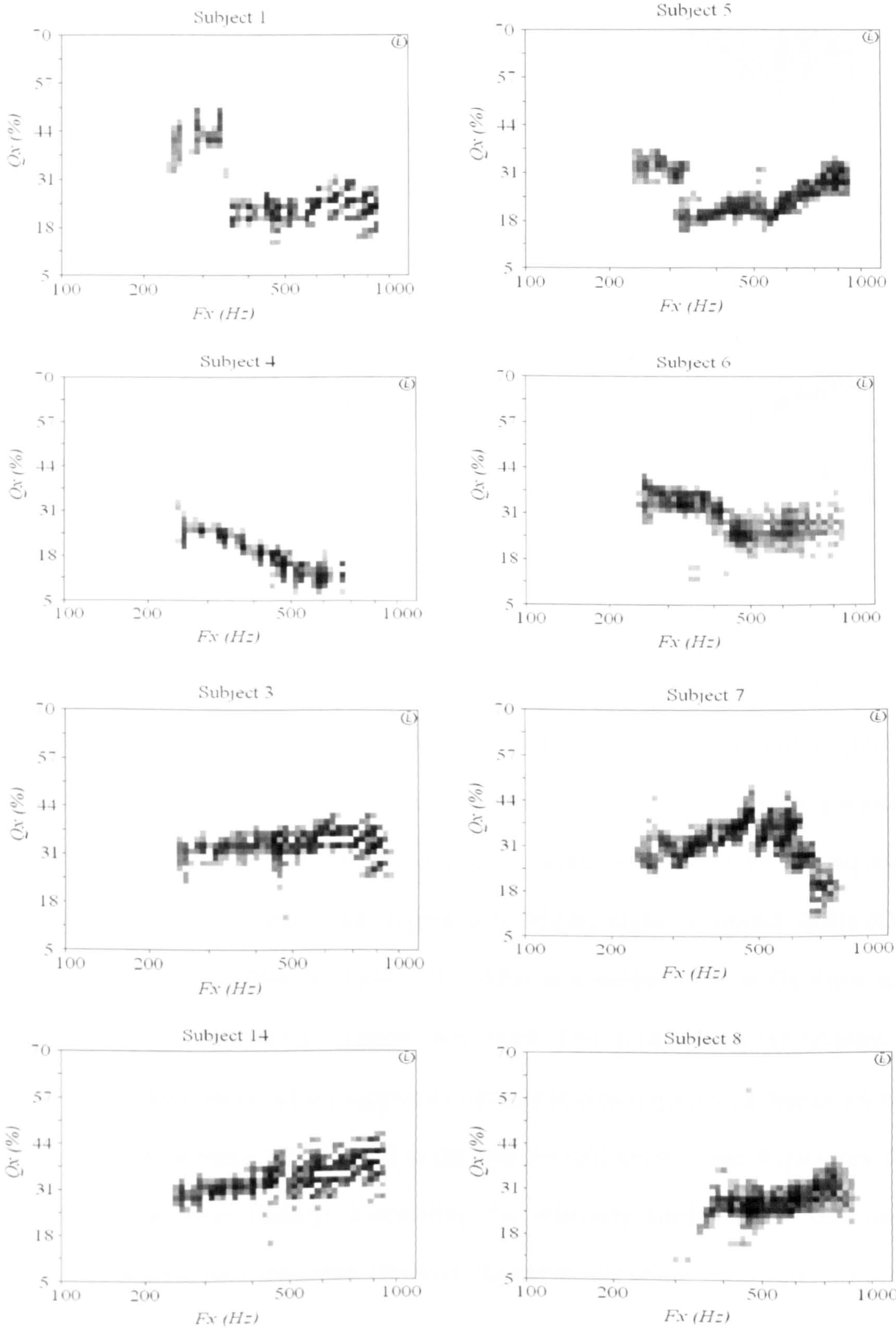
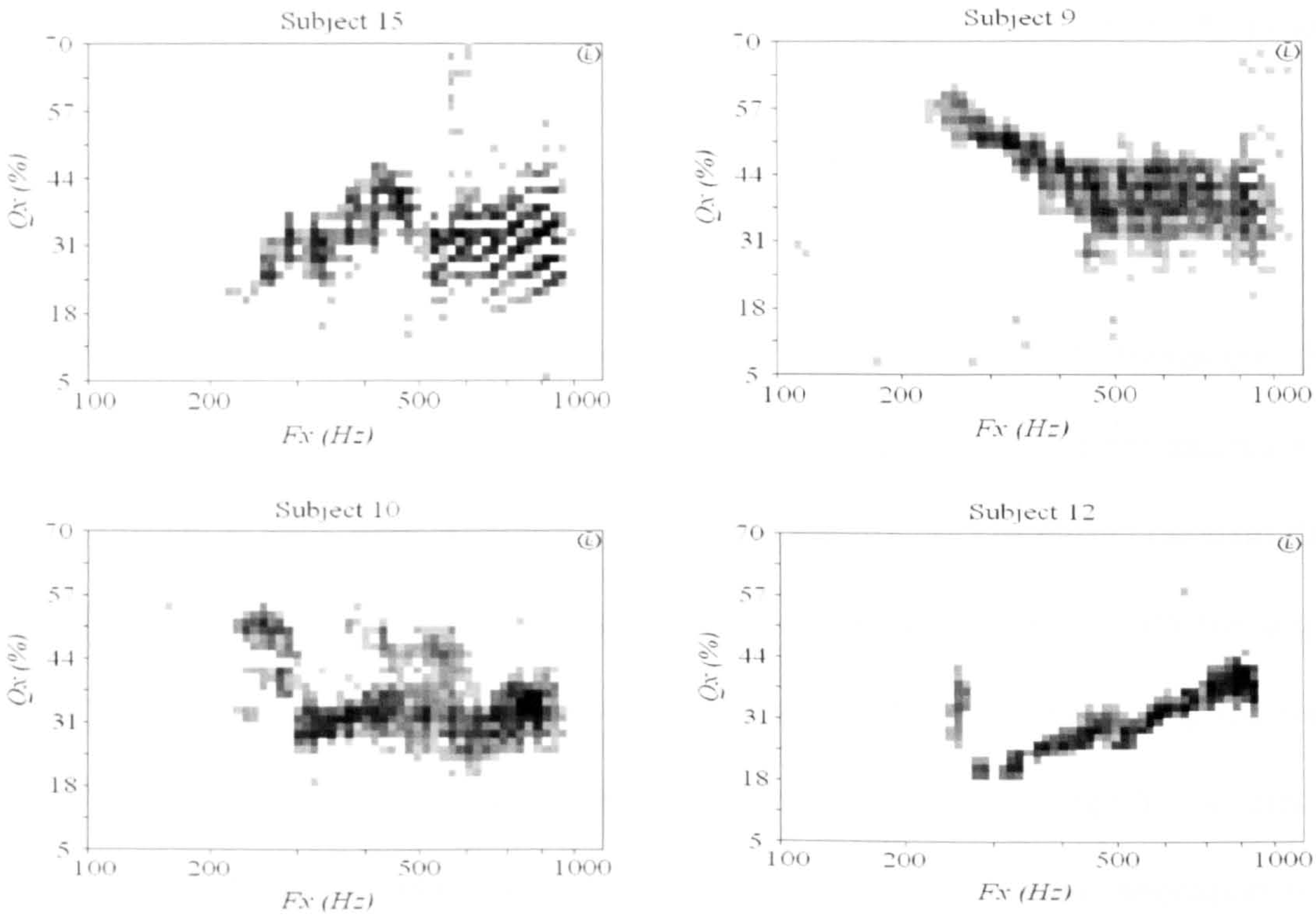


Figure 6 shows closed quotient data from the 12 subjects that provided a good signal when they sang the ascending Bb major scale of two octaves to the vowel [i]. The data is presented as Qx plots which were produced in speech studio. Each vocal fold cycle is plotted as a dot on the graph area with the percentage closed quotient on the y–axis against fundamental frequency (f0) on the x–axis. The considerable number of vocal fold cycles plotted produces blocks of data allowing any patterns in closed quotient, and particularly relationships between closed quotient and fundamental frequency to be observed. As chapter 3 explains in more detail, no significant link between the singers' production of closed quotient and their performance specialism is identified, however, there are some interesting differences between the subjects as a whole.

Figure 6 Qx plots of 4 singers from the early music group (first 5 on the left column) and 6 Singers from the opera group (right column and final row) singing ascending two octave scale

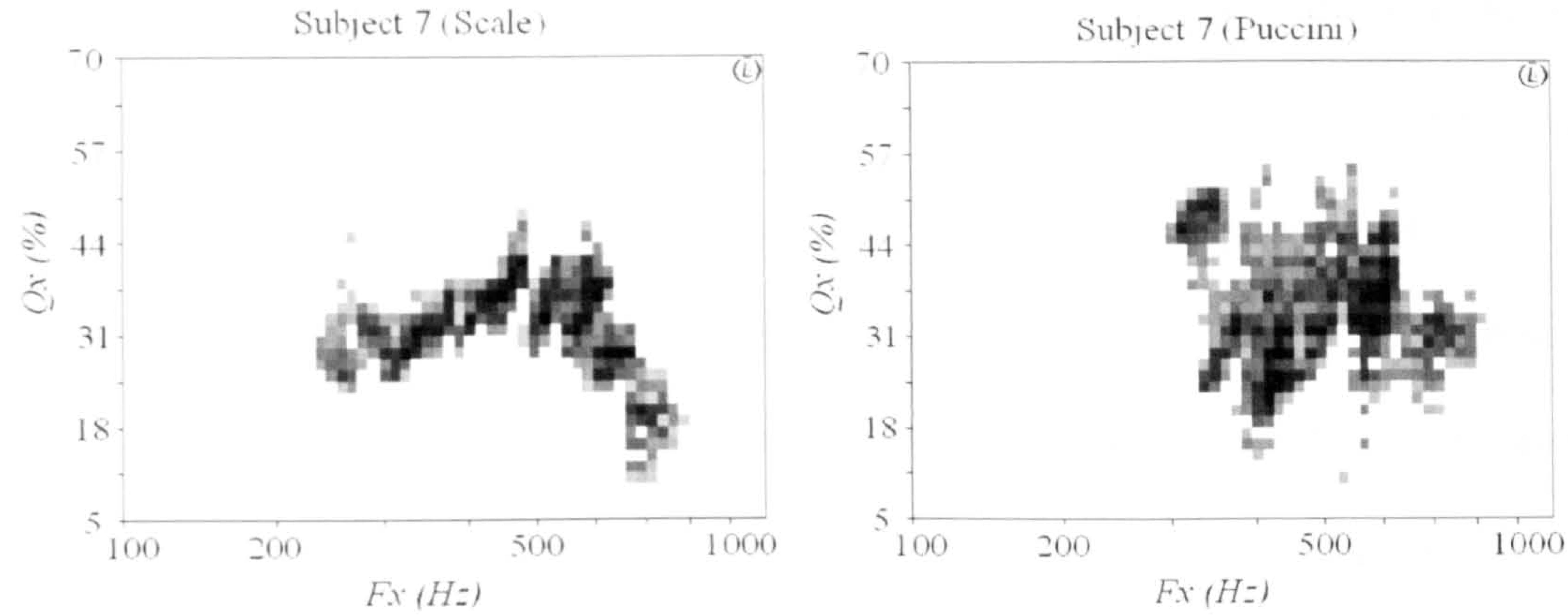




Subjects 1, 5 and 12 present most notably with relatively high Qx at low fundamental frequencies in their range, with a sudden drop in Qx values when they reach a specific pitch at around 300Hz (D4). This is consistent with research that suggests a register ‘break’ in this frequency region in females (See, for example Miller, 2000: 47), although other experiments found the ‘break’ region to be slightly higher at around 400Hz (G4) (Sundberg, 1987: 51; Howard, 1994: 170). After this sudden drop in Qx there is a tendency for values to increase steadily with pitch. This trend reflects the findings of Howard discussed above, which suggest an increase in closed quotient at higher pitches in females. The absence of this trend in the data for subjects 4, 7 and 9 questions the significance of these findings considering the relatively small sample size once inaccurate data has been discarded. However, the movement of the larynx resulting in an insecure signal could account for the decrease in Qx at higher frequencies seen in those two subjects.

The absence of any data at frequencies above 720Hz for subject 4 strengthens this theory as it suggests the larynx height increased gradually as the singer ascended in pitch until vocal folds were no longer between the electrodes. The closed quotient data for all the tasks sung by subject 4 was found to be very low, often with the upper fundamental frequencies missing. However, as figure 7 shows, when singing the song extracts subject 7 did not display a significant drop in Qx values at high frequencies as found in the scale, this could suggest the employment of a different phonation type between the tasks, with the use of a phonation type indicative of glottal leakage in the scale task implied by the lower Qx values (Herbst and Ternström, 2006). This highlights the relevance of changing phonation type on the interpretation of the electroglottograph signal. The research that was outlined above suggested that in 'falsetto' type phonation the electroglottograph may not register vocal fold closure due to the characteristic abduction of this phonation type (Herbst and Ternström, 2006). This could therefore account for the significantly lower Qx values found when singing a scale compared to speaking, and could also be a reason for the lowering of the Qx values at increasing pitches for certain subjects. Without endoscopic images providing specific information on vocal fold closure it is difficult to infer precise laryngeal behaviour from the electroglottograph signal at high fundamental frequencies.

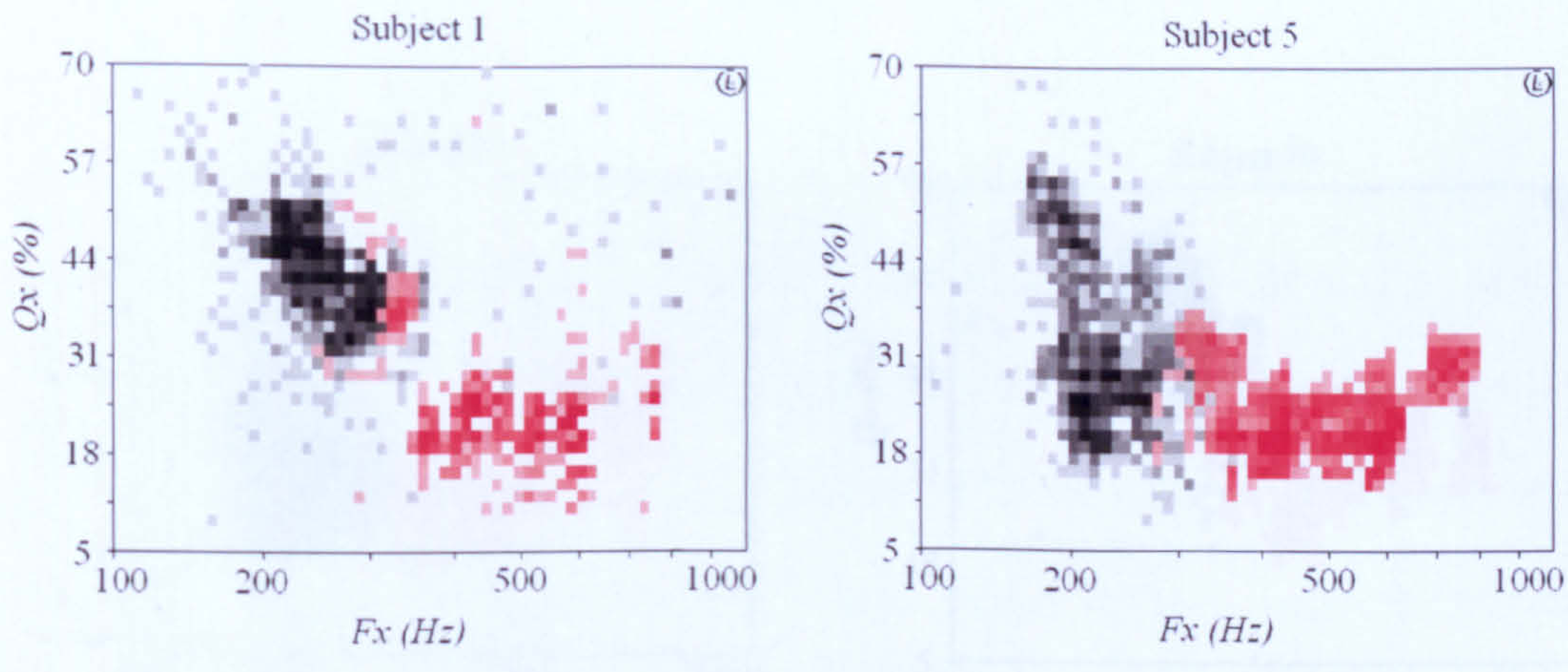
Figure 7 Showing the Qx values for subject 7 singing a two octave Bb major ascending scale (Left) and an extract from Puccini's 'O Mio Babbino Caro' (Right)

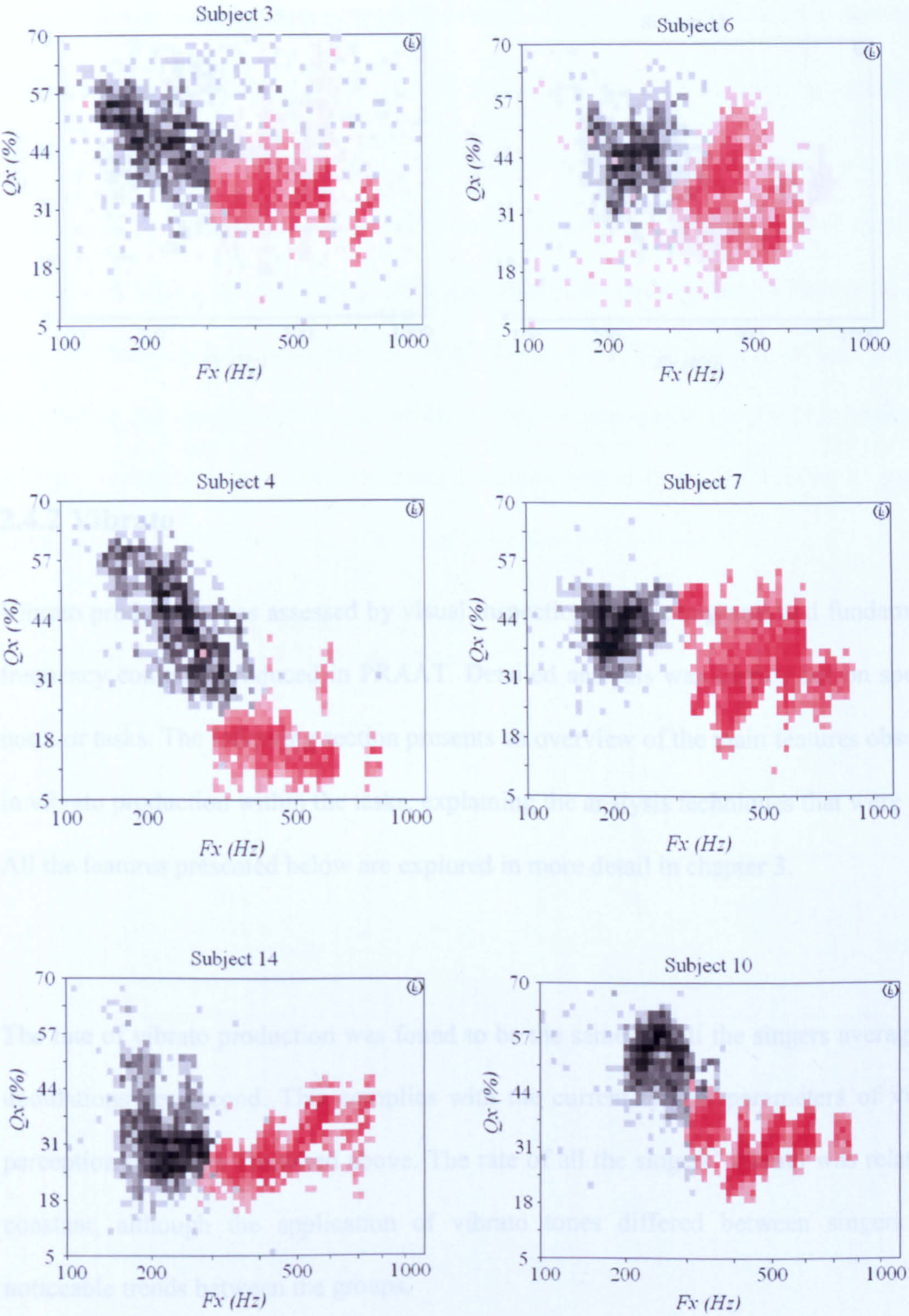


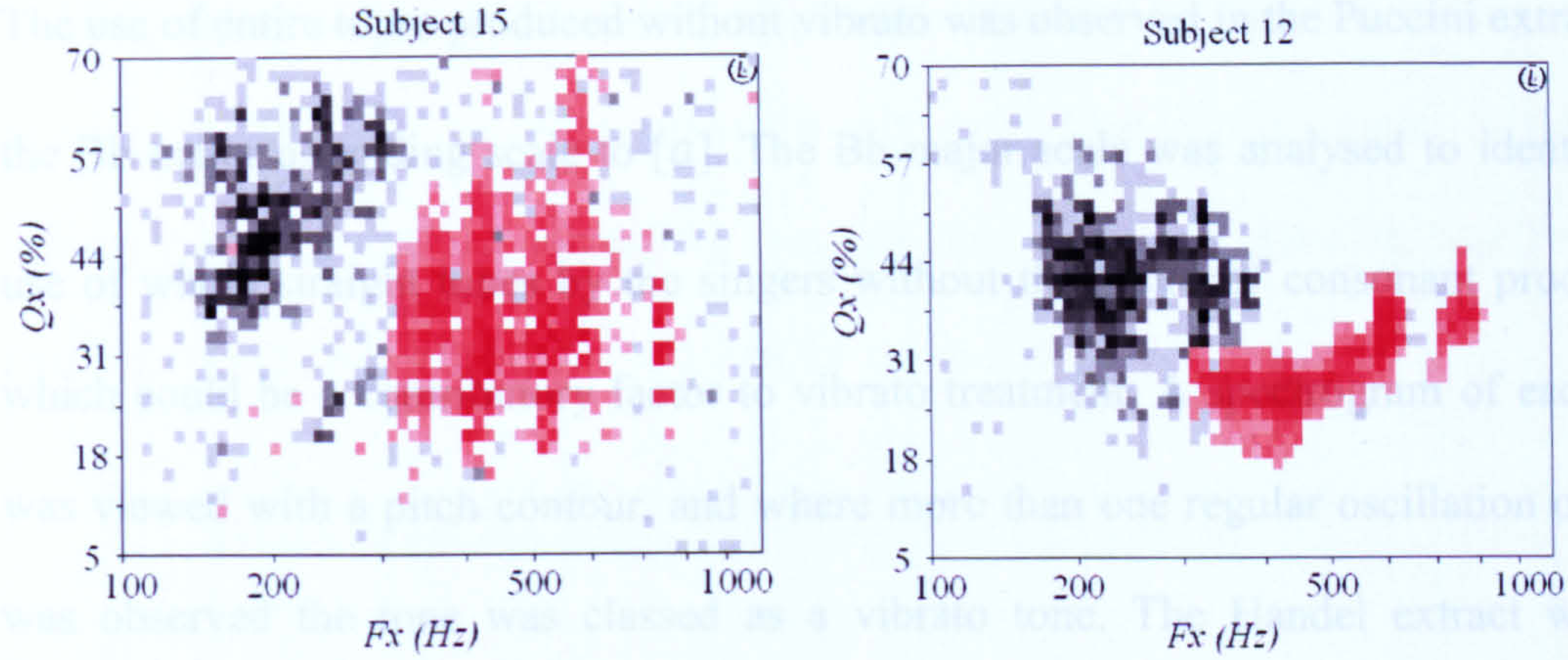
Subjects 5 and 12, both from the opera group, display another change in Qx above the previously mentioned drop at a possible change in phonation registers. After the initial drop at around 300Hz, the Qx values of all the subjects (apart from 4 and 7) rise gradually, though to varying steepness, however, subjects 5 and 12 present with another less significant drop in Qx at around 600Hz before the values continue to rise. This change could again be characteristic of a change in the mode of phonation as this is another region in which register change has been identified in female voices (Sundberg, 1987: 51). Although, recent research suggests that perceived 'breaks' in female voices in this frequency region are not attributable to significant changes in phonation but are the results of F0-H1 tuning (Miller, 2000: 52). Subject 15 seems to display a similar attribute of dropping Qx values at around 600Hz although this subject's recording did not provide a consistently reliable signal, making the implied change less dependable.

Figure 8 shows both the spoken sample and the Puccini extract overlaid on Qx plots for the same subjects1, 3 and 14 from the early music group and 5, 7 and 12 from the opera group. This comparison is particularly important considering the relationship between spoken and sung Qx values in trained singers which was discussed above (Howard, 1990). All subjects produce lower Qx values overall when singing than when speaking. Although this appears to contradict the expectation of trained voices, previous research in this area has used male voices (Howard, 1990) who may use different phonatory strategies to trained females, especially considering the different compass of fundamental frequencies utilised by the two sexes. Possible explanations for these results are considered in chapter 3 alongside their significance as a representation of the techniques being employed by the singers in the two groups.

Figure 8 Graphs showing Subject 1, 3, 4, 14 and 15 from the Early Music Group (left) and Subject 5, 6, 7, 10 and 12 from the Opera Group (Right) Qx for spoken text (Black) and Puccini (red)




Subject 3
Subject 6
Subject 4
Subject 7
Subject 14
Subject 10
Qx (%)
Fx (Hz)
70
57
44
31
18
5
100
200
500
1000



2.4.2 Vibrato

Vibrato production was assessed by visual inspection of spectrograms and fundamental frequency contours produced in PRAAT. Detailed analysis was carried out on specific notes or tasks. The following section presents an overview of the main features observed in vibrato production within the tasks, explaining the analysis techniques that were used. All the features presented below are explored in more detail in chapter 3.

The rate of vibrato production was found to be the same for all the singers averaging 6 undulations per second. This complies with the current typical parameters of vibrato perception that were discussed above. The rate of all the singers' vibrato was relatively constant, although the application of vibrato tones differed between singers with noticeable trends between the groups.

The use of entire tones produced without vibrato was observed in the Puccini extract and the Bb major ascending scale to [ɑ]. The Bb major scale was analysed to identify the use of whole straight tones by the singers without the factor of consonant production which could be a contributory factor to vibrato treatment. A spectrogram of each tone was viewed with a pitch contour, and where more than one regular oscillation of pitch was observed the tone was classed as a vibrato tone. The Handel extract was not included in this comparison due to the prevalence of semiquavers in the piece making it difficult to determine the vibrato content throughout the extract. The number of straight tones produced by all the subjects in these tasks is shown in table 2.

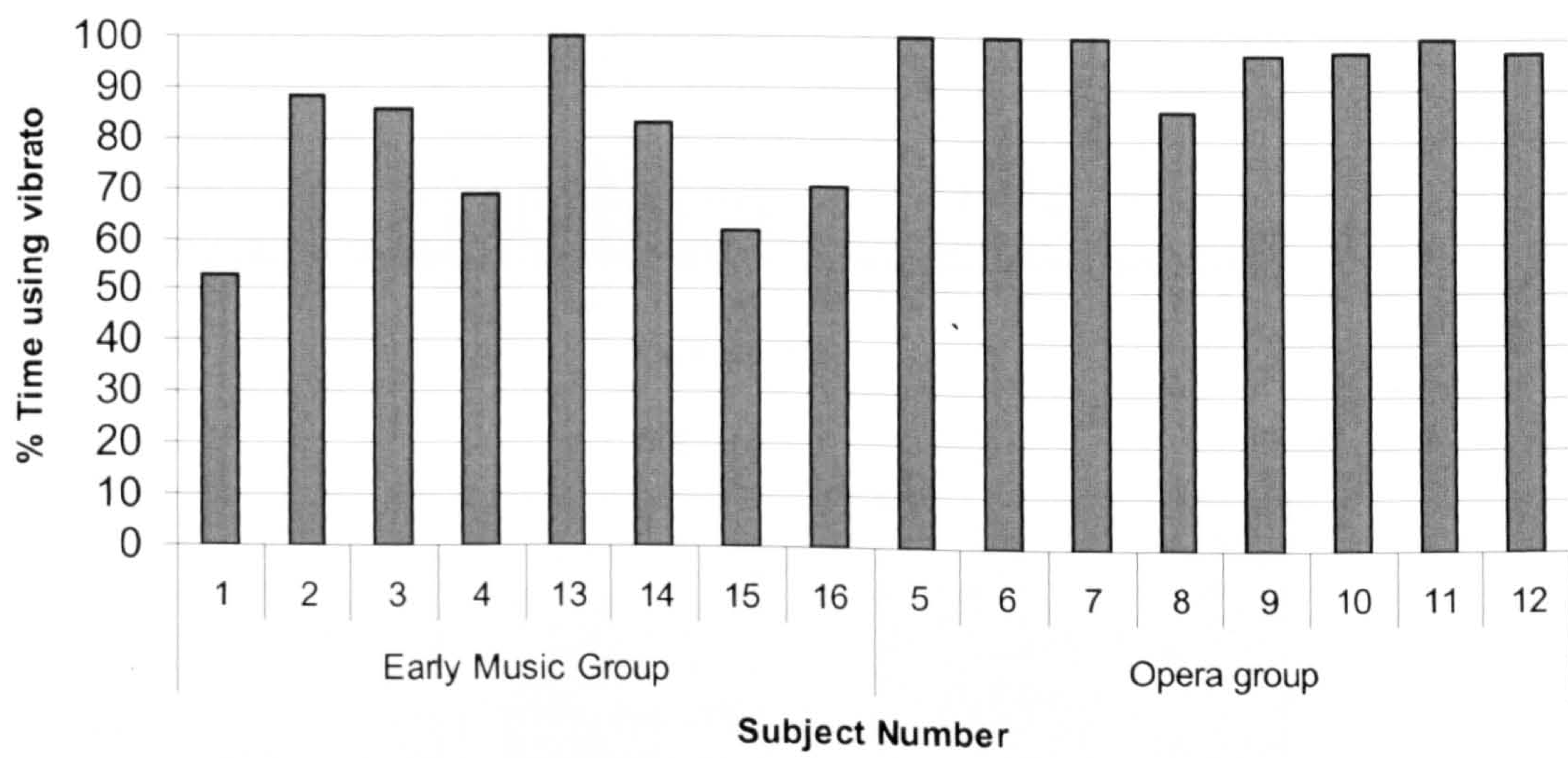
Table 2. Number of tones produced without vibrato (straight tones) by all singers in the Puccini extract (left) and the two octave ascending scale (right)

Puccini		Subject	Straight
	Early Music Singers	1	7
		2	0
		3	2
		4	5
		13	0
		14	0
		15	8
		16	4
	Opera Group	5	1
		6	0
		7	0
		8	4
		9	0
		10	1
		11	0
		12	0

Scale		Subject	Straight
	Early Music Singers	1	6
		2	0
		3	2
		4	4
		13	0
		14	0
		15	1
		16	1
	Opera Group	5	0
		6	0
		7	0
		8	0
		9	0
		10	0
		11	0
		12	0

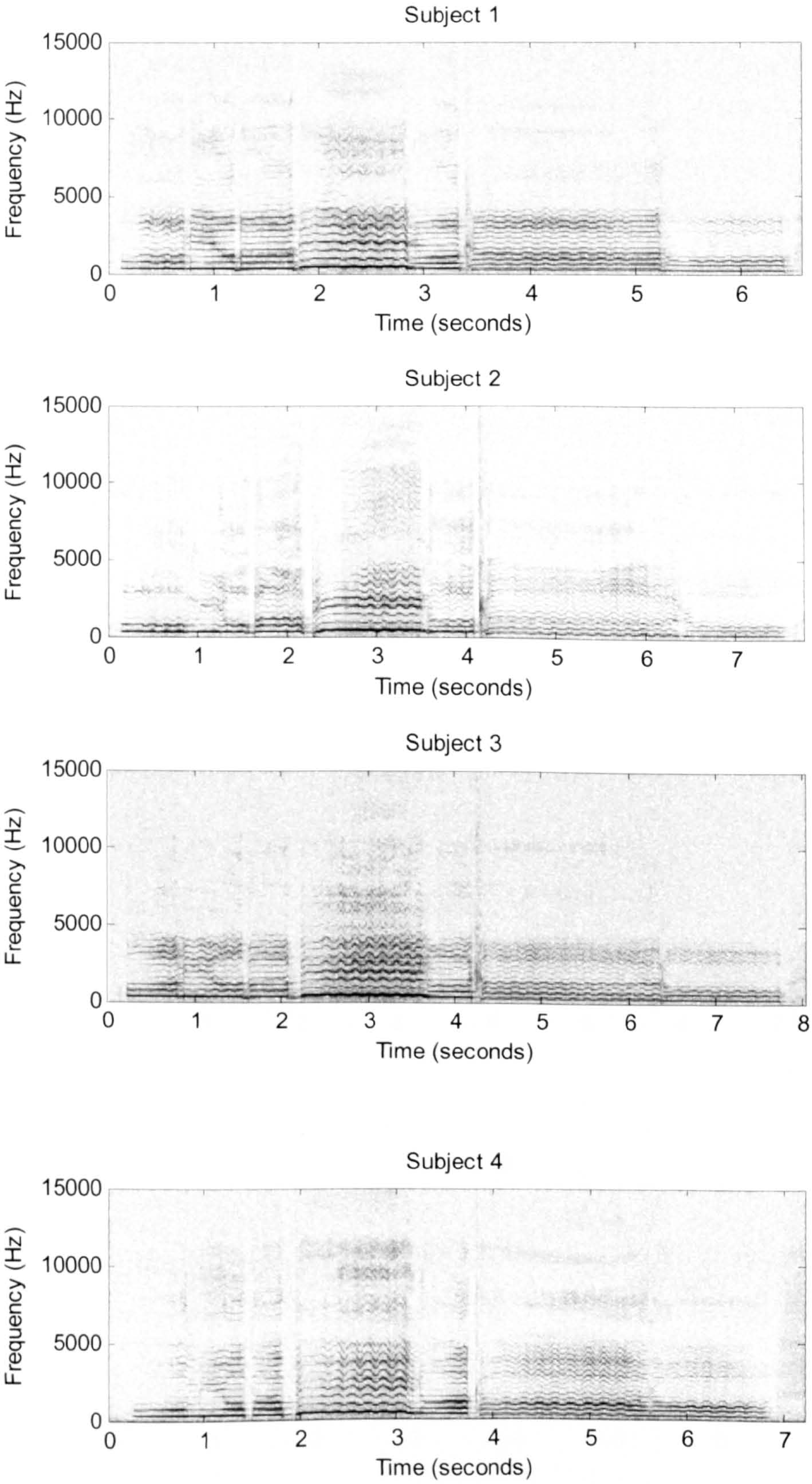
Figure 9 shows the percentage usage of vibrato throughout the ascending scale considering both vibrato and straight tones. This was calculated by measuring the percentage time that vibrato was produced in each note of the scale from a spectrographic image of each note. The overall vibrato usage throughout the scale was then calculated from the information for each note. The use of vibrato in the tasks reflects the results of the number of straight tones produced, showing that the early music group use less vibrato overall than the opera group.

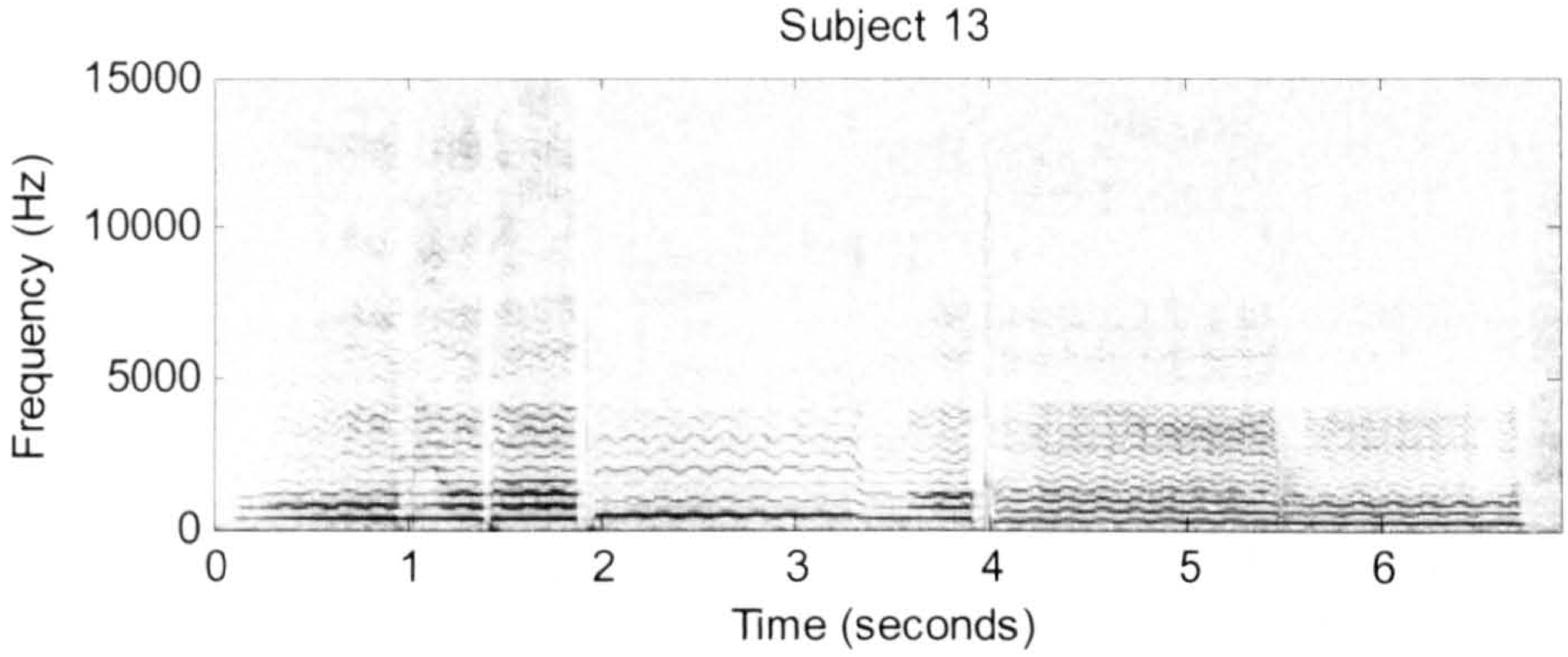
Figure 9 Graph showing vibrato usage (% time) by all subjects in a two octave ascending scale

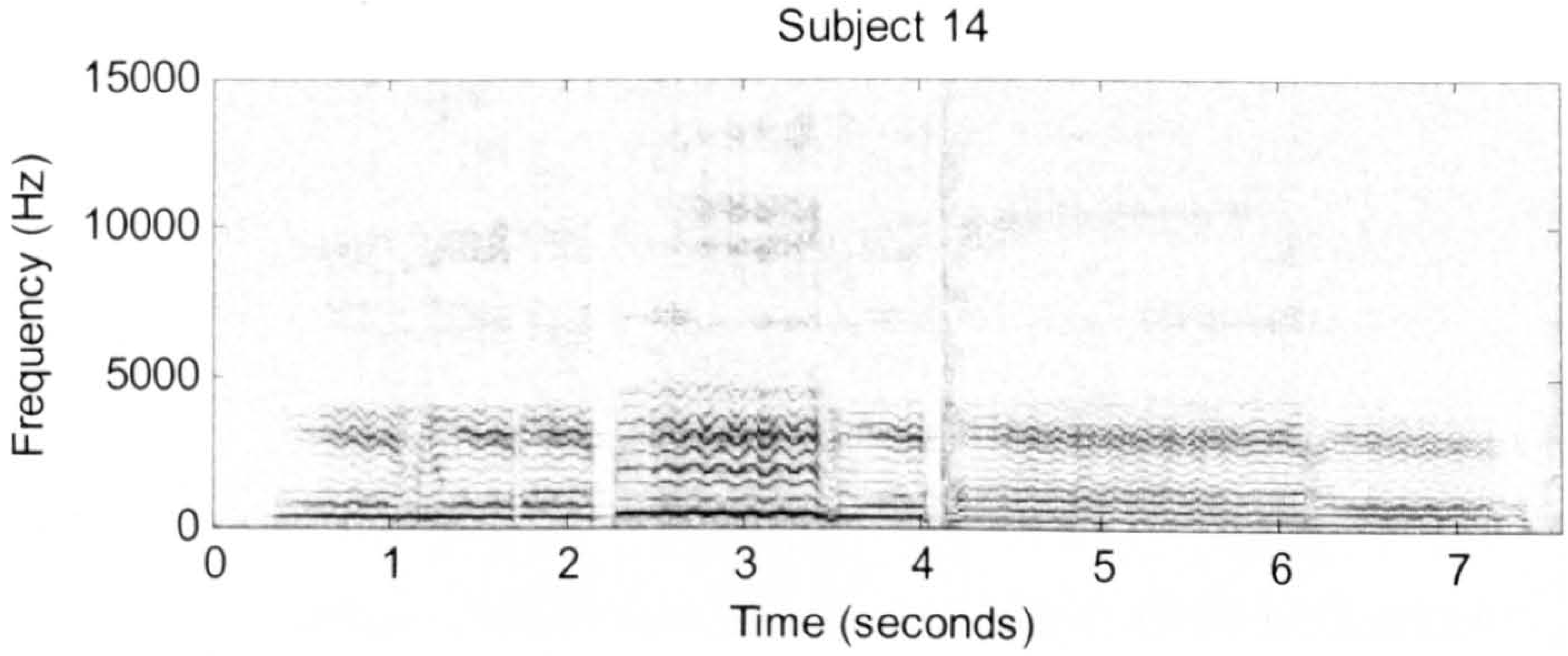


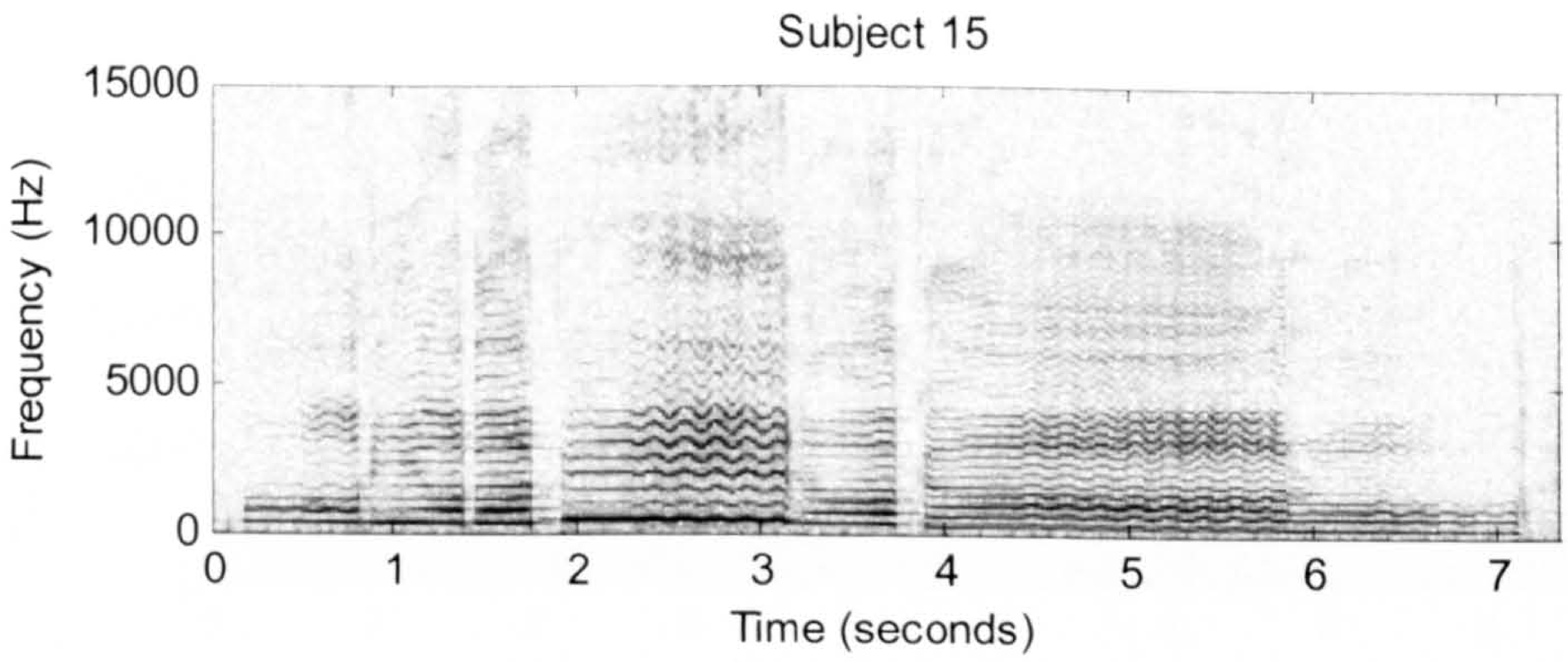
Spectrograms from all subjects singing the first phrase of the Puccini extract are shown in figure10 and illustrate that there is generally more consistent employment of vibrato throughout notes by the singers in the opera group than the singers in the early music group. The delay in vibrato onset which is characteristic of the singers in the early music group can clearly be observed in this example, particularly by subject 1.

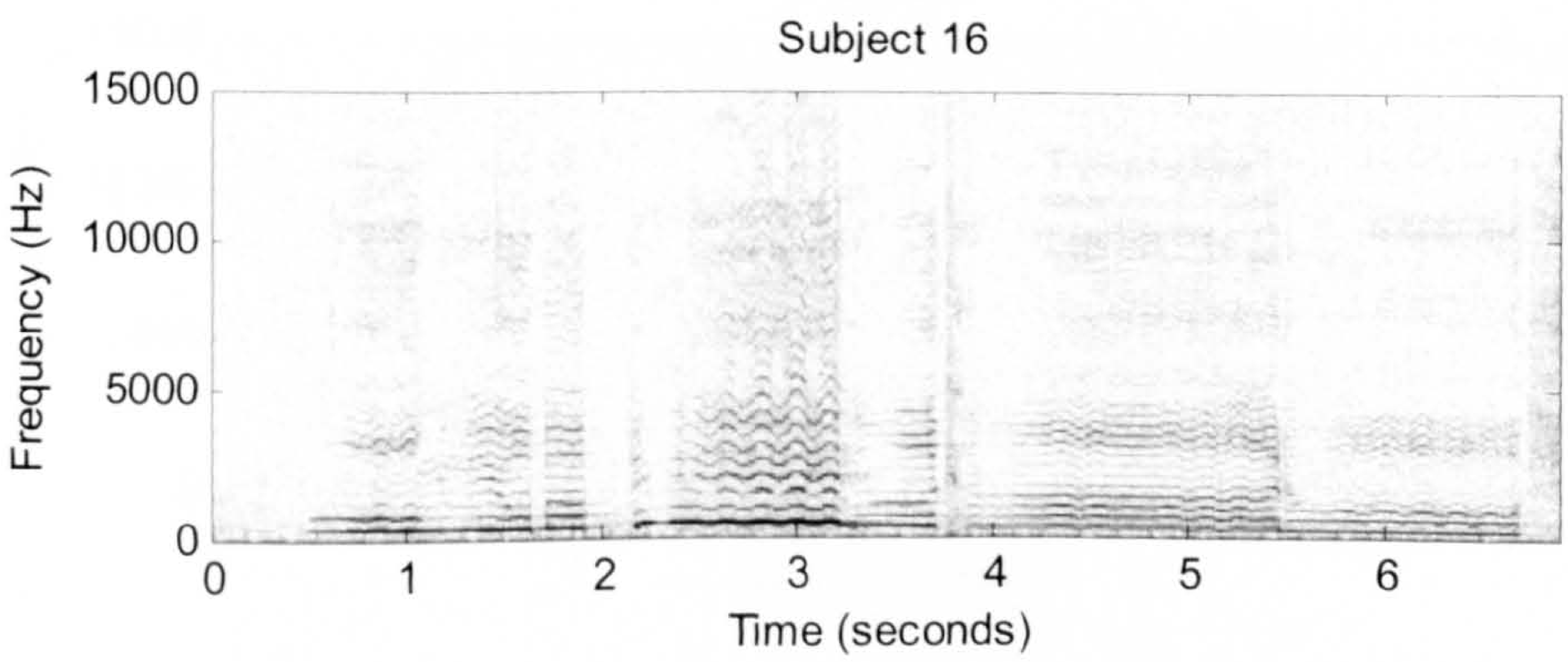
Figure 10 Spectrograms of the first phrase of the Puccini extract sung by all subjects

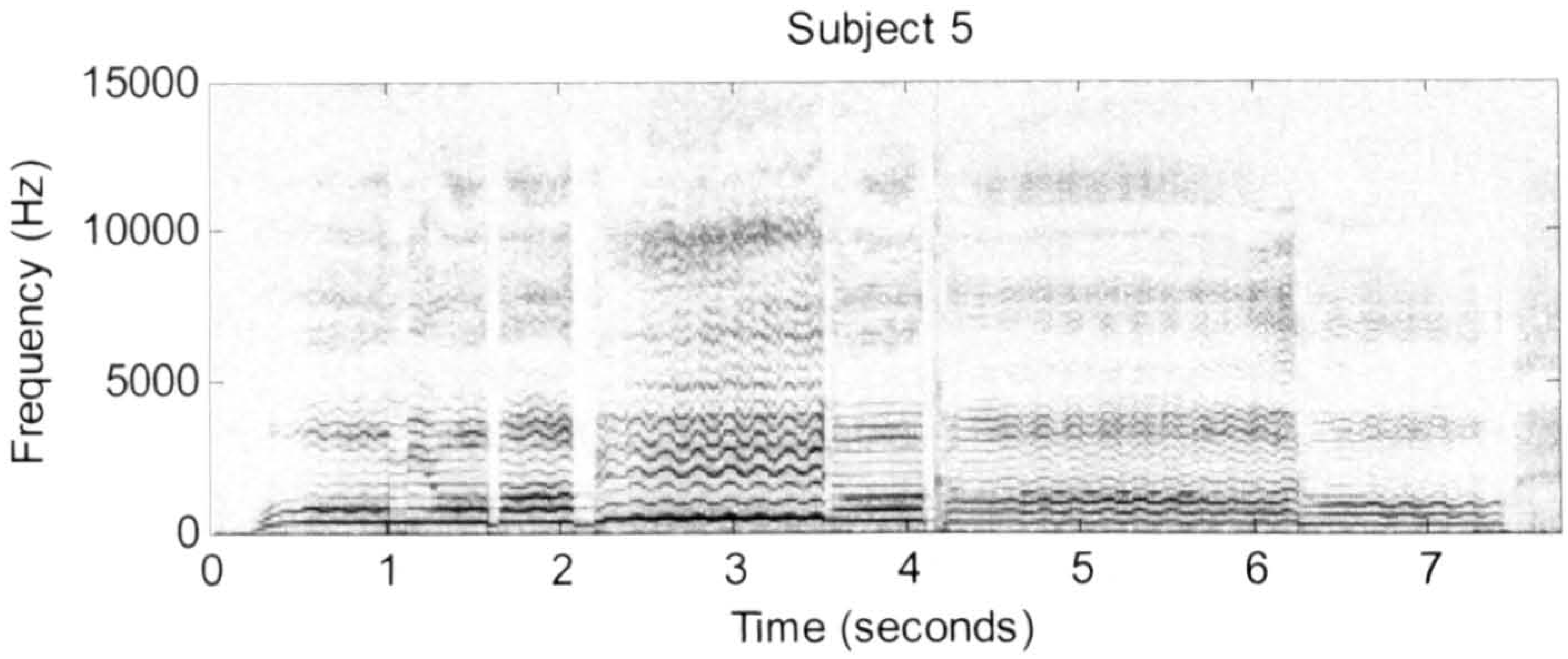


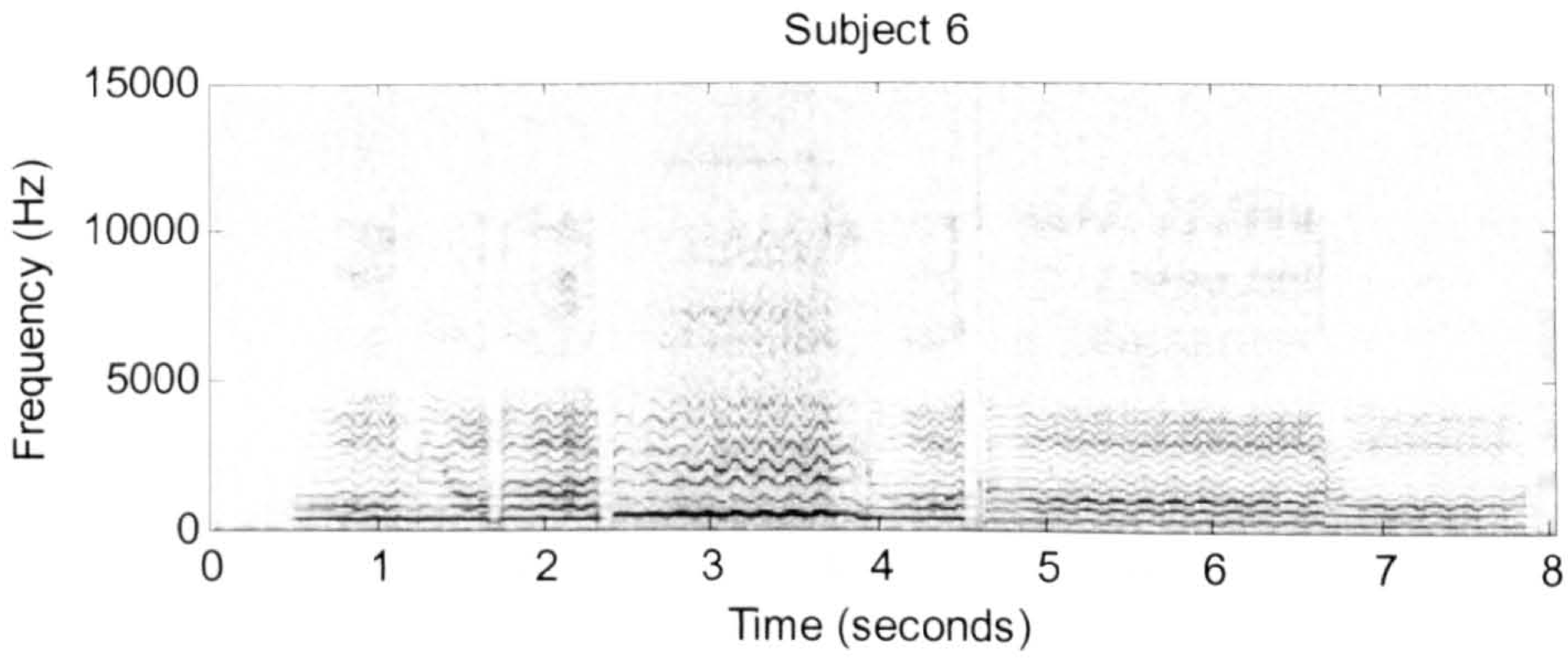

Subject 13
15000
10000
5000
0
Frequency (Hz)
0 1 2 3 4 5 6
Time (seconds)

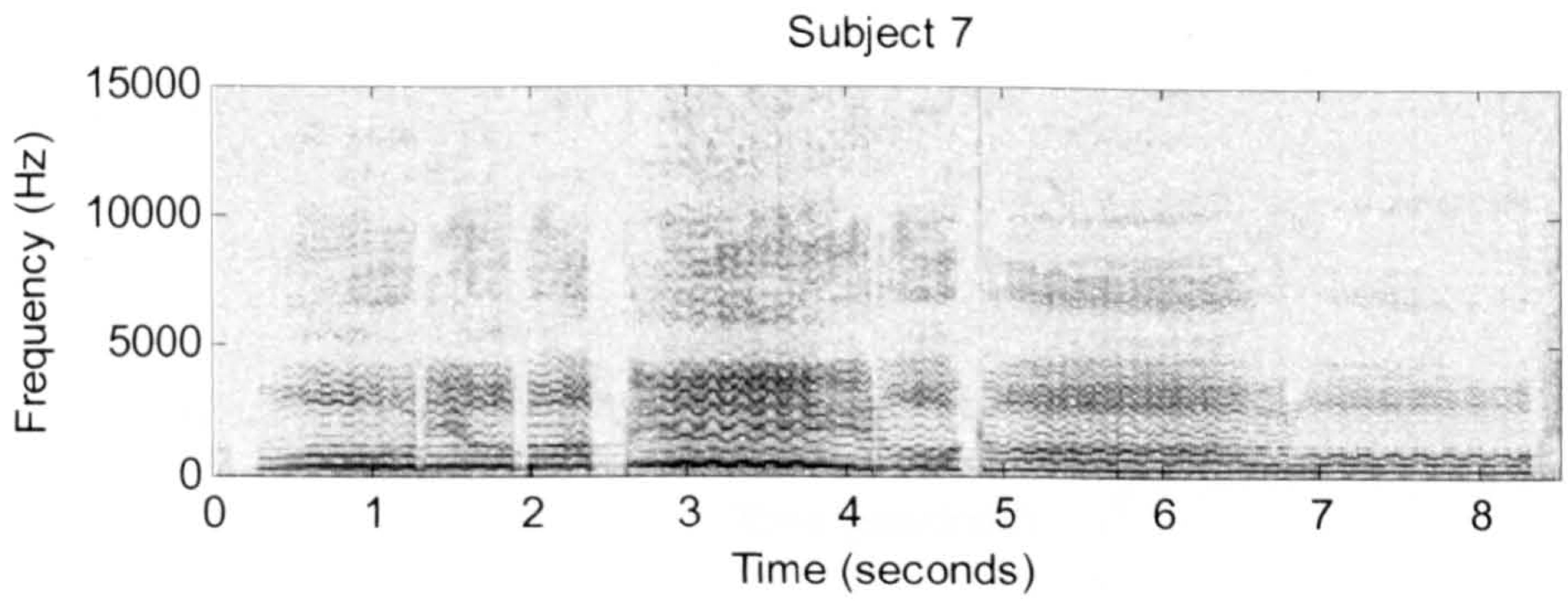

Subject 14
15000
10000
5000
0
Frequency (Hz)
0 1 2 3 4 5 6 7
Time (seconds)

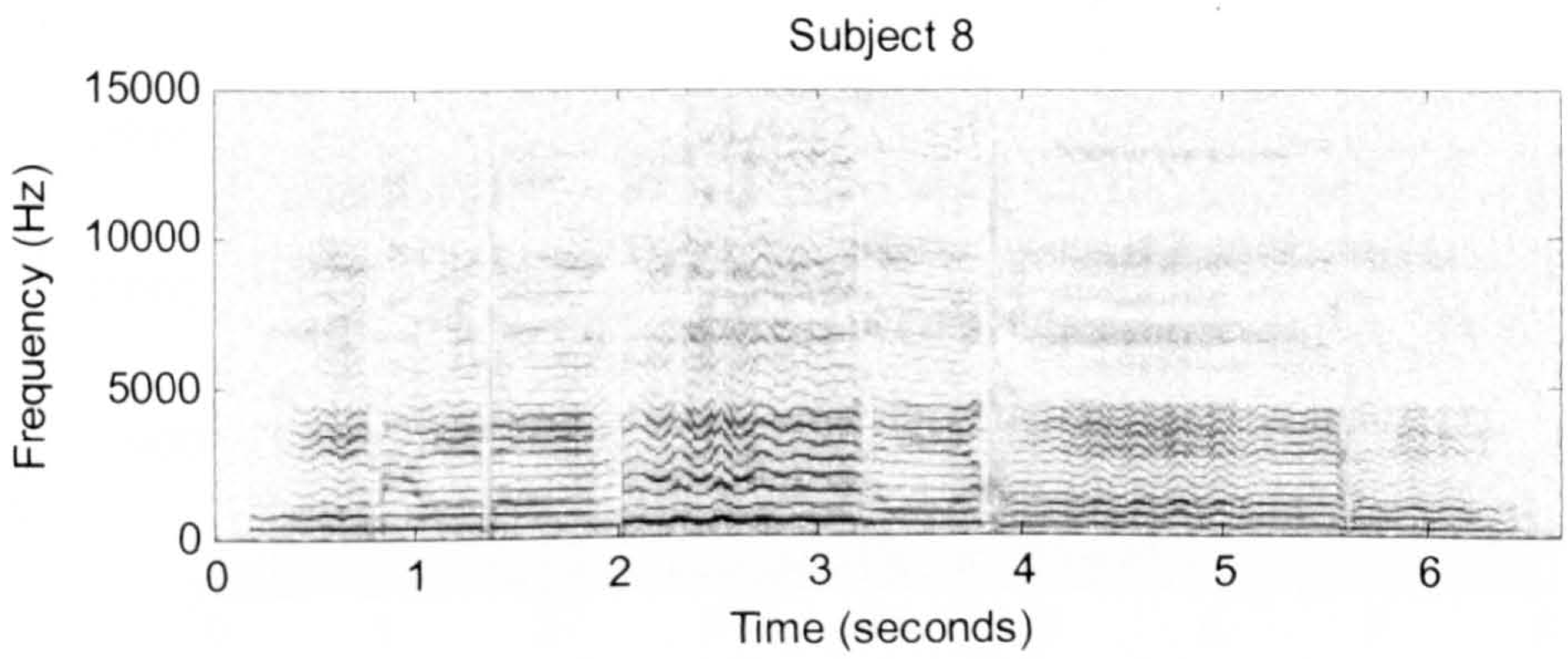

Subject 15
15000
10000
5000
0
Frequency (Hz)
0 1 2 3 4 5 6 7
Time (seconds)

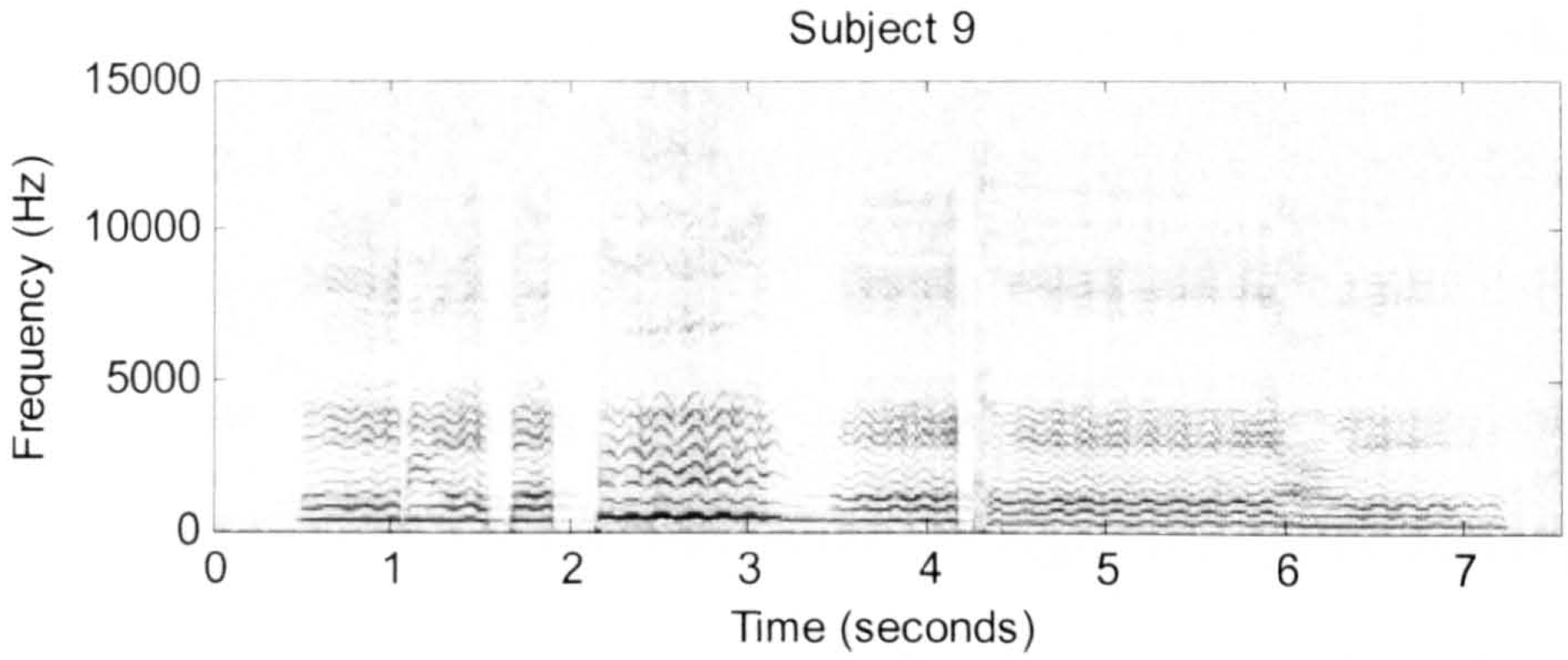

Subject 16
15000
10000
5000
0
Frequency (Hz)
0 1 2 3 4 5 6
Time (seconds)

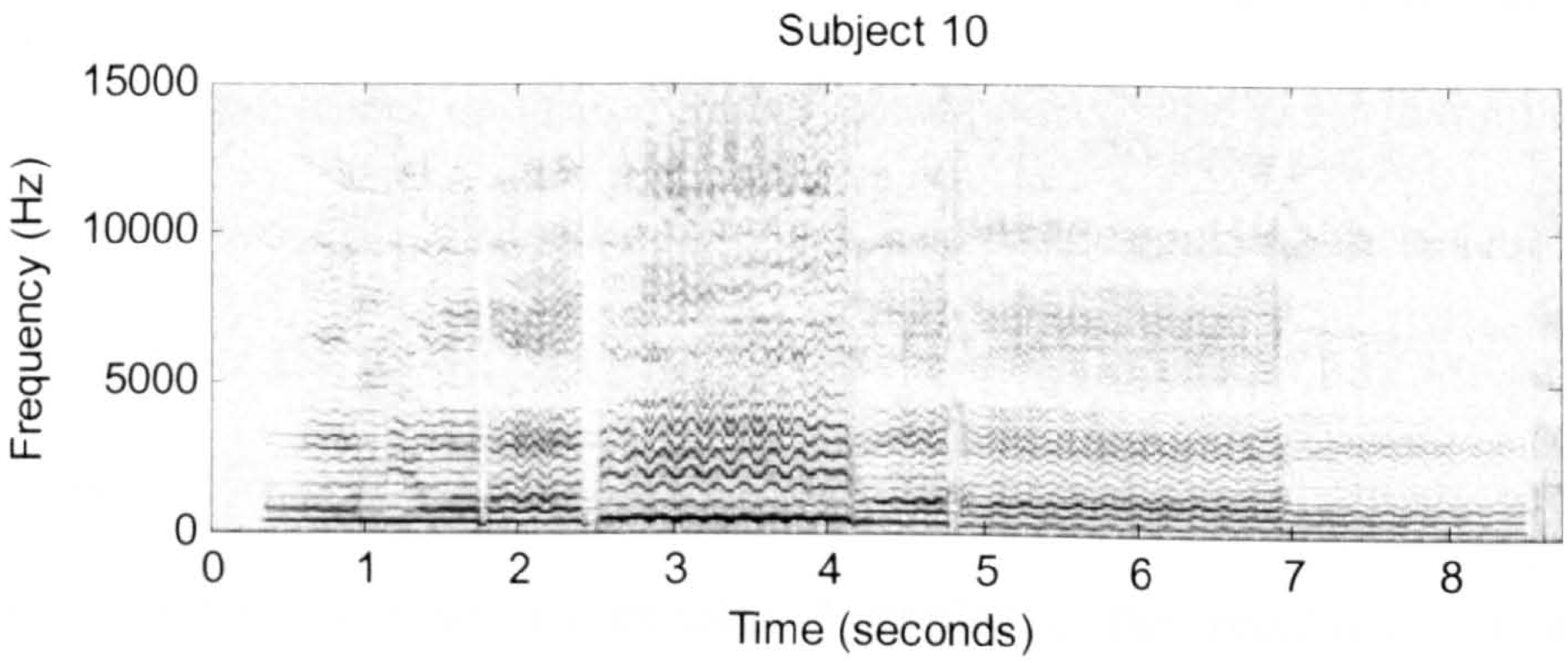

Subject 5
Frequency (Hz)
15000
10000
5000
0
0 1 2 3 4 5 6 7
Time (seconds)

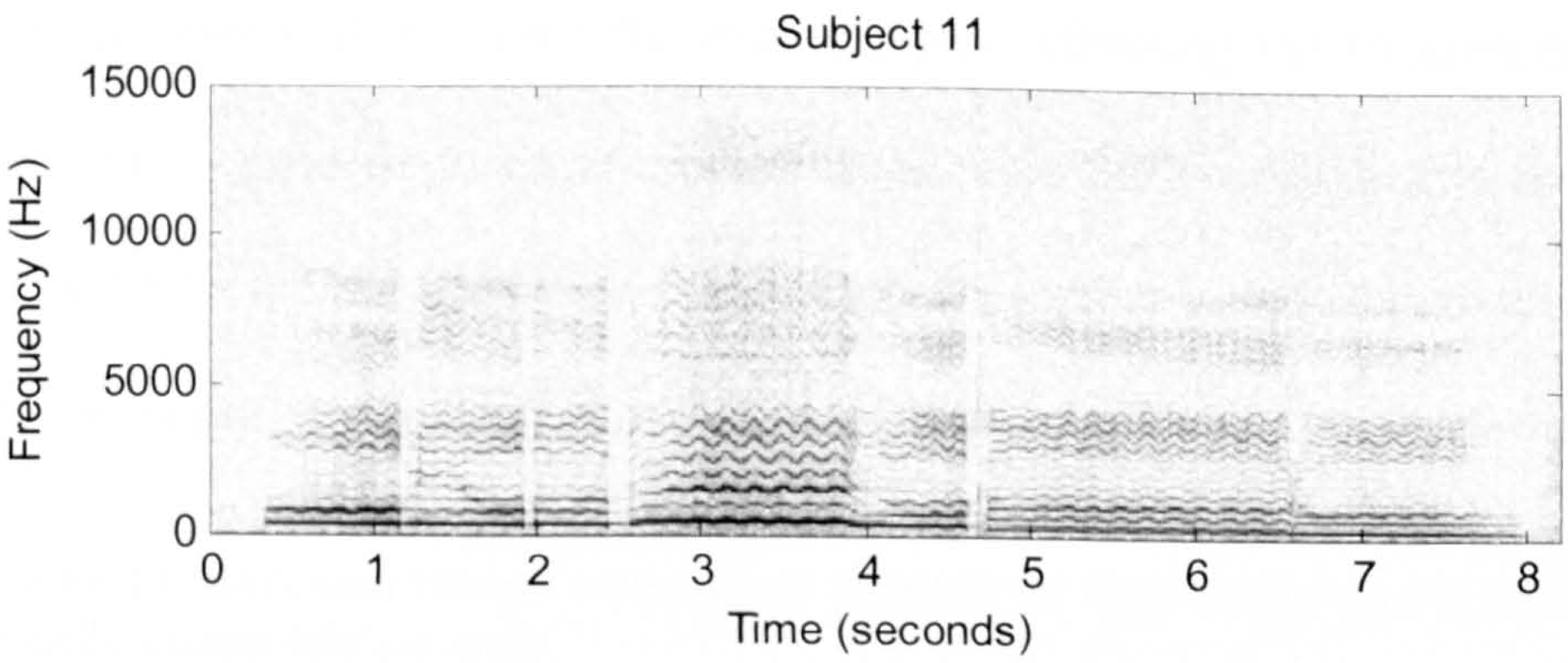

Subject 6
Frequency (Hz)
15000
10000
5000
0
0 1 2 3 4 5 6 7 8
Time (seconds)

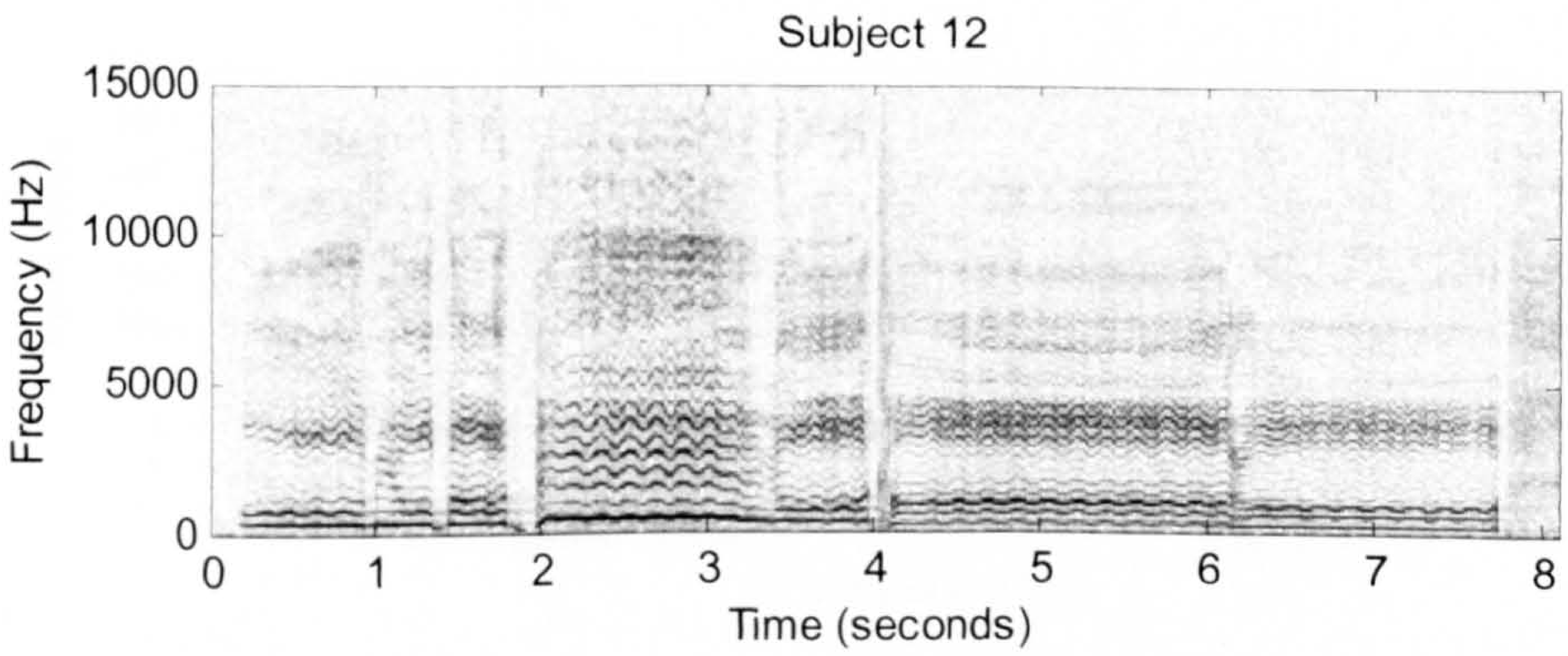

Subject 7
Frequency (Hz)
15000
10000
5000
0
0 1 2 3 4 5 6 7 8
Time (seconds)


Subject 8
Frequency (Hz)
15000
10000
5000
0
0 1 2 3 4 5 6
Time (seconds)


Subject 9
Frequency (Hz)
15000
10000
5000
0
0 1 2 3 4 5 6 7
Time (seconds)


Subject 10
Frequency (Hz)
15000
10000
5000
0
0 1 2 3 4 5 6 7 8
Time (seconds)


Subject 11
Frequency (Hz)
15000
10000
5000
0
0 1 2 3 4 5 6 7 8
Time (seconds)


Subject 12
Frequency (Hz)
15000
10000
5000
0
0 1 2 3 4 5 6 7 8
Time (seconds)

The final two notes of the first phrase of the Puccini extract which is shown in figure 10 were isolated for analysis of vibrato extent. The vibrato cycle with the maximum extent for both notes was measured for all singers using the fundamental frequency tool in PRAAT and the results are shown in figure 11. There are no notable differences in maximum extent between the two groups although the largest extent is produced by the singers from the opera group and the smallest by a singer in the early music group. The mean vibrato extent for these two notes was also determined for all subjects by averaging the extent of each vibrato cycle produced within the two tones obtained from the 'pitch listing' command in PRAAT and then calculated in 'Excel'. The results for each subject are shown in figure 12 and the mean extent of the two groups is shown in figure 13. This provides a more adequate representation of vibrato extent employed by the subjects, because, as chapter 3 explains, the regularity of extent can vary considerably within a tone for some subjects effecting the maximum extent but not necessarily reflecting overall vibrato usage. This further calculation shows that overall the subjects in the early music group employ a smaller vibrato extent than the subjects in the opera group, the significance of which is also explored in the following chapter.

Figure 11 Maximum vibrato extent (peak to peak) for each subject in the final two notes of the Puccini extract (phrase one)

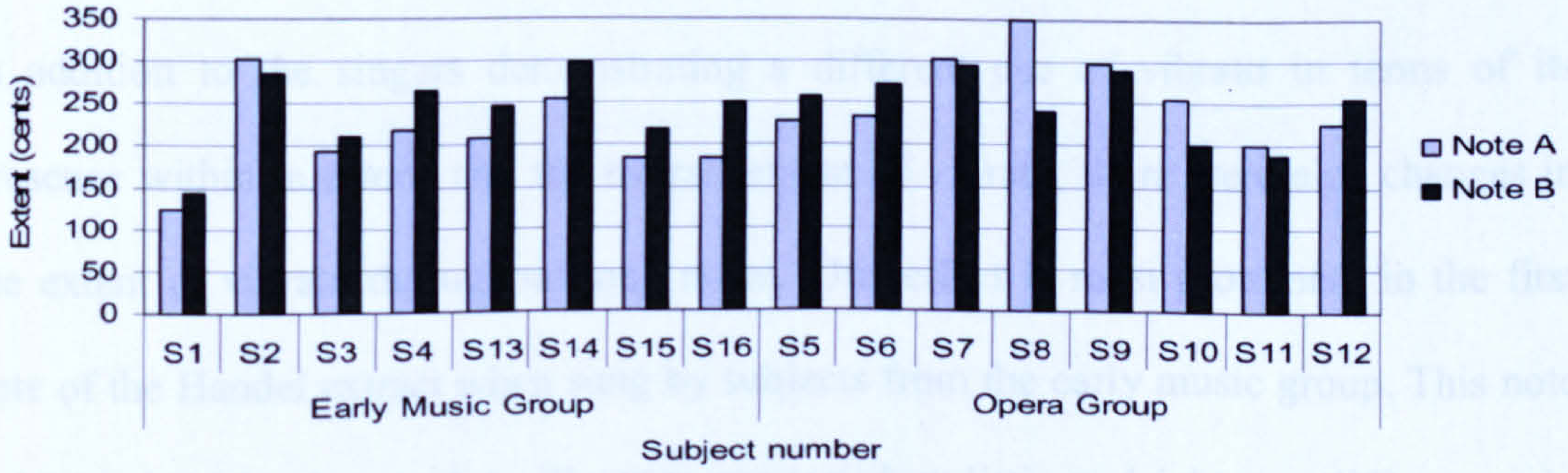


Figure 12 Graph showing the mean peak to peak extent of vibrato by all subjects in the final two notes of the Puccini extract

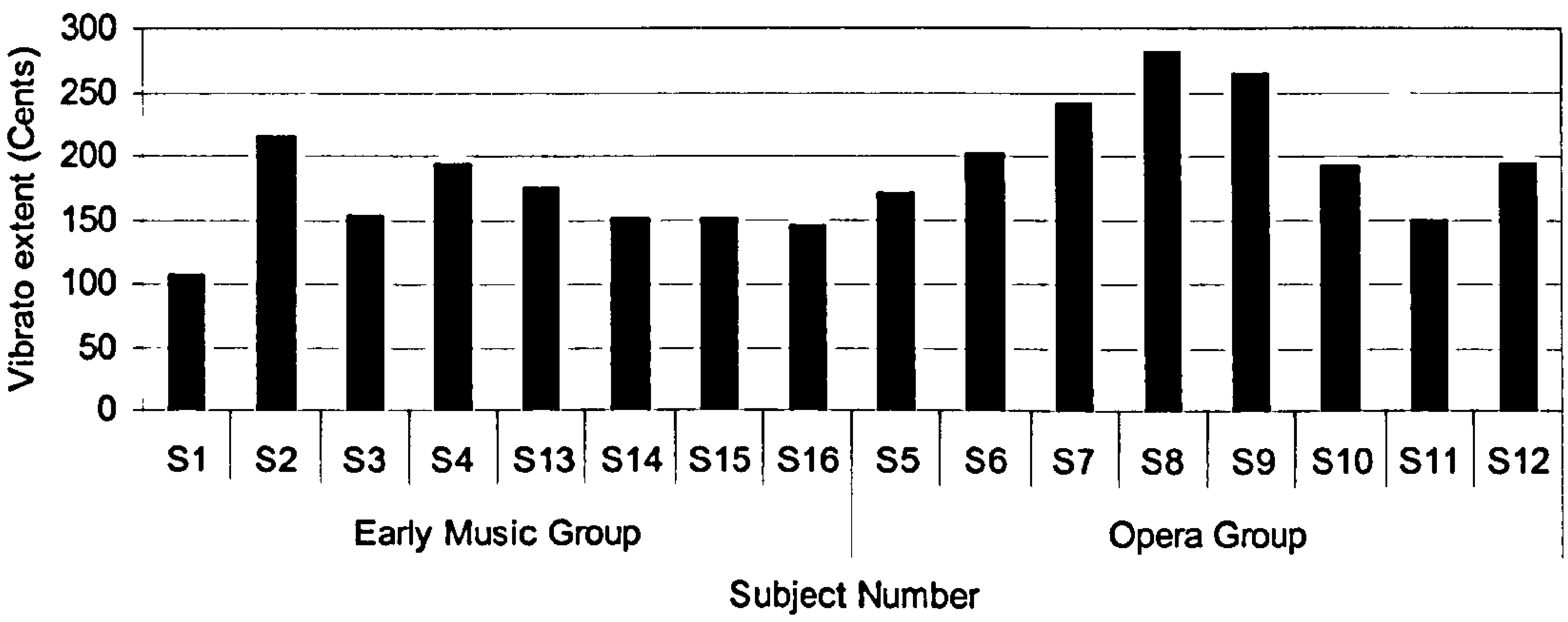
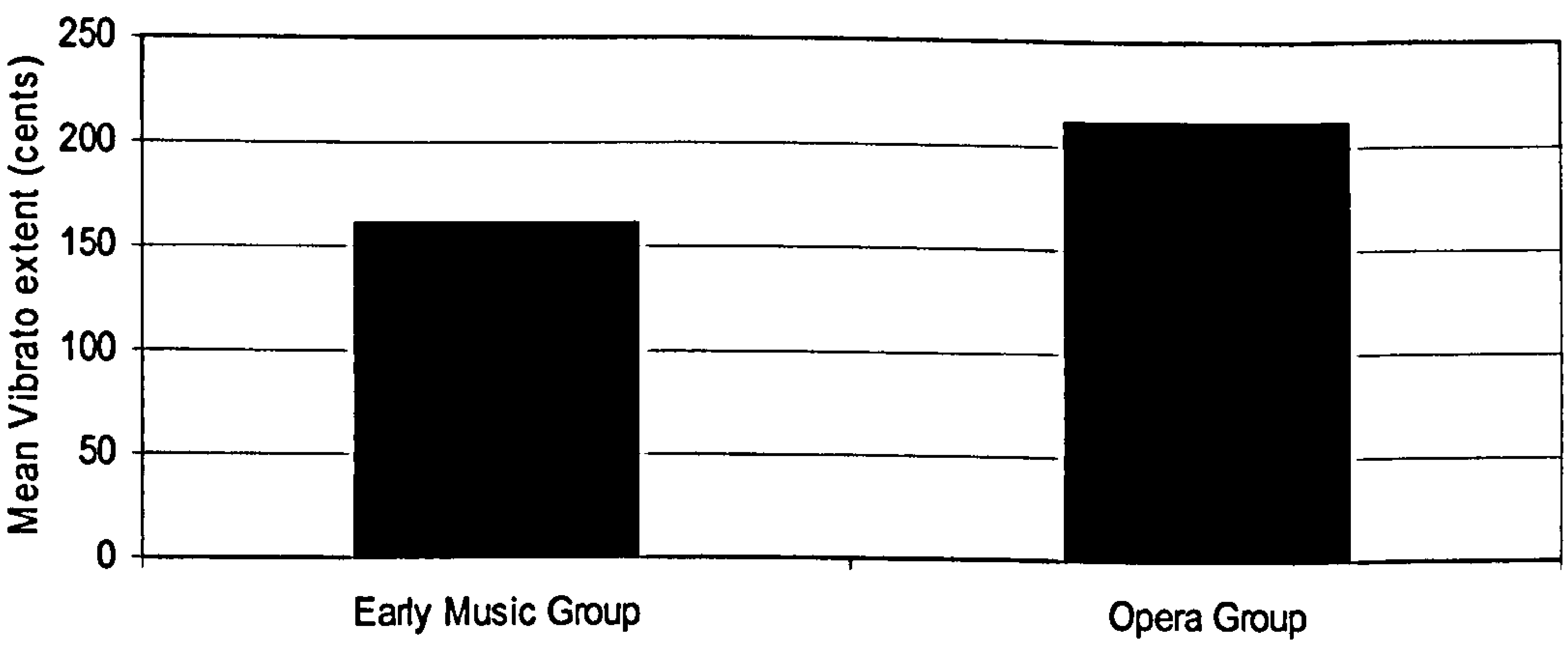
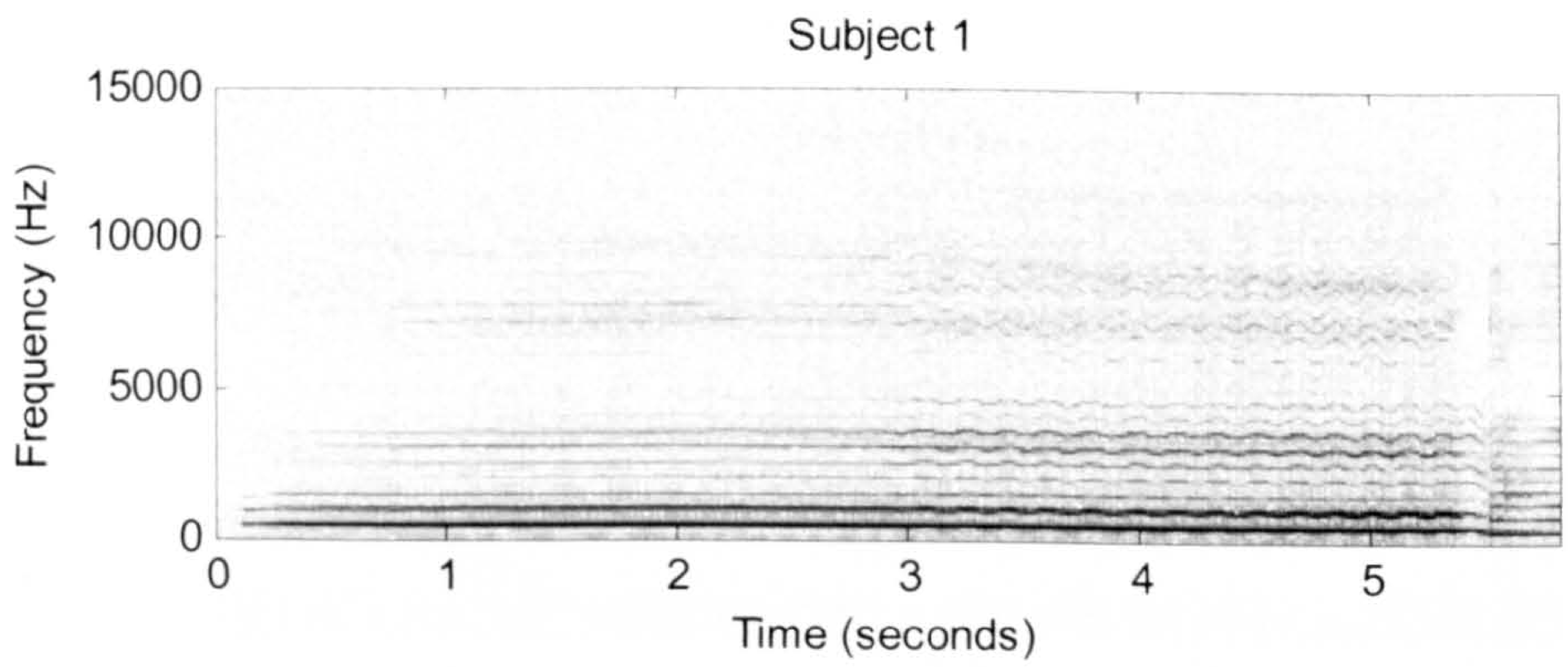


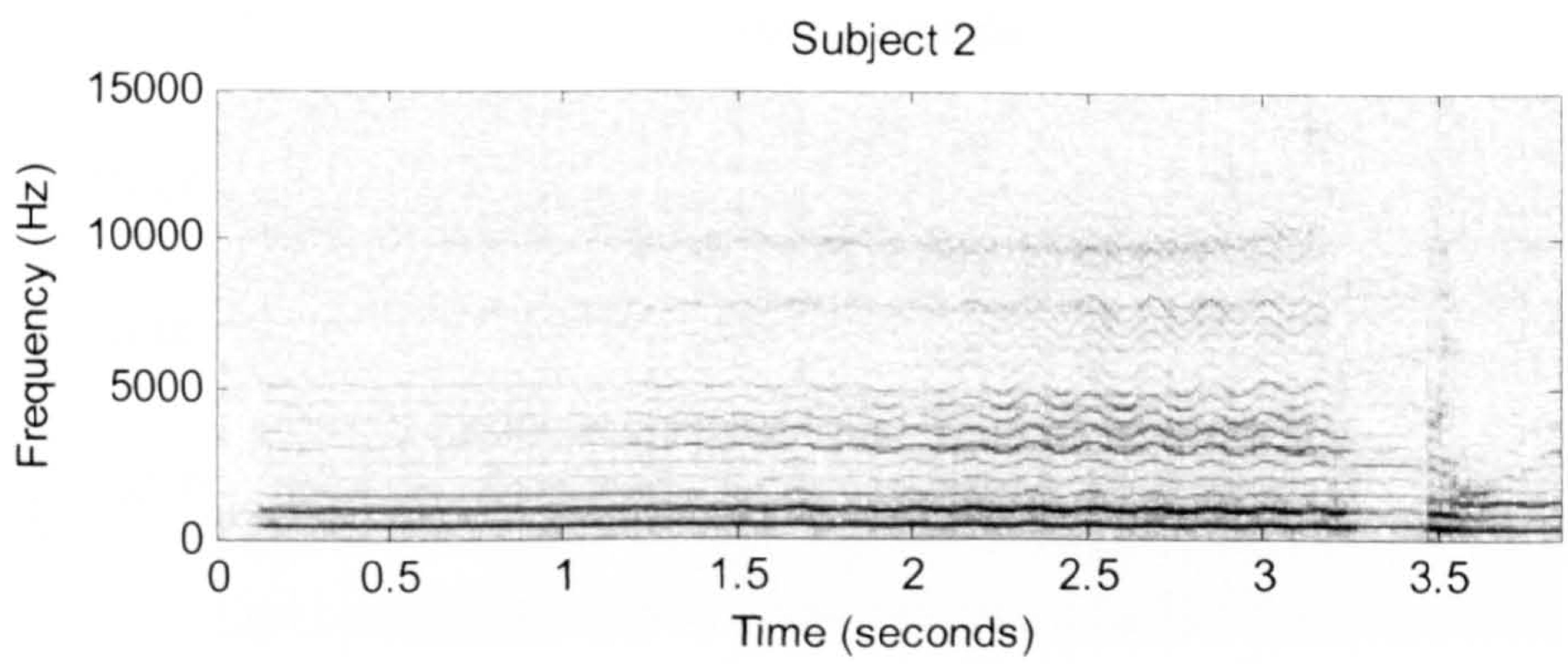
Figure 13 Graph showing the mean peak to peak vibrato extent employed by the two groups in the final two notes of the Puccini extract

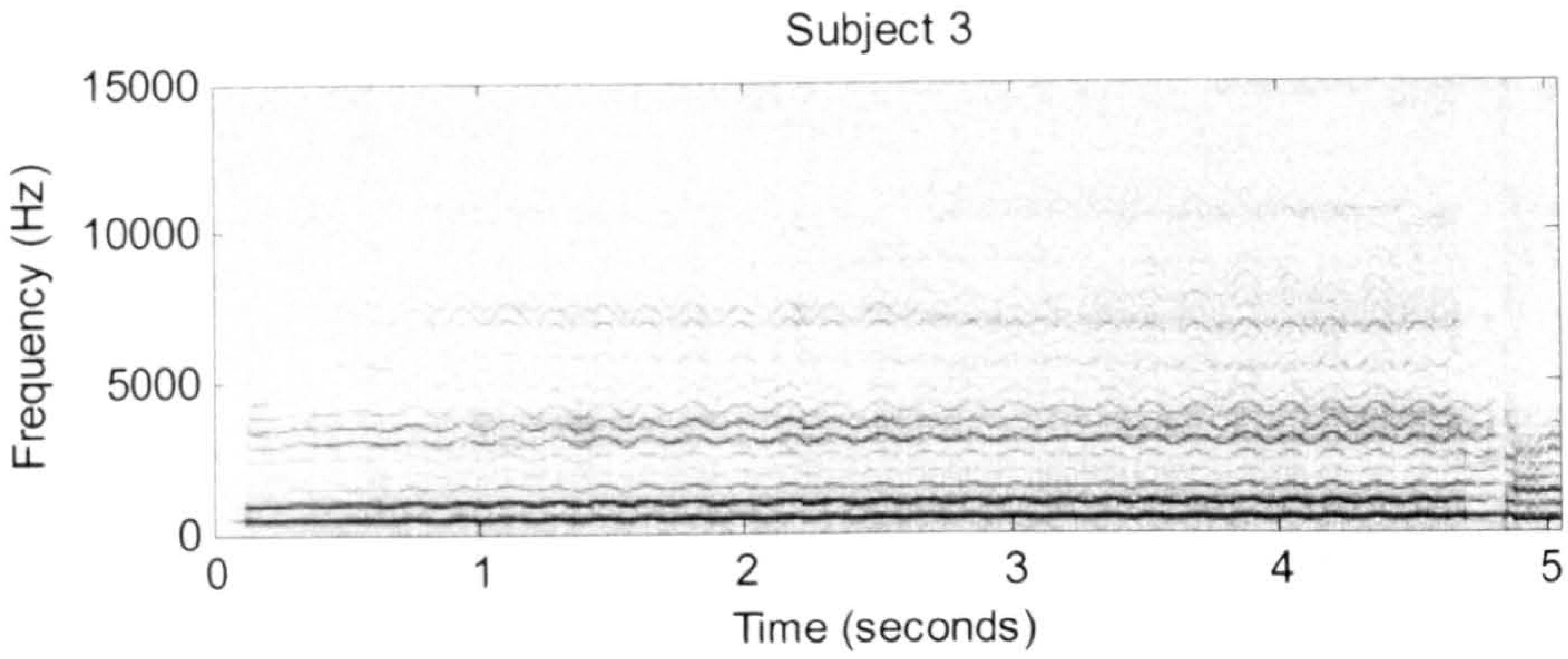


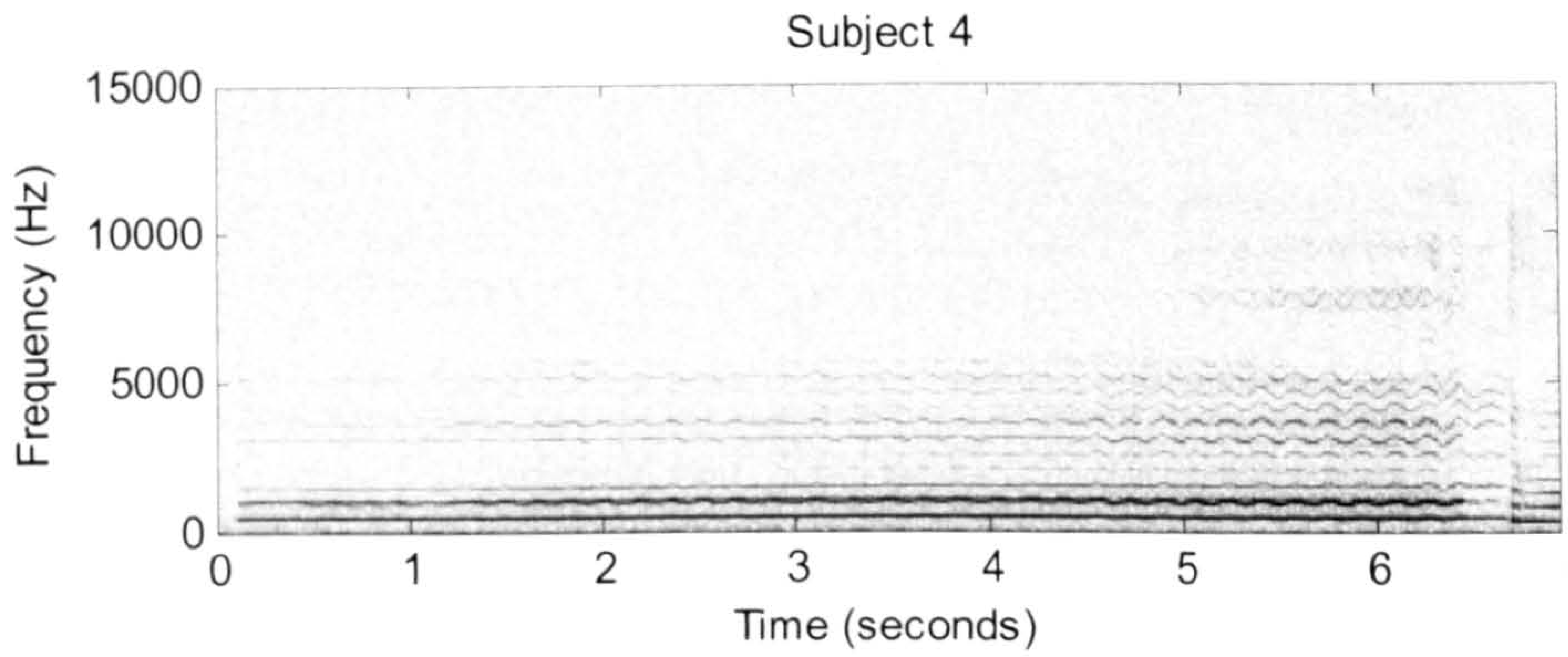
In addition to the singers demonstrating a different use of vibrato in terms of its presence within in a tone and the overall extent of vibrato, there were also changes in the extent of vibrato throughout long notes. This effect is most prominent in the first note of the Handel extract when sung by subjects from the early music group. This note is highlighted in chapter 3 to illustrate suggested stylistic and inherent differences in vibrato usage between the two groups. As figure 14 shows, there is a tendency for the subjects to produce a tone with little or no vibrato at the beginning of the note and then once vibrato has been established, to increase the extent throughout the tone. This effect corresponds with an increase in intensity as the singers all crescendo through the note. Specific patterns that occur in the use of vibrato in certain tones by specific subjects are considered alongside a detailed discussion of these results in chapter 3.

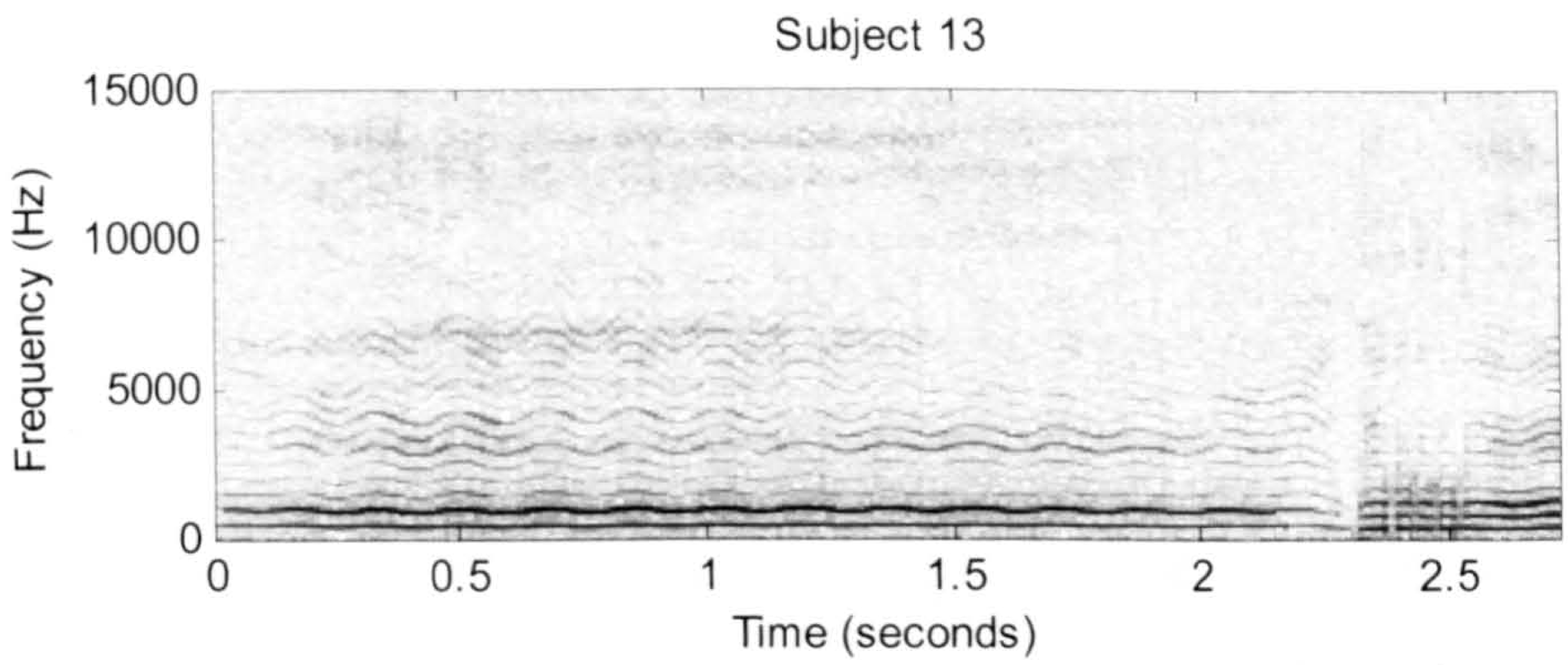
Figure 14 Showing spectrograms of all the subjects singing the first note of the Handel extract. The first eight show the early music group and the second eight the opera group.

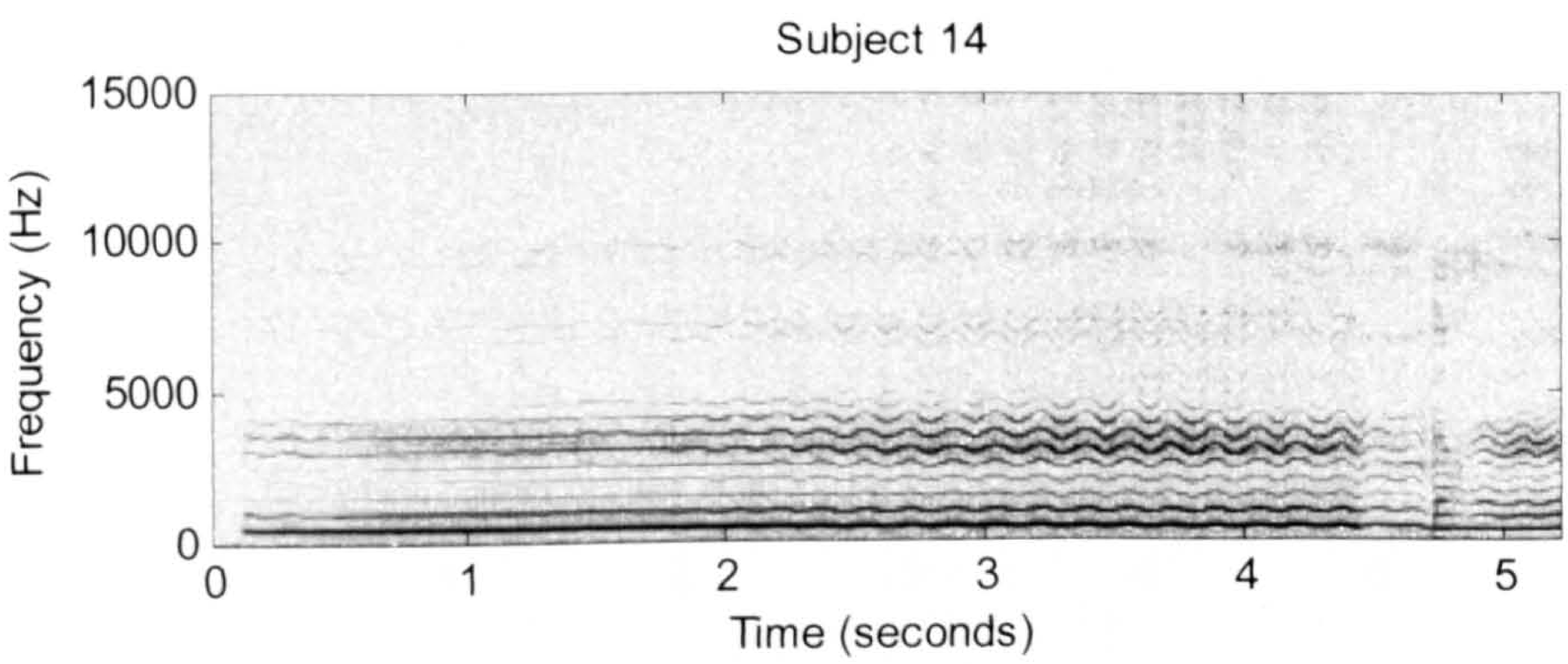


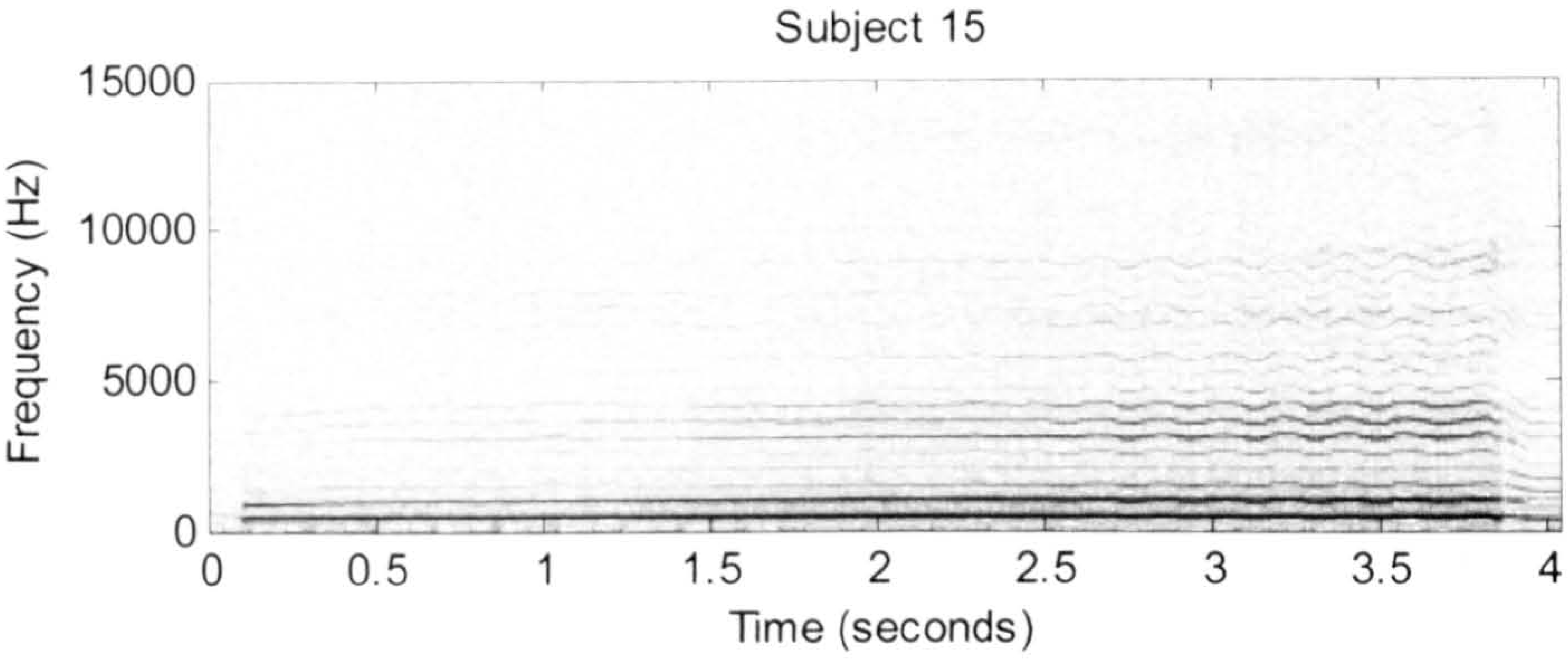


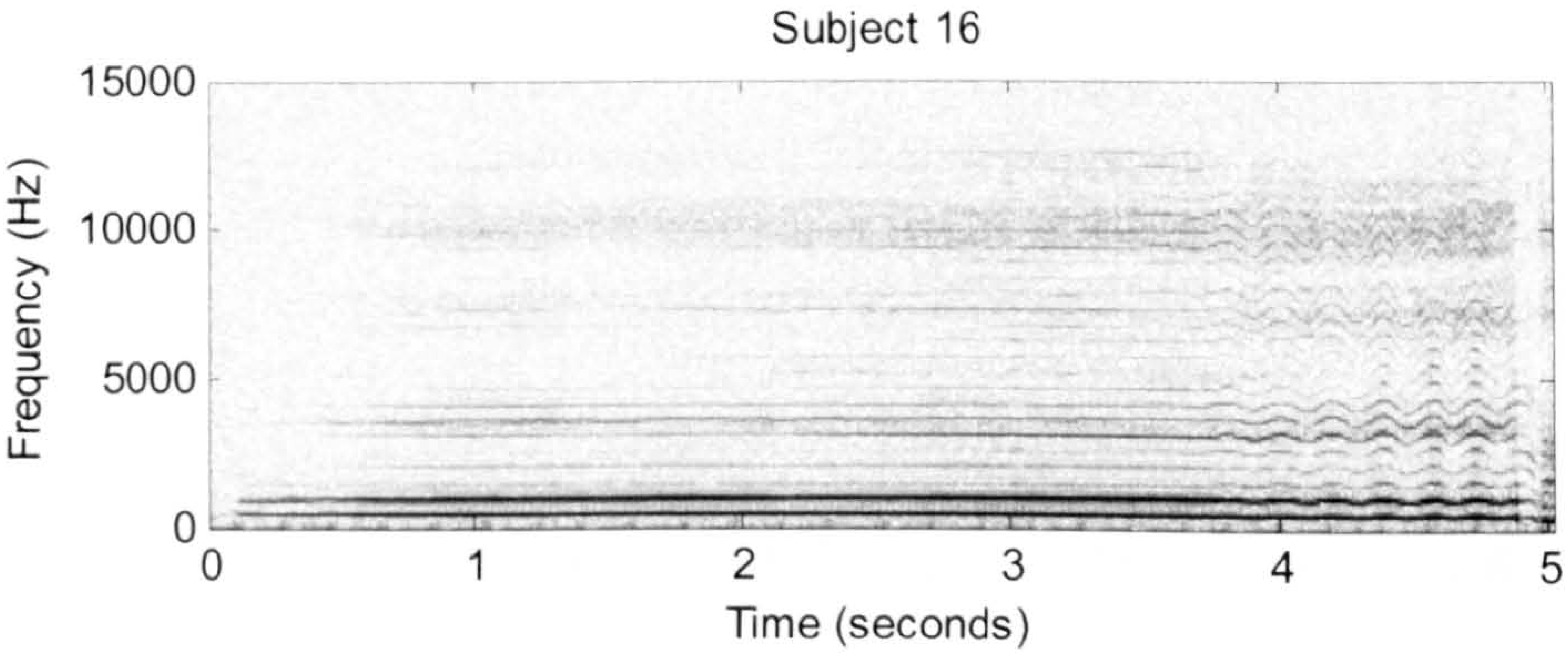

Subject 3
Frequency (Hz)
Time (seconds)

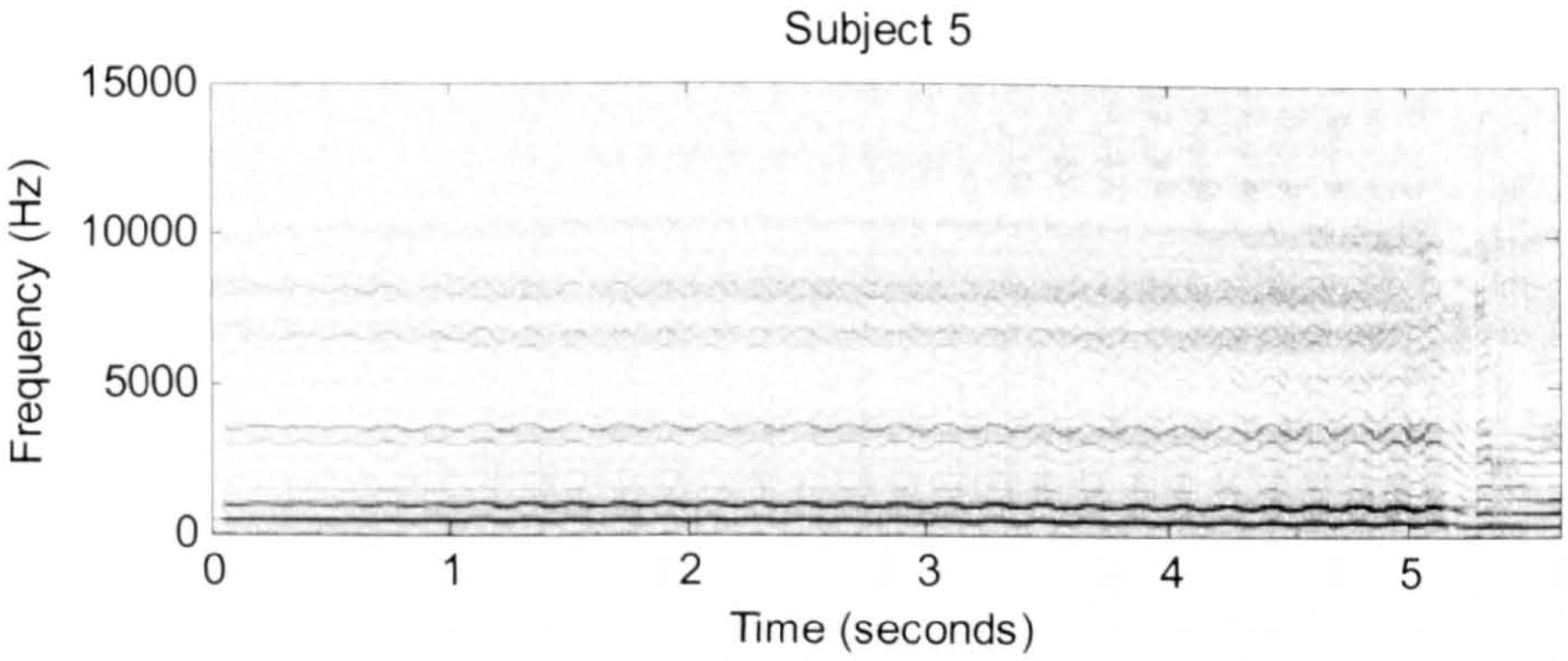

Subject 4
Frequency (Hz)
Time (seconds)

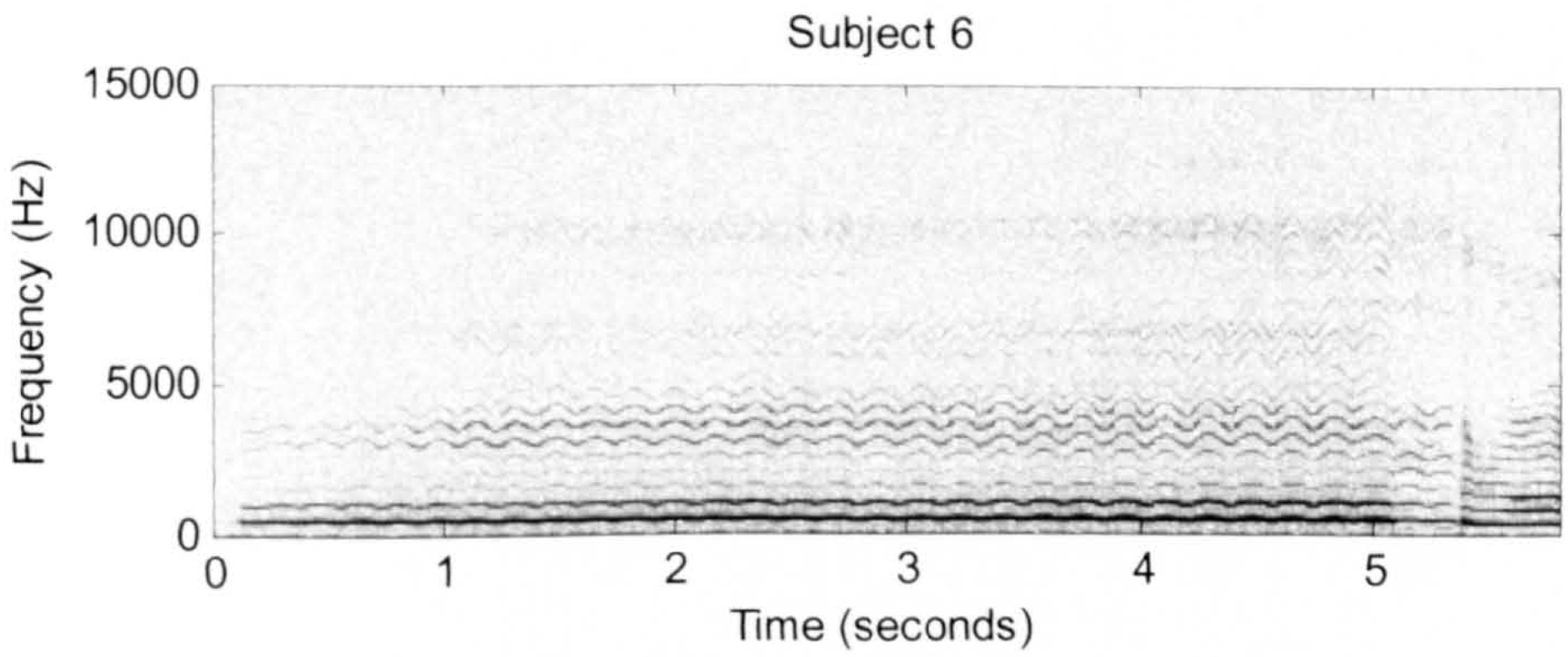

Subject 13
Frequency (Hz)
Time (seconds)

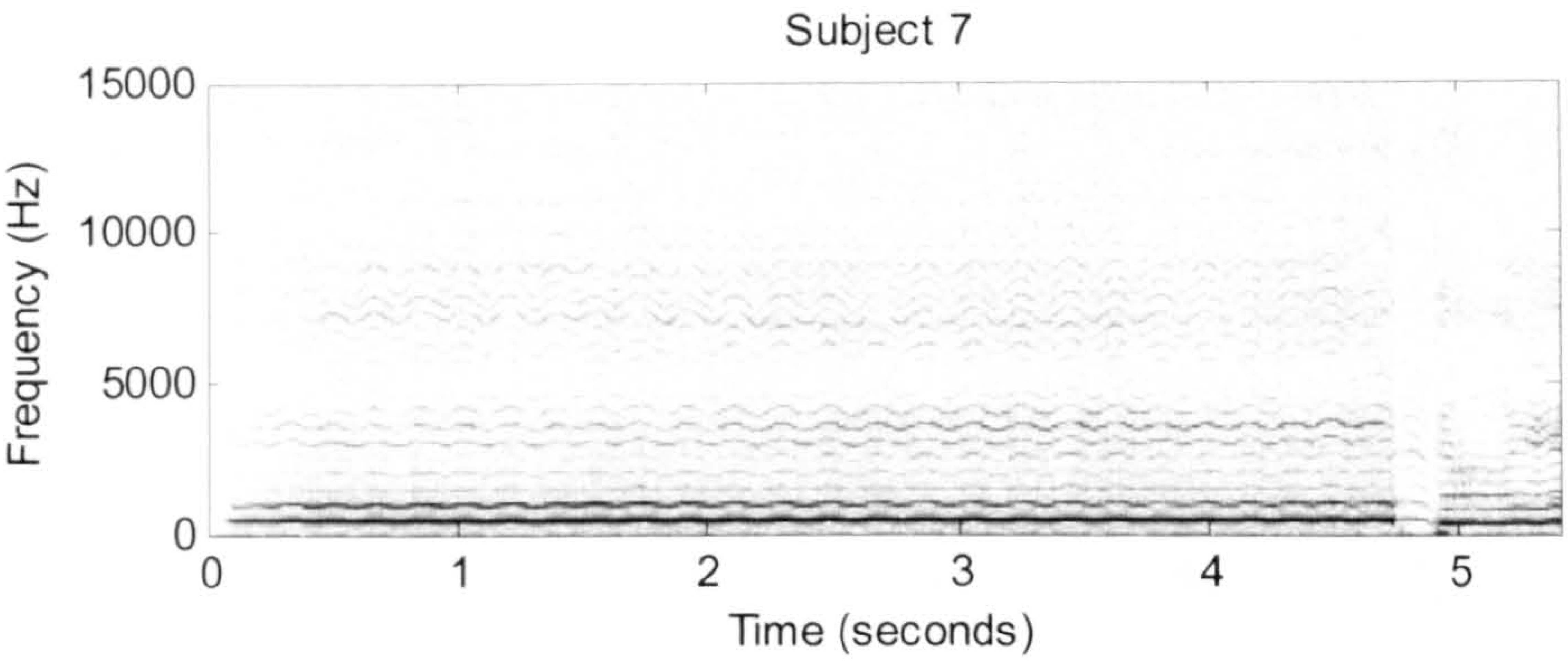

Subject 14
Frequency (Hz)
Time (seconds)

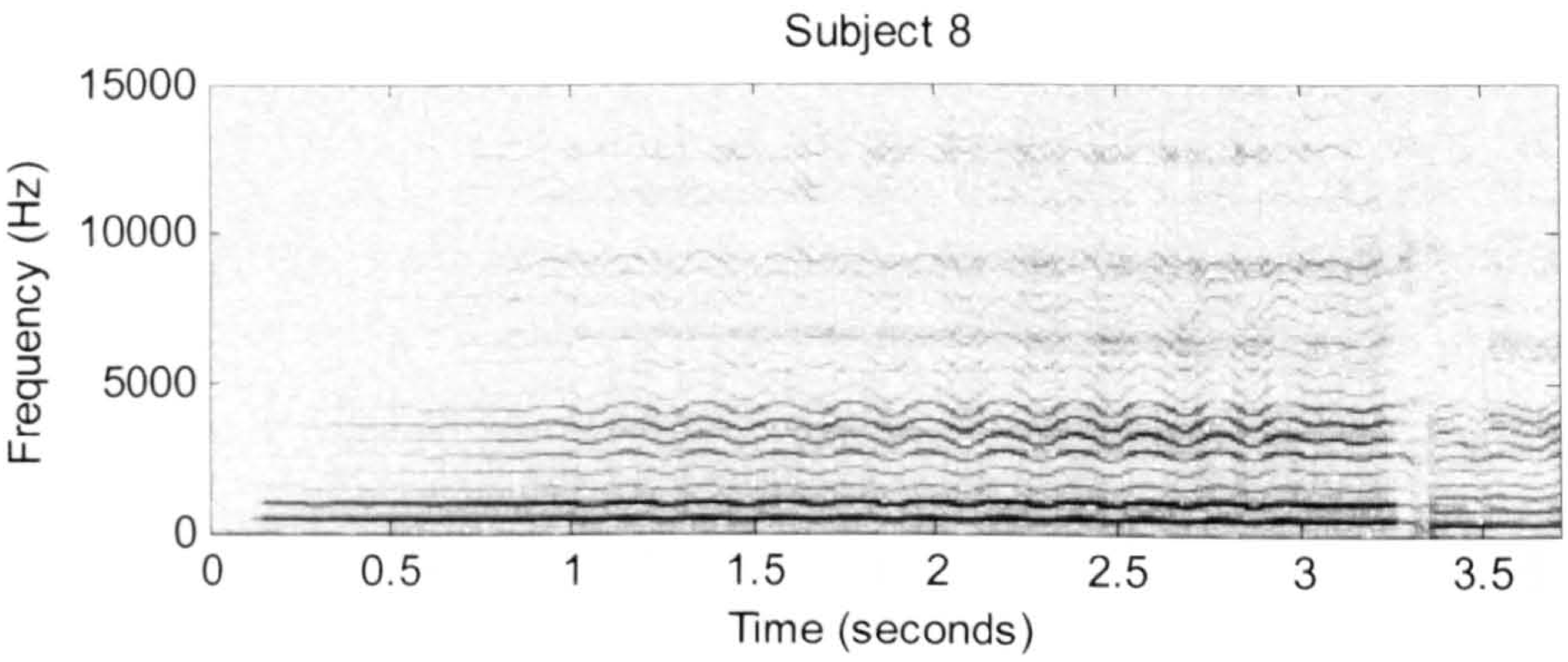

Subject 15
15000
10000
5000
0
Frequency (Hz)
0 0.5 1 1.5 2 2.5 3 3.5 4
Time (seconds)

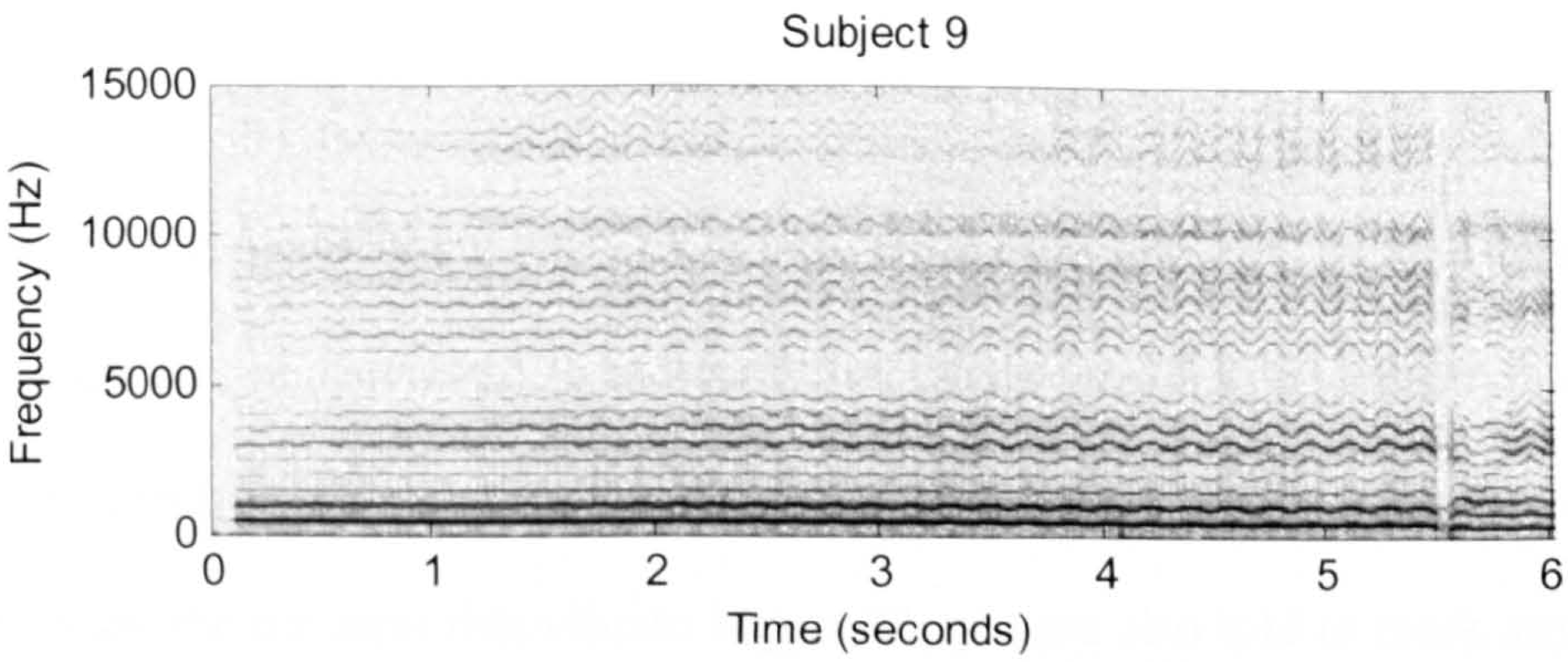

Subject 16
15000
10000
5000
0
Frequency (Hz)
0 1 2 3 4 5
Time (seconds)

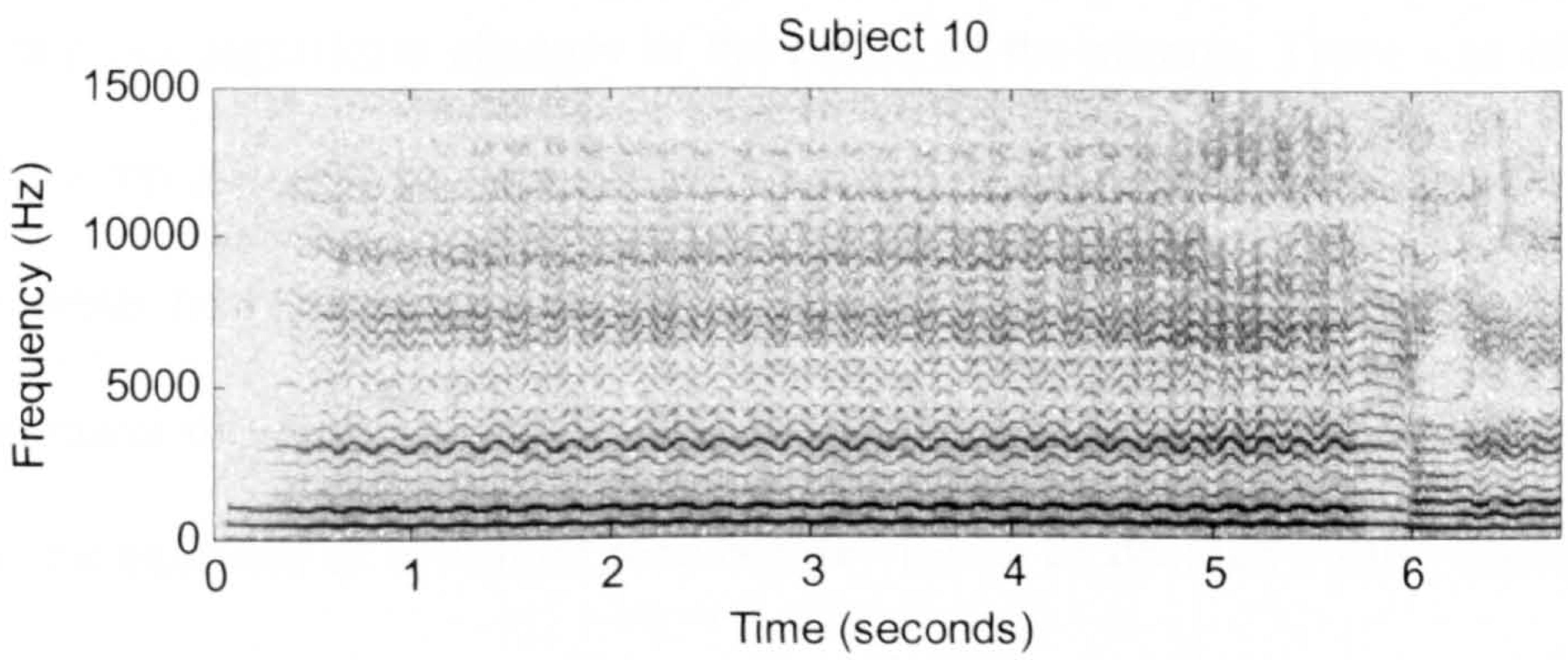

Subject 5
15000
10000
5000
0
Frequency (Hz)
0 1 2 3 4 5
Time (seconds)

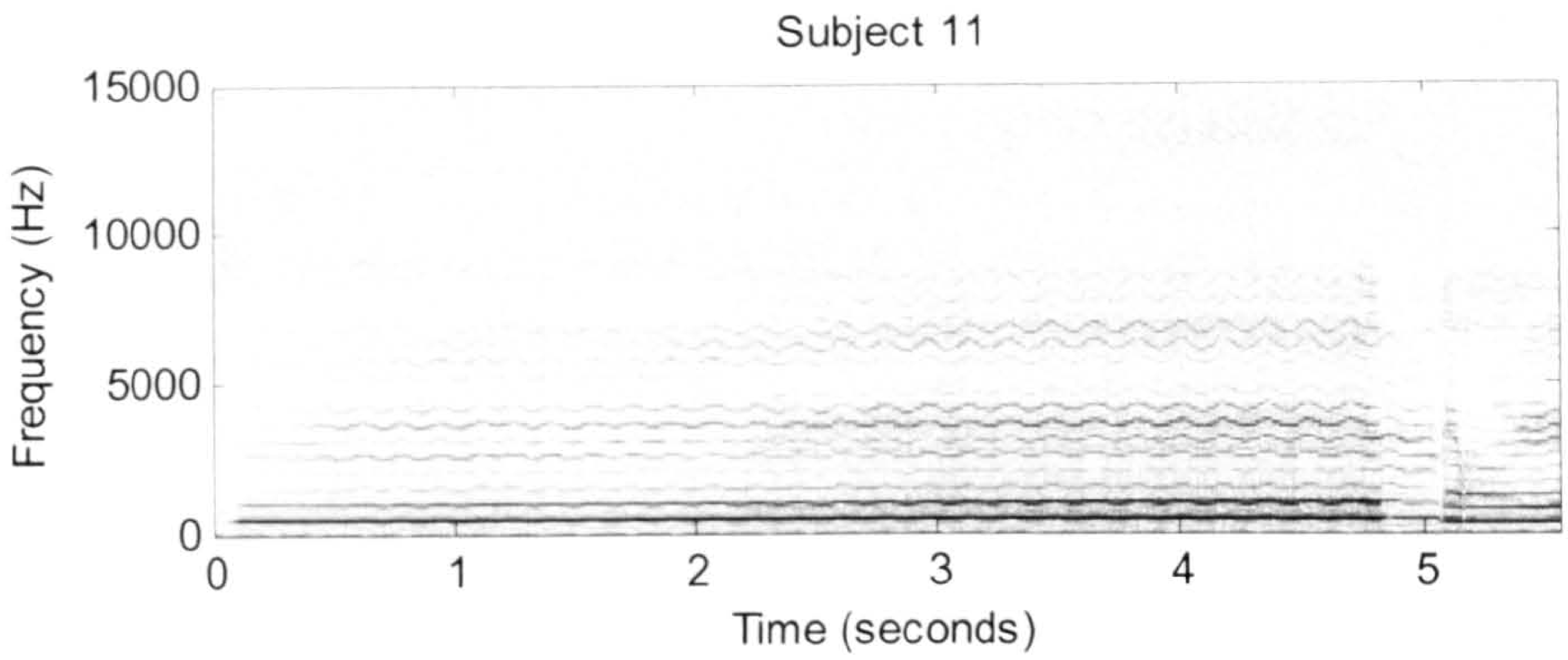

Subject 6
15000
10000
5000
0
Frequency (Hz)
0 1 2 3 4 5
Time (seconds)

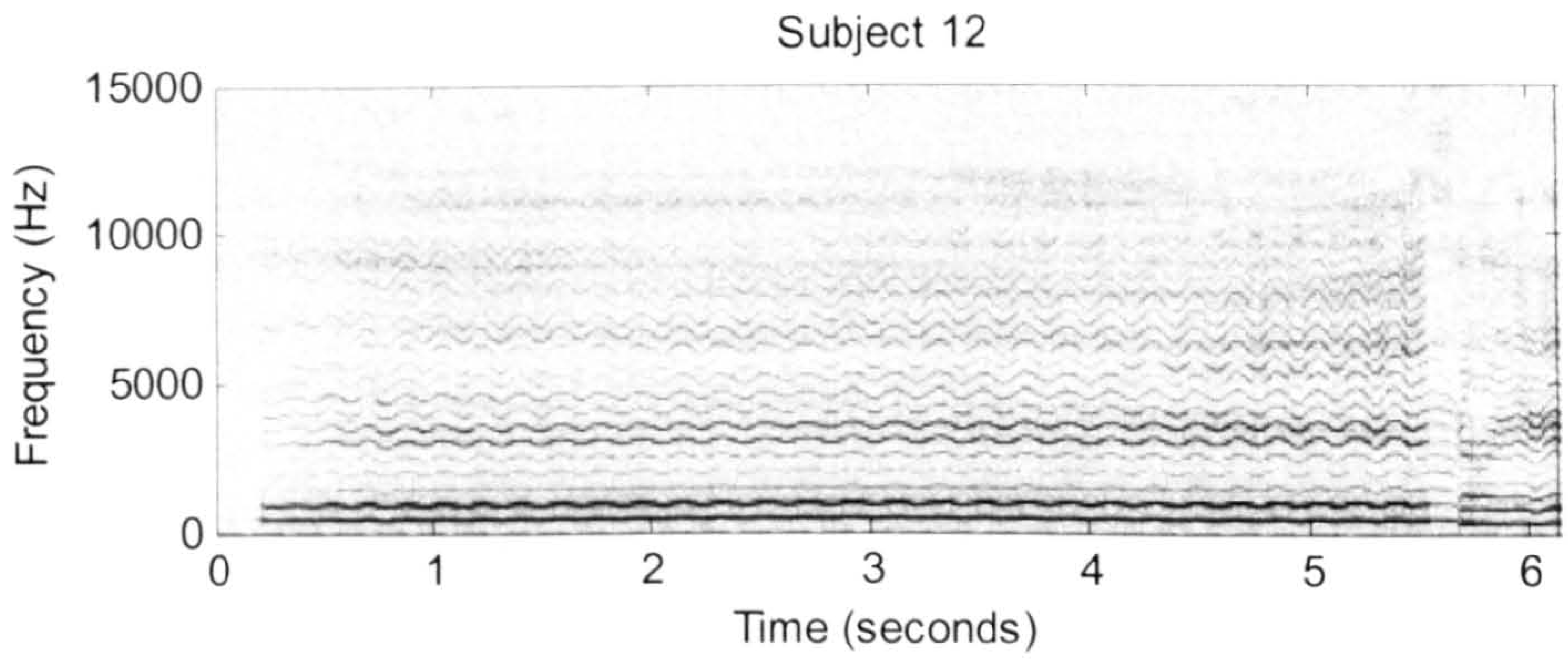

Subject 7
15000
10000
5000
0
Frequency (Hz)
0
1
2
3
4
5
Time (seconds)


Subject 8
15000
10000
5000
0
Frequency (Hz)
0
0.5
1
1.5
2
2.5
3
3.5
Time (seconds)


Subject 9
15000
10000
5000
0
Frequency (Hz)
0
1
2
3
4
5
6
Time (seconds)


Subject 10
15000
10000
5000
0
Frequency (Hz)
0
1
2
3
4
5
6
Time (seconds)





In order to quantify the onset of vibrato within the first note of the Handel extract, eight researchers not involved in the study but used to reading spectrograms were presented with spectrogram images of this note for each subject in a randomised order and asked to mark the moment that vibrato began. They were also told to mark any moment where they saw significant changes in the extent of the vibrato. There was usually agreement between all eight participants within a few milliseconds when identifying the onset of vibrato, however when this was not the case the choice of the majority was taken as the moment of vibrato onset. Table 3 shows the percentage of the note that was considered to be executed as a straight tone before vibrato as decided by the majority of the panel. The findings of the panel illustrate that the early music singers generally sang 'straight' tones for much longer.

Table 3 Portion (%) of note 1 of the Handel extract which did not contain vibrato

	Subject Number	Portion of note (%) before vibrato onset
Early Music Group	1	54
	2	33
	3	10
	4	68
	13	0
	14	36
	15	65
	16	77
Opera Group	5	0
	6	3
	7	0
	8	22
	9	21
	10	5
	11	8
	12	2

A peak to peak fundamental frequency measurement was made in PRAAT of the first full vibrato cycle after the identified onset and also of the vibrato cycle three cycles from the end of this note. The vibrato cycle with the largest extent was also measured, as well as vibrato tones that occurred at moments identified by any panel participants as a point of change in vibrato usage throughout the tone. The results are shown in table 4 and show that the divide between the two groups in their maximum extent is not as pronounced as their treatment of vibrato extent throughout the note. Whilst the largest extent was produced by subject 10 from the opera group with a peak to peak extent of 279 cents, this proved to be unusually high for all the singers. Five of the singers in the opera group displayed a vibrato extent of more than 200 cents, whilst this was the case with only two of the early music singers. The lowest maximum extent was observed in subject 15 from the early music group, and she was the only singer with a maximum extent under 100 cents. The results of this analysis are carefully considered with the implications of these changing extents on the integral and stylistic use of vibrato by all the subjects in chapter 3.

Table 4 Changing and maximum peak to peak vibrato extent in the first note of the Handel extract

	Subject Number	Part of note	Peak to peak Extent (cents)	Diff between max and min extents cents
Early Music Group	S1	Beginning	55	
		End	**108**	54
	S2	Beginning	64	
		End	**192**	128
	S3	Beginning	127	
		Change	78	
		End	**209**	82
	S4	Beginning	69	
		Change	118	
		End	**198**	129
	S13	Beginning	**220**	
		End	145	75
	S14	Beginning	47	
		End	**180**	134
	S15	Beginning	67	
		Change	**99**	32
		End	86	
	S16	Beginning	125	
		End	206	
		Max	**212**	87
Opera Group	S5	Beginning	42	
		End	**251**	209
	S6	Beginning	65	
		Change	160	
		End	**223**	158
	S7	Beginning	52	
		Change	**133**	82
		End	86	
	S8	min	113	
		Max	**204**	91
	S9	Beginning	35	
		Change	135	
		End	**150**	115
	S10	Beginning	167	
		Change	**279**	113
		End	271	
	S11	Beginning	83	
		End	**113**	30
	S12	Beginning	100.09	
		End	**190.98**	90.89

The notable differences between the singers' vibrato production and particularly the trends that occur between the two groups suggest that it is an important defining characteristic for the singers' specialty. It is therefore considered with specific subjects and notes highlighted in further detail in the following chapter.

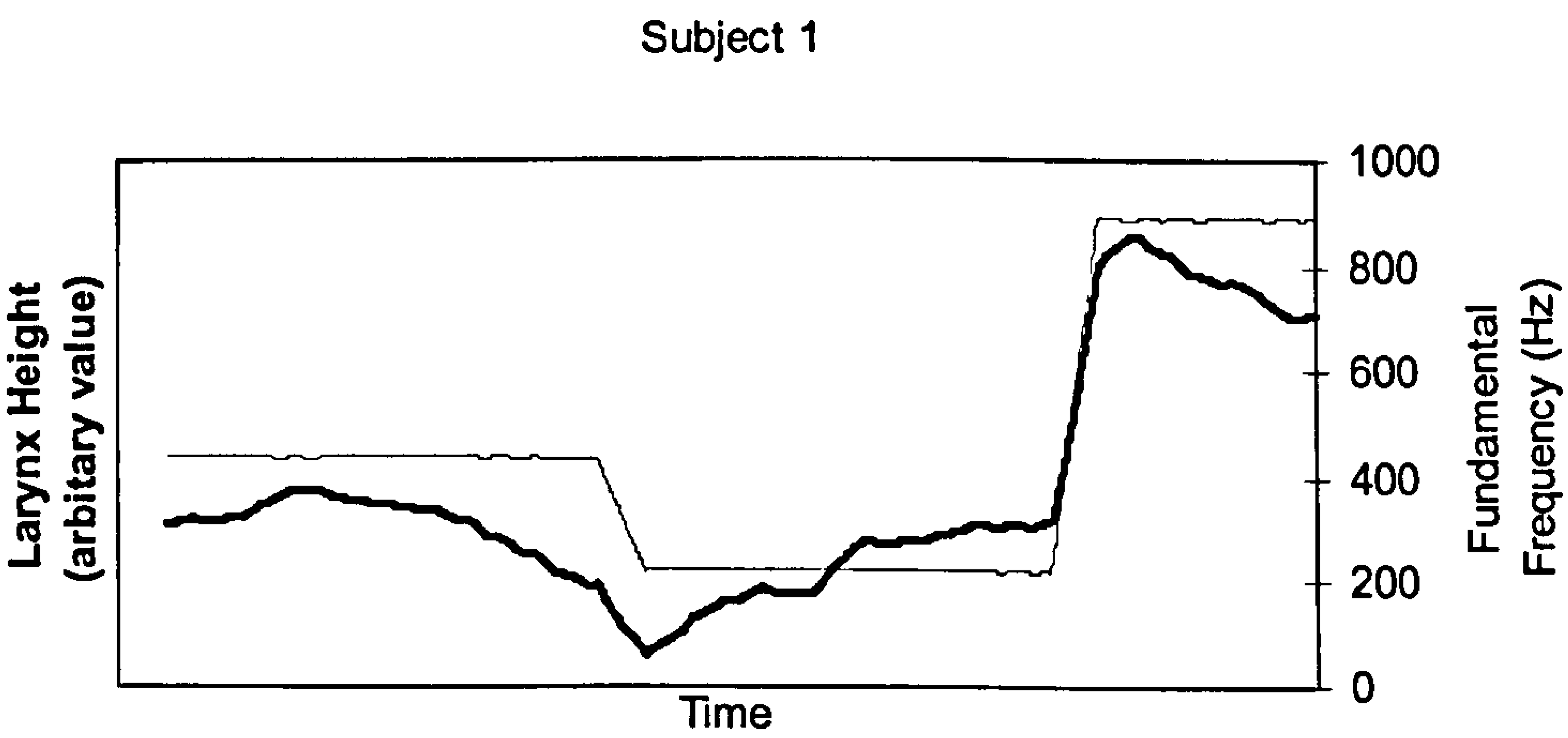
2.4.3 Larynx Position

As information regarding larynx position was obtained with the electroglottograph, results were dependent on a good electroglottograph signal. Therefore, whenever the signal disappeared or became weak the larynx position could not be determined. The calibration exercise indicated that the laryngeal tracking was accurate when a signal was present, as the octave As (A3 to A5) presented with the same movements when found by palpation and by the electroglottograph. Figure 15 shows the larynx position for subject 1 from the early music group and subject 5 from the opera group when performing the calibration task whilst wearing the electrodes. The lighter line represents the fundamental frequency being sung and the dark line represents the vertical larynx position of the subject taken from the fundamental frequency contour of the oscillator. The contour clearly shows the larynx positions changing considerably as the three octaves were sung, from the lowest position with the lowest fundamental frequency to the highest position with the highest fundamental frequency. This pattern was observed in all subjects.

As discussed in the 'Closed Quotient' section above, for some subjects a good electroglottograph signal was not obtained and for these subjects the oscillator data was discarded. For a number of subjects who presented with good signals the signal occasionally weakened to a point that the larynx height could no longer be determined from the oscillator pitch reading. This was particularly the case when the subjects were singing very high fundamental frequencies in their range. This significantly reduced the sample size available for this aspect of the results making any overall group-based conclusions less reliable.

Figure 16 shows the oscillator results for the subjects with good signals singing the ascending two octave scale to an [i] vowel. Where there was no visible 'stability' in the fundamental frequency contour of the oscillator because of a loss of signal, either due to electrode movement away from the vocal folds or a breath taken by the singer, such moments have been discarded. There is clear stepwise movement in the laryngeal positioning of most singers as the sung pitch rises, however, there is often more significant movement at higher pitches. The first octave of the scale shows more differences between subjects than the second octave. There is a tendency for subjects to change the direction of larynx height with fundamental frequency, particularly at the beginning and end of the scale, however often lowering larynx position as fundamental frequency increases for mid-range pitches. This effect is highlighted in specific subjects in chapter 4. In view of the reduced sample size for this aspect of the results, further accurate recordings and analysis are needed for any significant differences between the two groups to be identified. However, the current results imply that larynx height behaviour was similar between most subjects with the larynx rising overall with fundamental frequency.

Figure 15 Graphs showing changing vertical larynx position in the calibration task sung by two singers. Subject 1 from the early music group (above) and subject 5 from the opera group (below). The bold line represents the relative larynx position and the dotted line shows the fundamental frequency being sung.



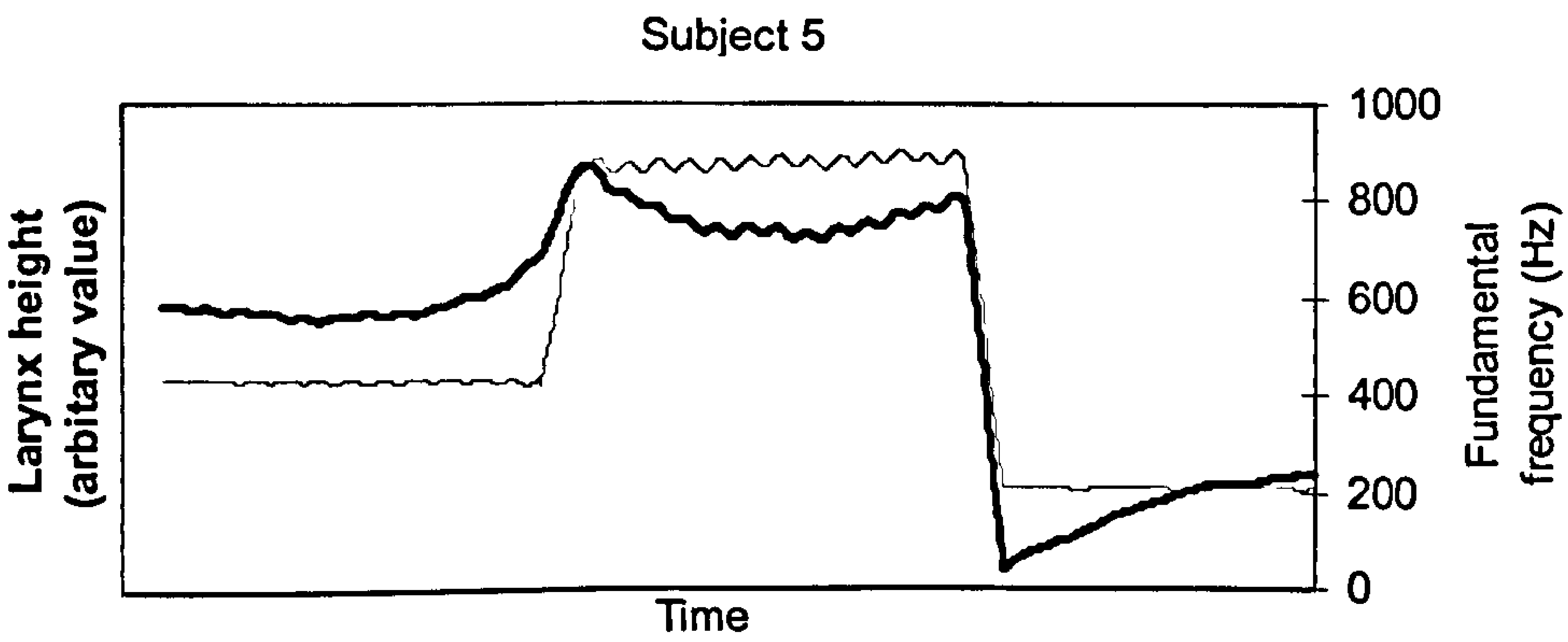
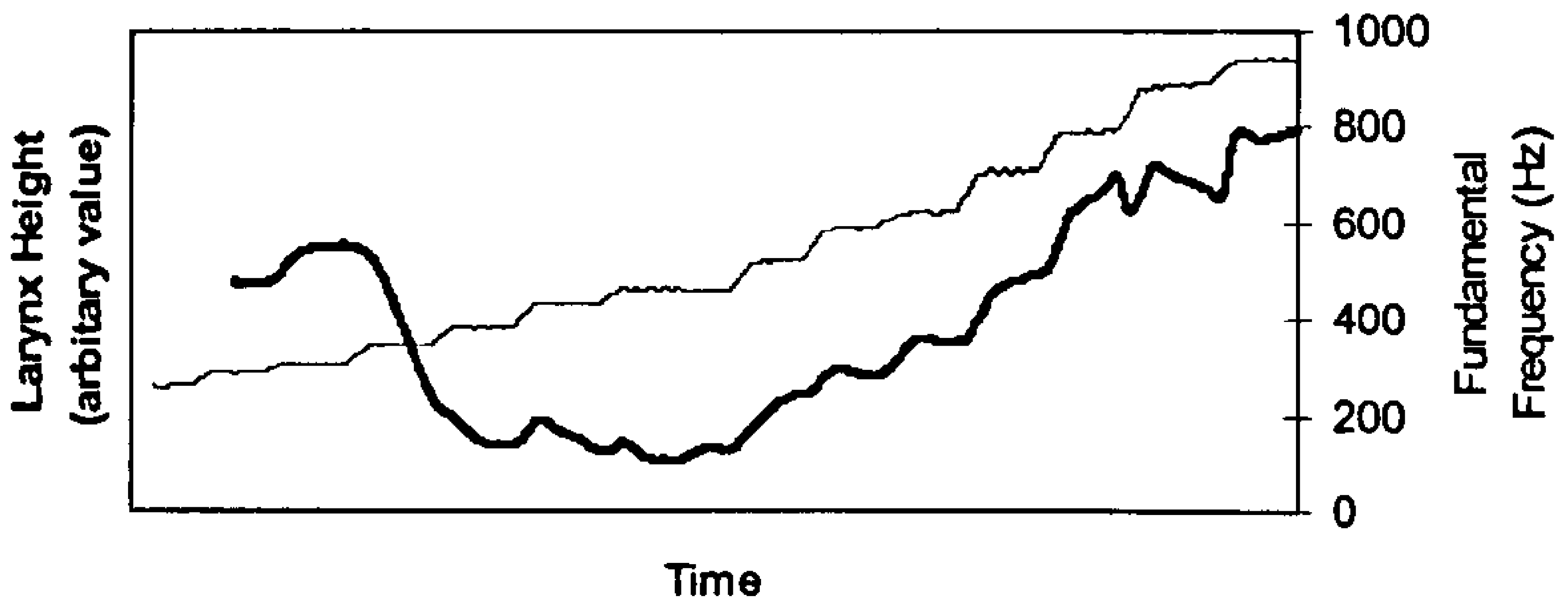
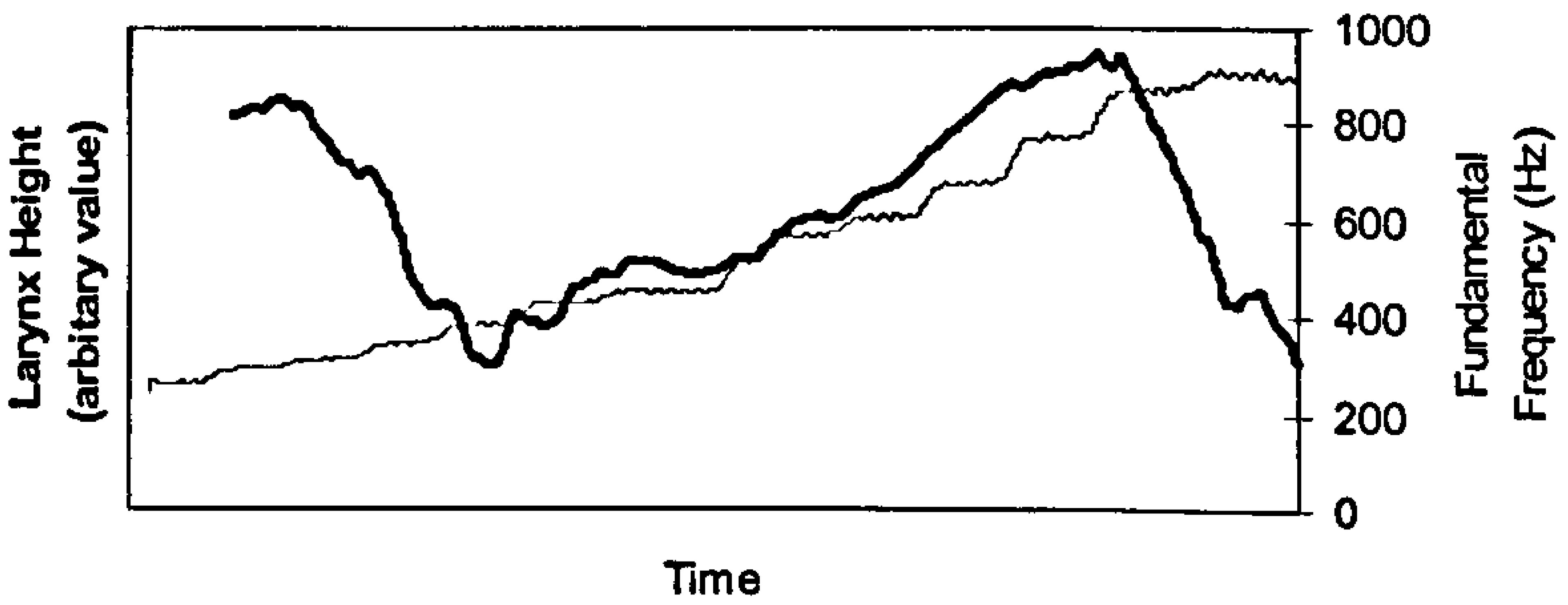


Figure 16 Larynx height movements during an ascending Bb major scale sung to the vowel [i] by subjects 1, 3, 14 and 16 (early music group) and subjects 10, 5, 7 and 12 (opera group).

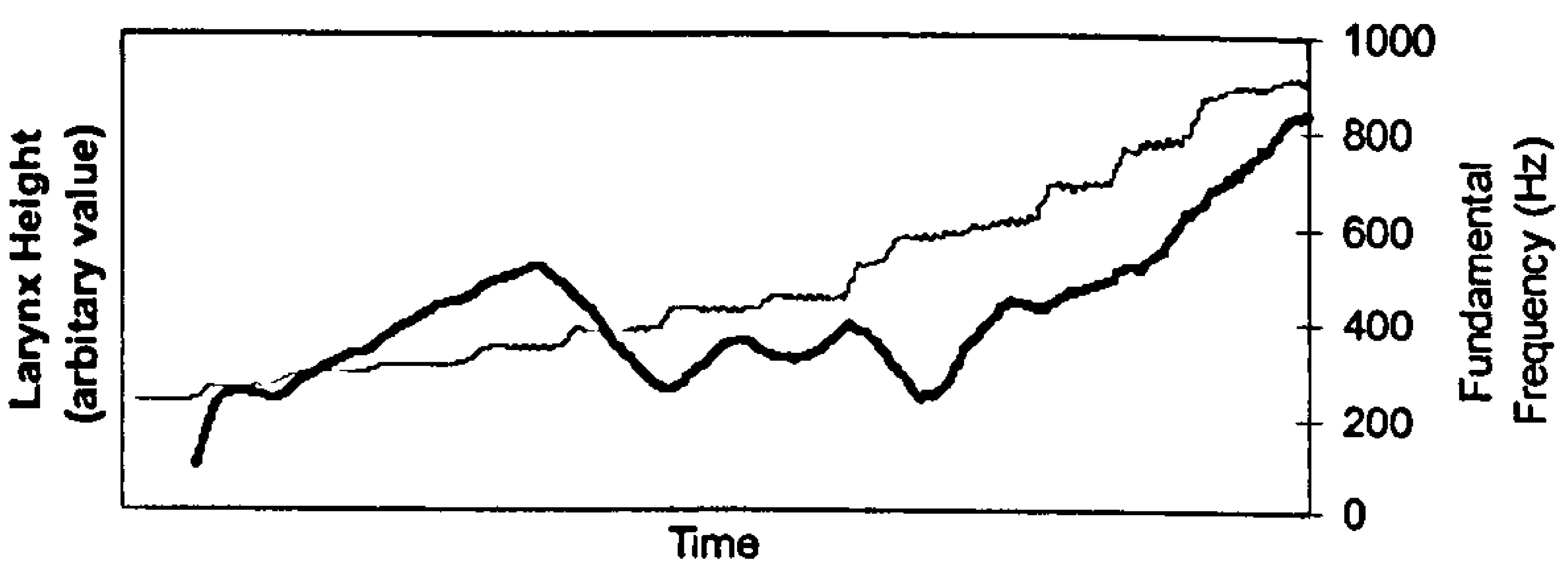
Subject 1



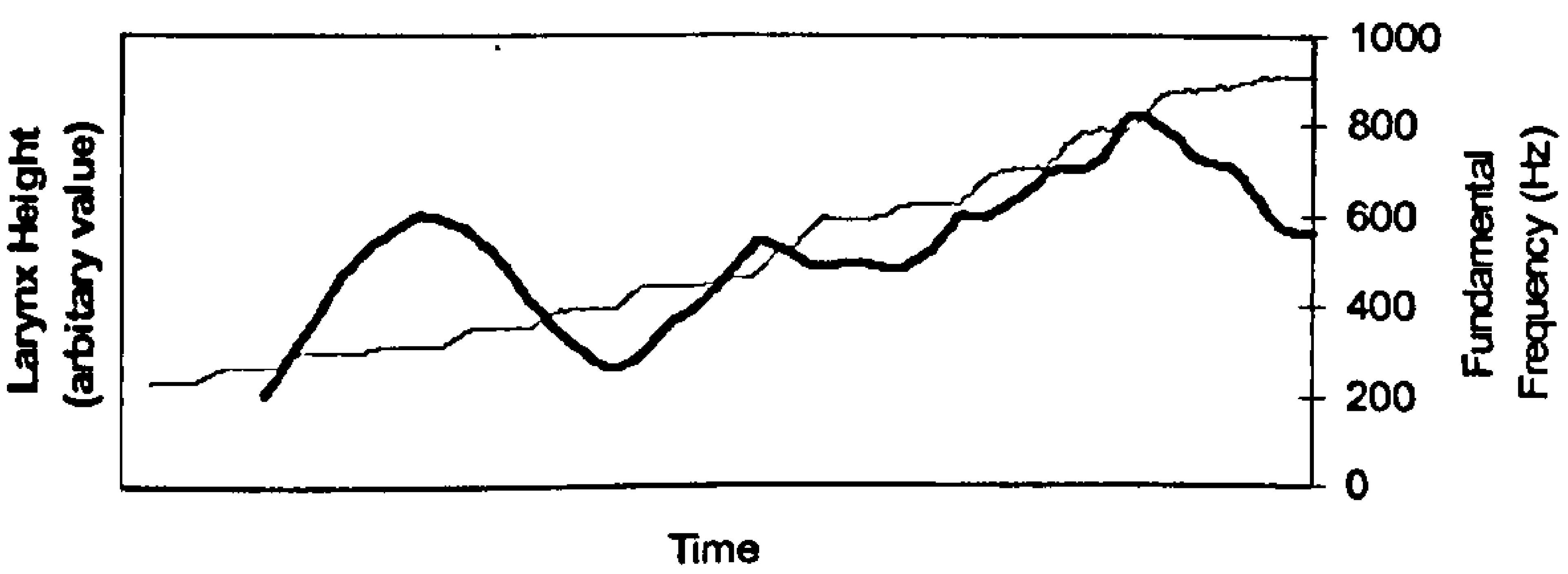
Subject 3



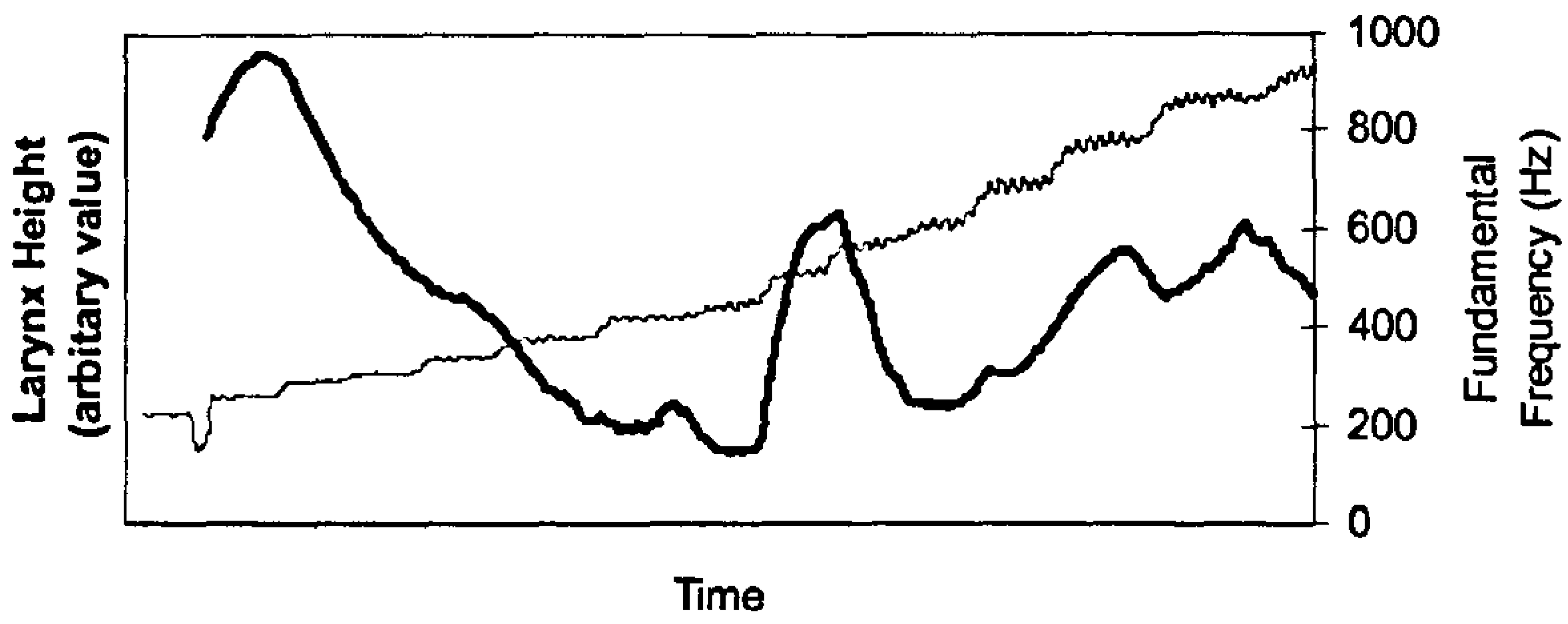
Subject 14



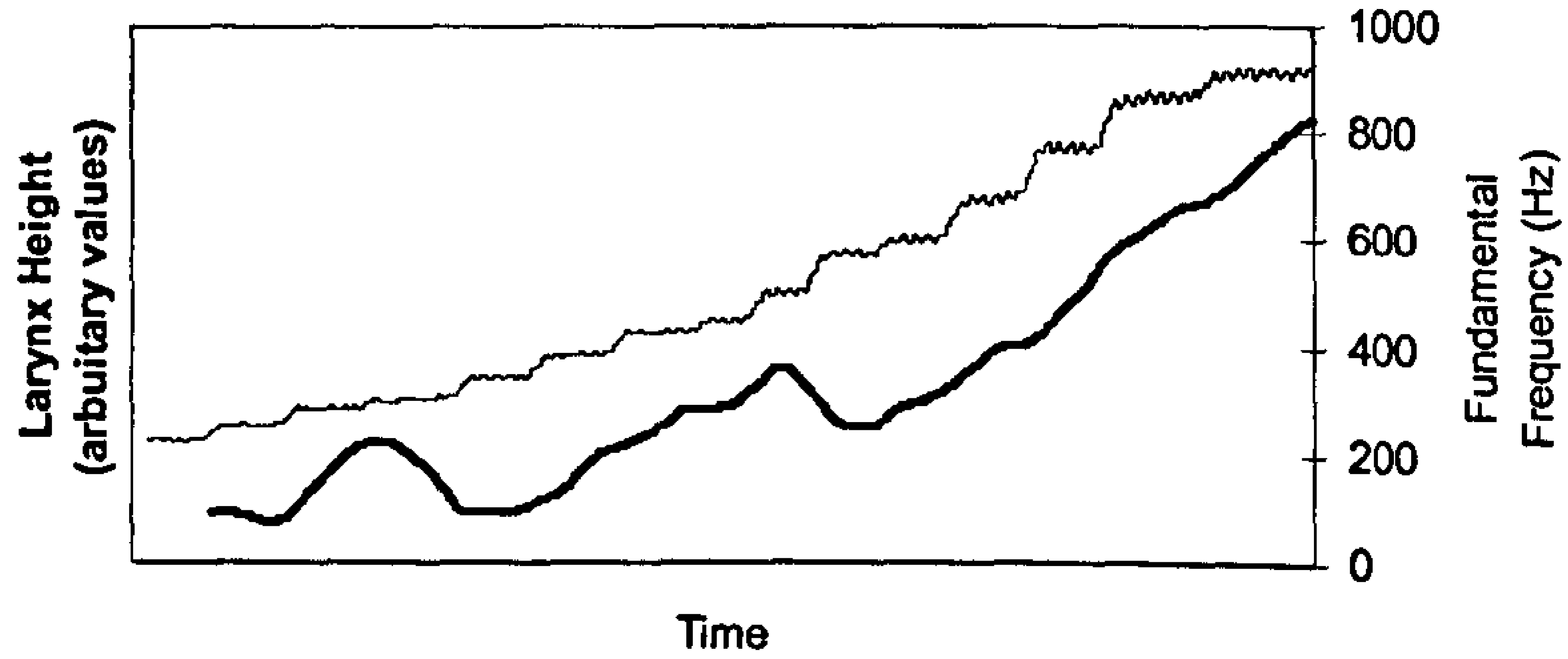
Subject 16



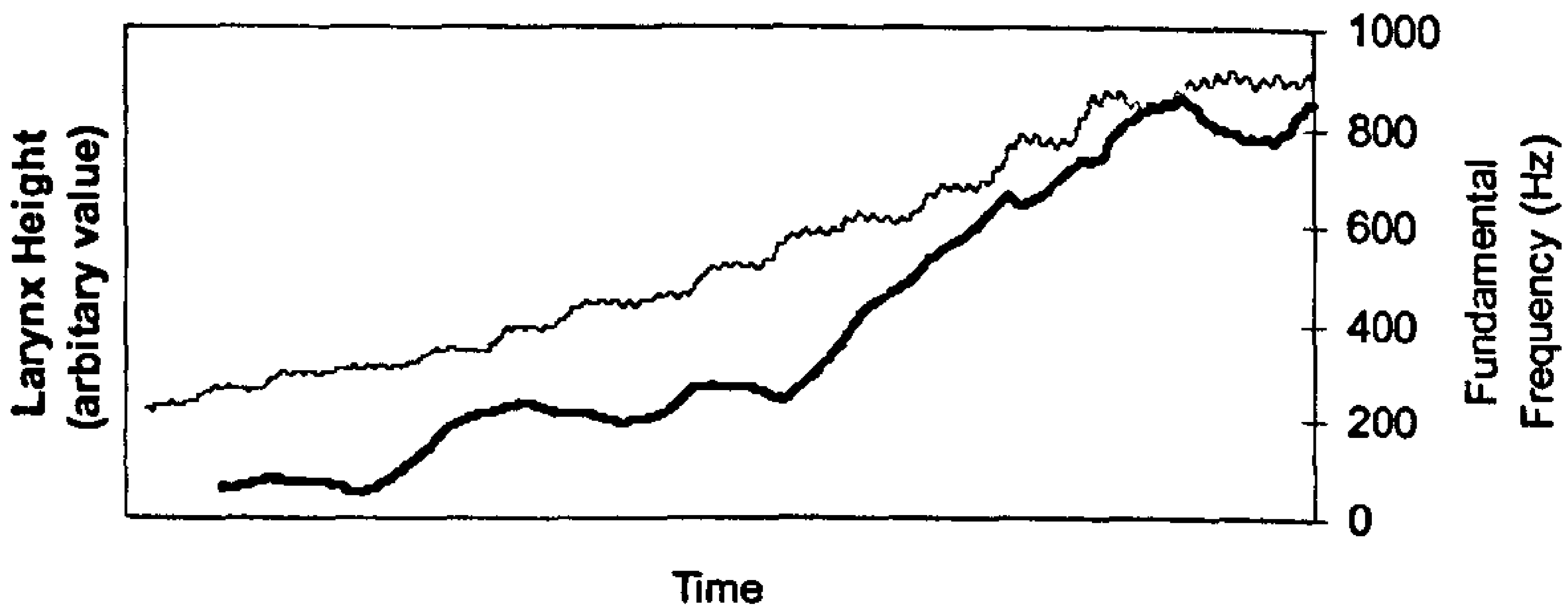
Subject 10



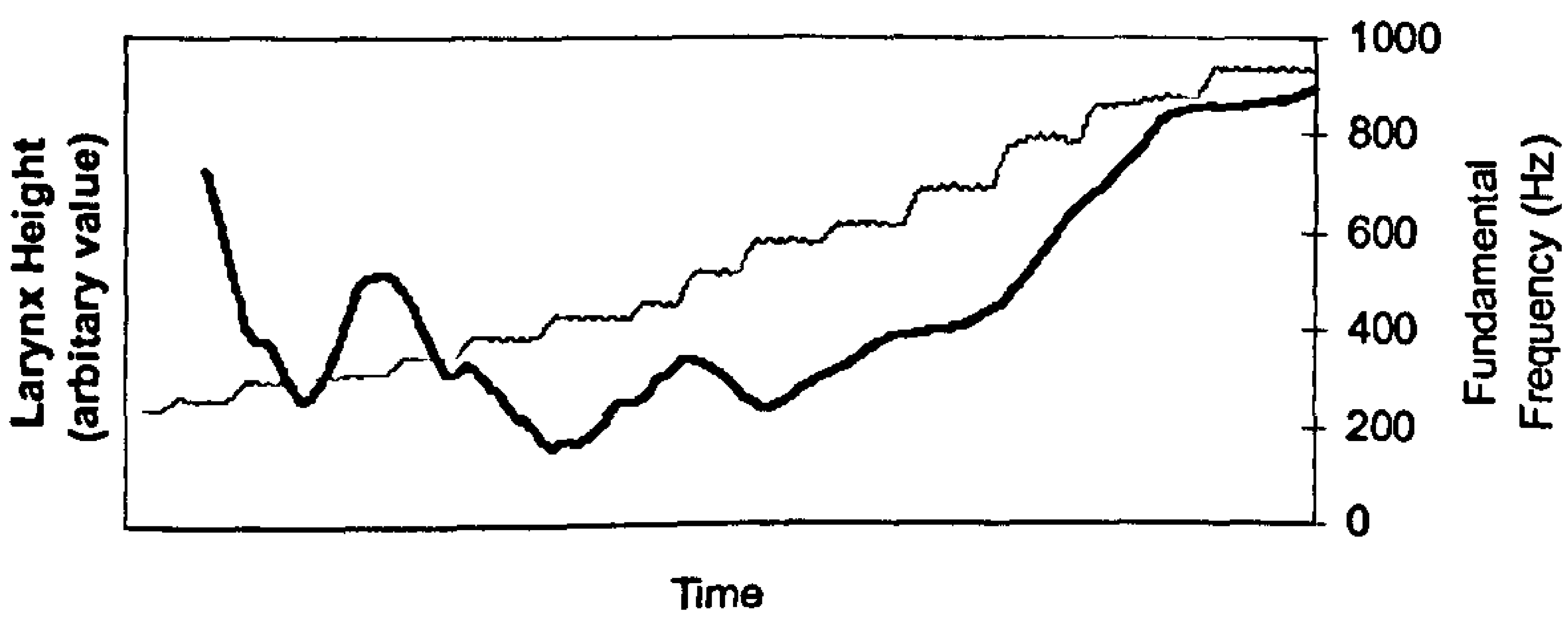
Subject 5



Subject 7



Subject 12



2.4.4 Timbre

Issues of timbre were assessed mainly through the visual inspection of spectrograms, particularly to allow observations of changing spectral energy over time. Figure 14, which shows the first note of the Handel extract, illustrates some important differences between the spectral content of the note as sung by singers from the two groups which are explored in depth in chapter 5. The introduction of individual harmonics by the early music singers during and after the onset of the note in contrast to the opera singers' use of distinct bands of energy which appear close to onset in most subjects from this group is considered particularly important to the perceptions of the specialising groups. For example, it takes subject 1 over a second before all the spectral energy she exploits within the note is introduced as opposed to just 0.2 seconds for subject 12.

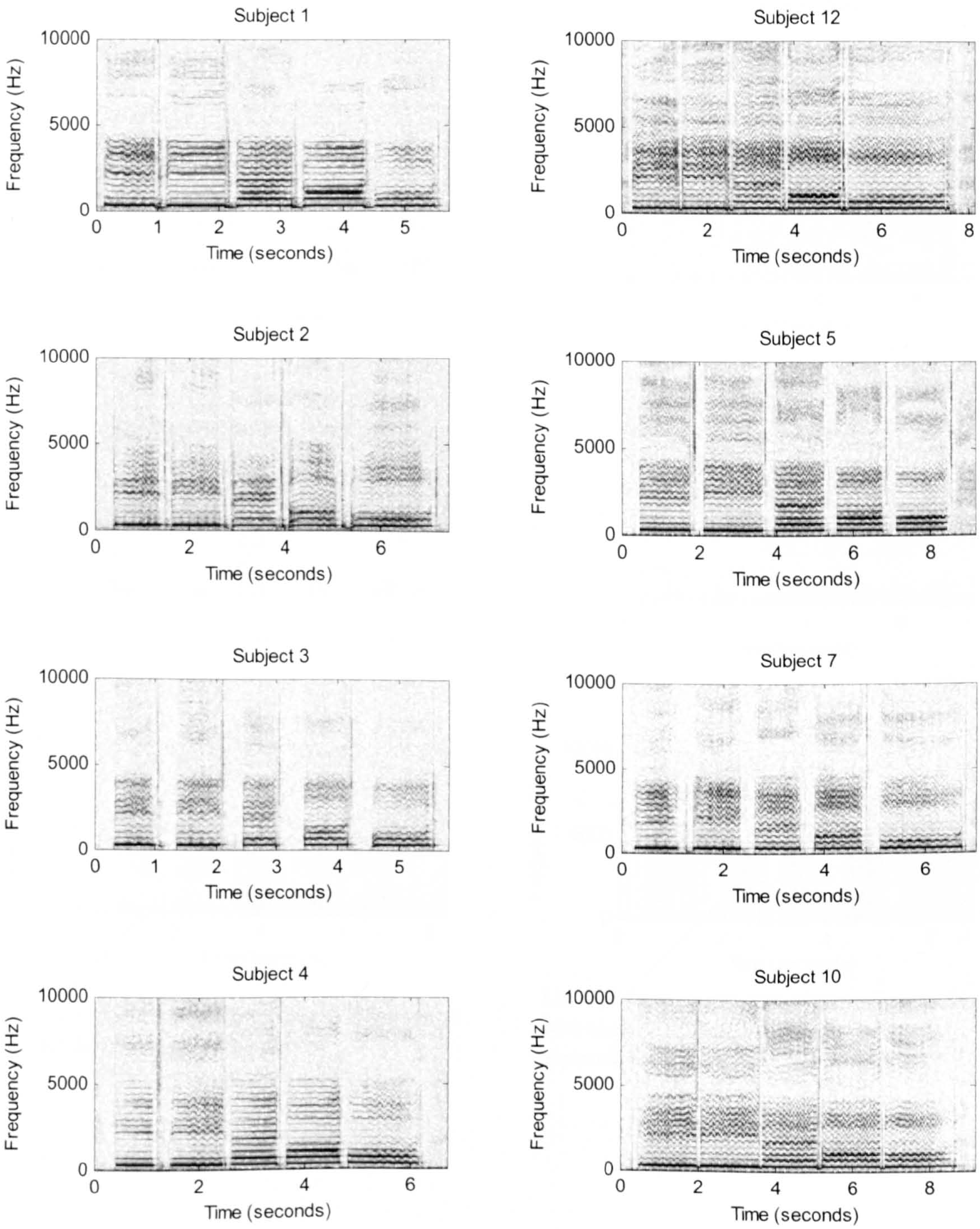
Many of the timbral characteristics seen in the spectrograms of the subjects relate to the trends seen in vibrato production and the singer's formant cluster production. The introduction of higher frequency energy in the spectra of singers from the opera group is often connected to the point at which the vibrato is introduced to the note. This is particularly noticeable in subjects 8, 9 and 10. However, with the early music singers there is a trend for their vibrato to be introduced in isolation from any spectral effects (see figure 14).

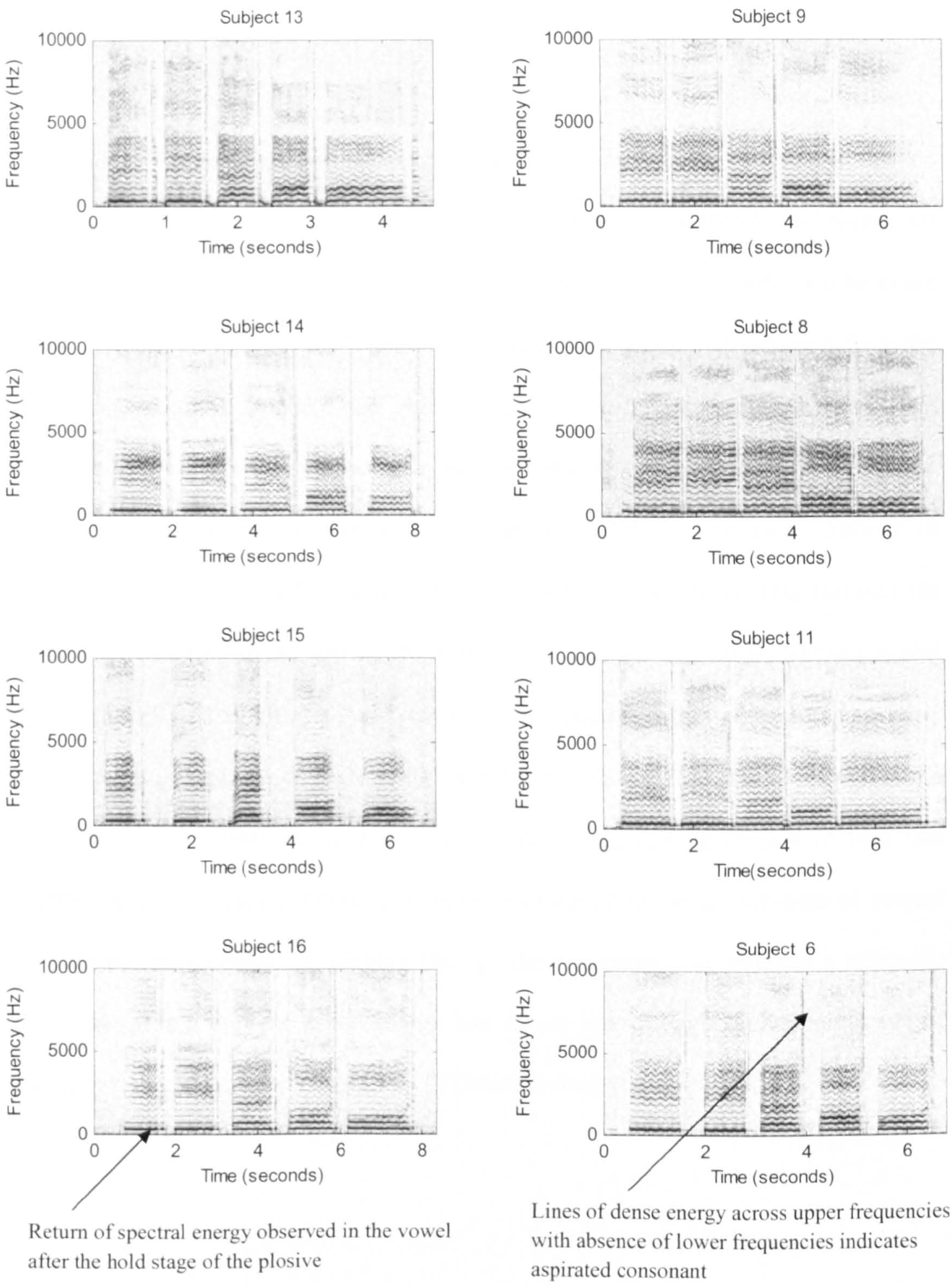
Figure 10 shows spectrograms of the Puccini extract by all subjects and illustrate the tendency for the subjects from the opera group to display more dense and consistent spectral content than the subjects from the early music group. Whilst high energy bands are observed consistently across the spectrum up to 15000Hz in many of the examples from the opera group, the energy tends to lessen at lower frequencies in the early music group. The first note of the Handel extract sung by subject 10 (see figure 14) from the opera group illustrates an extreme of this characteristic as in the last quarter of the note where the spectrum becomes very dense with high energy across the frequencies, with no clear bands of energy. Such spectral features are likely to be representative of perceived timbral differences between the singers and are considered further through LTAS analysis in the section 'resonance strategies' below.

Singers from the early music group tended to establish the maximal spectral energy of a note later than subjects from the opera group, a trend which was also observed in the singers' production of vibrato. The possibilities of this feature being a consequence of different techniques and objectives of text production and overall vocal performance, or symptomatic of the deliberate variation of timbral features as stylistic components of the individuals' specialism is considered in depth in chapter 5.

The actual production of consonants varies slightly between subjects but no significant differences are present between the two groups. There are discrepancies, for example, between the production of 'd's between the singers as some introduce false vowels and others pronounce the consonant like an Italian 't' (see figure 17).

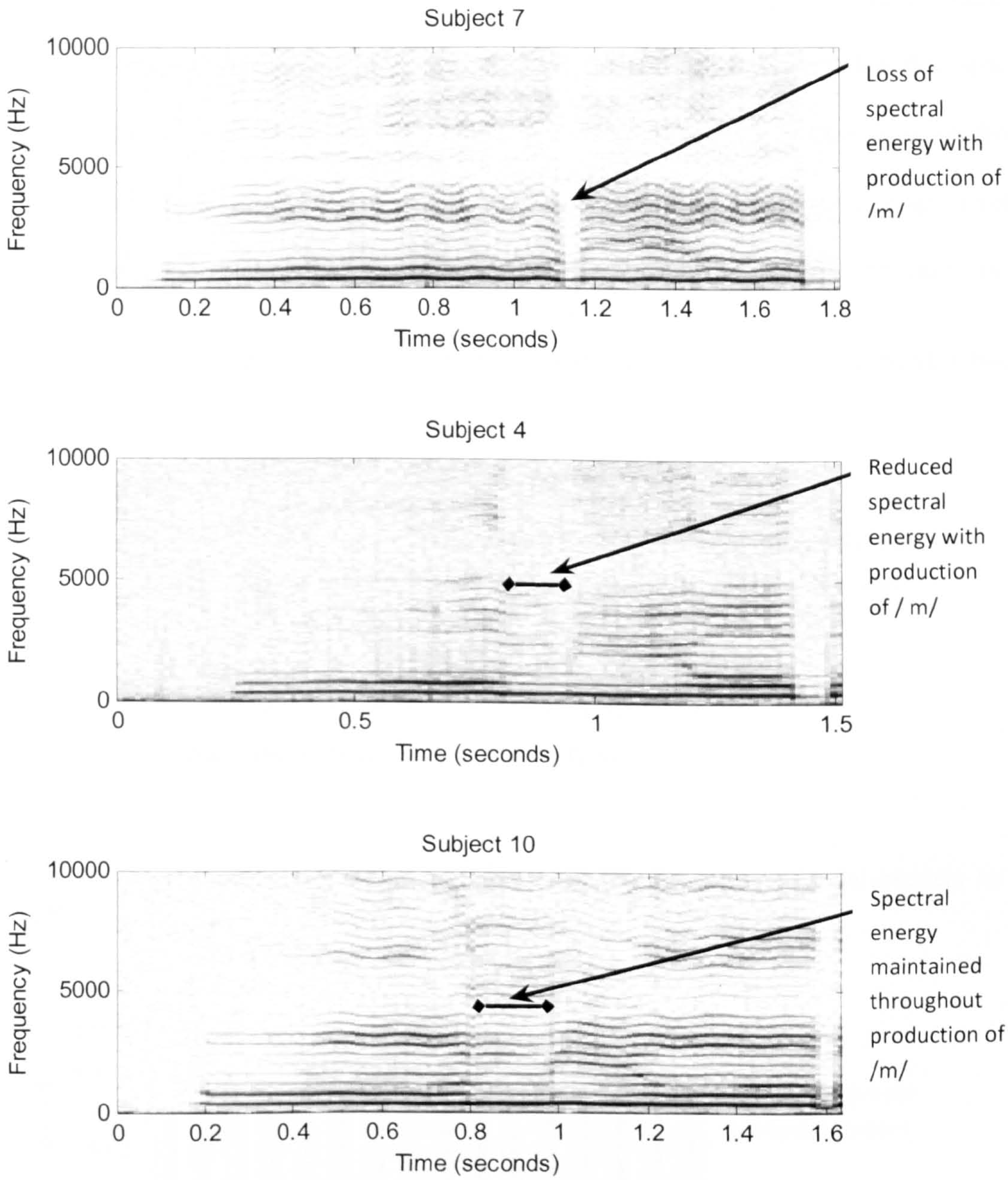
Figure 17 Spectrograms of subjects singing the words 'bid, bead, bed, bard, bored' to a midrange pitch (F#4) illustrating the different production of the consonant 'd'. Spectrograms of subjects 6 and 16 are annotated to show an Italian 't' type production with equal energy across the upper frequencies of the spectrum and the creation of a 'false vowel' after the 'hold state' respectively.




Subject 13
Subject 9
Subject 14
Subject 8
Subject 15
Subject 11
Subject 16
Subject 6
Frequency (Hz)
10000
5000
0
Time (seconds)
Time(seconds)
0
1
2
3
4
6
8
Return of spectral energy observed in the vowel after the hold stage of the plosive
Lines of dense energy across upper frequencies with absence of lower frequencies indicates aspirated consonant

The amount of time spent on consonants tends to be similar and differences that do occur are usually in voiced consonants. Figure 18 shows the different techniques for producing the 'm' in 'O Mio' in the Puccini extract. Spectrograms of these two notes are shown in figure 18 for subjects 7 and 10 from the opera group and subject 4 from the early music group to illustrate this point. Subject 7 represents the production of this consonant by most subjects producing a 'gap' in spectral energy between the two notes, which is labelled on the spectrogram and presents as white vertical strips. Subject 10 exhibits the most acute differences to the other subjects by 'resonating through the consonants' resulting in no gap in the spectral energy between notes. Subject 4 also exploits this effect though to a lesser extent as the spectral energy lessens considerably as the consonant is produced even though it doesn't disappear. Subject 10 also produces other consonants notably faster than other subjects, reducing the amount of time that spectral energy is reduced. Traits such as these observed in the spectrogram of subject 10 could be characteristic of 'singing through the consonants' to maintain a relatively consistent spectral content to the sound, and legato line through near continuation of voicing which are considered a priority in classical singing training.

Figure 18 Spectrograms showing production of /m/ in the phrase 'O Mio' by three subjects



2.4.5 Intensity

The maximum and average intensity was calculated for both the Puccini extract and the Handel extract for all subjects taking the intensity readings from PRAAT. The values obtained in PRAAT were calibrated using the SPL meter readings from the calibration tone. The results are shown in figures 19 and 20 and show no notable differences between the groups, although the highest and lowest intensity readings were from subjects in the opera group (subject 10) and early music group (subject 1) respectively. There were no noticeable differences between the two groups in their overall intensity.

Figure 19 Graph showing the average intensity of the Puccini and Handel extracts by all subjects

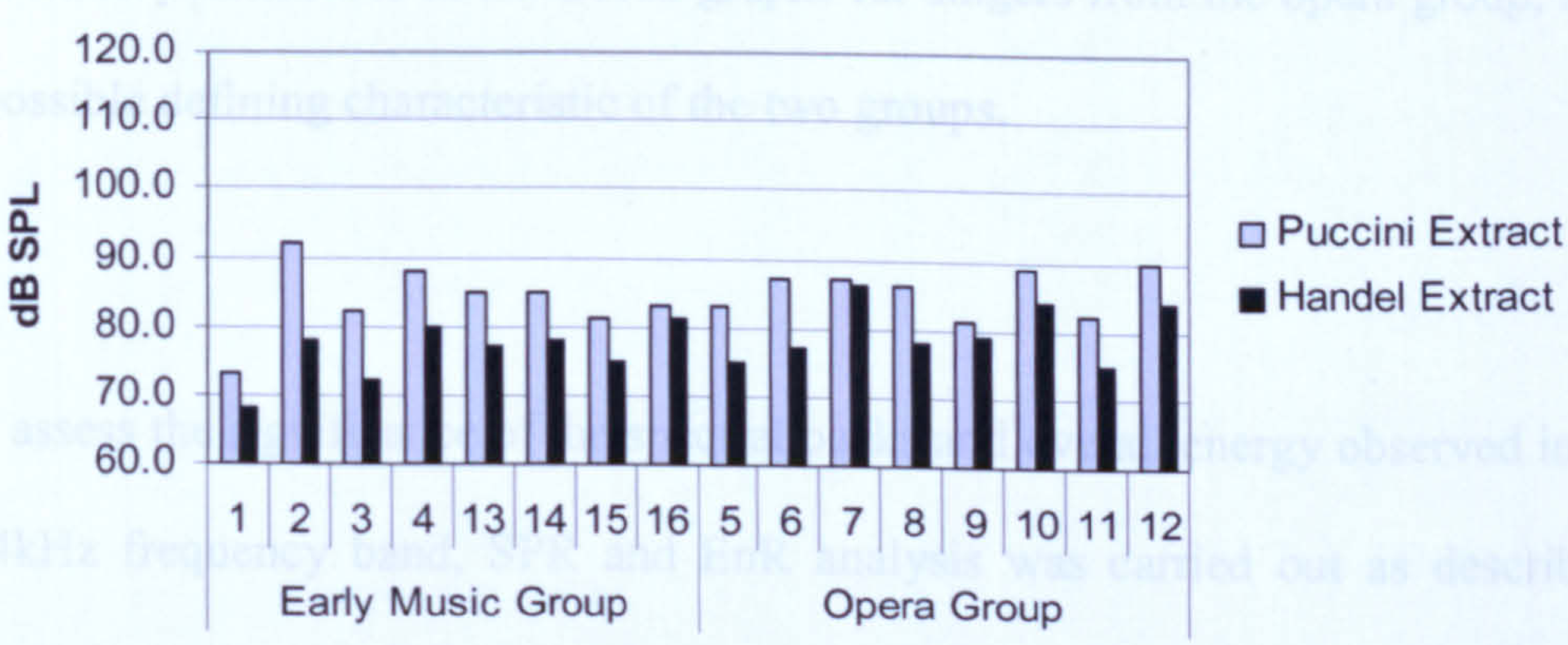
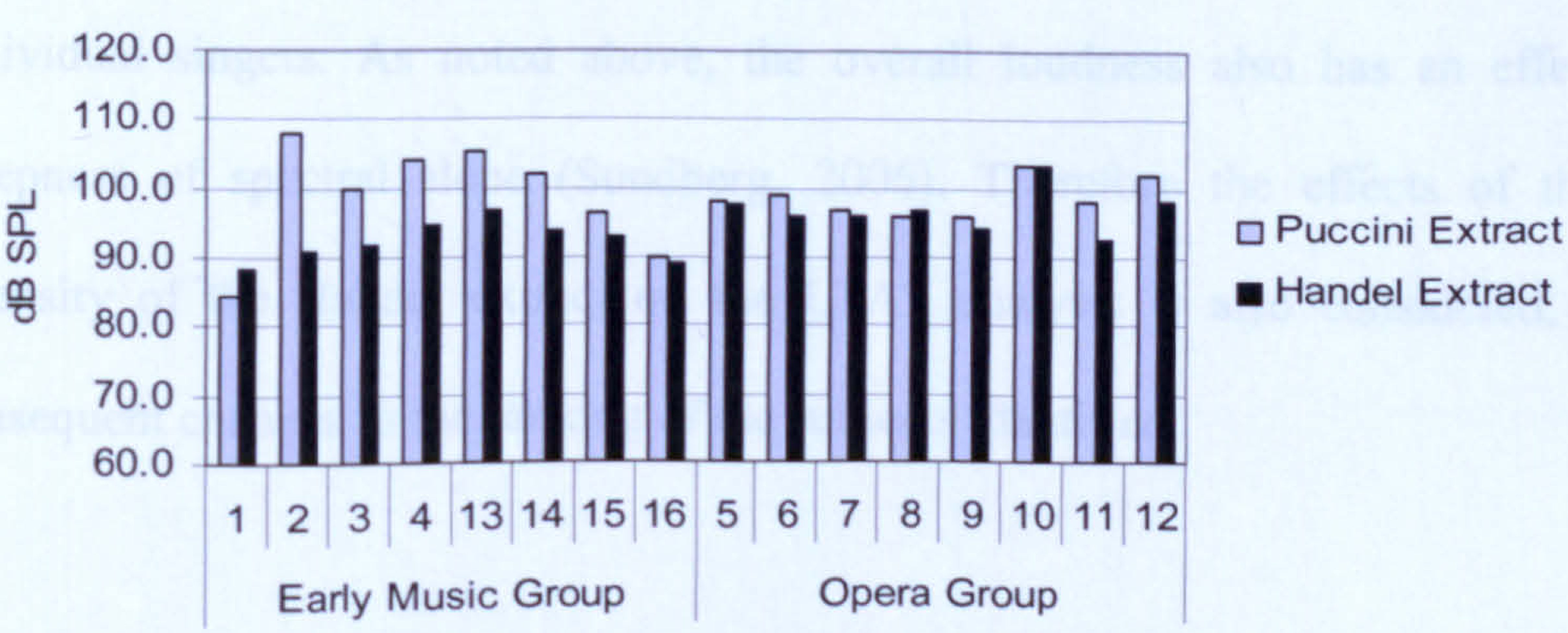


Figure 20 Graph showing the maximum intensity of the Puccini and Handel extracts by all subjects

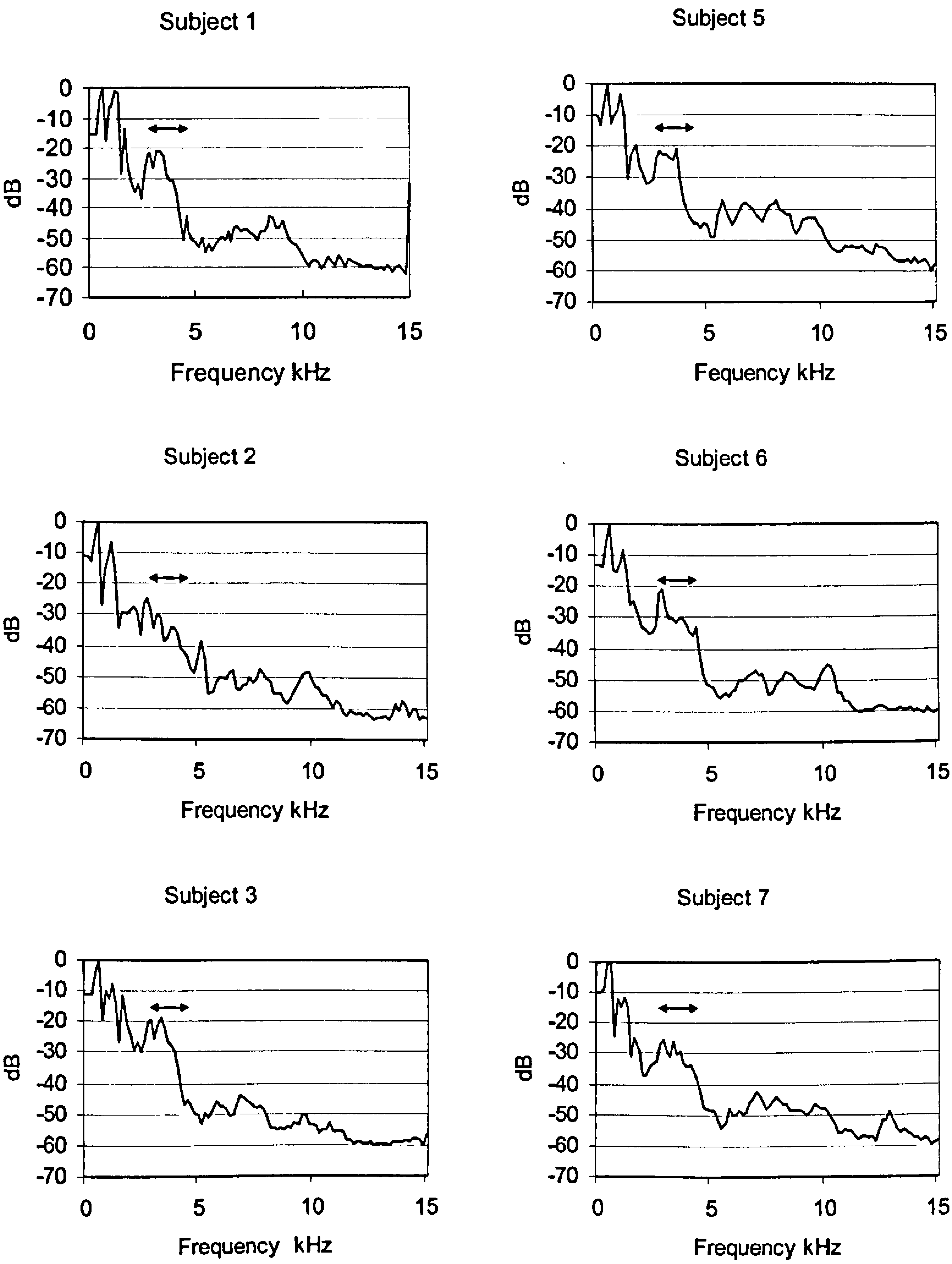


2.4.6 Resonance Strategies

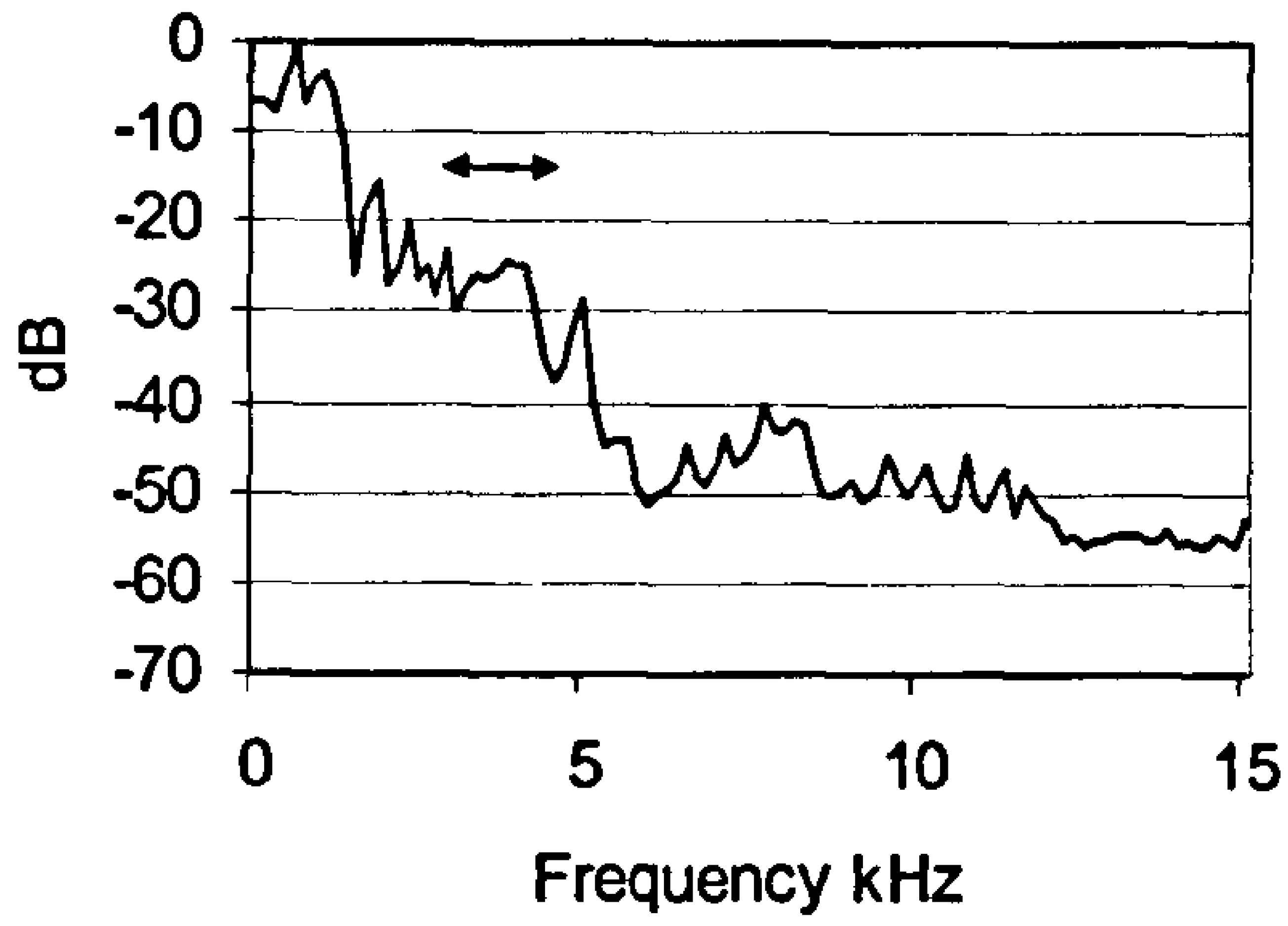
As guidelines suggest a sound sample of at least 20 seconds for LTAS analysis to provide a stable representation curve (Sundberg, 2001), the Handel extract was used for analysis. Figure 21 shows LTAS curves to 15kHz for each of the subjects with noticeable peaks labelled on each graph. The LTAS curves show considerable peaks in the 2kHz – 4kHz frequency region for all subjects, suggesting characteristics common to identified classical singing techniques in all subjects. Individual subjects are isolated in chapter 6 when particularly extreme trends are observed. The LTAS graphs also show an additional peak in the spectral envelope in the frequency band 5kHz – 10kHz. This is particularly noticeable in the LTAS graphs for singers from the opera group, suggesting a possible defining characteristic of the two groups.

To assess the significance of the spectral peaks and overall energy observed in the 2kHz – 4kHz frequency band, SPR and EnR analysis was carried out as described in the 'Analysis' section of this chapter. The values for both EnR and SPR are shown in table 5 and show a range of results across the groups. These values are carefully considered in chapter 6 with particular attention given to the relationship between the results for the individual singers. As noted above, the overall loudness also has an effect on the steepness of spectral slope (Sundberg, 2006). Therefore the effects of the overall intensity of the Handel extract on the LTAS analysis is also considered, with any consequent changes in the ranking of the subjects identified.

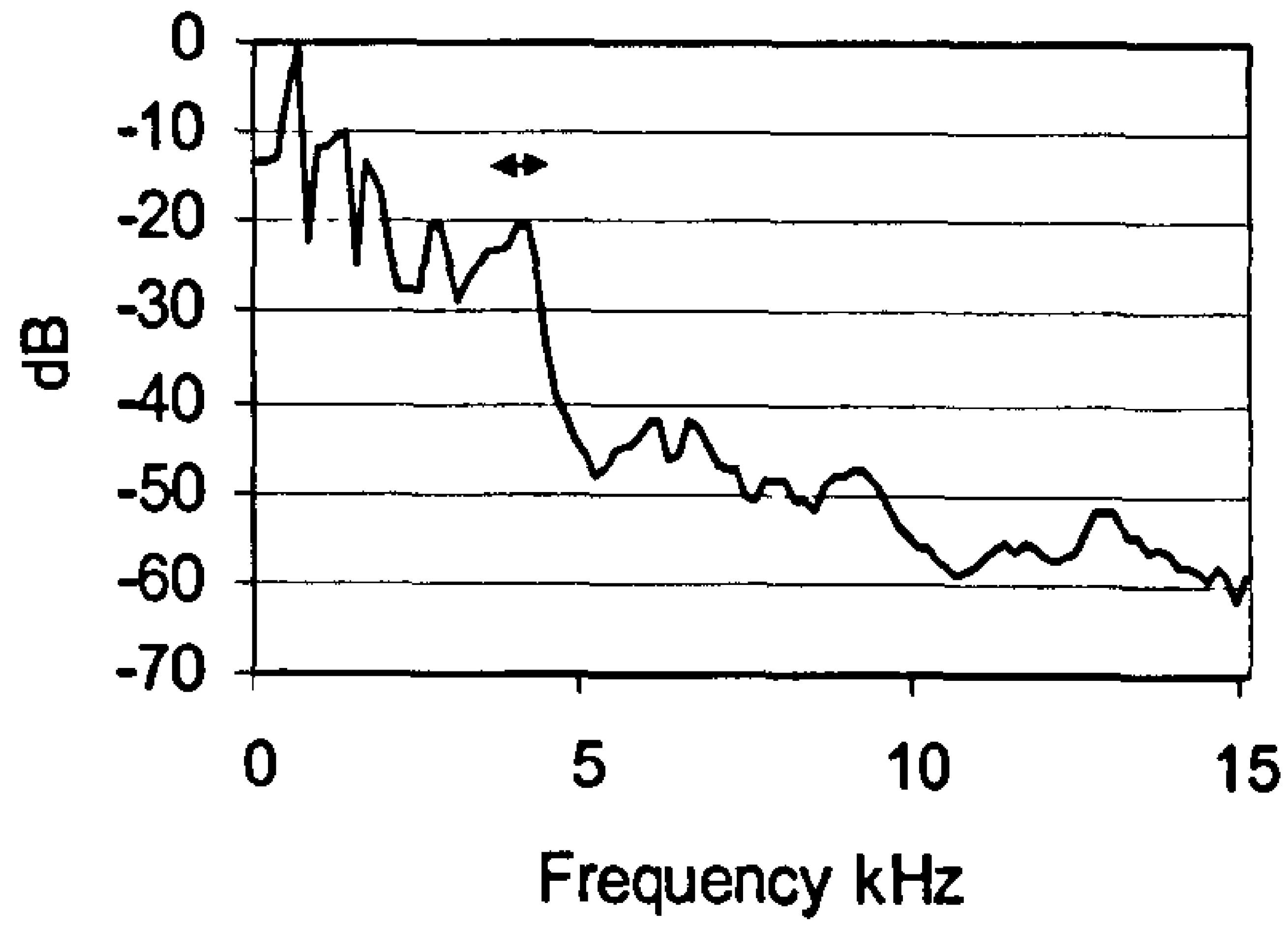
Figure 21 Normalised LTAS graphs for all subjects singing the Handel extract (Early Music Group – left column Opera Group – right column)



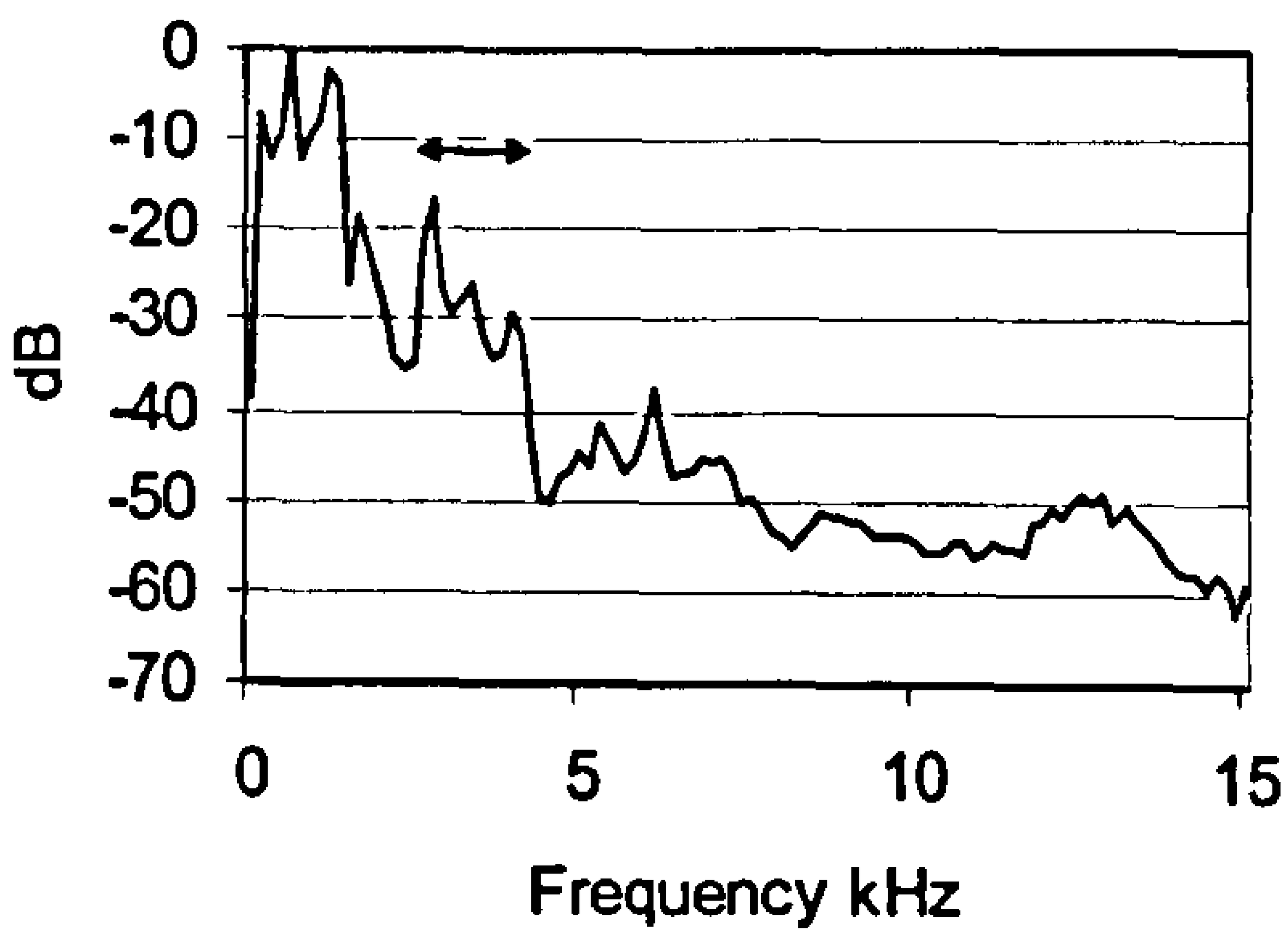
Subject 4



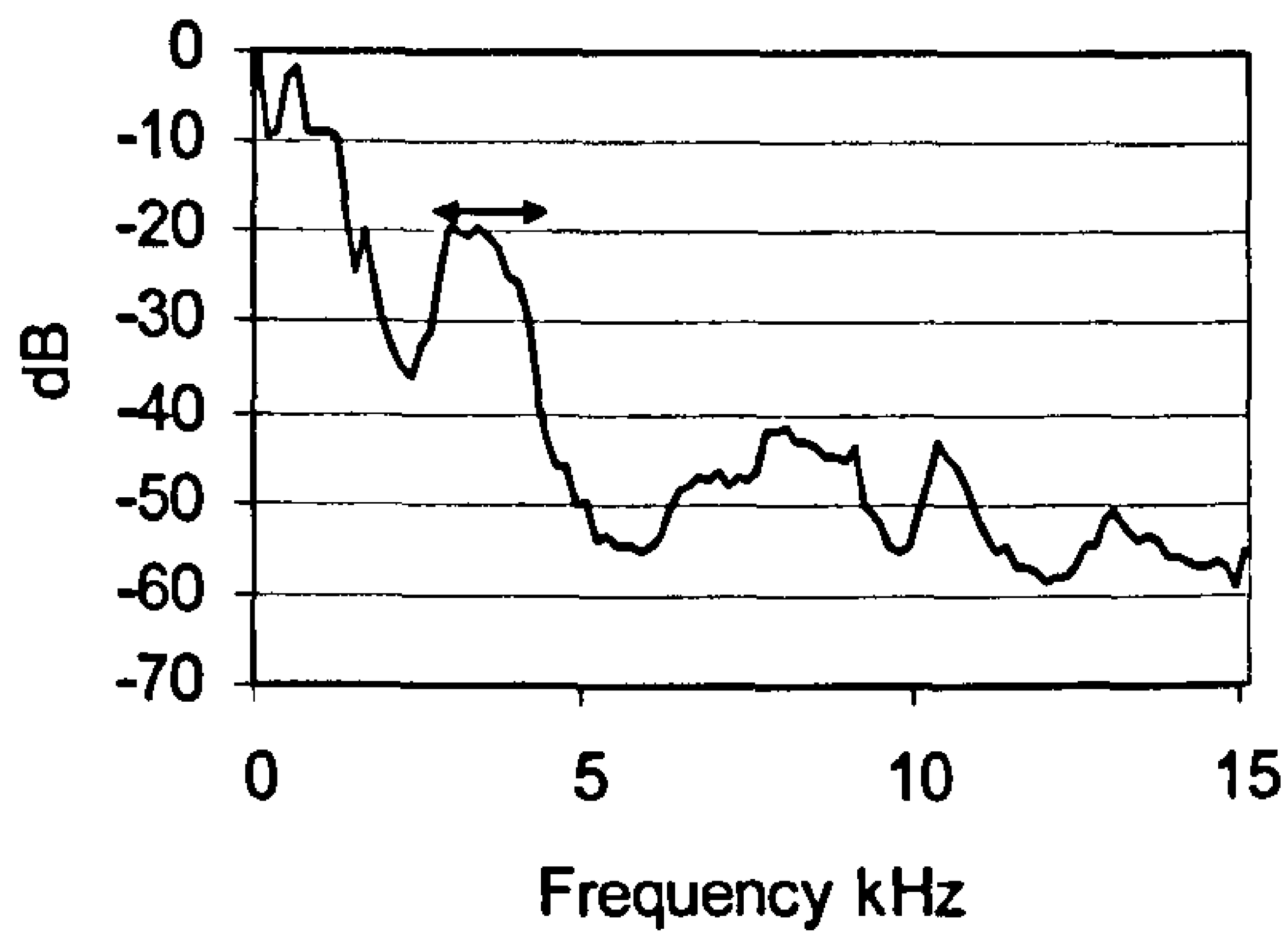
Subject 8



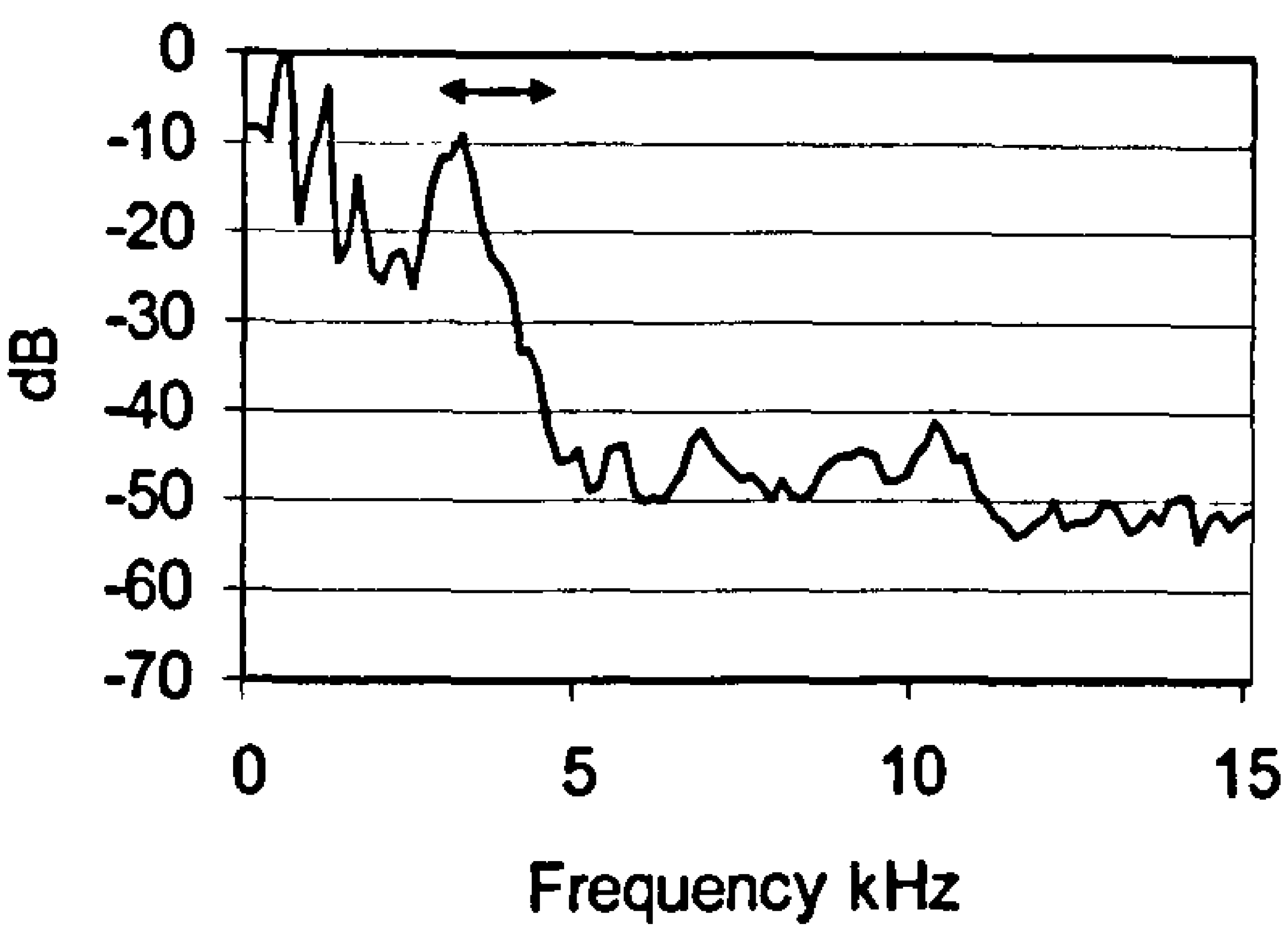
Subject 13



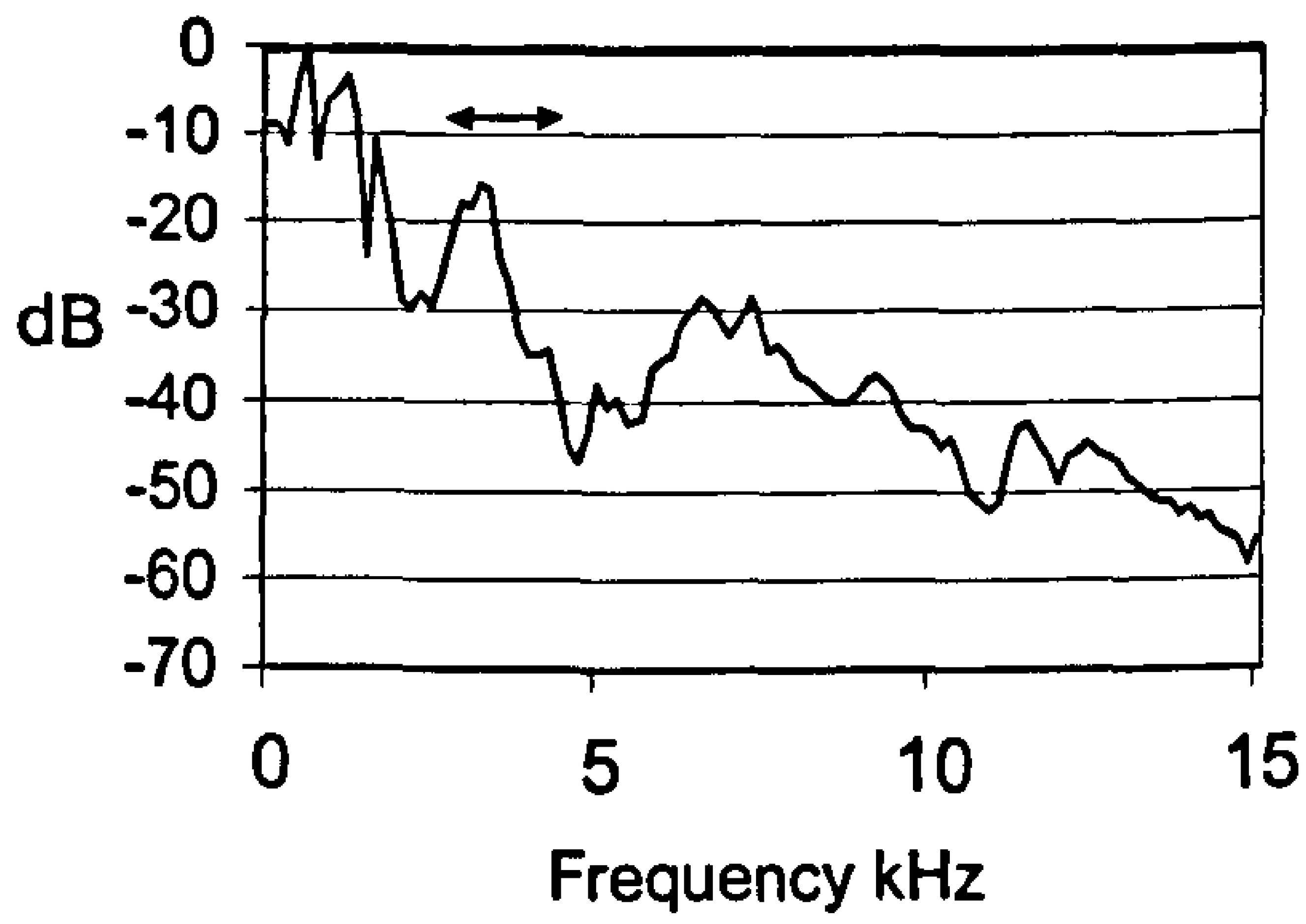
Subject 9



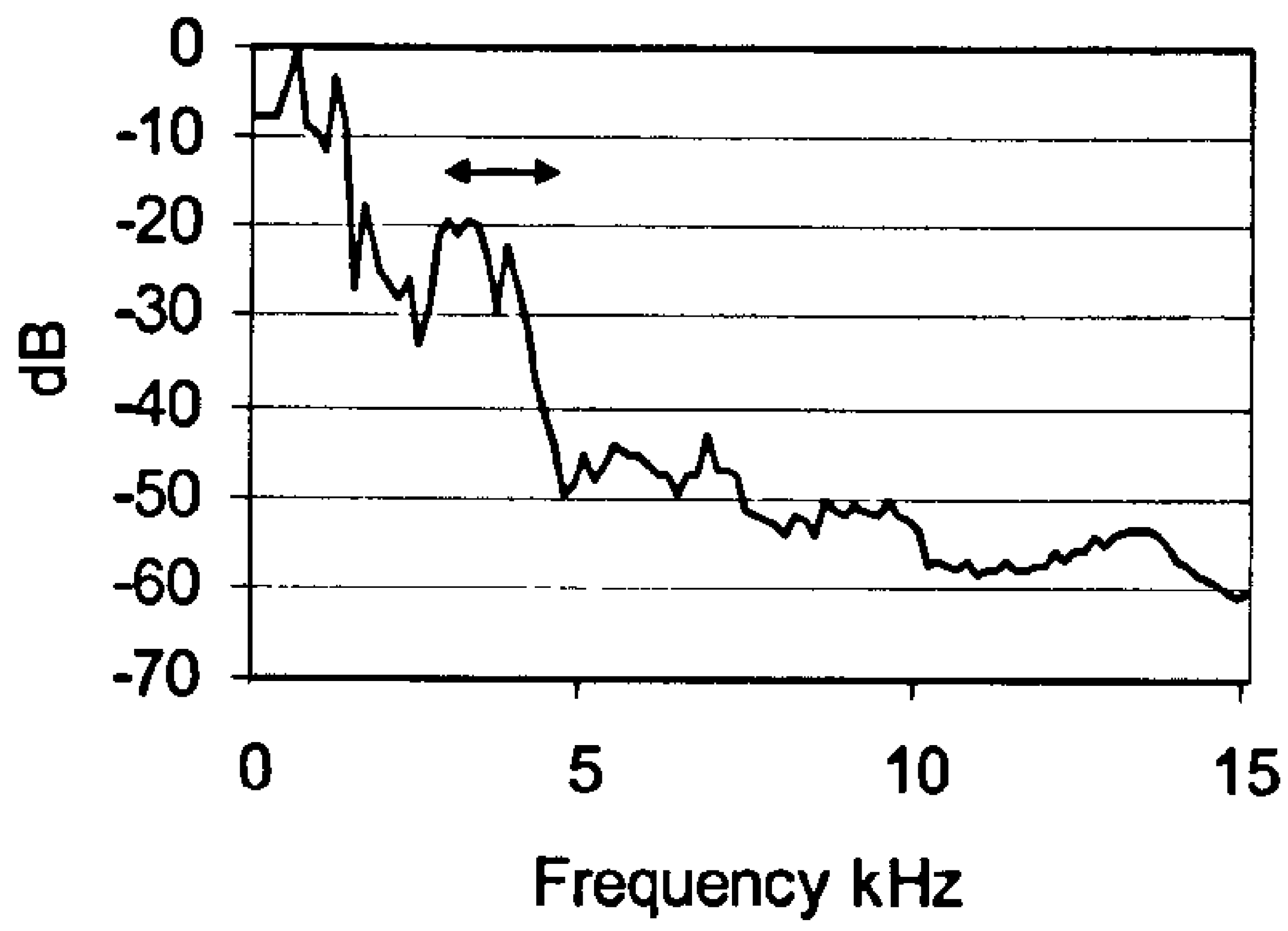
Subject 14



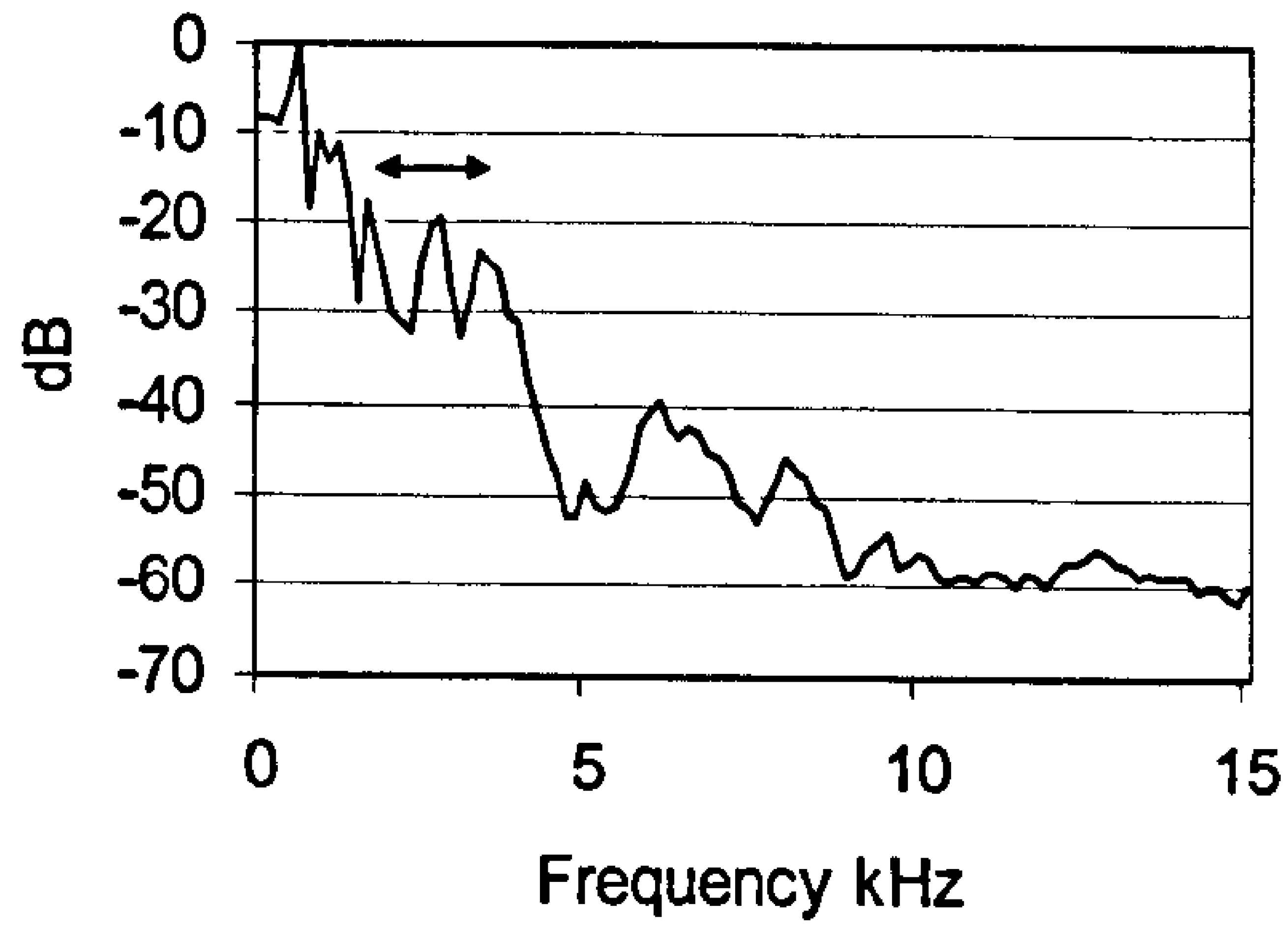
Subject 10



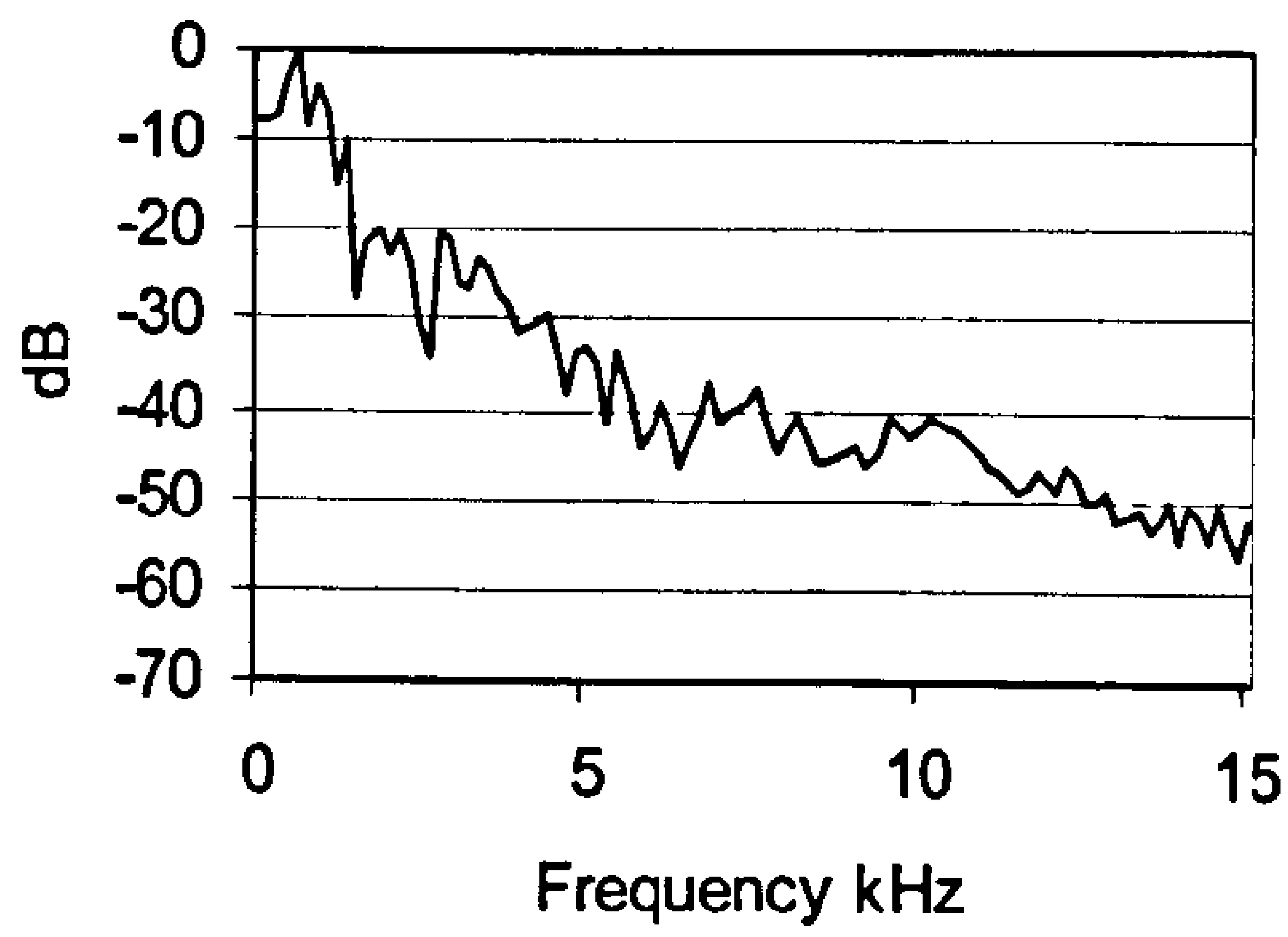
Subject 15



Subject 11



Subject 16



Subject 12

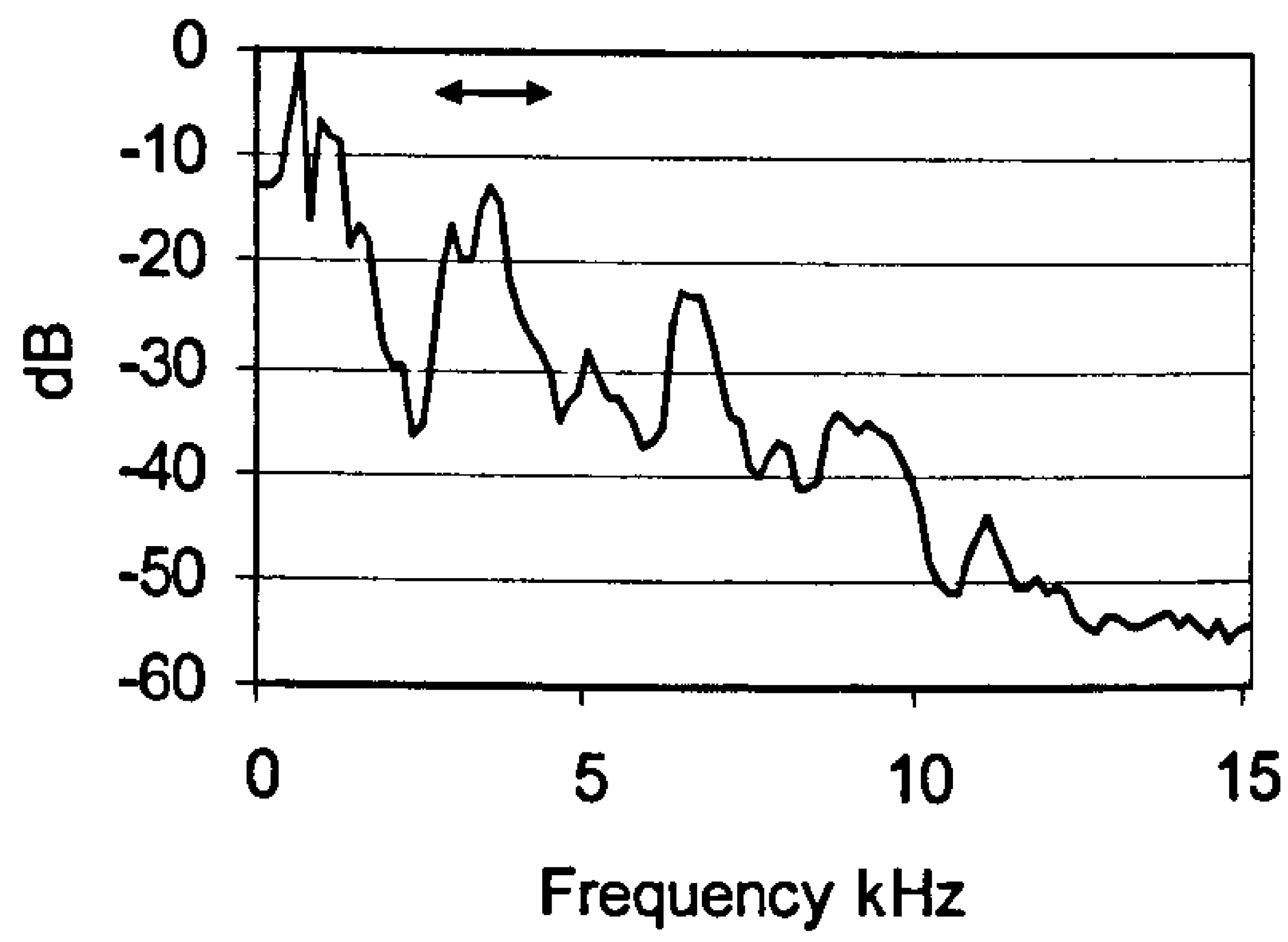
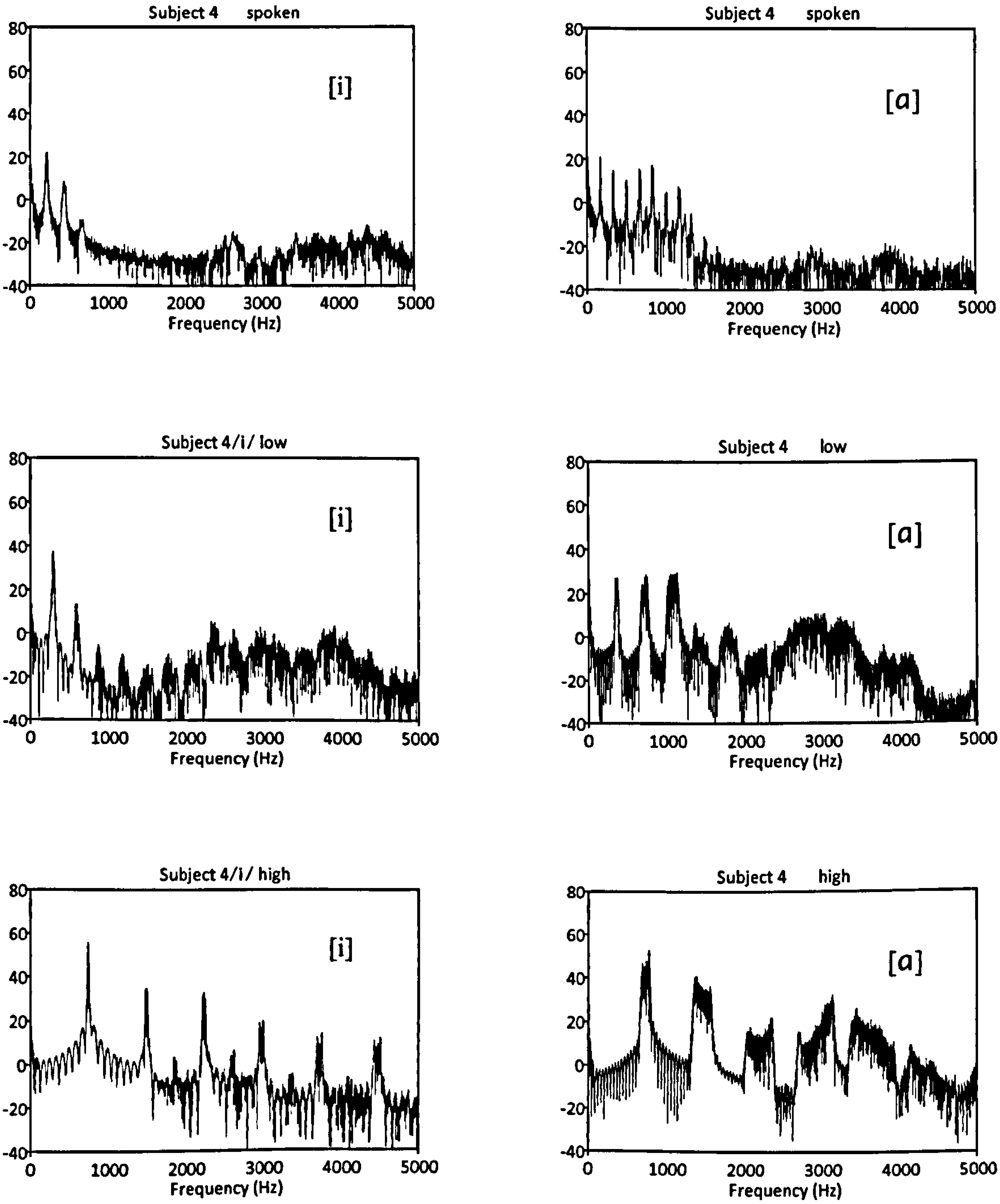


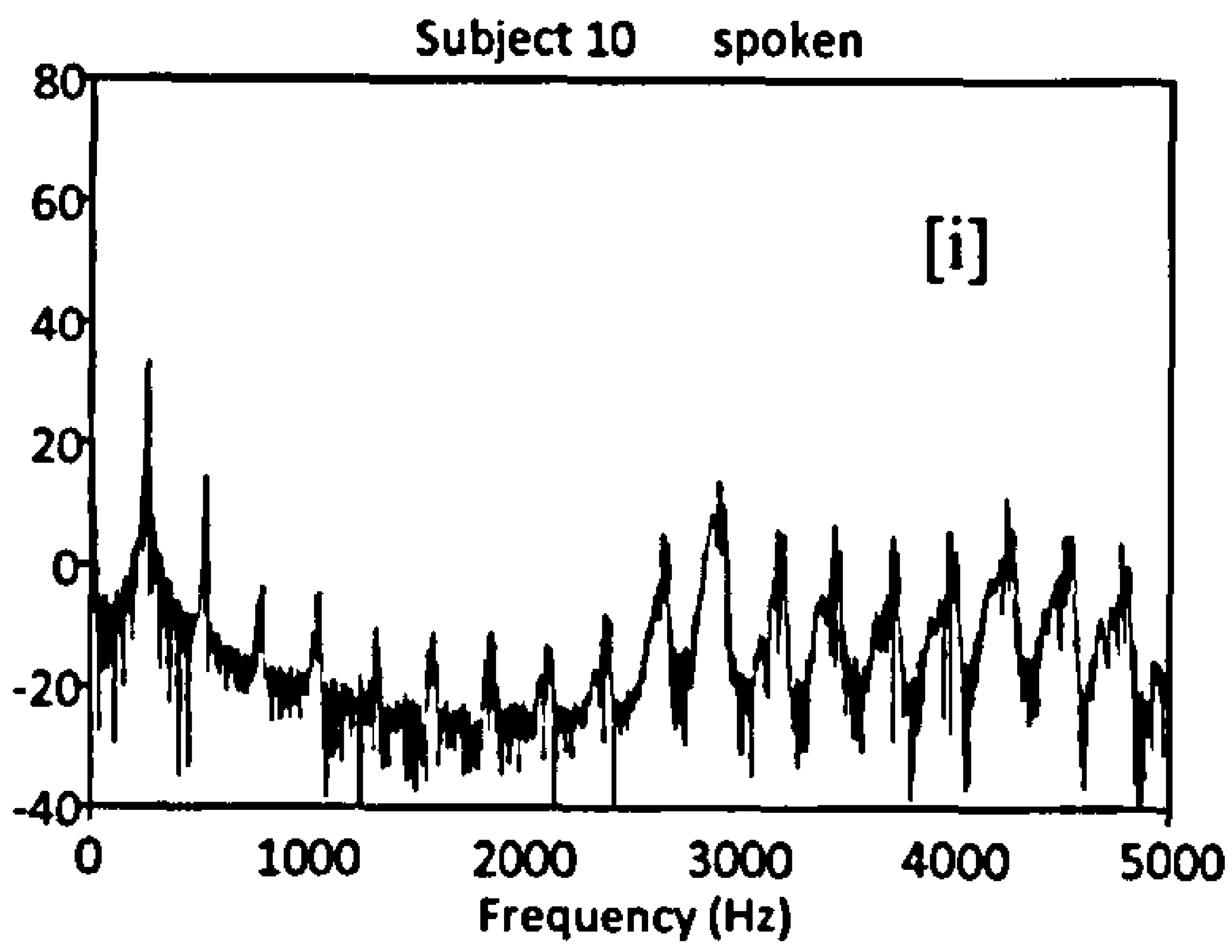
Table 5 Showing the EnR, SPR and Average Intensity for each subject with group averages (Handel extract)

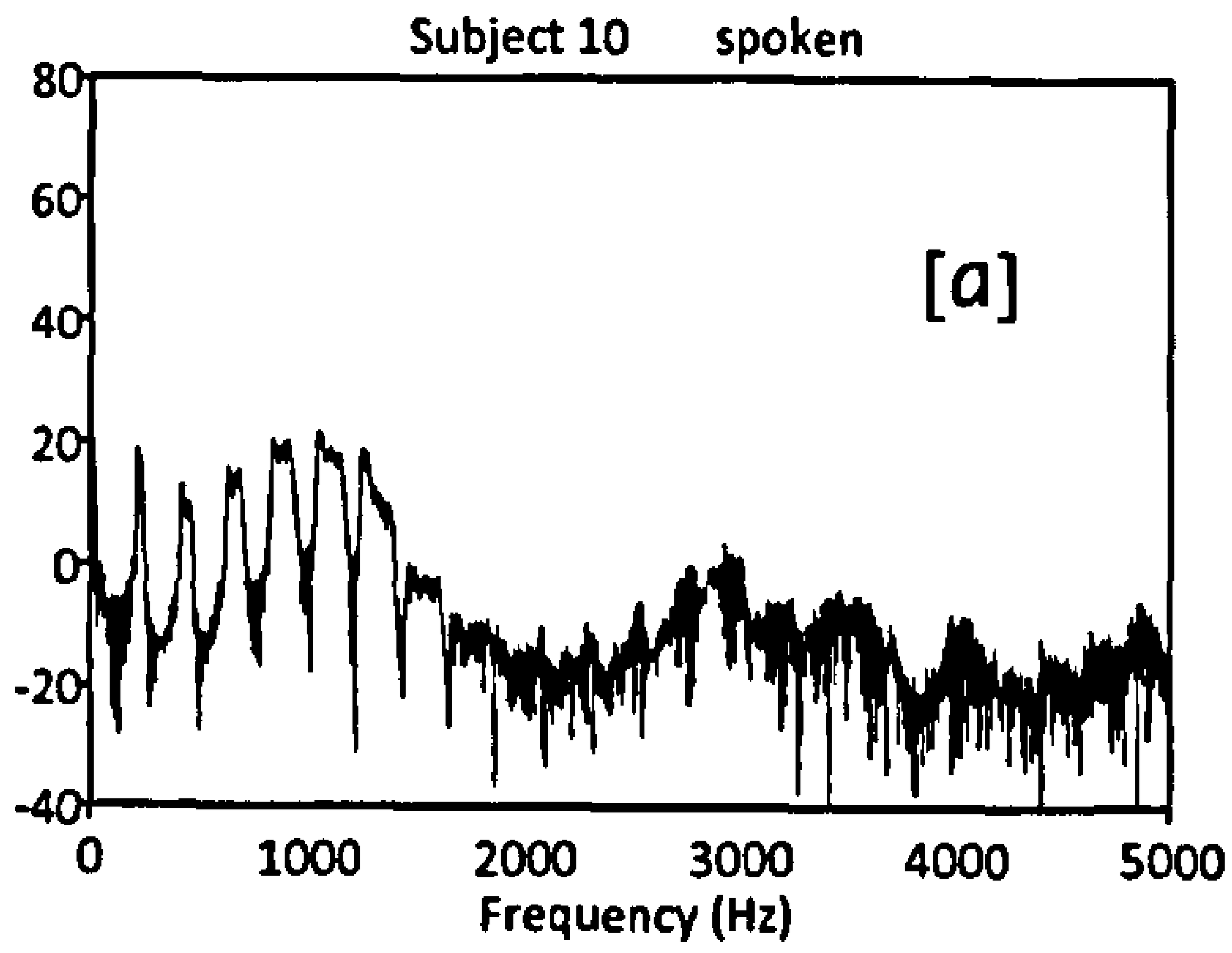
	Subject no	EnR (dB)	SPR (dB)	Average intensity (dB)
Early music group	1	**21**	**24**	68.5
	2	**24**	**27**	78.5
	3	**21**	**20**	72.9
	4	**27**	**26**	80.4
	13	**23**	**21**	77.2
	14	**12**	**13**	78.4
	15	**23**	**18**	75
	16	**22**	**22**	81
	Mean	**22**	**21**	76
Opera Group	5	**22**	**20**	75
	6	**22**	**21**	77.9
	7	**24**	**31**	86
	8	**17**	**20**	78.5
	9	**18**	**22**	79.7
	10	**18**	**14**	84.3
	11	**22**	**18**	75.4
	12	**13**	**13**	84
	Mean	***19***	***20***	79

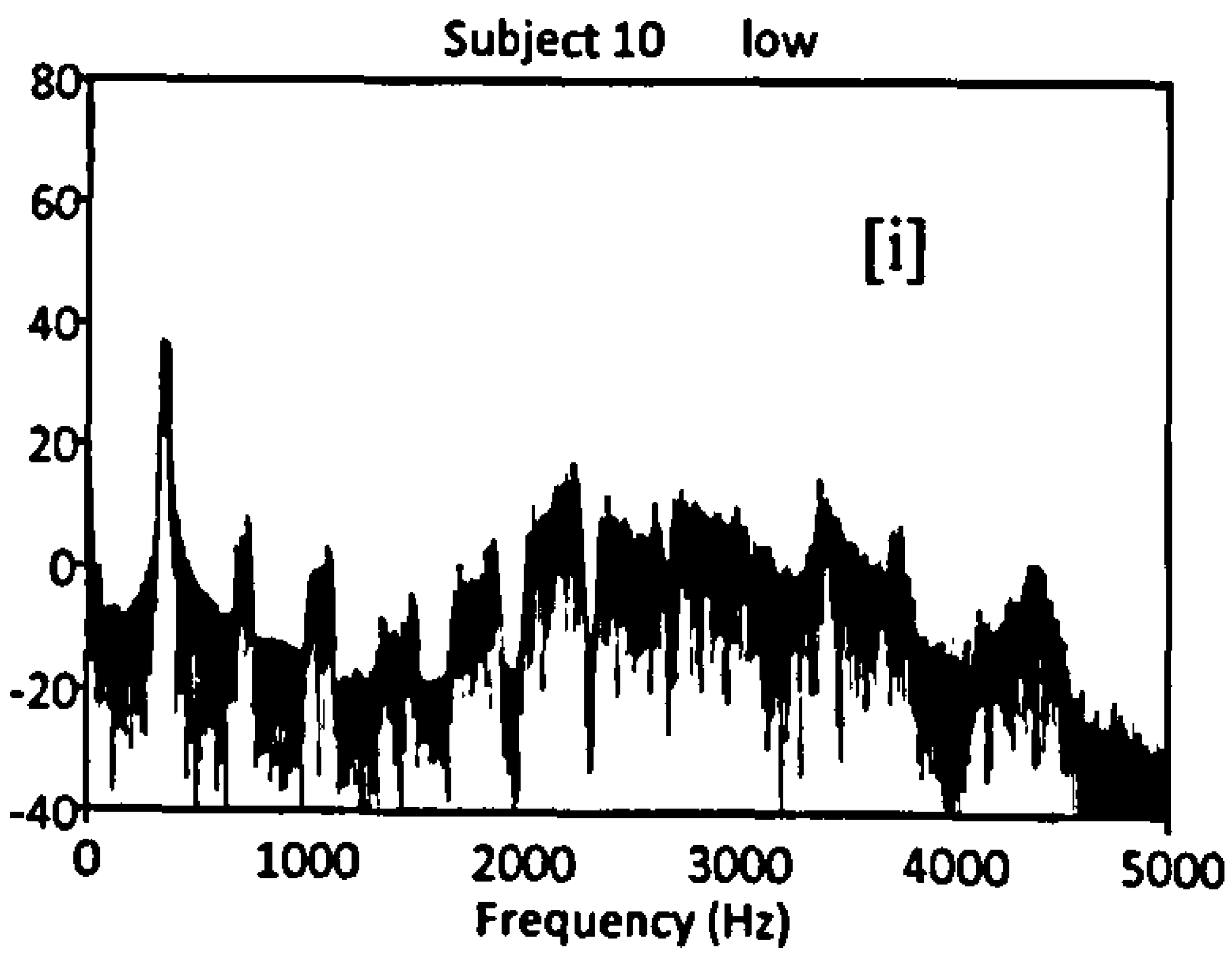
Subject 4 from the early music group and subject 10 from the opera group were selected for spectral analysis of specific vowels to identify characteristics indicative of formant tuning being employed by the singers. Figure 22 shows the spectra of the vowels [i] and [ɑ] taken from the text 'bead' and 'bard' from the appeggio task sung at F# 4 and F#5 and when spoken. In each case the spectrum was taken from the steady state of the note and in sung samples over two stable vibrato cycles. As chapter 6 explains in more depth, the observations of the vowels seem to reflect findings of current research (*e.g.* Barnes *et al.*, 2004; Joliveau *et al.*, 2004; Miller *et al.*, 1997). However, the absence of a specific methodology within this study to measure the formants, such findings can only be speculative (Sundberg, 1975).

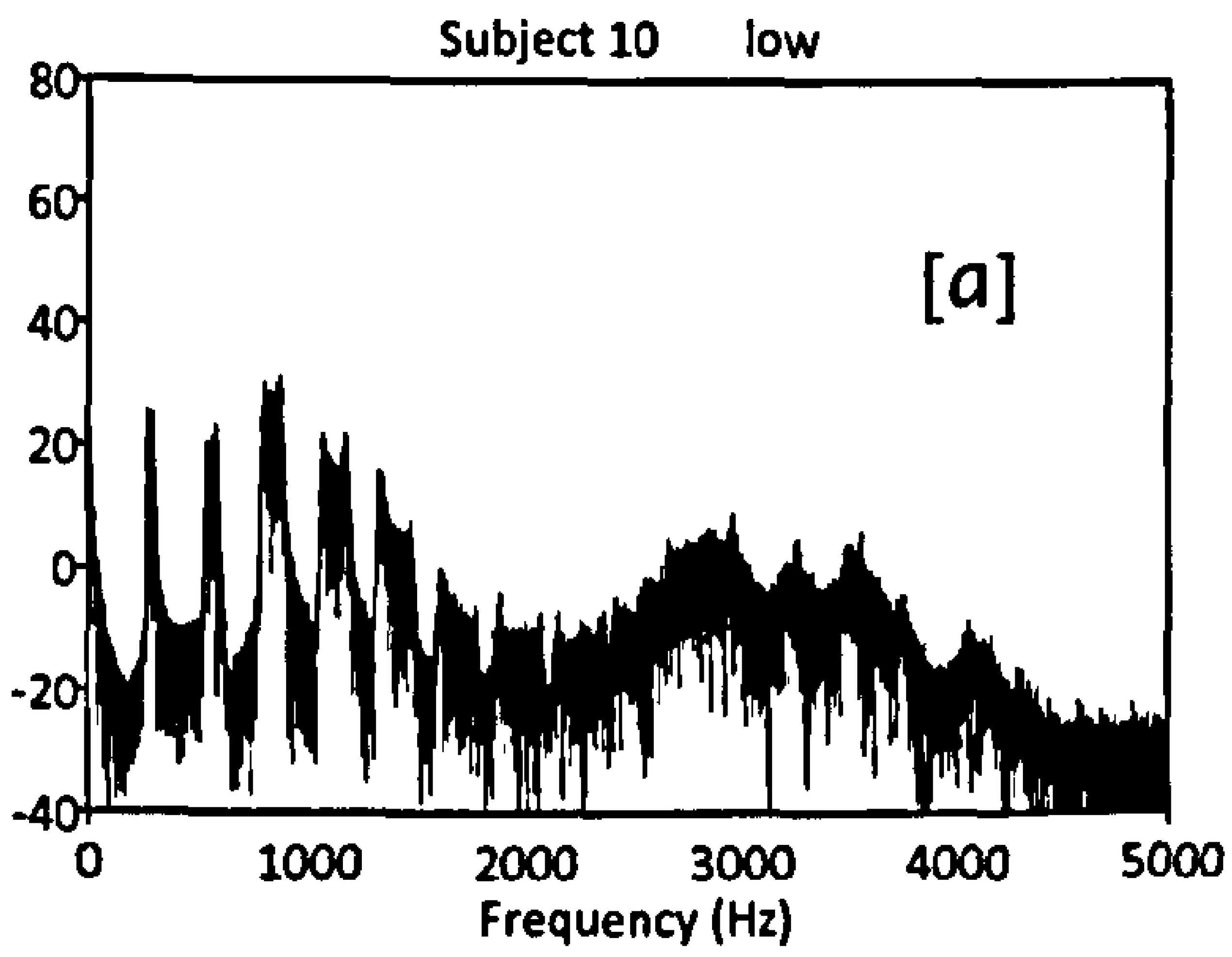
Figure 22 Spectrum graphs of subject 4 from the early music group and subject 10 in the opera group speaking and singing [i] and [ɑ] vowels at low and high pitches and when spoken

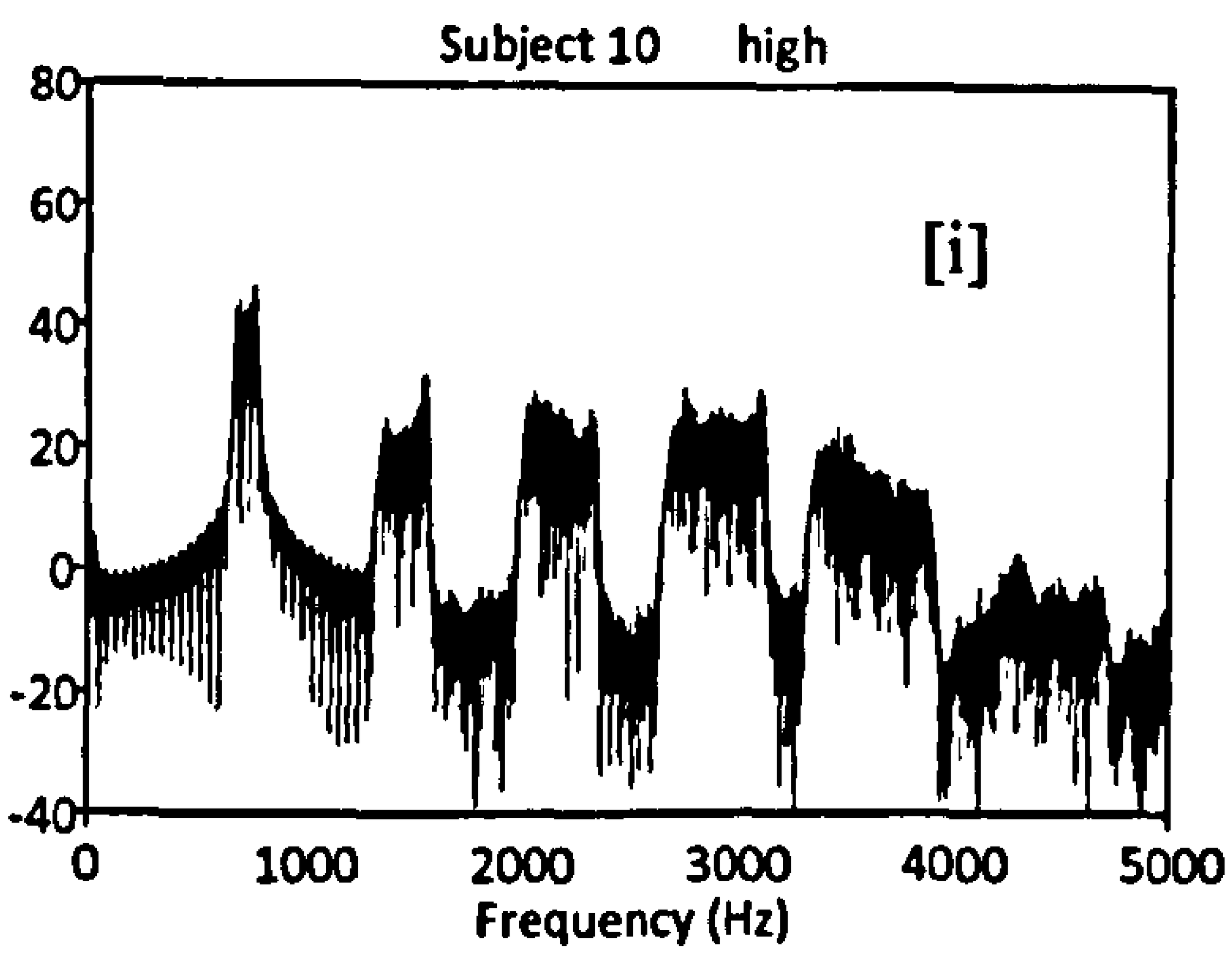


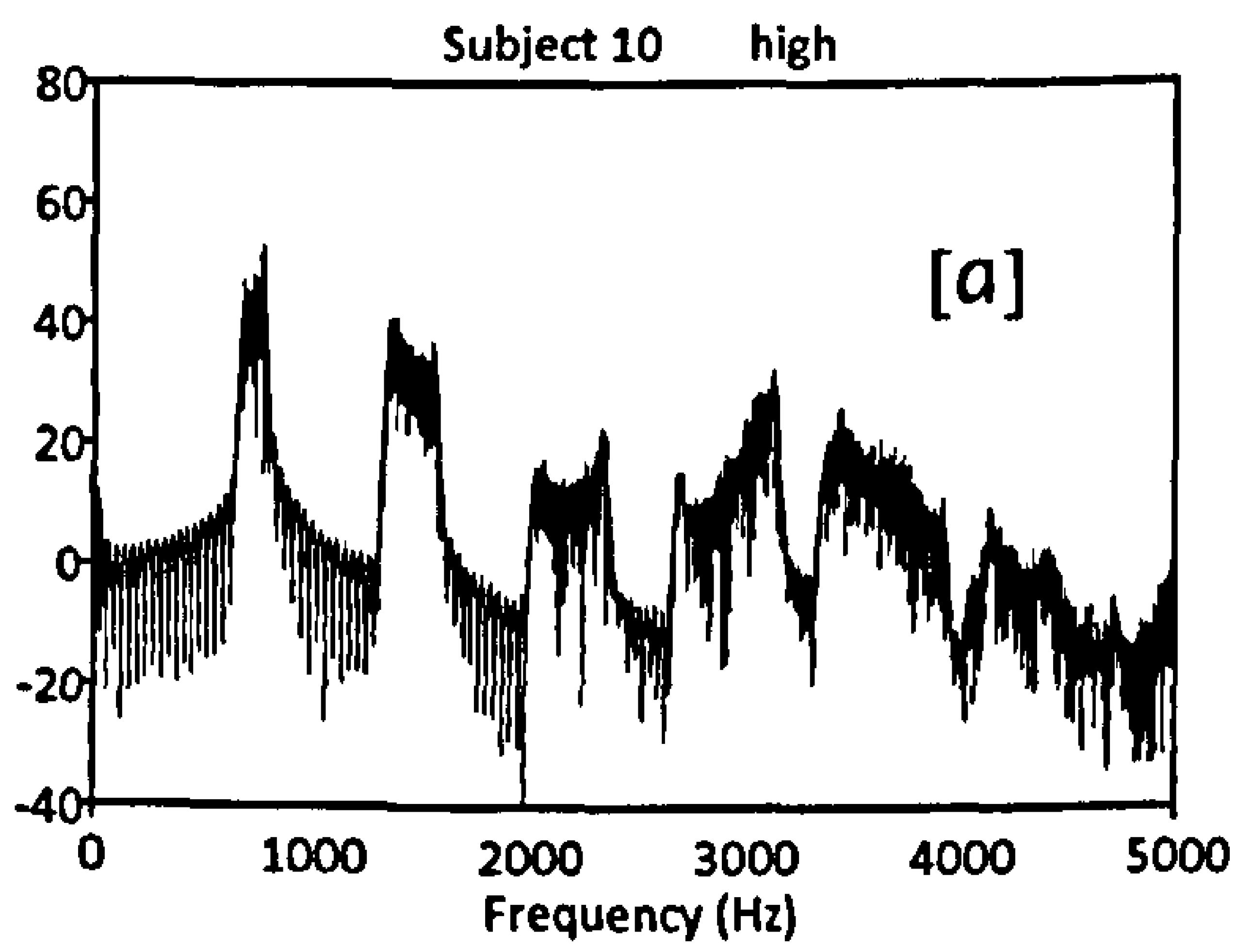

Subject 10 spoken
[i]
80
60
40
20
0
-20
-40
0
1000
2000
3000
4000
5000
Frequency (Hz)


Subject 10 spoken
[ɑ]
80
60
40
20
0
-20
-40
0
1000
2000
3000
4000
5000
Frequency (Hz)


Subject 10 low
[i]
80
60
40
20
0
-20
-40
0
1000
2000
3000
4000
5000
Frequency (Hz)


Subject 10 low
[ɑ]
80
60
40
20
0
-20
-40
0
1000
2000
3000
4000
5000
Frequency (Hz)


Subject 10 high
[i]
80
60
40
20
0
-20
-40
0
1000
2000
3000
4000
5000
Frequency (Hz)


Subject 10 high
[ɑ]
80
60
40
20
0
-20
-40
0
1000
2000
3000
4000
5000
Frequency (Hz)

2.5 Problems with the Study

Overall, the results of the experiment suggest that the setup and protocol used extracted useful data for the present study. However, a number of factors could have improved the experimental protocol which for practical reasons could not be applied to the experiment.

- Ideally the same room would have been used to make all the recordings to prevent the room acoustics effecting the results. Although all the singers in the opera group were recorded in the same room, it was not possible to record the singers from the early music group in the same place as convenience was a priority in obtaining high-class professional singers for the study. Although an anechoic chamber is often used to record voices in studies which assess acoustic data this was not considered appropriate for the experiment. It was vital to maintain as 'natural' a performance environment as possible for the experiment by using a room that the singers were used to practising in.

- Although the sample size used in this experiment is congruous with other research in the area of voice science, a larger number of subjects would provide greater statistical power of the results and more dependable representation of the two genre specialties.

- Ideally the subjects would all have known the songs they were asked to sing in advance of the recording. However, again due to convenience for the singer and the decision for all singers to perform the same extract to allow for reliable comparison, this was not the case: all the singers knew the songs to listen to but not all the subjects had sung the songs before. The professional status of the subjects reduces the significance of this issue as situations such as these would not be expected to have an effect on their technique at their level.

- Due to the use of professional singers in the study, there were restrictions on the time available for the experiment with certain subjects. This prevented any control on the time the singers spent warming up their voices before the recording and for some subjects meant they did not have long to look through the extracts before singing them.

- The song tasks the subjects sang would ideally have been performed with accompaniment in order to gain a true representation of singing pieces from those eras, especially considering the implied importance of the changing accompanying forces and compositional styles (Daffern, 2005). No accompaniment was provided either live or through headphones in order to maintain as natural an environment for the singer as possible and obtain recordings for acoustic analysis.

- Unfortunately, due to the time restrictions of the experiment, it was not possible to make duplicate recordings. However, comparing replications of the same exercises by the same singers would indicate more reliability the extent to which the analysed sections were indicative of the subject's usual vocal behaviour.

Chapter 3
Vocal Fold Activity

In addition to being an essential component in all voiced sounds whether spoken or sung, the voice source has been found to play an important role in producing the characteristic traits associated with classical singing (Sundberg, 1987: 49). In particular, it is thought that throughout classical singing training laryngeal behaviour is modified contributing to the efficiency of the classical voice. Factors such as larynx closed quotient and subglottal pressure are adapted by the singers to maximise the potential of various factors including loudness, projection techniques and breath control (*e.g.* Sundberg, 2003: 18). The methods used by vocal teachers to strive for efficiency in vocal fold activity tend to be holistic, drawing on imagery and analogous references rather than explicitly stating, or necessarily understanding the physiology behind the technique (*e.g.* Salaman, 1990; Chapman, 2005; Harrison, 2006). Historical literature illustrates a similar attitude to teaching, although a more limited knowledge of the physiological workings of the voice source.

The first half of this chapter considers the closed quotient results obtained in the current study alongside the literary suggestions of potential historical voice source behaviours and the compliance of this data set with previous studies on the classical voice. The second part of this chapter deals with results pertaining to vibrato in the present study. The use of vibrato by all the subjects is analysed in depth to consider the potential objectives of the singers in light of their performance specialty. Theories of vibrato production in historical vocal techniques are reviewed alongside perceptions of vibrato in modern performances, and are addressed in light of the results.

3.1 Closed Quotient

Comprehensive research into the intricate workings of the laryngeal muscles and the various modes of phonation produced by the vocal folds is still in its infancy, but understanding is rapidly improving with modern technologies such as video imaging. The previous chapter provides a description of the mechanisms of vocal fold closure and various procedures that are available to measure vocal fold activity.

There is little specific interest in voice source activity in modern literature concerning historical vocal techniques. This is understandable considering that there is no simple means of measuring aspects of laryngeal activity and because the technology now developed which contributes to current knowledge is so recent. There is, however considerable discussion of larynx positioning (see chapter 4) and some speculation on register usage in contemporary literature concerning the history of singing which can in turn have implications on voice source activity. There is an interest in these features of vocal technique, partly because these aspects were being discussed during the periods that are of interest to the modern scholars, and, in the case of larynx position, there is a visual physical reference making the relevant literature a more reliable reference. Issues of register are complex and confusing in modern research in terms of physiology and perception (*e.g.* Sundberg, 1987: 49). This makes the historical literature, especially the vocal treatises, which is so eagerly translated by modern scholars more perplexing and the conclusions drawn from them less reliable. It is now understood that, certainly some of the perceived register changes in the voice, and presumably therefore some of those discussed in the historical literature, are attributable to changes in voice source characteristics, and whilst there is still no common consensus amongst researchers as to the number of registers or the exact role of the vocal folds between them, the importance of aspects of vocal fold contact is being realised.

Although discussions of early music singing compared to opera singing tend not to address issues of vocal fold activity beyond the positioning of the larynx and references to vocal registers, it is an important aspect to consider given how basic it is to voice production. Sundberg states that 'apart from resonatory aspects, the vibrations of the vocal folds are obviously crucial in singing where the demands are high on dynamics in loudness, pitch and timbre' (Sundberg, 1994: 69). This comment has direct implications as to the importance of considering vocal fold activity when considering early music singers compared with opera singers. The singers' environment has changed significantly over the last 400 years in terms of performance space, accompanying forces and compositional style, and all these changes effect the demands on the performer to varying degrees of loudness, pitch and timbre.

3.1.1 Vocal Efficiency

The interest in vocal fold activity and particularly closed quotient in classical singing (and specifically opera singing) is heavily associated with efficiency in singing. Classical singers strive for maximum vocal output with minimum vocal effort allowing them to sing long phrases without wasting breath and to be heard over large orchestral accompaniments (Howard, 1999: 124-125). The amount of time the vocal folds spend together in each vibratory cycle (the closed quotient) has been shown to increase with classical training and is thought to be a factor contributing to this efficiency (Barlow and Howard, 2002; Howard, 1995; Howard *et al.*, 1990 and chapter 2 of this thesis).

It is thought that the training methods of singers and therefore 'classical' singing techniques have changed significantly over the last 400 years, particularly since the establishment of opera on the stage. Discussions of past techniques based on the interpretation of historical literature can be found in for example, Wistreich in ed. Potter, 2000:178-191. Although there can be no direct reference to closed quotient values within historical literature, the implications of the research which shows an increase in closed quotient values specific to modern classical training practices could imply that closed quotient values would have been lower in techniques employed in previous eras of vocal training. This is supported by theories of very different objectives in pre-nineteenth century singing training which are thought to include the promotion of stronger similarities to speech than modern day techniques (Potter, 1998: 53). In turn this suggests that if today's singers specialising in the performance of early music were to base their technique on the findings of the historical literature, they too would produce lower closed quotient values.

A study carried out by Howard investigated closed quotient values of one professional singer singing in three different styles, modern operatic, modern early music and Elizabethan (Howard, 1992: 47-62). He found that closed quotient values were highest in the opera style and lowest in the Elizabethan style, concluding that 'the vocal fold acoustic efficiency is highest for the operatic style and lowest for the Elizabethan style' (Howard, 1992: 59). Whilst these findings seem to solidify the hypothesis above of changes in laryngeal activity of 'classical' singers over time, there are a number of factors which prevent such findings from being conclusive. Firstly, and unavoidably, the singer being used was a modern classical singer, and therefore, as Howard acknowledges, will have intrinsic features of a modern technique. The tenor recorded for the experiment was John Potter who sang with the Hilliard Ensemble, and so would be expected to demonstrate results typical of the modern early music style. However, being essentially an early music singer himself, the extremes of the other two styles observed in the study may not be typical of singers of those genres, due again to intrinsic characteristics of his technique from singing early music repertoire. The Elizabethan style poses most problematic as although Howard explains the Elizabethan style 'involves the use of Elizabethan English pronunciation sung in what is considered an appropriate style' (Howard, 1992: 48), the findings are based on the assumption that the style and pronunciation used are true reflections of Elizabethan singing.

The theories on the efficiency of vocal technique and stylistic aspects of vocal technique use environmental factors to presume changes in technique over time, and in this case that 'Again it is only voice training evolved after the need to sing on the opera stage that produces these CQ training; no such demands were made of Elizabethan singers' (Howard, 1992: 59). Potter's academic investigations into historical techniques do make the results more reliable from a perspective of musical style, in that he is informed in his performance decisions. The uniformity between the stylistic objectives and technical results does support the theory, although both the musician and the scientist are basing their theories on the same presumptions.

As mentioned above, in terms of literature concerning laryngeal activity besides the discussion of perceived 'register' changes, information is relatively scarce. However, evidence of registers, particularly scientific evidence, can be used to speculate on possible physiological traits of singing in terms of techniques, and in turn to deduce possible acoustic parameters of historical voices. Although, when dealing with historical literature, issues of perception must be paramount to the interpretation as descriptions can be confusing and may not relate directly to the physiological or acoustic issues they appear to address. This is apparent when discussion of 'registers' appears in eighteenth century literature, identifying a 'chest' and a 'head' or 'falsetto' register suggesting that the sound emits from these parts of the body (Mancini, 1774 in ed. Foreman 1967). Current knowledge can be used to suppose that these figures were discussing registers in terms of their perception of sound and sensation while singing, as tones clearly cannot be emitted from the chest or head. Although these terms continue to be used today, it is the terminology rather than the concept that has been retained.

Wistreich uses a quote from Mancini to illustrate the connecting of the registers as a main objective of vocal training in the eighteenth century, 'After the scholar has ascertained the compass of the Natural Voice, his great study should be to contrive to unite the Natural to the first Note of the falsetto, to blend them with such nicety, that the union be imperceptible' (Mancini in Wistreich ed. Potter, 2000: 185). This 'blending' of the registers is likely to refer to the removal of a register 'break' which remains a priority of modern day vocal training. Registers are the product of laryngeal activity, although, as Sundberg suggests the smoothing process could also be acoustic (Sundberg, 1987: 49-51). The issue of registers is ubiquitous amongst performers, teachers, acousticians, throat specialists and musical scholars and will be a controversial matter for the continued research of all these experts for the foreseeable future. The importance for this thesis, beyond an example of the confusion such issues can create, is the connection between possible register issues and larynx closed quotient, a parameter which can be measured within the scope of this experiment.

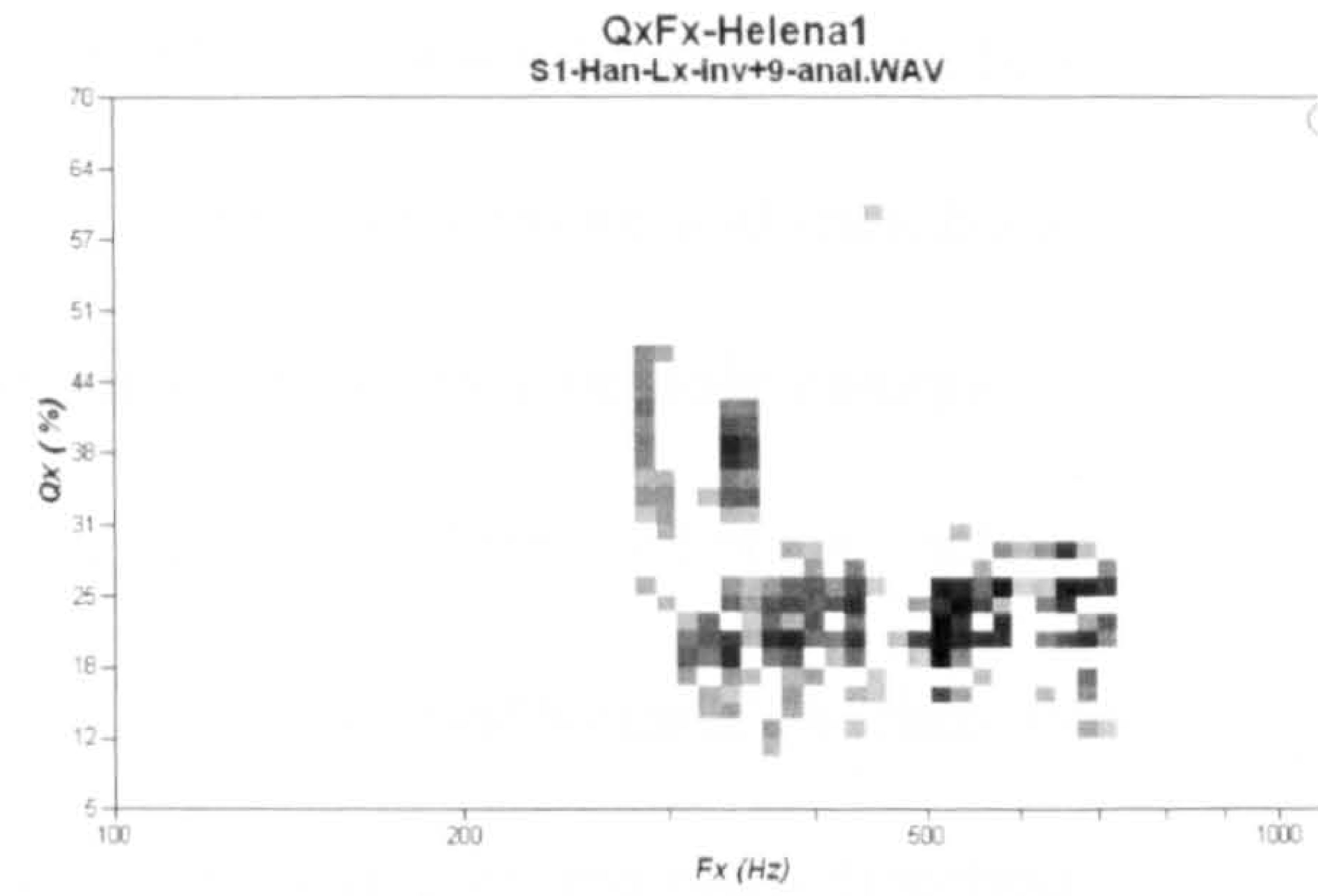
The closed quotients results obtained from the current study are explored in the following section, drawing specifically on similarities observed between the subjects and the possible significance of any differences on the subjects' specialty. The results of this feature were discussed with particular detail given to the reliability of the findings in the previous chapter alongside the overview of results pertaining to all the factors that were assessed.

3.1.2 Experimental Findings

No significant differences were found in closed quotient values between the subjects in the opera group and early music group. Figure 6 in the previous chapter shows Qx plots for all the subjects singing an ascending two octave scale and describes the main differences observed between the singers. Notably, it was discussed that the significant drop in closed quotient values at around 320Hz (E4) observed in subjects 1, 5 and 12 provide evidence of a laryngeal register change around this frequency especially considering the evidence of previous research (See, for example Miller, 2000: 47).

Considering the results of these subjects in more detail, figure 23 shows that similar closed quotient results are present for subjects 1 and 5 when singing the Handel extract, however the closed quotient values for subject 12 remain low at the lower frequencies, effectively smoothing the Qx to create a linear slope of increasing closed quotient with fundamental. This change could be indicative of the conscious smoothing of the voice to avoid register changes within the song, and could also be influenced by the context of the lower fundamental frequencies within the phrase. When singing the scale the singers ascended from the lowest note, whereas in the Handel extract, even though the second phrase began on a low note, the preceding phrase had been higher in their range, beginning at C4 and then descending to G4.

Figure 23 Showing Qx plots of subjects 1 (top right) 5 (bottom right) and 12 (bottom left) singing the Handel extract



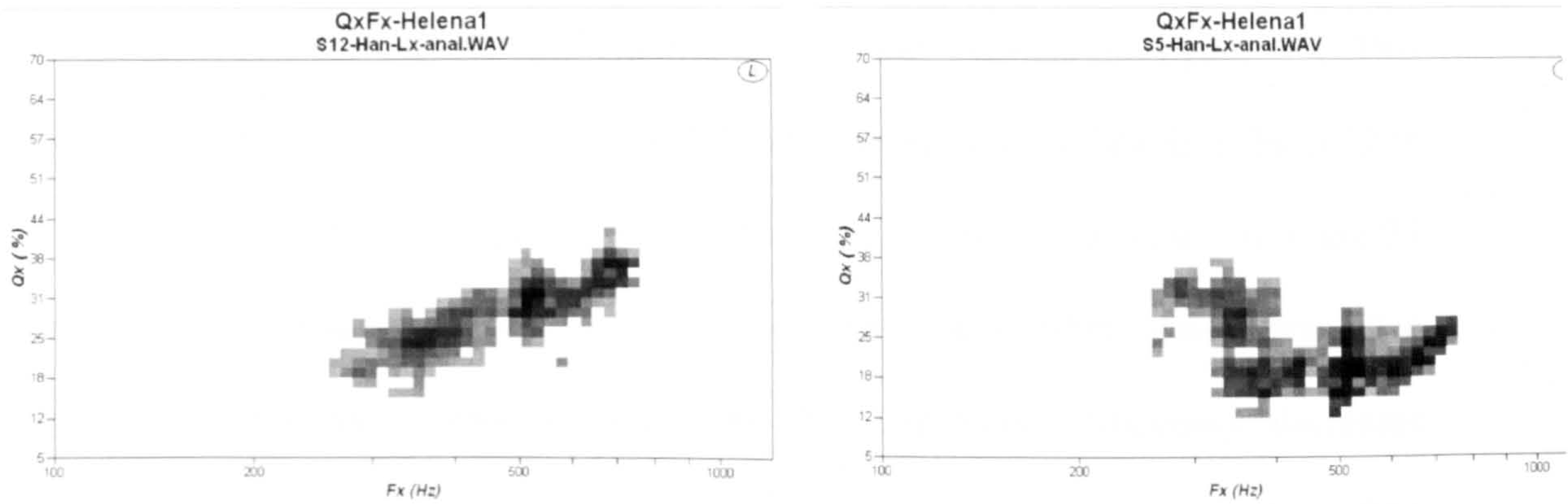


Figure 24 Graphs of the CQ analysis of the siren produced by subject 1 (above) and subject 12 (below) in the 'SPEAD3' software. Time is displayed on the x axes and F0 and Qx on the y axis. The upper panel represents the Lx waveform. The upper line in the each panel represents F0 and the lower line displays Qx data.

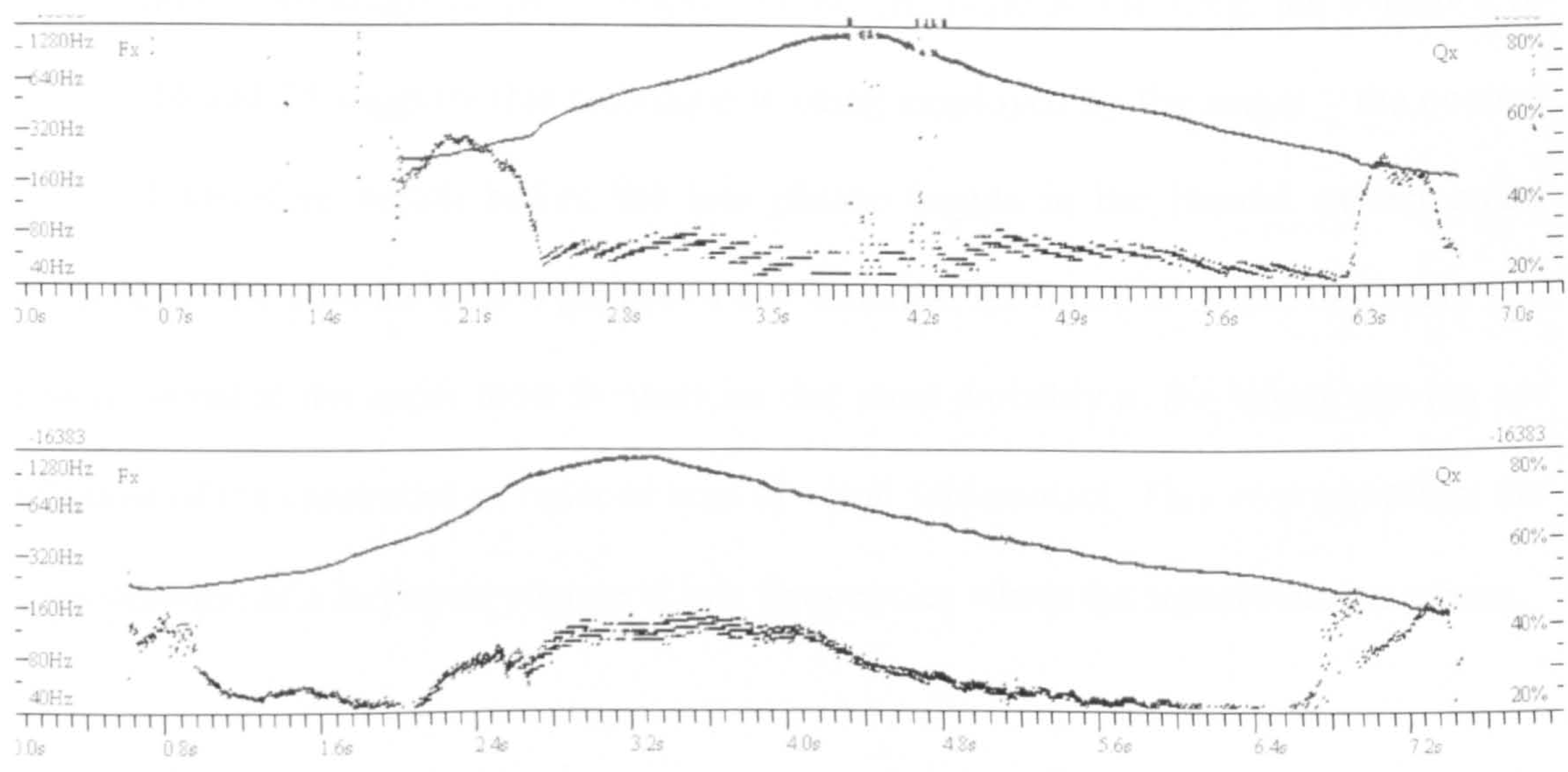
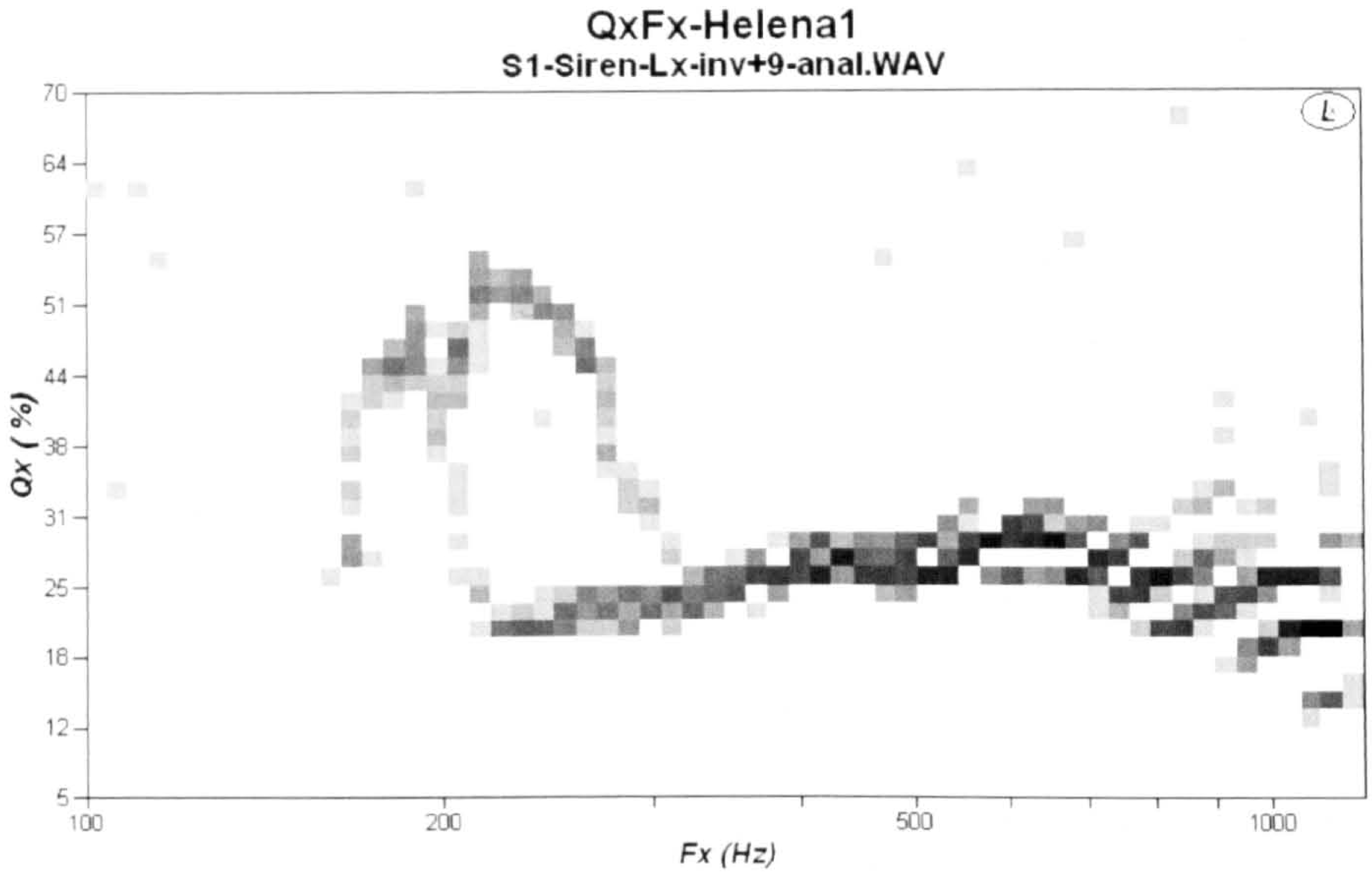


Figure 24 shows the distinct change in the Qx plots of subject 1 when producing a siren to the sound 'ng' from the lowest to the upper most regions of her range and then back down. When ascending from the lowest part of her range, there is a notable change in closed quotient when the subject reaches approximately 327Hz, whereas, when descending, the closed quotient continues to decrease until the fundamental reaches as low as 211Hz. This suggests a change in register usage depending on the pitch direction and is easily visible on the Qx graph of the same exercise in figure 25. This complements the theory presented for the different closed quotient data for subject 12 in the Handel extract. The siren produced by subject 12 which is also shown in figure 24 shows a less dramatic change in closed quotient values when descending than ascending, shown by a smoother curve as the fundamental frequency decreases compared to the steps that are evident when ascending, the descent is also slower than the ascent for both singers, however the fundamental frequency at which subject 12 displays a significant drop in CQ values is not particularly different when ascending or descending. Although subject 1 doesn't show this trend in the song, the evidence of figures 24 and 25 suggests this technique is being employed by the singer – the notated rest and therefore breath before the low phrase begins in the Handel extract could account for the absence of this pattern in this instance. As figure 24 illustrates, there is a loss of signal at the upper most frequencies due most probably to the larynx moving out of range of the electrodes or reduced area of vocal fold contact. This does not effect the consideration of a laryngeal change at low frequencies where the signal remains strong.

Figure 25 Qx plot for subject 1 producing a siren



Comparing the Qx data of all the subjects with their own data for speech provides an insight into the reliability of the data graphs for the sung exercises as well as presenting an interesting comparison. Qx plots comparing the Puccini extract and speech were presented in figure 8 in the previous chapter for all subjects. The closed quotient values during speech for all the subjects were generally higher than when singing. This is contrary to the results of Howard who found that closed quotient values for male singing subjects maintained CQ values 'towards the high end' of those found in speech (Howard *et al.*, 1990: 205-212). However, considering the average pitch at which the subjects spoke, the lower closed quotient values in singing could be explained by the proposed 'register' changes in phonation at different pitches. The inclusion of higher closed quotient values at higher fundamental frequencies in the spoken text could then be justified by the technical performance objectives of the singer.

When singing an ascending scale to the uppermost regions of the singer's range, they are likely to vocally 'prepare' by altering their phonation type. When speaking however there is no need for the singer to 'prepare' for any extremes of vocal activity and so can allow the vocal folds to function in only one phonation register, seemingly with high closed quotient values.

Research using female subjects further suggests that closed quotient values will increase with the fundamental frequency. As shown above, this study found that the singers consistently produced lower closed quotient values when singing than when speaking and found no consistent results to conclude increasing closed quotient with fundamental frequency. As the previous chapter explains, this could be in part due to the register usage of female singers in speech compared to singing, using a 'head' voice when singing compared to 'chest' voice with high closed quotient values when speaking. However, these results could also be indicative of the problems of using electroglottographs to measure closed quotient in females, the common loss of signal at high fundamental frequencies supporting this consensus.

3.1.3 Relation of Findings to Previous Research

The strong evidence of higher closed quotient results at extreme low fundamental frequencies in the ranges of the subjects, suggestive of 'chest' register usage, is in keeping with the findings of other studies including a study comparing voice source differences between registers in female musical theatre singers (Björkner *et al.*, 2005). These findings also have implications on vocal fold vibration amplitude as research suggests that mode of phonation is controlled by the force of glottal adduction (Sundberg, 1994: 79). Sundberg found that 'efficiency is clearly low in the modes associated with a glottal leakage, leaky phonation and voiced whisper' (Sundberg, 1994: 73). This implies that loudness of vocal fold vibration is potentially higher in chest register where glottal leakage is likely to be less prominent and corresponds with the findings of modern scholars in historical literature which promotes loud singing in churches compared to secular works in the sixteenth century (Zarlino, 1558: 253). From the treatise of Zarlino and the evidence of a few of his contemporaries, modern scholars have developed theories on conventions of differing vocal techniques in secular and sacred music; Wistreich states, 'I propose that in church, *all* singers sang *only* in chest or modal voice, although there were exceptions.' (Wistreich, 2002). Whilst to link these literary findings with the scientific findings of the modern voice is entirely speculation and beyond the scope of investigation within the present study, the implications would make for interesting development in later research.

The shortage of speculation on laryngeal activity in pre-nineteenth century vocal techniques in contemporary literature and the subsequent lack of expectation on current methods of performing early music make investigation into current practices difficult to assess. Register changes are still difficult to examine without invasive procedures which compounds the uncertainty of any speculation on historical ideals of a largely unknown vocal phenomenon. Only elements of voice that are possible to investigate through non-invasive methods could be quantified in the present study and therefore certain features such as register changes cannot be confirmed. It is however possible to speculate on laryngeal issues such as register between the singers from the data collected. The absence of obvious differences between the groups both in their overall closed quotient values and in any change in closed quotient across the singers' ranges implies similar laryngeal techniques employed by all the singers in the study. Changes of closed quotient observed between tasks by the same subjects, such as the different treatment of the lower fundamental frequencies by subject 12 in different musical situations implies a deliberate (though perhaps subconscious) manipulation of laryngeal activity, which is consistent with both historical and current ideals of 'blending 'the registers.

3.2 Vibrato

Vibrato is considered within this chapter to be 'vocal fold activity' because it is thought to be a pulsation of the laryngeal muscles (Seashore, 1936: 196), although considerations of the experiment results are made from an acoustic and perceptive rather than physiological perspective. There are extensive studies into vibrato perception and production in music and singing as well as a profusion of references in musical literature, both formal and informal discussing and assessing vibrato in singing (*e.g.* ed. Dejonkeres, 1995). Seashore defined a good vibrato as 'a periodic pulsation, generally involving pitch, intensity, and timbre, which produces a pleasing flexibility, mellowness and richness of tone' (Seashore, 1931: 623). The significant research carried out by

Seashore in the 1930s is still used as the basis of our understanding of the physiology and perception of vibrato today.

In the presentation of his conclusions it was common for Seashore to make reference to the ability of the singer and attributes his results to parameters of human perception that were not and cannot be measured. For example after explaining that 'the pitch vibrato is practically universal' and 'no good singer sings without it' he suggests 'it is present wherever sustained vocalisation expresses genuine emotion' (Seashore, 1937c: 30). Such research illustrates that whether scientific or musical, discussions of vibrato often come down to issues of like or dislike.

3.2.1 Musical Theories

The subjective aesthetics of vibrato continue to dominate discussions in scientific and musical literature, with it being condemned by some and revered by others.

In the 1920s Edison conducted research into vibrato believing that 'If this defect could be eliminated, nothing would exceed the beauty of the human voice, but until this is done there will be only a few singers in a century who can emit pure notes in all registers' (Edison in Westerman, 1938: 48). As Westerman explains in his article, Edison was surprised to find that only 22 out of 3800 singers in his study actually produced what he considered 'straight tones'. This is unsurprising when Schoen in 1926 found that a monotone 'to the ear sounds dull, hard and strident' (Schoen, 1926: 283), the other extreme which they classed as 'the trained, musical voice' was found similar to 'the untrained, musical voice' in terms of 'the tone sounds bright in comparison… and a slight pulsation is clearly heard' with the addition 'that both the pulsations and pitch fluctuations are more markedly present' in the trained voices (Schoen, 1926: 284). Reinders puts forward a different theory regarding straight tones, claiming that 'In so-called straight tones, in which the larynx is kept quiet, there will be enough activity in the thyroids, the hyoid bone, the laryngeal tensors and depressors, and in the respiratory muscles to prevent the tone from sounding dead' (Reinders in ed. Dejonckere, 1995: 141).

Although Edison's investigations were intended to substantiate his personal opinion that vibrato is a defect in the voice they proved to discredit his theory. By employing a scientific method to his personal aural reaction he demonstrates the individualistic nature of vibrato perception. Although based on his perception he thought that straight tones were the recipe for a beautiful voice, once they were analysed he became aware of the presence of vibrato. Edison's findings therefore solidify Seashore's deduction that 'Scarcely any two persons hear a given vibrato alike.' (Seashore, 1937a: 31). This makes it very difficult to assess any literary comments on vibrato objectively without supplementary acoustic evidence such as that provided by Edison. Comments such as 'the incessant *tremole* upon every note and word. To my idea it is monotonous and unmusical' (Blandford, 1937: 447) can therefore only authoritatively illustrate an individual's reaction and should be used cautiously when making assumptions as to actual vibrato production.

The presence of vibrato in most sung tones by trained singers has led to investigations into its production and questions of the integral rather than conscious inclusion of vibrato in the voice,

> The critical question here is whether the vibrato is a vocal embellishment which the singer enlists at will, more or less independently of other elements of voice production, or whether it is integral with the finely balanced muscular forces which constitute the cultivated singing voice
> Stark, 1938: 151

The suggestion of vibrato being integral to singing was developed from the acoustic findings concerning the rate of vibrato combined with the seeming subconscious attitude of singers towards the phenomenon. Research exploring the muscular activity involvement of vibrato also support the theory as it has been noted that the standard rate of vibrato 'is nearly the same as that of some other involuntary oscillation of skeletal muscles or striated muscles' (Hirano *et al.* in ed. Dejonckere, 1995: 9)

'When the singer was told to control the pulsation in the voice, that is, to try to eliminate it, she could do so only for a fraction of a second' (Schoen, 1926: 284). Other studies have also been conducted concerning the conscious control of vibrato (*e.g.* Seidner *et al.*, in ed. Dejonckere, 1995). In spite of research findings such as these, opposing beliefs on the topic are still firmly held, often by musicians; 'The so-called natural vibrato does not exist' (von Ramm, 1976: 12). This is in part due to the parallel rather than merged execution of scientific research and musical performance theory. Performers were (and in some cases still are) unaware of the acoustic and scientific research into aspects of performance that could further their understanding and inform performance decisions, whilst those such as von Ramm writing from their personal experiences as accomplished performers could also facilitate scientific research. The conflict between the scientist and the artist remains that of experience and acute perception on the musician's side and quantitative evidence on the side of the acoustician.

3.2.2 Theories of a Historic Vocal Vibrato

The inevitable involvement of personal opinion when discussing the perception and physiology of vibrato, and the inconsistency of these reactions, makes the interpretation of historical documents to extract possible vibrato usage in voices of the past more challenging and less reliable. Much like the contradictory comments of singers that infuse the literature of the last hundred years, mention of vibrato in historical texts remains ambiguous with any attempt at clarification made more difficult by the lack of scientific understanding or audio reference. Potter, when drawing conclusions on the changing use of vibrato in singing, notes that 'As with all aspects of the voice in the pre-gramophone era the subject is problematic because of the difficulty of knowing just what the sources mean' (Potter, 1998: 56). Conclusions, however, are still drawn by theorists as to historical vibrato production; Reinders, for example, comments that 'Unlike the Baroque singer, the singer of the later 20th century is not always conscious of his vibrato' (Reinders in ed. Dejonckere, 1995: 143)

In spite of ambiguous references to vibrato production involved in past vocal techniques, there is an established convention within the modern performance of early music which promotes little or no vibrato, at least in comparison to modern day opera singers. Discussing the new performance style in the 1970s which resulted from the early music revival, Ebisawa admires the 'soloists as well as choir [who] sing most clearly, respecting the articulation, restraining their vibrato, and stressing the nuances of the text' (Ebisawa, 1992: 286). The reduction of vibrato usage at this time was based on the theory that distinctive use of vibrato was introduced to singing in the 1830s as part of the new technique including 'chested' top Cs by tenor voices and the *voix sombre* aided by the lowering of the larynx (Potter, 1998: 56). Potter explains 'In the sixteenth- and seventeenth-century treatises vibrato is rarely discussed, but by the second half of the nineteenth century the term appears in musical dictionaries and is clearly an issue' (Potter, 1998: 56).

The absence of direct reference to the term in historical literature leads to strong opinions of historical performance practices. In 1976 Ramm presents an assertive argument instructing the use of vibrato in the performance of early music: 'One vibrato is only volume change, to intensify a sound and to give colour, life and expression. It may change the pitch definition slightly and when it does it becomes completely useless for early music' (von Ramm, 1976: 13). Reinders states that 'Steadiness of tone, as is called for in vocal Renaissance music or in early Baroque opera does not mean the absence of a natural vibrato' (Reinders in ed. Dejonckere, 1995: 141).

Although the term vibrato wasn't introduced into the literature until the nineteenth century there are a considerable number of references to voice quality using terminology that could relate to the term and suggest that it was practised within historical vocal techniques;

> Three hundred years ago the "brilliant shake" in Baldassare Ferri's voice was considered of outstanding merit in the beautiful singing of this famous male soprano. Two hundred years ago "a shake as admirable as it was rare" described the singing of Carlo Broschi, who was reported as having the most beautiful voice ever heard by the critics of his generation. One hundred years ago this "shake" was given a name, and Giovanni Battista Rubini, the "king of Tenors", with a range from low E to G above high C, was reported to be "the earliest to use that thrill of the voice known as vibrato"
>
> Westerman, 1938: 48

Whilst interpretation of historical comments, such as Westerman's above, can plausibly lead to conclusions of vibrato as part of past singing techniques, other possible meanings need to be considered. For example the 'shake' could reasonably refer to the trill rather than vibrato. In his Treatise of 1723 Tosi includes the Shake in the chapter 'Of Passages *or* Graces' explaining 'There are likewise five subaltern Embellishments *viz.* the *appoggiatura*, the *Shake*, the *putting forth of the voice*, the *Gliding*, and *Dragging*' (Tosi, 1723 in ed. and tr. Galliard, 1742: 174). Although identifying it as an ornament (though inferior to *Judgement, Invention, Time, Art and Taste*) the Shake is not mentioned again within the chapter, implying that it is either less important or not necessary to teach as opposed to the other mentioned embellishments. It is however mentioned earlier in the treatise as being a feature that is attained 'after a long Exercise' (Tosi, 1723 in ed. And tr. Galliard, 1742: 89). If reference to the 'shake' is consistent with the modern day use of the term vibrato, the reference above to its rarity also has implications as to its usage, suggesting that vibrato was not commonly employed by all singers but only the special few. The issue of like and dislike seems no different to the present day as Westerman goes on to reference a quote which contradicts the comment above by demeaning the Ferri's 'shake', 'Ferri's "tremolo was a ludicrous and incessant wabble"' (Westerman, 1938: 48).

There are many other references to the voice which use other terminology in keeping with the attributes of vibrato. In 1619 Praetorius records the first requirement for good singing as being 'a beautiful, pleasing, trembling and vibrating voice' (Praetorius in Westerman, 1938: 48). The confusion of terminology when assessing vibrato is often in association with musical ornaments and the styles of the period relevant to the reference. Terms such as 'Shake' or 'Tremolo' are often used and presumed to refer to a specific motivic ornament rather than a vibrato. Stark assesses the ambiguous treatment of the terms within several historical treatises, and considers that Zacconi's description of the Tremolo 'sounds more like a description of a normal vibrato than of glottal articulation' (Stark, 1938: 124) which he supports with Bovicelli's description of it being 'nothing other than the trembling of the voice over a single note' (Bovicelli in Stark, 1938: 125). Stark goes on to assess the terminology of the historical treatises in terms of possible suggestions of a modern vibrato showing clear evidence of the use of vibrato since the seventeenth century. He attributes the Rubini phenomenon to an exaggerated vibrato, connected to Garcia's disapproval and reference to Rubini's 'aging' sound and Metfessel's account of Rubini's vibrato being an emotional and tremulous expression (Stark, 1938: 137).

The confusion induced by the literature has created much conflict in the performing world of early music, with each interpretation of the historical sources leading to different conclusions as to the 'correct' use of vibrato in historical performance. After stating clearly the appropriate use of vibrato in early music von Ramm clarifies; 'The vibrato question is one of stylistic responsibility and of course, artistic ability too' (von Ramm, 1976: 14).

In 1970 Dennis Steven's defends his record of Monteverdi which has been attacked for excessive vibrato saying 'my Accademia has always used [vibrato] as a means of ornamentation and expression, in accordance with 16^{th}- and 17^{th}-century custom' (Stevens, 1970: 388) going on to clarify ''Our structural use of vibrato is not excessive because we reserve it for the embellishment of key words or phrases' (Stevens, 1970: 388). Stevens goes on to quote a number of historical tutors which seem to promote the use of vibrato and states 'No treatise known to me asserts that such passionate or hilarious pieces should be performed with an Anglican hoot or a Cambridge coo' (Stevens, 1972: 388).

The concept of the 'informed' use of vibrato as an ornament to express emotion in early music is likely the product of a combination of several sources both modern and historical. Although there is some dispute over whether vibrato is natural to the voice and so always present, there is a consensus of vibrato being a successful tool to convey emotion. This is true of both the scientific research that suggests vibrato is produced in the speaking voice during heightened emotion: '[vibrato] is also occasionally found in speech, especially in the sustained vowels of emotional and dramatic speech' (Seashore, 1931: 623), and the musical references which promote it as a deliberate mode of 'emotional, tremulous expression' (Stark, 1938: 137). Seashore compounds this attitude with comments such as 'the genuine vibrato is automatic and expresses the truth, like the smile and the frown.' (Seashore, 1937a: 30). This understanding combined with the confusion of terminology in the literature, in which vibrato may be the topic of certain ornamental styles, seems to conform to the premise that vibrato was an additional stylistic device in early music.

Seashore also refers to vibrato as 'the most systematic, natural, and essential of musical ornaments' (Seashore, 1937a:30). However, Seashore also states that vibrato is 'present in the voices of the great artists in about 95 per cent of their phonated time' (Seashore, 1931: 623). The latter point presented by Seashore is a comment on the singers that were performing in the 1930s when the research was taking place and is not a comment on historical singing; however, he still classifies vibrato as a musical ornament. Presumably, therefore, Seashore is not referring to a stylistic ornament in the sense of a melodic motif to be added to a musical score, but an unconscious integral device which 'ornaments' the music. If this is the case, further possibilities arise for the interpretation of the historical texts. The natural production of vibrato in singing could account for its lack of reference in treatises concerning singing, in that because it is always present it is not discussed. This is supported by the instructions to instrumentalists to employ techniques which promote vibrato in their quest to imitate the singing voice, for example if learning the recorder: 'when imitating the vivacity of a human voice, you must ornament accordingly.... You must regulate your breath with special deliberation and dexterity' (Ganassi 1535, in tr. Swainson, 1956: 89). The importance of the rhetorical declamation of text in performance, and thus expected expressive variety, particularly of the Baroque period promotes the idea that vibrato would have been employed as it is in speech at moments of heightened emotion.

Mozart conveys his opinion of a singer in a letter to his father in 1774 writing that,

> Meisner, as you know, has the bad habit of making the voice tremble at times, turning a note that should be sustained into distinct crotchets, or even quavers – and this I never could endure in him. And really, it is a detestable habit and one which is quite contrary to nature. The human voice trembles naturally – but in its own way – and only to such a degree that the effect is beautiful.
>
> Mozart in ed. Anderson, 1985: 552

This account of the young Mozart supports the theory of a natural vibrato and the use of vibrato in historical singing techniques. It also shows the subjectivity of vibrato perception, especially when no means are available to quantify and therefore standardise the description. Matters of like and dislike as well as propaganda also cloud the reliability of the historical sources. The figure of Rubini, for example, was well promoted by a controversy of introducing an entirely new manner of singing, including, according to the above reference, vibrato. The artistic licence employed by musicians when discussing vibrato was condemned by Seashore when he began his scientific investigations;

> The effect of attitude of the musician has been demonstrated in a shocking manner by the history of the attitude toward the vibrato – the inadequate and ridiculous descriptions that have been given, the fanciful explanations,

> the mystical implications, the groundless musical criticisms, the ill-directed and wasteful musical pedagogy as affecting the vibrato. These musical tragedies have their common root in the absence of correct knowledge of the nature of the vibrato
>
> Seashore, 1937a: 31

A review in 1983 which commends a singer for being '...not only a most delightful warbler, but also an excellent actress' (anon. The British Magazine and Review vol. 3 1983) demonstrates the continued use of terminology besides vibrato well beyond Seashore's attack of such terminology.

There is much speculation on the historical use of vibrato and strongly expressed opinions on the current practices of vibrato by singers which promotes a so called 'historically informed performance'. However, there is little analysis of the actual vibrato production of modern singers using the techniques now available beyond the consideration of acceptable parameters within modern 'opera' singing.

Rothman *et al.* carried out an experiment using commercial recordings to assess the extent, rate and intensity of vibrato in historical and contemporary opera singers and historical and contemporary Jewish cantors (Rothman *et al.*, 2000). They found that differences between the two historical groups and two contemporary groups were not significant, but that the historical groups had a faster pulse rate than the contemporary group. The opera contemporary group also varied their vibrato frequency more than the other groups. Significant differences that were observed were between eras rather than between groups within a time period. 'These differences may be the reason that we often think of historical singers' vibrato as being a tremolo rather than an ideal vibrato: faster pulse rate and a narrower, tighter frequency and amplitude variation above and below the mean sustained frequency and amplitude' (Rothman *et al.*, 2000: 211).

The data collected in the present study was assessed qualitatively to compare the vibrato production of the singers case-studied the findings of which were outlined in chapter 2. As well as assessing integral vibrato differences between the individuals and the two groups, in the following section possibilities of stylistic treatment of vibrato are considered in light of the theories of historical performance practice that were discussed above.

3.3 Experimental Findings

There were differences observed in the vibrato usage between the two groups of singers case-studied although all the singers used vibrato on most tones. The rate of vibrato was consistent in all singers averaging 6 oscillations per second, although small changes were observed in the length of consecutive cycles. The main differences observed in vibrato usage between the singers and the two groups were in the extent of vibrato and the use of straight tones or partial straight tones. Considering the different treatment of vibrato within individual tones by the two groups, the treatment of certain notes within the song tasks are thought to be stylistic rather than integral characteristics of the singers' techniques. The first note of the Handel extract is isolated for analysis to explore the possible stylistic objective of utilising vibrato as a musical feature.

3.3.1 Rate of Vibrato

As mentioned above, the rate of vibrato was consistently found to be almost exactly 6 oscillations per second for all subjects. This rate is consistent with the current 'acceptable' parameters of vibrato as it is currently acknowledged that 'a vibrato rate of less than 5.5 undulations per second sounds unacceptably slow, and vibrato rate exceeding 7.5 undulations per second tend to sound nervous' (Sundberg, 1987: 164). That the two groups of singer analysed in this study produced equal rates of vibrato is suggestive of changing vibrato fashions over time – although the early music singers are performing historical music they still conform to the current tastes which have been evaluated for classical opera singing. This also supports Rothman's findings which showed that the singers in historical recordings used a faster pulse rate than contemporary singers irrespective of their genre, implying that fashion overrides any 'authenticity' (Rothman *et al.*, 2000).

Vibrato was used within most tones by all the subjects in all of the tasks. However, some straight tones were produced by certain subjects, mainly from the early music group. In order to ascertain the general usage of vibrato without interference of consonant production or stylistic interpretation, the ascending Bb major scale sung to the vowel [ɑ] was analysed for each subject. The tones that appeared as straight tones were noted. Tones with slight fluctuations in pitch that did not create periodic vibrato were classed as being 'straight'. The Puccini extract was analysed in the same way in order to observe any differences that may occur when the singers sing exercises as opposed to performing a song. The results are shown in table 6.

None of the singers in the opera group produced any straight tones when singing the scale. However, when singing the Puccini extract subjects 5 and 10 produced one straight tone and subject 8 produced four. Each of these subjects produced these straight tones on shorter notes within the extract. Only three of the subjects in the early music group produced vibrato tones in all the notes of the scale and the same singers also used vibrato in all tones in the Puccini extract. The tendency for more straight tones being present in the Puccini extract than the scale, and the random use of straight tones in the Puccini extract suggests that the singers are aiming for a consistent vibrato throughout tones within their general technique. When singing shorter notes or perhaps producing consonants the vibrato production becomes less consistent with some subjects, an effect not dependent on their performance specialty. The inclusion of more straight tones by singers in the early music group indicates that consistent vibrato production is a less prominent characteristic particularly as a constant feature essential to their performance specialty.

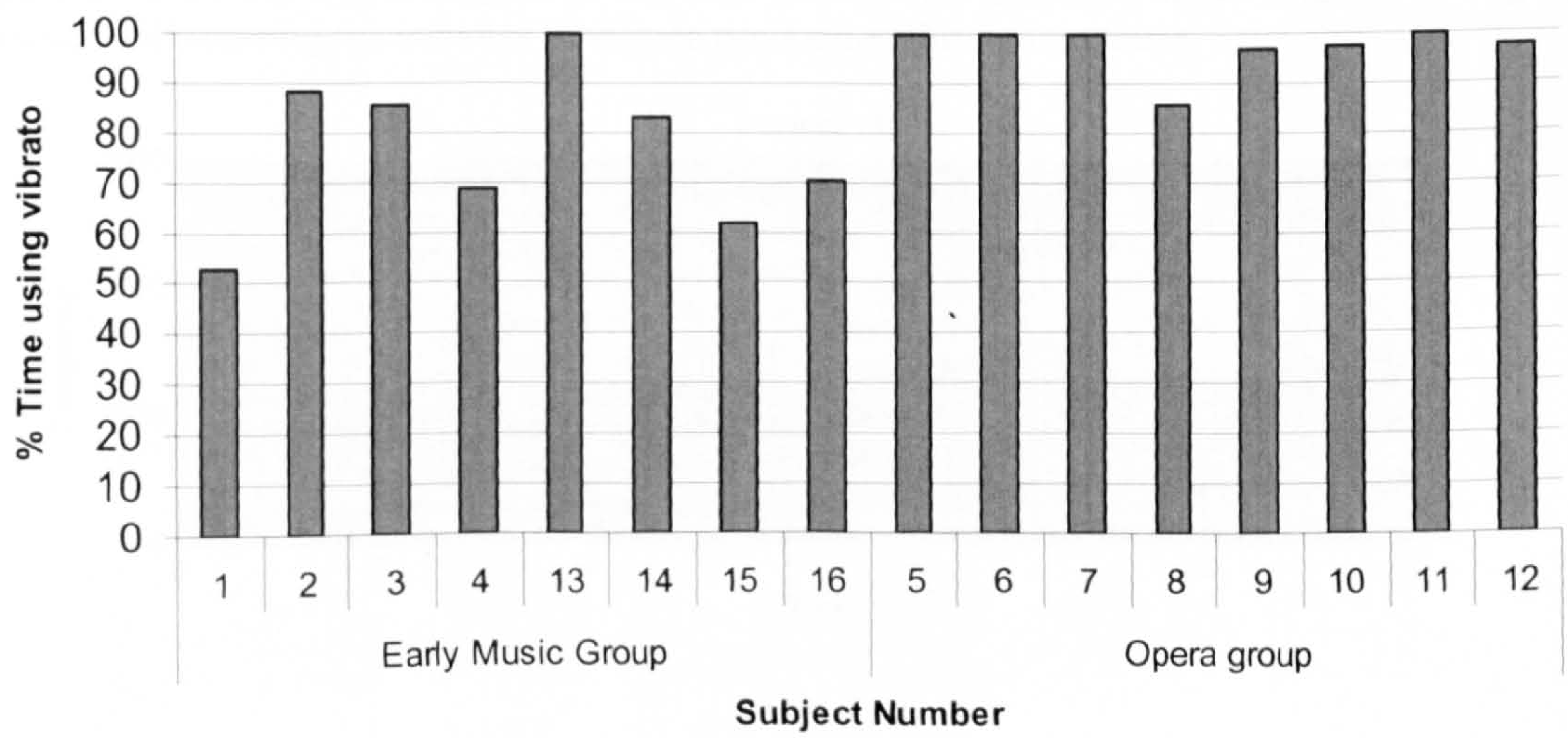
Whilst the inclusion of straight tones by the singers can provide evidence of intrinsic technical features of the voices of the subjects, some notes which are classed as vibrato tones do not utilise vibrato throughout the whole tone. The amount of each note produced as a straight tone was calculated for all subjects singing the scale and was explained in chapter 2. Figure 26 shows the percentage of the phonation time for which vibrato was present within the scale, and illustrates that the singers in the early music group produce vibrato less consistently than singers from the opera group.

Table 6 The number of straight tones sung by all subjects in the Puccini extract (left) and ascending Bb major scale (right)

	Subject	Straight
Puccini	1	7
	2	0
	3	2
	4	5
	13	0
	14	0
	15	8
	16	4
	5	1
	6	0
	7	0
	8	4
	9	0
	10	1
	11	0
	12	0

	Subject	Straight
Scale	1	6
	2	0
	3	2
	4	4
	13	0
	14	0
	15	1
	16	1
	5	0
	6	0
	7	0
	8	0
	9	0
	10	0
	11	0
	12	0

Figure 26 Vibrato usage (%time) in a two octave ascending scale to the vowel [ɑ]



As figure 26 shows, subject 13 is the only singer in the early music group to produce vibrato throughout all tones in the scale. Apart from subject 8 who produces vibrato for only 86% of the tone, all the opera singers produced vibrato over 95% of their total phonation time which adheres to Seashore's findings for 'great singers' (Seashore, 1931: 623). The lower values observed for the singers in the early music group are mostly the result of introducing vibrato some time after the onset of the note as illustrated in the spectrogram of the lower octave of the scale sung by subject 14 in figure 27. This characteristic could also be symptomatic of the stylistic tendencies of the early music group, the implications of which are explored in detail below through analysis of the first note of the Handel extract under the heading 'stylistic usage'. Subject 1 of the early music group displays notably more straight tones than most of the other singers. This subject also produces vibrato for the least time within the notes and utilises a pattern of vibrato production not observed in the other singers. Figure 28 shows that subject 1 produces almost alternate straight and vibrato tones when singing the upper octave of the scale. This effect is less prominent in the lower octave of the scale.

Figure 27 Showing a spectrogram of the first octave of a Bb major ascending scale sung by subject 14 illustrating the increase in vibrato production throughout tones

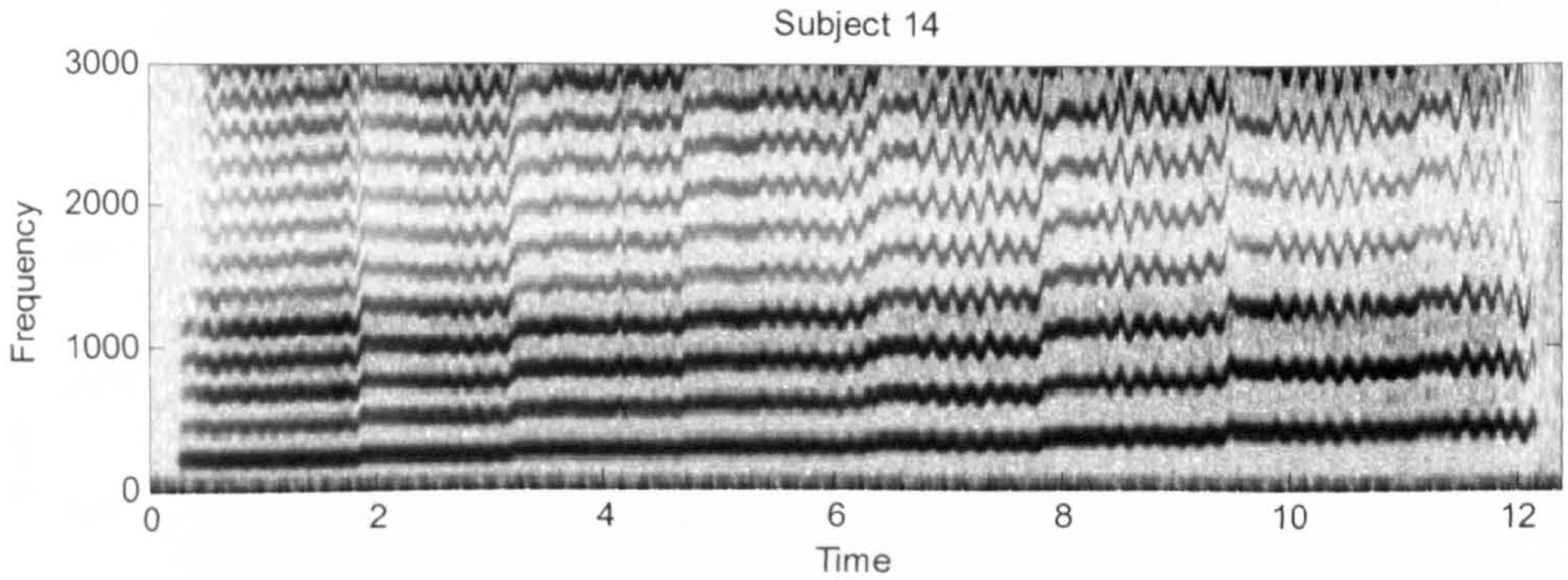
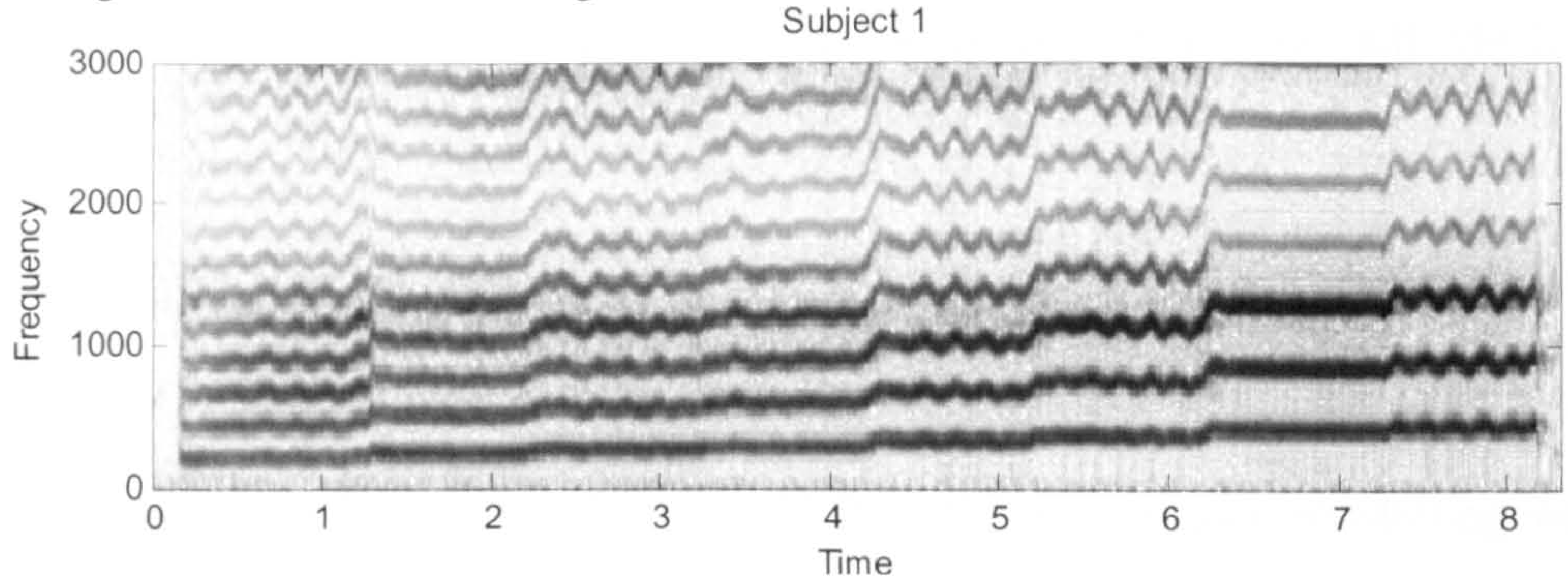


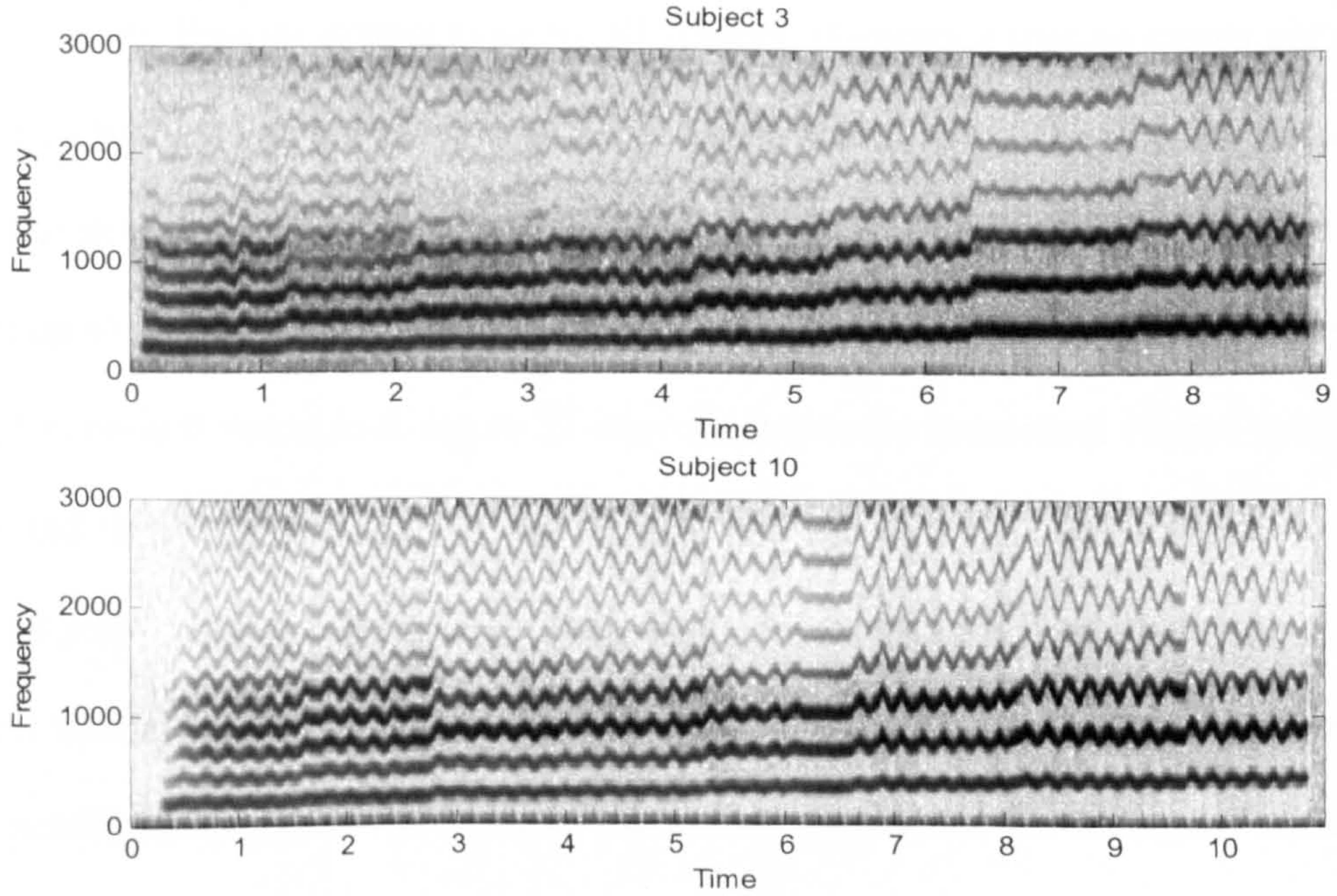
Figure 28 Showing a spectrogram of the second octave of a Bb major scale sung by subject 1 illustrating the alternate use of straight tones.



3.3.2 Extent of Vibrato

As well as differences between the amount of time in which vibrato is present within each note, there are also differences between the extent of vibrato between the singers. Both the overall extent and the consistency of extent vary between subjects, with some general differences being observed between the two groups.

Figure 29 Spectrograms of subject 3 from the early music group (above) and subject 10 from the opera group (below) singing the first octave of an ascending Bb major scale showing differences in the consistency in extent of vibrato tones



The ascending scale which was analysed for the presence of vibrato above also illustrates the varying consistencies in the extent of vibrato by individual singers throughout tones. There is a tendency for singers in the early music group to noticeably vary the extent of vibrato throughout tones more than the subjects from the opera group. Figure 29 shows spectrograms of the first octave of the ascending scale sung by subject 3 from the early music group and subject 10 from the opera group, illustrating the visual differences in the vibrato production between the subjects. Subject 3 shows a tendency to noticeably increase and decrease their vibrato throughout a tone reaching the maximum extent towards the centre of the note. Whilst on initial inspection the spectrograms of the opera group indicate generally higher extents of vibrato, analysis of individual vibrato cycles reveals that no significant differences occur between the maximum extents utilised.

Figure 31 shows the maximum vibrato extent measured in the final two notes of the first phrase of the Puccini extract sung by all singers, illustrating that no trends are present between the groups. A number of the extents produced by the singers, particularly subjects in the opera group are larger than expected in vibrato which is currently thought to be up to ±200cents (Easley in Seashore, 1936; Sundberg, 1987: 164). Although most subjects exceed this extent, figure 31 only illustrates the maximum vibrato cycle in the tone and therefore may not be representative of the average vibrato extent. This is a crucial point when assessing the vibrato extent, especially considering the fluctuations in extent which occur within a tone which was noted above. The irregularity of extent in the penultimate tone of the Puccini phrase by subject 14, for example, creates two vibrato peaks at random points within the note that extend far beyond the pitch of other cycles (See figure 30). It is also important to note Seashore's findings that 'oscillation of pitch is heard as if it were only one-fourth to one-half of its actual extent and a similar under-estimation occurs for intensity' (Seashore, 1931: 626).

Figure 30 Spectrogram showing the inconsistency in vibrato in the penultimate note of the first phrase of the Puccini extract sung by subject 14

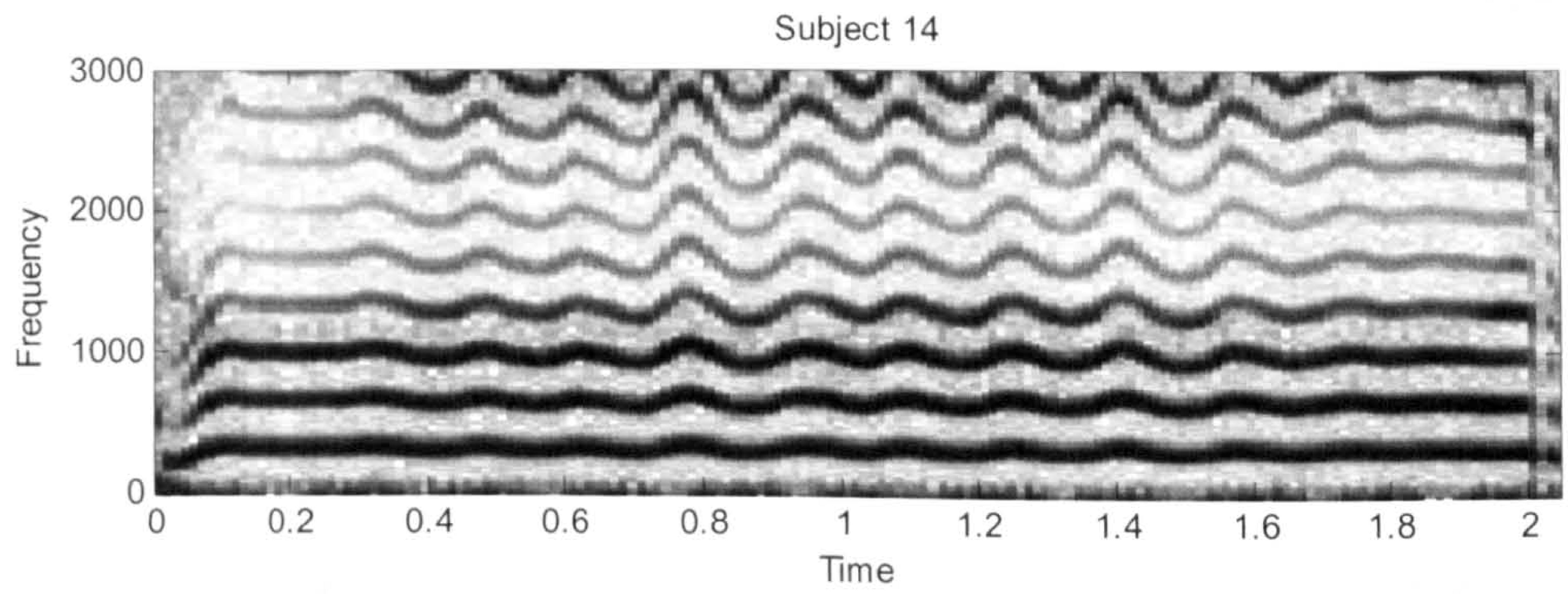
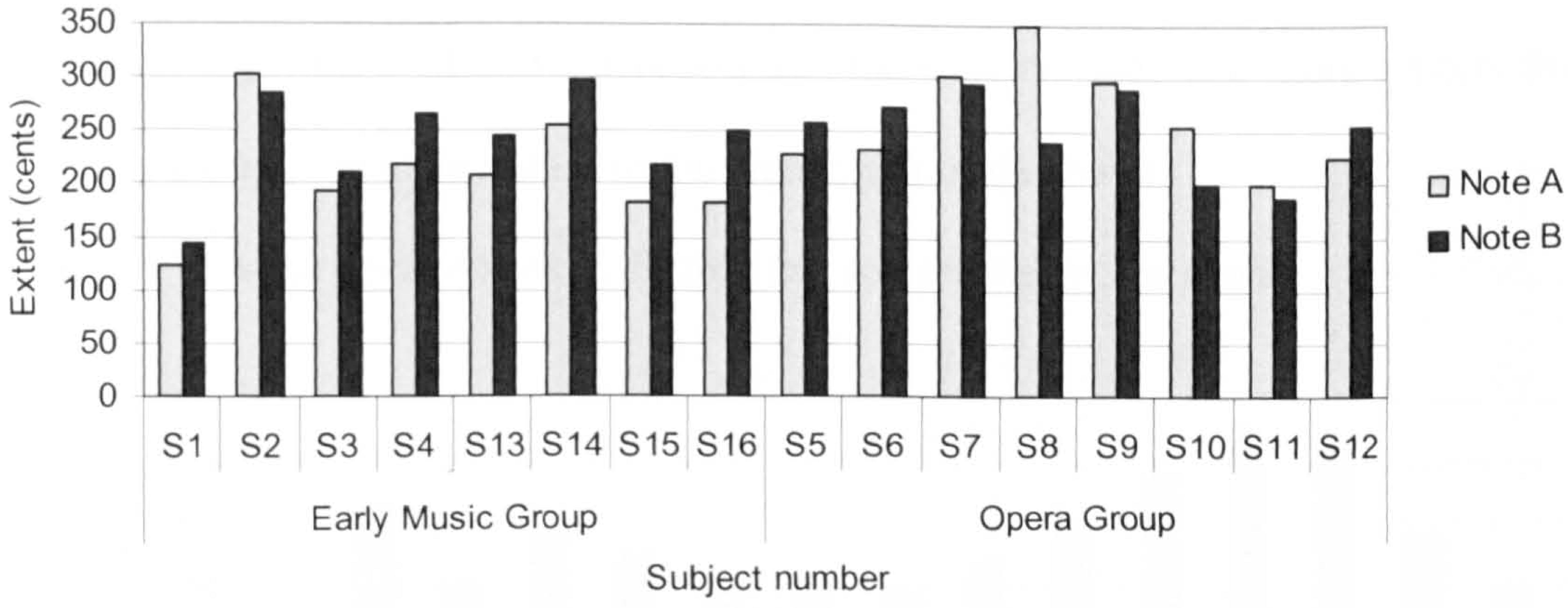


Figure 31 Maximum vibrato extent in the final two notes of the Puccini extract



In order to assess the degree to which the maximum vibrato extents recorded above are representative of the tones being sung, a further calculation was taken estimating the average extent of vibrato throughout these two tones which was explained in chapter 2.

The mean extent of these two tones for each subject are shown in figure 32 and table 7 where the mean extent (see also figure 33) and standard deviation across the two groups are also given. These figures show that once vibrato extent is considered throughout a tone differences become more apparent in vibrato extent between the groups. Although taking an average across each group is not necessarily a fair representation when dealing with a small sample sizes as in this example, the mean extents for each group do show that overall the early music group utilise a smaller vibrato extent than the opera group.

Considering the individual subjects supports the finding of the group average, in that the singers in the opera group tend to use a larger peak to peak extent than singers in the early music group with the smallest extent being represented in the early music group by subject 1 and the largest in the opera group by subject 8. In spite of these differences observed in the extreme examples from each group, the subjects in both groups tend to utilise a peak to peak vibrato extent of between 150 – 200cents, with more early music singers applying a vibrato extent towards the smaller value and more singers from the opera group producing values in the higher part of that band.

Figure 32 Mean vibrato extent in the final two notes of the Puccini extract

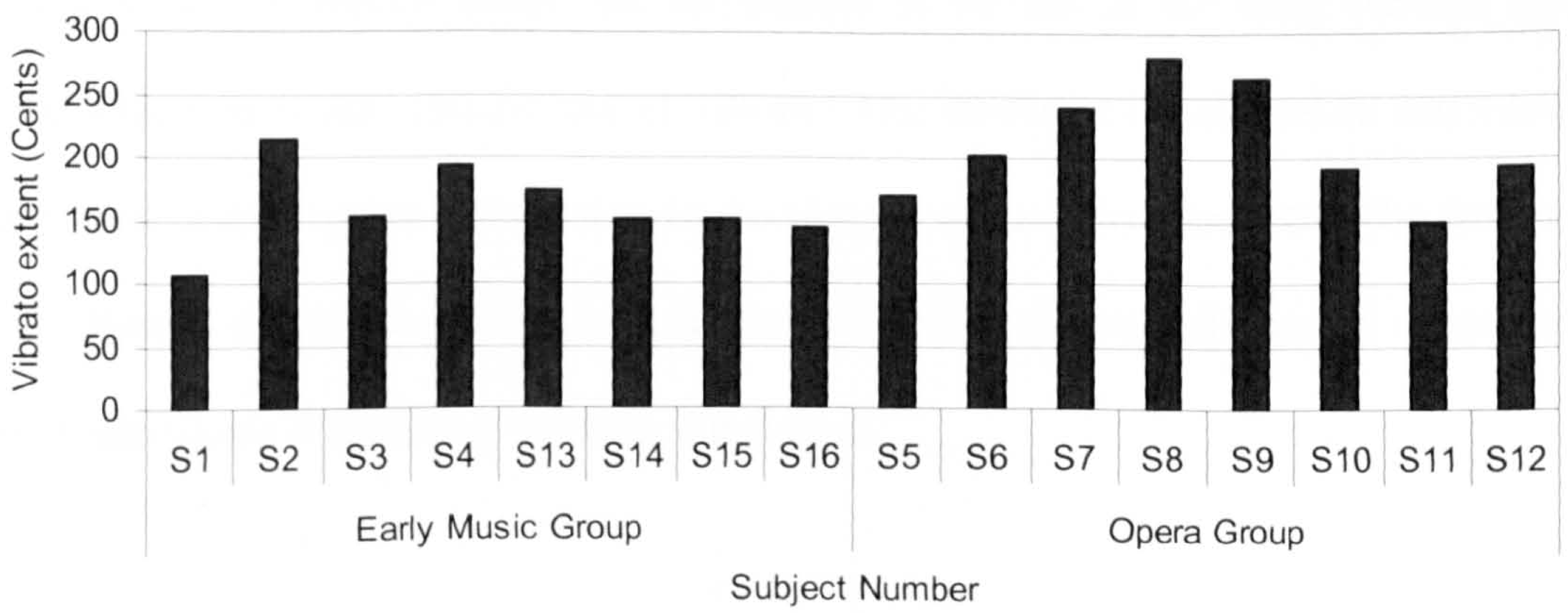
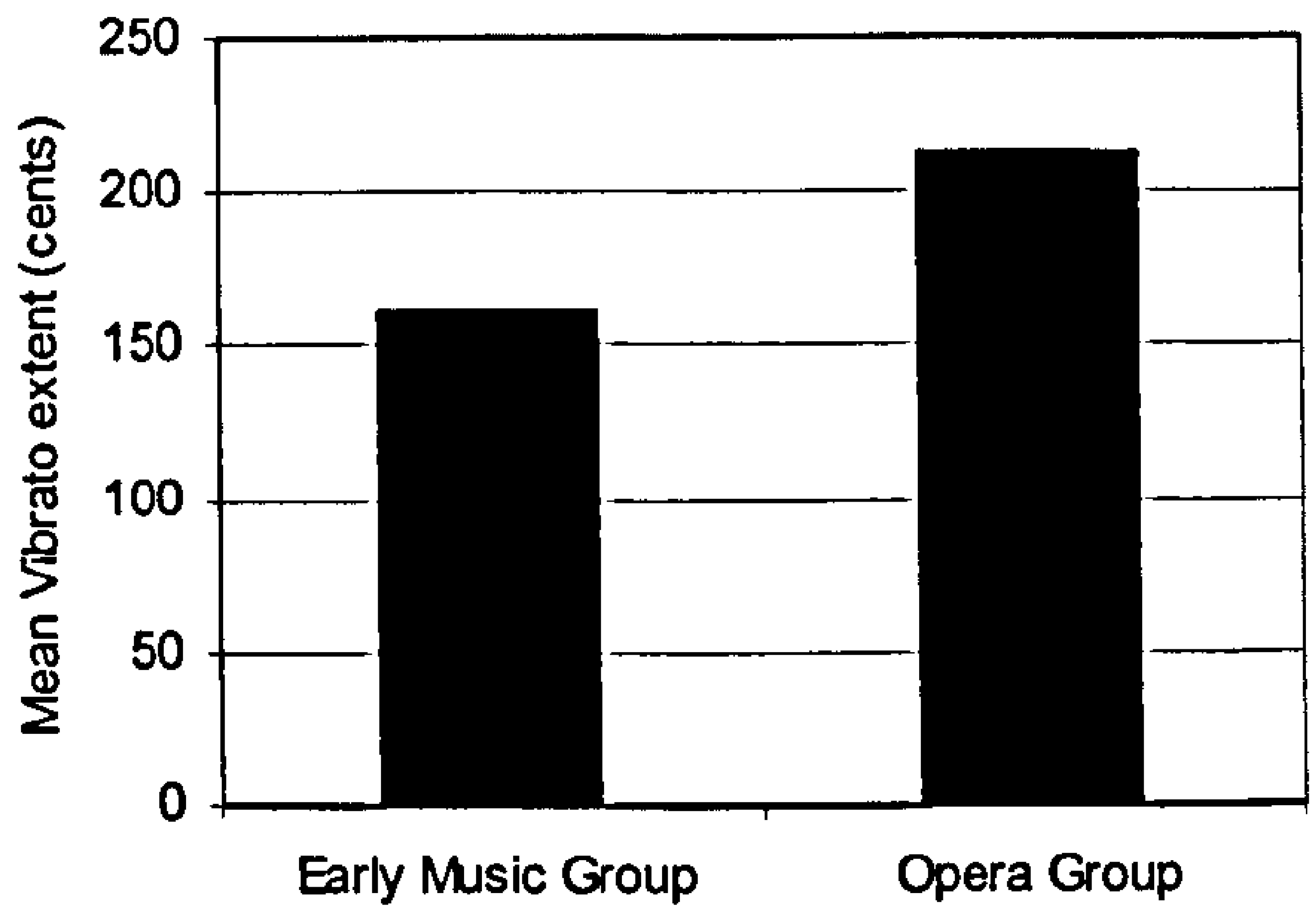


Table 7 Mean vibrato extent for all subjects

Group	Subject Number	Average extent (cents)	
Early Music Group	S1	106	
	S2	215	
	S3	152	
	S4	195	
	S13	174	
	S14	151	
	S15	151	
	S16	145	STDev
	MEAN	161	33
Opera Group	S5	171	
	S6	203	
	S7	241	
	S8	282	
	S9	264	
	S10	192	
	S11	148	
	S12	194	STDev
	MEAN	212	46

Figure 33 Mean vibrato extent used by the two groups in the final two notes of the first phrase of the Puccini Extract



3.3.3 Stylistic Usage

It was discussed above that the vibrato content is often different between the song extracts and the exercises. As well as being representative of intrinsic techniques when singing longer or shorter tones, the differences in vibrato in the song extracts show strong evidence of the stylistic use of vibrato. The tendency for singers to use vibrato more often in the Puccini extract than in the Handel extract illustrates this. The first note of the Handel extract provides an ideal tone to analyse the stylistic use of vibrato and shows significant differences between the singers.

Visual inspection of spectrograms of the first note of the Handel extract reveals that the singers in the early music group add vibrato to the tone much later than the singers in the opera group. These findings are in keeping with the results discussed under rate of vibrato above which revealed a tendency for early music singers to use straight tones for a higher percentage of a note. As chapter 2 explained, a panel of researchers was used to regulate the interpretation of the spectrograms when evaluating vibrato onset. There was mostly agreement within a few milliseconds, however when discrepancies did occur the majority agreement was taken as the moment of vibrato onset for analysis. Table 8 shows the percentage time of the note sung as a straight tone before the vibrato was introduced. Only subjects 3 and 13 from the early music group introduced vibrato into the tone within the percentage time observed for all subjects in the opera group, subject 3 only singing the first 10 per cent of the tone without vibrato and subject 13 producing vibrato from the onset.

The lengthy production of a straight tone by most subjects in the early music group is suggestive of a conscious stylistic effect. Although other notes were also found to contain less vibrato for tones sung by subjects from the early music group than the opera group, the time spent on straight tones was relatively short. The data which is discussed above is suggestive of an objective to utilise vibrato consistently on long notes by all singers and supports the theory of the conscious application or reduction of vibrato rather than a representation of an integral part of their technique. Schoen's research which found that trained singers couldn't maintain a straight tone for more than a fraction of a second contributes to this theory, suggesting that once the objective is achieved it cannot be suppressed (Schoen, 1926:284).

The inconsistencies in the panel's identification of the vibrato also imply techniques being employed by the singers consciously to create an expected stylistic affect. As expected when producing the 'straight' tone slight fluctuations in pitch are visible for all subjects; however, the 'straightness' of the tones varies quite considerably and in some of the singers it is difficult to determine whether the small oscillations that are visible constitute a vibrato. An example of the indeterminate nature of some tones is seen in the spectrogram of Subject 4. Whilst table 8 indicates that the first 68 per cent of the tone produced is vibrato-less, there are clear oscillations in pitch, although their periodicity and extent are inconsistent resulting in four out of the six panel participants discounting this period of the tone as a vibrato tone. If the indeterminate part of the tone had been factored as vibrato only the first 18 per cent of the tone would be classed as 'straight'. This is still a considerable percentage of the note compared to other tones and again implies intentional control of the vibrato.

The irregular 'fluctuating' tone could also be representative of the singer deliberately attempting to suppress their vibrato for stylistic affect. A similar effect is visible in the spectrogram of subject 9 from the opera group. Although the vibrato was identified after the first 21 percent of the note, there are clear, though irregular, fluctuations in pitch from the onset of the note. This could again be an attempt at 'ironing out' the vibrato in order to comply with the modern ideals of performing early music. Stark's description of vibrato in trained voices also suggests that the vibrato feature being observed is a conscious reduction rather than inclusion of vibrato, stating that 'Vibrato should not be seen regarded as a secondary element in an otherwise straight tone, but rather as a primary element in the sophisticated vocal matrix of the cultivated voice' (Stark, 1938: 151). Interestingly subject 9 was the only participant in the opera group to have previously specialised in early music, suggesting that she would be well informed of modern performance conventions suitable for this period of composition. Subject 9 was also one of the two opera subjects to create the longest straight tone before introducing vibrato, further solidifying the theory. The spectrogram of Subject 14 shows a pitch oscillation at the onset of the note which could be identified as a vibrato cycle, however there are no further noticeable fluctuations in pitch until the obvious production of periodic oscillations 36 percent into the tone as noted in table 8. This evidence is again suggestive of an apparently intentional suppression of an integral vibrato in the voice.

Table 8 Percentage time at which vibrato begins of the first note of the Handel extract.

Subject Number	Vibrato onset % time
1	54
2	33
3	10
4	68*
13	0
14	36
15	65
16	76
5	0
6	3
7	0
8	22
9	21
10	5
11	8
12	2

Another interesting aspect of vibrato production which is highlighted by this note is the seemingly deliberate changes in extent throughout the tone. Seashore identified the use of varying the extent of vibrato throughout a tone commenting that; 'The extent may be large or small; it may increase or decrease within a single tone or in a succession of tones, but the change must be gradual and smooth' (Seashore, 1937a, 30). All subjects apart from subject 13, increase their extent of vibrato throughout this first note of the Handel extract; however, some vary the extent at identifiable stages while other subjects produce a 'smooth and gradual' change. When asked to identify the onset of vibrato in the note the panel were also asked to record any points at which the vibrato altered suddenly.

Table 9 shows the changing extent of vibrato throughout the tone for all subjects. As chapter 2 explained, the first full vibrato cycle after the identified onset and then the vibrato cycle three cycles from the end of the note (labelled as 'End' in the table) were measured. The final cycle was not usually measured because there is a tendency for the extent to reduce and become less regular at the very end of the tone. When a specific change was identified in the spectrograms of the tone by one or more of the panel the extent was measured and appears on the table. The vibrato tone with the maximum extent was also measured and is recorded at the relevant part of the sequence of measurements in the table. In some circumstances the extent of vibrato at the point of change is the largest that appears in the tone. The largest extents appear in bold to show when this occurs. Subject 13 from the early music group was the only subject to reduce their vibrato extent throughout the note, decreasing the peak to peak extent by 74 cents over the 2.3 seconds for which she held the tone.

Table 9 Showing the vibrato extents as measured in the first note of the Handel extract at points of vibrato onset (Beginning), identified change (Change), three cycles from the end of the note (End) and the maximum extent.

	Subject Number	Part of note	Peak to peak extent (cents)	Diff between max and min extents (cents)
Early Music Group	S1	Beginning	55	
		End	**108**	54
	S2	Beginning	64	
		End	**192**	128
	S3	Beginning	127	
		Change	78	
		End	**209**	82
	S4	Beginning	69	
		Change	118	
		End	**198**	129
	S13	Beginning	**220**	
		End	145	75
	S14	Beginning	47	
		End	**180**	134
	S15	Beginning	67	
		Change	**99**	32
		End	86	
	S16	Beginning	125	
		End	206	
		Max	**212**	87
Opera Group	S5	Beginning	42	
		End	**251**	209
	S6	Beginning	65	
		Change	160	
		End	**223**	158
	S7	Beginning	52	
		Change	**133**	82
		End	86	
	S8	min	113	
		max	**204**	91
	S9	Beginning	35	
		Change	135	
		End	**150**	115
	S10	Beginning	167	
		Change	**279**	113
		End	271	
	S11	Beginning	83	
		End	**113**	30
	S12	Beginning	100	
		End	**191**	91

The majority of the early music singers use lower vibrato extents to begin with than the opera singers. As mentioned above, subject 13 is an anomaly to this trend both in terms of the overall extent being noticeably higher, and in the decrease rather than increase in vibrato extent throughout the tone. The largest differences in vibrato extent from the beginning to the end of the tone are present in the opera singers group, most notably subjects 5 and 6 who presented with the largest differences of 208.9 cents and 157.8 cents respectively. Both of these singers produced the increase from the beginning to the end of the note.

A distinct point of change in vibrato was identified by at least one panel participant in six of the sixteen subjects. Analysis of these moments of the spectrograms reveals that for subjects 4,6 and 9 this change was part of an overall increase of vibrato throughout the note. The spectrogram of subject 9 is shown in figure 34 and illustrates the three distinct vibrato stages employed by the singer increasing the vibrato extent throughout the note. The first stage marked 'a' on the spectrogram consists of the slight fluctuations in the pitch that were discussed above as not being classed as vibrato due to their irregularity. An introduction of a steady peak to peak extent and rate of vibrato of 35 cents and 6 oscillations per second occurs 21% into the note marked 'b', with an increase to 135 cents at the noted change, the vibrato continuing to increase gradually to 150 cents towards the end of the note (labeled 'c'). Although the onset of vibrato in the spectrogram of subject 4 was noted as beginning at 68% due to the majority decision of the panel, those who considered the onset of vibrato early in the note at 18% also identified a change at 68%. Therefore, analysis of the vibrato extent was carried out at both of these points. The irregularity of both the extent and rate of the pitch oscillations during the first 68% of the note for this subject makes the lower extent of 69 cents peak to peak less significant in terms of being part of an overall increase. This is particularly significant as the extent decreases again before the point of change at 68% (see figure 35).

Figure 34 Three stages of vibrato extent (a, b, c) in the first note of the Handel extract sung by subject 9 displayed on a spectrogram.

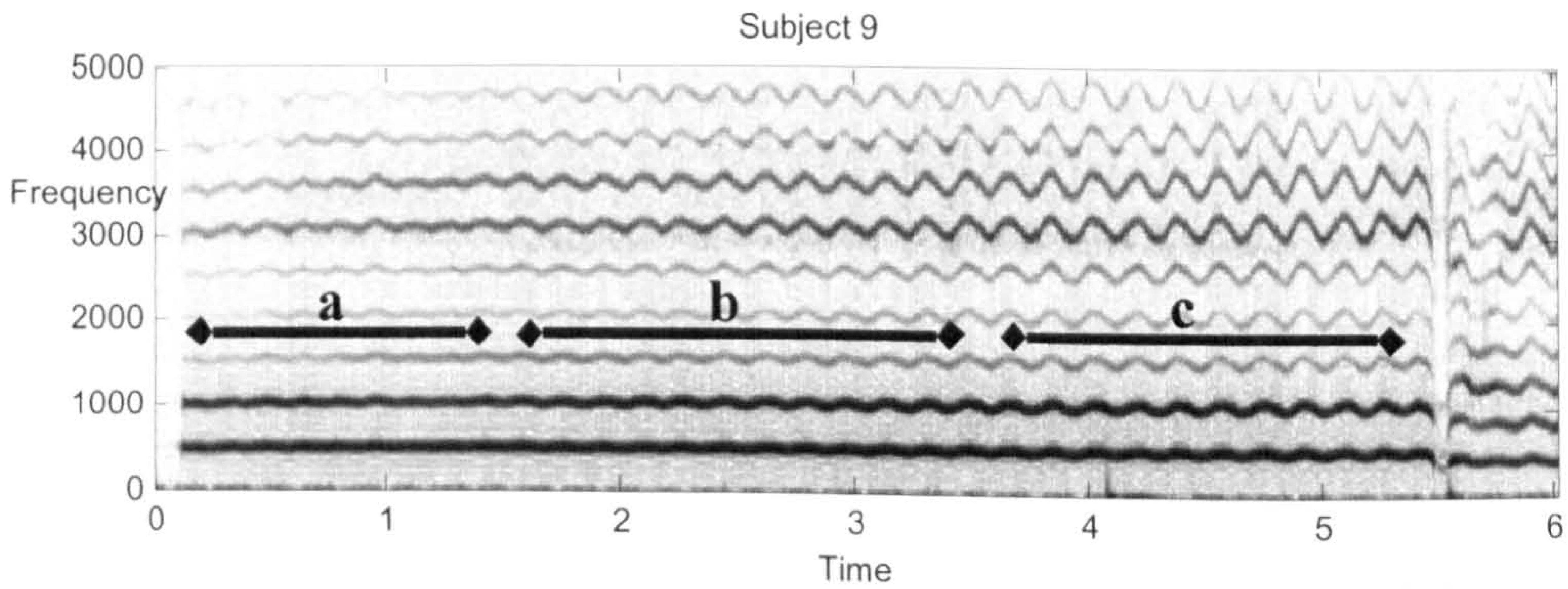
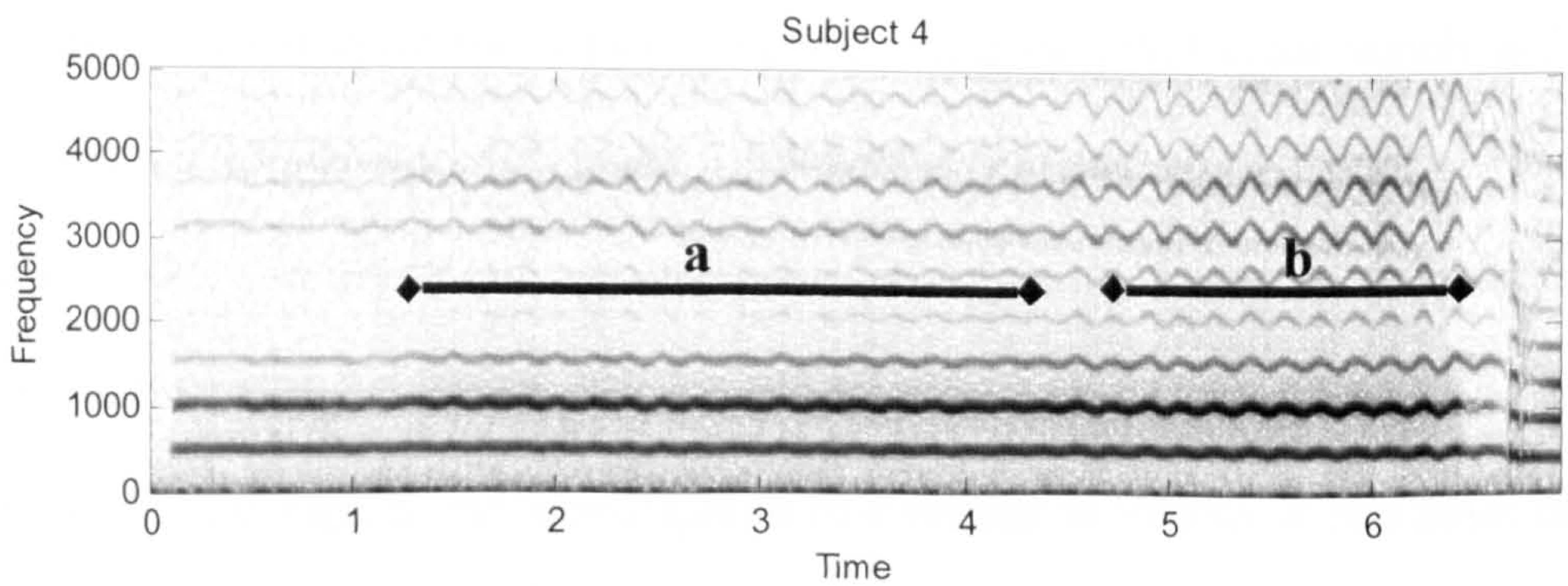


Figure 35 The vibrato observed on the spectrogram of subject 4 singing the first note of the Handel extract. Irregular fluctuations not classed as vibrato by most panel participants is marked 'a' and the period of 'steady' vibrato marked 'b'.



Although there was a unanimous decision as to the onset of vibrato for subject 6, a point of change was only identified by three of the six panel participants. The same moment was identified by each of these panel members, for which reason it was included in table

9 as a point of change, however, closer inspection of the spectrogram reveals that rather than a significant change in vibrato, other spectral factors may have influenced the judgment of vibrato. The vibrato change was observed at approximately one second into the note, at the same time that the spectral energy at 3kHz – 4kHz increases and energy bands appear between 6kHz – 7 kHz.

In order to determine the extent to which this is a transitional moment of vibrato extent as well as spectral energy, further analysis of the individual cycles was necessary. The peak to peak extent of each vibrato cycle occurring before one second and one cycle after was calculated to observe any significant changes in extent. Table 10 shows the maximum and minimum extents for the seven vibrato cycles that were measured with the peak to peak extent shown in cents in the final column. The fundamental frequency contour of these vibrato cycles is shown in figure 35. Figure 36 shows a graphical representation of the results in cents and illustrates that the vibrato change occurring at the sixth cycle does not exceed the extent of vibrato observed in the previous 5 cycles. Although the sixth cycle has a peak to peak extent of 159.9 cents which is 37 cents wider than the previous vibrato cycle, the fourth cycle has a larger extent of 191.7 cents (peak to peak), diminishing the significance of the seeming increase in the overall extent at the point noted by the panel. The inconsistencies in vibrato extent in this first second of the note could explain the identification of a change in vibrato at this point therefore identifying the point at which the vibrato 'settles' into a steady rate of extent. However, slight variances in extent continue to appear in individual cycles throughout the note whilst the overall extent increases, implying that it was the spectral change was being noted on the spectrogram rather than a changing vibrato extent.

Table 10 Peak to peak extent of the first seven vibrato cycles sung by subject 6 in the first note of the Handel extract

Vibrato cycle	Lowest extent	Highest extent	Difference
1 (Beginning)	528.5 Hz	509 Hz	65.09 cents
2	549.1 Hz	504.9 Hz	145.29 cents
3	542.1 Hz	497.4 Hz	148.98 cents
4	558 Hz	499.5 Hz	191.74 cents
5	543.4 Hz	506.2 Hz	122.77 cents
6 (Change)	548.6 Hz	500.2 Hz	159.9 cents
7	541.93 Hz	503.9Hz	125.96 cents

Figure 35 The first 7 vibrato cycles sung by subject 6 labelled on a pitch contour extracted in PRAAT.

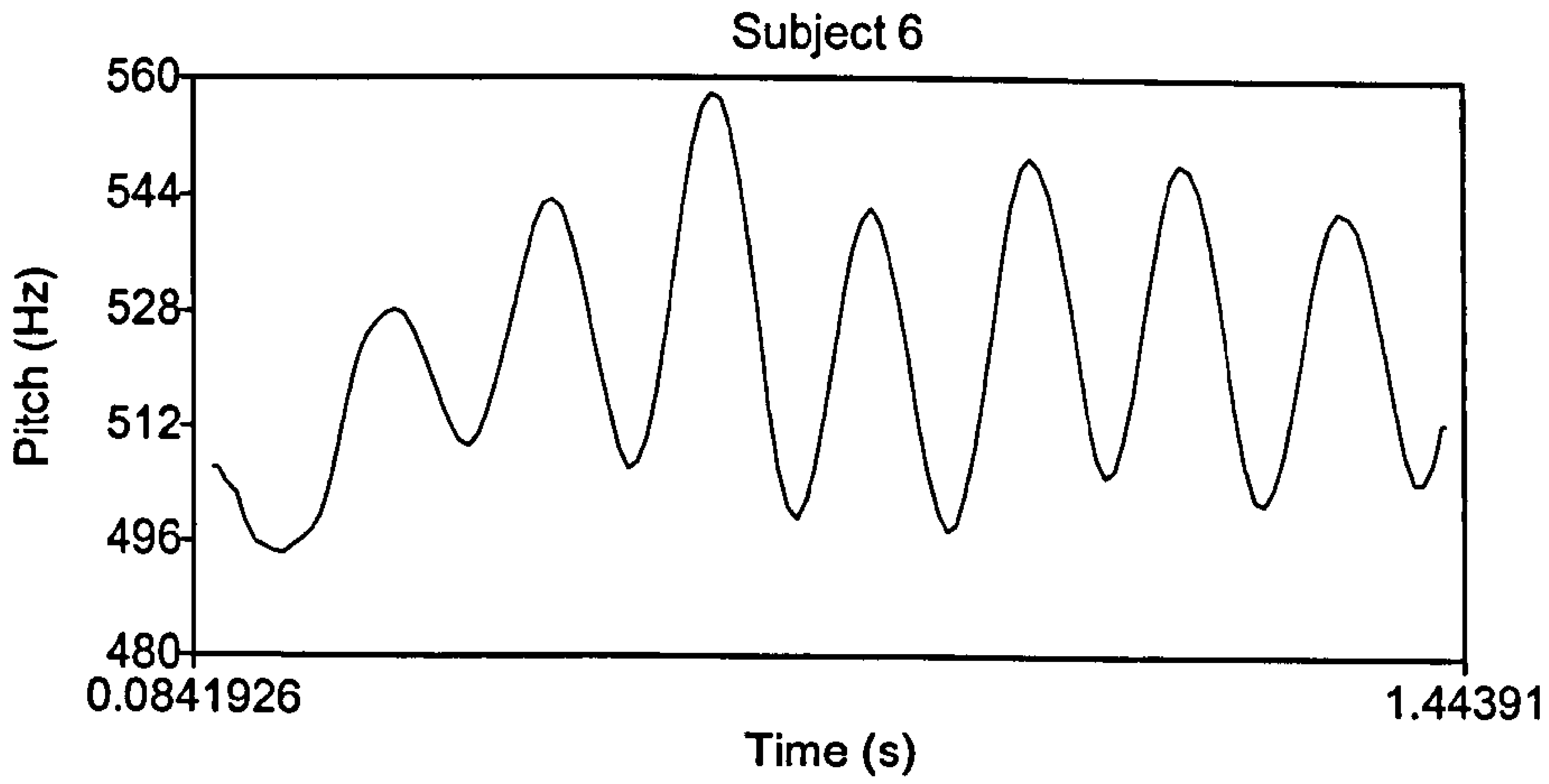
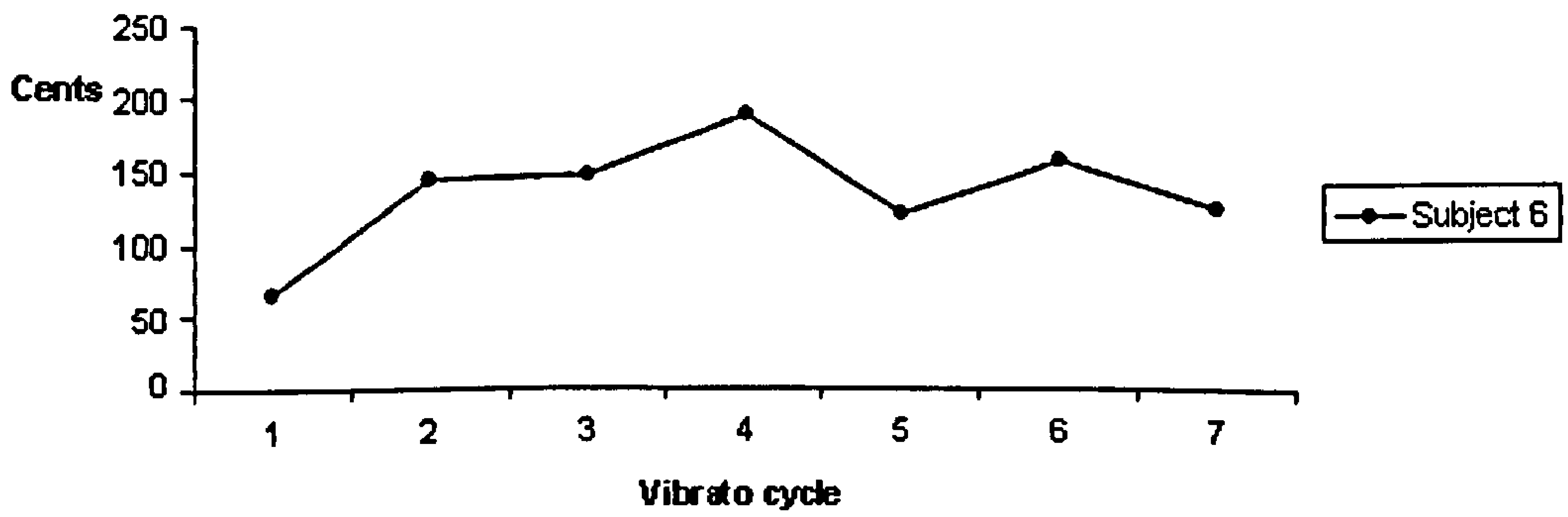


Figure 36 Peak to peak extent of first 7 vibrato cycles for subject 6 singing the first note of the Handel extract



Subjects 7 and 10 were the only subjects to produce the largest extent of vibrato at the point that a change was identified by the panel rather than towards the end of the note as the result of an overall increase in extent throughout the tone. This feature is not of significant importance for subject 10 as the change was observed towards the end of the note which is consistent with the other subjects. The slight decrease observed in vibrato extent for the third final cycle for subject 10 can be attributed to the ending of the note. Subject 7 is therefore the only subject to employ a vibrato which changes throughout the note by a gradual increase to almost half way through the note with a gradual decrease at the end of the note.

Once apparent differences such as the specific changes of vibrato extent throughout the note are explored in more detail a clear trend appears in the treatment of the note by all subjects. Except for subject 7, whose vibrato extent increases to the middle of the note and then decreases to the end, and subject 13 who decreases the extent of vibrato from the onset of the note, all the subjects increase the extent of vibrato throughout the note until the last few vibrato cycles when the extent diminishes slightly for some subjects. Whilst this is the longest note that the subjects sang within the musical extracts, this treatment of vibrato is suggestive of a stylistic feature. The complete reduction of vibrato in most of the subjects in the early music group at the beginning of the note emphasises this feature and complements the literature which promotes the use of vibrato as controlled feature in early music; 'The vibrato question is one of stylistic responsibility and of course, artistic ability too' (von Ramm, 1976:14). The absence of this feature in other notes of either extract by any of the subjects, aside from slight irregularities in extent as discussed above, further supports this theory. If it was a characteristic indicative of the vocal technique of either group it is likely to have been more obviously present in other tones.

That the majority of the singers from the opera group presented with vibrato from close to the onset of the note rather than executing a straight tone is suggestive of the intrinsic techniques of the singers from that group. The idiom in which the opera singers perform most of the time is expectant of a constant, relatively large vibrato. This could be due in part to the environmental factors with which they are faced. The average vibrato extent of an opera singer in comparison to that of string players is also a factor, Seashore notes when predicting the perfect vibrato rate and extent infers that the singers' vibrato is high; 'What would it mean to the musical world if our great singers were to reduce their vibrato to the extent now prevailing in the violin?' (Seashore, 1937b:29). Although Seashore's comment observes vibrato trends in the 1930s rather than today, the possible implications of the comparison remain: singing with a different rate of vibrato and larger extent than the instruments could provide the singer with another acoustic advantage over the orchestra. The increased extent of vibrato throughout the note perhaps shows their stylistic awareness of expected performance styles of historical music, but could also be illustrative of the natural stylistic objectives of musicians to 'warm through' particularly long notes and into musical phrases. The gradual increase in intensity throughout the note by all subjects supports this possibility.

3.4 Summary

The tendency for tones sung by subjects in the early music group to present with vibrato for less time than the singers in the opera group supports the hypothesis of a stylistic attitude being applied to vibrato in singers specialising in early music performance. The evidence of common application of the conscious control of vibrato as identified in the first note of the Handel extract could also be emerging within other tones as an integral feature of their technique. This would explain the tendency for less vibrato being used throughout tones by the early music singers.

This distinctive feature of singers in the early music group could imply a conscious effort by singers to utilise a vocal technique which is informed by research into historical vocal practices. As a stylistic trait it could also result from a conscious or subconscious mimicking of performance characteristics admired in their peers. This feature could also be symptomatic of the natural development of the current fashions of early music performance which have resulted from performing in difference environmental conditions to 'grand opera' singers. The smaller orchestral forces and period instruments with which early music singers tend to perform are in themselves, at least partly, reflections of historical performance practices. This in turn suggests that any changes in vocal production by modern early music singers which emerge as subconscious reactions to their performance environment could be the cultivation of a natural historically informed technique. However, any differences, particularly in vibrato production, could also be partly due to the remains of the 'Cambridge coo' of the singer's choral training, or another factor in the commercial necessity to sound 'different' to opera singers.

The common use of straight tones by the singers in the early music group seems to contradict the research which was outlined above, suggesting that trained singers could not remove the vibrato from their sound for more than a fraction of a second. However this feature was most prevalent in the subjects that did not have music college training backgrounds which has implications for the effects of different backgrounds on integral vocal techniques within classical singing. It could also suggest that the desirable features of voices specialising in early music involve the employment of 'opera techniques' to a lesser extent than singers who perform grand opera. Such theories can only be proposed as speculation whilst understanding of vibrato production is still incomplete and the controversial theories of the existence of a 'natural' vibrato are not resolved.

Chapter 4

Larynx Position

A large importance is placed on the positioning of the larynx in both singing and speech (Sundberg, 1987; Iwarsson, 1998; Chapman, 2005). Within vocal pedagogy larynx position is often singled out as a physiological aspect to change and voice therapists often consciously work to alter larynx placement in dysfunctional voices by various exercises and tasks (Iwarsson, 1998). In both scientific research and as a goal in voice teaching a specific positioning of the larynx has been associated with classical singing and particularly opera singing (*e.g.* Field-Hyde, 1950; Foreman, 1969; Sundberg, 1987). The employment of a lowered larynx position is thought to account for a number of the common acoustic traits of opera singing such as a consistently dark timbre and the singer's formant cluster. Many considerations of larynx positions in classical singing techniques are based on conclusions formed from acoustic evidence and studies involving male subjects (*e.g.* Shipp, 1975; Shipp and Izdebski, 1975). This chapter considers the current research on vertical larynx position alongside literature expressing theories of past and present techniques. The acoustic data used to formulate current theories and, in the case of historical techniques, literary sources, are reviewed. Conclusions on the changing vertical larynx position of the subjects in the current study are considered in respect to this literature and any results showing differences between the two groups identified.

4.1 Previous Studies on Vertical Larynx Positions in Singing

The various methods for measuring larynx height, including x-ray imaging, videofluorographic techniques and multi-channel electroglottography (EGG), were reviewed in chapter 2. The established conclusions on vocal technique based on research using those methods are outlined below. A general consensus on the intrinsic treatment of larynx position has been established that when fundamental frequency increases in speech, the larynx rises (Sundberg, 1987: 96). This contrasts with the common opinion for the treatment of larynx position by professional singers.

A common agreement amongst voice teachers which is often generalised amongst researchers is that, in contrast to speech and untrained singers, professional singers lower their larynx as fundamental frequency increases (Sundberg, 1987: 99). Shipp and Izdebski (1975) found that whilst untrained singers relied on vertical larynx position to change fundamental frequency, professionals used the intrinsic laryngeal muscles, utilising the 'horizontal pulling forces provided by the cricoth[y]roid muscle contraction almost exclusively for increasing frequency' (Shipp and Izdebski, 1975: 1106) noting that professionals 'tend to maintain a larynx position near or well below the physiologic resting level as voice frequency is raised' (Shipp and Izdebski, 1975: 1106). Using intramuscular, hooked-wire electrodes to measure laryngeal activity including vertical larynx position in a different study, Shipp found no correlation between larynx height and register change, whilst also substantiating the findings that in untrained voices the vertical larynx position tracks the direction of fundamental frequency (Shipp, 1975). A pilot study conducted by Echternach *et al.* (2008) produced similar findings.

These studies contribute to understanding the role of vertical larynx position in phonation and provide an insight into vertical larynx position in trained and untrained voices. However, all the studies cited above use male participants, and therefore do not necessarily reflect the behaviour of larynx positioning in professional female singers. In a study using x-ray images to track larynx movement, Johansson *et al.* found that the opposite was true for female soprano voices compared to males, and that, as phonation frequency increased, larynx height also rose in females (Johansson *et al.*, 1982). Pabst *et al.* (1992) found similar trends in female voices, when using two sopranos and one mezzo soprano subject, 'the vertical larynx position increased with pitch in the upper or top part of the range' (Pabst *et al.*, 1992: 76). The same study also observed that sopranos tended to sing with a larynx position just above resting position.

In addition to pitch having an effect on larynx position, breathing and specifically lung volume is also known to influence vertical larynx position. An experiment using untrained singers carried out in 1997 showed that 'high lung volume was clearly associated with a lower larynx position as compared to low lung volume' (Iwarsson *et al.*, 1998; 159). In a later study which was inconclusive due to the methodology restricting the subjects' posture, Iwarsson attributed this previously identified effect to 'an increased tracheal pull at high lung volume' (Iwarsson, 2000: 391). Other studies have also undertaken to consider the role of the diaphragm, abdominal wall movement and lung pressure during phonation, some of which are summarised by Sundberg (1987: 31). Whilst more research needs to be done in the area, particularly in the assessment of trained singers, results from such experiments do have significant implications for singers. Beyond our understanding of modern operatic techniques, the current findings can be used to consider larynx height in historical techniques through a re-examination of references to breathing techniques in the literature. Various theories which have been established through this sort of literary evaluation are discussed later in this chapter.

4.1.1 Acoustic Implications

Consideration of the acoustic implications of changes in larynx position presents some of the advantages of lowering the larynx for professional male singers, but can also provide further theories of larynx positions in females.

The positioning of the larynx has been identified as having various acoustic roles in terms of its affect on the sound spectrum. This is partly due to the lowering or rising of the larynx respectively lengthening or shortening the vocal tract, having an effect on the quality of the sound emitting from the mouth. Vertical larynx position is also known to alter during speech and to be associated with vowel sounds and consonants (Sundberg, 1987: 97; Hoole *et al.*, nd; Elliot *et al.*, 1997). It has been shown in a number of experiments that vertical larynx position (VLP) is affected by fundamental frequency and vowel (Sundberg, 1987: 133) and that '/u/ is mostly associated with a low VLP and /i/ with a high VLP' (Elliot *et al.*, 1997: 174). In singing, it seems to be an objective of the professional to reduce the vowel dependent movements of the larynx in favour of a more consistent vertical placement (Sundberg, 1987: 117) and consequently more consistent timbre with vowel articulation being achieved through movements of the tongue and lips. As shown above, current research suggests that in contrast to untrained singers, particularly in professional males, larynx height during phonation is lower than rest position and is not dependent on fundamental frequency. Sundberg explains that the acoustic effect of the overall lowering of the larynx is to lower all the formant frequencies as it causes the lengthening of the vocal tract (Sundberg, 1987: 99). Lowering the formant frequencies will have a subsequent effect on the timbre of the voice, contributing to the darkness identified in the sound of professional singers, and has implications on theories of historical techniques which are discussed below. A depressed larynx in speech is identified with a dark vowel quality 'while the voice seems more shrill when the larynx is elevated' (Sundberg, 1987: 113).

The main acoustic significance of lowering the larynx in terms of the professional male voice is in connection with the singer's formant cluster. The acoustic characteristics of the singer's formant cluster were explained in chapter 2 and are considered in the context of the current study in chapter 6. Briefly, the singer's formant cluster is identified as a peak in the spectral envelope at around 3kHz. It is thought to be a primary device used by singers to enable their projection over an orchestra, and is the result of a clustering of the third fourth and fifth formant frequencies (Sundberg, 1974). A low positioning of the larynx is thought to be the main physiological factor to cause the clustering of these formants, partly as it lowers the fourth formant, reducing the distance between this and the third formant (Sundberg, 1987: 119). Sundberg explains that 'when the larynx is lowered, the pharyngeal sidewall tissues must be stretched, so that the lower pharynx is widened' (Sundberg, 1987: 114). He deduced in a previous study that for the clustering necessary for a singer's formant cluster to be produced, the 'cross-sectional area in the pharynx must be at least six times wider than that of the larynx tube opening' (Sundberg, 1974: 838).

Perceptual studies using synthesised sung tones have also indicated that raising the larynx results in a decrease in the amplitude of the fundamental and a rise in the formant frequencies (Sundberg and Askenfelt, 1981). Sundberg also found that 'an increase in pitch is associated with an increase of the larynx tube opening' explaining in order to maintain a larynx tube resonance of 2.8kHz 'the singer will have to lower his larynx more and more the higher the tones he sings' (Sundberg, 1973: 842-843).

There is still much debate on the existence of the singer's formant cluster in sopranos, and it is now commonly thought that sopranos utilise alternative resonance strategies to increase their projection capabilities (see chapter 6). The theories concerning singer's formant cluster characteristics in sopranos are discussed in detail in chapter 6 where the resonance strategies employed by the singers in the present study are compared. With relevance to larynx position, the absence of a singer's formant cluster, or its reduced prominence in female trained singers would remove the expectation on a lowered larynx position considering the primary connection with this technique and the singer's formant cluster in male singers. This provides an explanation for the absence of a lowering of the larynx, particularly with increased fundamental frequency, observed in the small amount of research which uses soprano subjects.

The theory that formant tuning is employed by sopranos to increase the intensity of the fundamental which in turn provides a more effective resonance strategy for sopranos singing at higher fundamental frequencies also supports the theory that larynx position will rise with pitch in females. Sundberg explains the acoustic advantage for females to raise their larynx 'since she has to sing at very high fundamental frequencies, thereby preferably tuning her first formant to the vicinity of the fundamental, she has an extreme need of raising her first formant frequency. An elevation of the larynx shortens the vocal tract and thus adds to the possibilities of raising the frequency of the first formant' (Sundberg, 1992: 133). Although larynx position is highlighted as a method for raising the first formant because of its relevance to the current chapter, other strategies such as jaw opening also produce this effect and are also known to be utilised by female singers (Sundberg, 1987: 128; Sundberg *et al.*, 1997; Sundberg, 2003; Joliveau *et al.*, 2004).

4.2 Larynx Position in Historical Techniques

Musical theorists interested in vocal performance have earmarked the early nineteenth century as a point of major change in the history of vocal technique (Uberti, 1981; Potter, 1998; Wistreich in ed. Potter, 2000). The positioning of the larynx is thought to be a primary factor in this evolution in singing practices. Relevant theories constructed by musicologists and performers are frequently attributed to the work and influence of singer, scientist and teacher, Manuel Garica (1805 – 1906).

4.2.1 Manuel Garcia

Garcia is highly acclaimed in both the scientific and musical world as a highly influential historical authority on the voice. He is revered in the science world for his perfection of the laryngoscope in 1855, which made it possible to view the vocal folds during phonation for the first time, and from which he formulated the most comprehensive understanding of the mechanics and acoustics of the voice of his time (Henrich, 2006: 3). Surrounded by world class professional singers within his family, his parents and both his sisters, Garcia was immersed in vocal music of the highest quality. His musical background combined with his scientific authority place him as an iconic figure in the history of the voice, and makes his vocal treatises invaluable to performers and historians.

Due to his scientific successes, his highly qualified singing background and long working life, it is understandable that modern musicologists consider that 'The most comprehensive nineteenth-century source for the historian of singing is Manuel Garcia II' (Potter, 2006: 528). As a result of his vast advances in voice science and the statements he made in his pedagogical works, a theory has been established that Garcia signifies a point of distinct change in vocal technique, from which a pre- and post-Garcia technique have been classified.

The introduction of a lowered larynx technique as standard in western classical singing is thought to be one of the main attributes of a post-Garcia technique: 'We know from

Garcia's treatise of 1841 that the lowered larynx position (the *voix sombrée)* was a novelty in the 1830s and was not known earlier, and this enables us to make certain assumptions about a pre-Garcian voice' (Potter, 1998: 53).

Garcia's reference to a new dark timbre labeled the '*Voix Sombre'* (Garcia, 1841 in ed. Paschke, 1984: 8) and its attribute to a lowered larynx method complies with the modern understanding of the effects of lowering the larynx. He had a firm grasp of the properties of vocal production, understanding that larynx position influences the timbre of a voice and therefore the importance of the vocal tract as a resonator. Potter draws attention to the similarities of Garcia's summary of the vocal process compared to the 1977 description composed by Johan Sundberg,

> *Garcia* (1841): The instrument in which the human voice is produced is formed in three parts...a bellows or air duct (lungs and trachea), a vibrator (larynx), a reflector or tone modifier (pharyngeal, nasal and buccal activities).
> *Sundberg* (1977): Functionally the organ has three units: a power supply (the lungs) and oscillator (the vocal folds) a resonator (the vocal tract).
> Potter, 1998:55

Although Garcia uses the term reflector rather than resonator he shows his understanding that 'The regular series of pulses from the vibrating vocal folds are modified by the acoustic properties of the vocal tract' (Howard, 2006: 208). In the passage entitled 'Formation of Timbres' Garcia explains that 'Hence the varieties of *timbre* will correspond to the multitudinous mechanical changes of which the vocal tube is susceptible' (Garcia, 1841: 7). He goes on to explain that the lengthening and shortening of the vocal tract is achieved through the raising and lowering of the soft palate and larynx; 'The short and gently-curved shape [made he says by lowering the soft palate and raising the larynx] produces the bright timbre; while the somber is cause by the lengthened and strongly-curved form [lowered larynx and raised soft palate]' (Garcia, 1841: 8). Whilst identifying the soft palate and larynx, here Garcia does not consider the role of the mouth and lips to change the length of the vocal tract (protrusion of the lips to lengthen the tube).

It is clear from Garcia's scientific discussion of timbre, that whilst the visual technology now heavily relied upon wasn't available, he had a firm understanding of vocal acoustics. He also presented his knowledge in a clear and logical manner aimed at a singer rather than a scientist. However, in doing so he, perhaps deliberately, over-simplified or lacked detailed explanations of certain aspects of both the physiology and acoustics of the singing voice. MacKinlay, a student of Garcia and Garcia's biographer, wrote that Garcia compared the larynx with an emotional barometer 'If it remained in a fixed position – either high, low, or at any point in between – emotion and tone-colour would remain fixed. This would be neither art nor nature' (MacKinlay, 1924: 641). Whilst the MRI images and spectrograms now available to voice scientists allow facilitated clarification of, for example, the manipulation of the acoustic space of the vocal tract, Garcia could only describe his findings in text and pictures. This allowed his reader a large margin for misinterpretation or over-simplification. In comments mentioning the lowering of the soft palate or rising of the larynx there is no quantitative measure to suggest the amount of movement or from what position any movement is being judged.

4.2.2 Primary Sources on the Larynx

Larynx position in vocal technique was not a new issue in the 1830s, nor is it a current concern associated only with the performance practice of music pre and post-Garcia. The larynx has been a topic of much dispute since its importance as an organ in vocal mechanics was investigated and partly understood. Uberti provides an illustration from a plate from Giulio Casseri's *De vocis auditusque organis historia antomicca* in Ferrara in 1600 which illustrates their contemporary understanding of the physiology of the voice (Uberti, 1981: 487). Whilst awareness of the larynx as an organ is apparent from as early as Aristotle (Zirin, 1980: 10 – 13) understanding of its function was still seriously lacking well into the eighteenth century. In his treatise of 1777 Mancini states, 'The air from the lungs works over the larynx in singing in the same manner as it works over the head of the flute, which one leans against the lips to play' (Mancini in ed. Foreman, 1969: 52). The role of the lungs as providing the breath, rather than the sound as previously thought, and the importance of space in the vocal tract are identified, but the role of the vocal folds and their vibration to cause phonation was not yet established fact.

In his comparison of Italian vocal tutors, Foreman highlights the agreement of Maffei in 1562 with Aristotle that there are two types of voice, the 'flexible' and the 'rigid', clarified as being 'sweet' and 'hard' (Foreman, 1969: 27). It is important to note that Mancini successfully identifies the sound modifiers and understands that 'The better these parts are organized, the more beautiful, strong and clear will be the voice'

(Mancini in Foreman, 1969: 52). It is unfortunate that he didn't understand how they alter the sound, making it difficult to form assumptions about what larynx position or timbre was desired. Once again modern theorists are forced to speculate on the techniques being used by interpreting descriptions of the sounds being produced with vague physiological descriptions lacking in specific instruction.

This demonstrates that voice science and the physiology of the vocal organs, including the larynx, and their function were of interest and being disputed long before Garcia's lifetime, although understanding was more restricted in certain areas than others. This makes speculation on the role of the larynx in historical techniques even more problematic. However, there is a common consensus that after the knowledge of Garcia's discoveries and teachings disseminated, attitudes to vocal pedagogy changed, adopting a new scientific confidence, which, particularly in the case of vocal pedagogy was still often entirely incorrect.

The lowered larynx theory of modern musicologists exploits historical descriptions of performance experience and sound quality in the literature alongside the knowledge that vertical larynx position changes vocal timbre. The above quote from Garcia, which explains that the raising of the larynx creates bright timbres whilst 'sombre' or dark timbres are symptoms of the opposite effect, is an example of the type of passage used to substantiate claims of changes in technique. As explained above, from this and common descriptions of dark vocal qualities in post-Garcian literature, the *voix sombrée* has been identified as a rich dark timbre characteristic of post-Garcia technique (Potter, 1998: 53).

The eagerness for modern musicologists to assign an entirely new vocal technique to the mid-nineteenth century is understandable when descriptions of the voice and acoustics such as those of Garcia appear for the first time. 'A lower larynx technique undoubtedly became the norm during the later nineteenth and twentieth centuries, to the extent that in the twentieth century it was taken for granted' (Potter, 1998: 55). However, there is uncertainty as to the role of Garcia's treatise in terms of the extent to which he is describing an entirely new vocal technique rather than providing a record of a technique, established or otherwise, that was being understood for the first time.

Garcia's continued work as an active researcher until his death at the age of 101 is considered advantageous by theorists as he provides a significant period of vocal practices to be recorded by one person. However, this also makes it more difficult to assert exactly when certain techniques he describes became common practice. Potter states that Garcia's research goes beyond a highly observant record of singing during the vast compass of his lifetime, concluding that because he was brought up listening to his performing mother and father 'Garcia's writings are therefore summative, giving us a picture not only of singing in the 1840s but also of the tradition on which it was built' (Potter, 2006: 528). In a review of Garcia's 'Hints on Singing' Oberlin also suggests 'The book's major value is that of an historical curiosity dramatizing the thinking of a bygone era' (Oberlin, 1972: 443).

4.2.3 Environmental Factors

Alongside the significant changes in vocal pedagogy and scientific understanding of the voice which are documented by Garcia, modern theorists use contemporary understanding of the modern operatic voice to formulate theories on historical vocal techniques. During the nineteenth century, when Garcia was documenting his findings, there were significant changes in compositional style and the performance environment of a professional singer. The dramatic increase in orchestral forces combined with more dense orchestral writing accompanying the voice is thought to be the main reason for the necessity of the development of the singer's formant cluster and other resonance strategies (*e.g.* Sundberg, 1987: 122; Potter, 1998: 50-54; Howard, 2006: 212). In turn the physiological need to lower the larynx in order to achieve the essential projection is then also a result of the evolution of performance environments in the nineteenth century (Potter, 1998: 50-54).

4.2.4 Breathing in Historical Techniques

The theories on the effects of breathing on larynx positions based on scientific investigations, which were discussed above, also have implications for laryngeal behaviour in historical techniques, providing an additional comparison with current acoustic understanding. Breathing and breath control has received particular attention in vocal treatises and voice training since its role in phonation has been understood. Considering records of breathing techniques in the history of singing can therefore provide further insight into larynx positions in past techniques. Once again, for the modern musicologist, Garcia marks a point of change to a 'systemised approach to breathing' (Potter, 1998: 54) and what is now often known as 'diaphragmatic' breathing, even though the intricate workings of the breathing system and the role of the diaphragm were still not fully understood by Garcia and his contemporaries.

The shift in emphasis on breathing in vocal techniques from the pre-Garcian writings of 1600 – 1850 to modern day tutorage is immediately apparent when comparing the literature: Potter asserts 'there is no significant evidence of diaphragmatic breathing until late in the eighteenth century' (Potter, 1998: 54). Most vocal tutors, by the late nineteenth century were placing a strong emphasis on breathing techniques and breath control, and often state that control of the breath is the starting point for any voice student (Monohan, 1978).

Literature before Garcia does not tend to place any importance on breathing techniques. Tosi's treatise of 1723 shows a lack of attention to the breath. The two chapters in which Tosi lays down the important basic stages of teaching vocal technique, 'Observations for One who teaches a Soprano' and 'Observations for a Singer' fail to mention breath at all. It is only in his chapter 'On divisions' that Tosi even makes reference to breathing: 'there are singers who give pain to the hearer as if they have asthma, taking breath every moment, with difficulty, as if they were breathing their last.' (Tosi 1723 in tr. Galliard, 1967: 24) From this description of incorrect usage of breath, it can be presumed that Tosi expected some form of breath control from singers, and that he disapproved of shallow breathing. Although he doesn't identify any specific method for the correct use of breath, it is understandable that Tosi foregoes any further explanation in physiological terms when knowledge was so basic at the time.

Whilst the lack of evidence of a systematic approach to breathing ostensibly supports the theories of those such as Potter quoted above, another perspective has been expressed concerned with the natural evolution of the voice. Hollinshead makes controversial statements on the use of breath in historical vocal techniques, and the consequential positioning of the larynx. He takes the viewpoint that 'With the march of civilization natural breathing was lost' (Hollinshead, 1924: 319). Hollinshead argues that the breathing technique used in speech has become more and more shallow over time as the speaking voice has lost power, resulting in a higher positioning of the larynx, concluding that 'This high position of the larynx was the position assumed to be correct by Garcia when conducting his laryngoscopic experiments' (Hollinshead, 1924: 319). Hollinshead deduces that the necessary control of breath and conscious breathing techniques is then a direct consequence of this new raised position of the larynx which appeared with the 'severance of direct emotional action from the voice' (Hollinshead, 1924: 319).

The concept of the lost natural art of emotional expression in the voice, first affecting speech and then transferred to song, is quite common in modern vocal training. The Husler method is one of the most famous techniques currently in practice which claims that the (classical) training of singing is in fact simply regaining the natural potential of the voice (Husler and Rodd-Marling, 1976).

Tosi's treatise could be interpreted to support the argument of Hollinshead. The fact that Tosi practically ignores breathing could be construed as supporting the theory that in the past a naturally lowered larynx position facilitated instinctive diaphragmatic breathing, meaning breath needed no direct attention in the tutorage of the singing voice. When Tosi refers to breathing it is always in connection with faults in breath production, rather than expressing or teaching a correct manner for a good technique, and in doing so implies such faults are relatively new to singers;

> Let him forbid the scholar to take breath in the middle of a word, because the dividing it in two is an error against nature, which must not be followed if we would avoid being laughed at. In interrupted movements, or in long division, it is not so rigorously required when the one or the other cannot be sung in one breath. Anciently such cautions were not necessary, but for the learners of the first rudiments; now the abuse, having taken rise in the modern schools, gathers strength and is grown familiar with those who pretend to eminence. The master may correct this fault, in teaching the scholar to manage his respiration, that he may always be provided with more breath than is needful; and may avoid undertaking what, for want of it, he cannot go through with.
>
> Tosi, 1723 in Galliard 1967: 24

Of course, without a standard against which to judge Tosi's observations, when he comments on 'asthmatic' breathing and the problem of not being able to complete a word in one breath, he could be identifying particularly poor singers who could never expect singing as their profession. He also, as mentioned above, fails to provide an adequate solution to the problems of breath, even though he states that incorrect breathing does need to be 'managed'. However, his reference to the emergence of the problem does make it valid for consideration alongside Hollinshead's theory, and corresponds with the modern day scientific understanding that larger lung volume effectively lowers the larynx. This also relates to the modern awareness that a lower, rather than elevated, larynx position is indicative of good vocal health.

4.2.5 Vocal Health

Vocal literature of the twentieth century becomes heavily pre-occupied with the health of the voice, rather than simply considering the aesthetics of the sound. The cause of pathology in professional singers during this time is often considered to be the fault of specific larynx positions in vocal techniques. Field-Hyde stresses, along with others, that when either the raised or lowered method is contrived, this will inevitably cause damage; 'To make students endeavor to modify the position of the larynx is fraught with possibilities of serious harm' (Field-Hyde, 1928: 536). Vocal health becomes far more of a concern in the post-Garcia era, especially in terms of identifying an intrinsic connection between vocal technique and vocal health.

This is probably due in part to the new understanding of the workings of the voice and in part due to the changing environments facing singers and the increasingly common problems of vocal health that were the result (Somerset-ward, 2004). As mentioned above, there was a period, which coincides with the theory of a change in technique in the mid-nineteenth century, when there is an influx of literature documenting the deterioration of operatic voices, particularly in association with Wagnerian operas (Sommerset-Ward, 2004: 233-245). This suggests that there had been some change or changes in voice production that were causing voices to wear out for the first time. The changes in the singers' environment are highly documented by musicologists as significant factors causing the change of vocal technique, not least the increasing size of concert halls and orchestras (*e.g.* Sommerset-ward, 2004; Potter, 1998; Wistreich, 2002).

Within modern culture, vocal health is an important consideration, and voice therapy is available for many different vocal defects for both singing and speaking. Larynx position is of significant concern in voice therapy, and one of the most common goals in treatment is to lower the larynx, 'a high vertical larynx position is often seen in hyperfunctional and strained voices' (Iwarsson, 1998: 159). Whilst it is often the direct concern of the speech therapist to change the positioning of the larynx, it is not the conscious concern of the patient, in that the therapist uses specific exercises to facilitate the natural lowering of the organ rather than instructing the patient to alter their positioning through sensation or palpation. Voice therapists use exercises that employ specific combinations of vowels and consonants to facilitate the lowering of the larynx (Elliot *et al.*, 1997).

4.2.6 Manipulation of Science

Monohan observed that Garcia's publications sparked a new scientific approach in voice tutors, and by 1891 almost every major new work on singing refers to anatomy physiology, breathing, phonation and resonance (Monohan, 1979). Potter notes that this is 'in marked contrast to the pre-1840 period when every manual was written either by a practicing singer or a singing teacher' (Potter, 1998: 56).

The marked contrast in written attitudes on the voice contributes to the opinion of theorists that this period denotes a distinct contrast in vocal techniques. However, there is a strong misrepresentation of science within vocal literature beyond Garcia. Anyone arguing theories of their trade, especially in a trade as esoteric as singing, will often use any device available to them. In singing the possibility of science to seemingly prove theories that previously relied on intrinsic psychological description was understandably too attractive to most not to exploit. Even at the level of understanding gained by Garcia, it is often possible to twist the science to 'prove' whichever approach the teacher or author is defending. This is evident from the contradictory accounts of teaching methods used by Garcia (MacKinlay; 1924; Rees-Pedlar, 1937; J.M.L, 1937); 'J.M.L. says "the lips (were) allowed to retire slightly at the corners when the vowels permitted it". I never heard the maestro [Garcia] advocate this' (Rees-Pedlar, 1937: 358). An aspect of vocal technique such as larynx position is particularly vulnerable to misrepresentation, as it is not only specific to each singer but is also a relative measurement within each individual, and a factor which is normally self-assed through sensation.

In his article entitled 'Recovery of the Lost Voice', Hollinshead presents his own opinions of vocal technique, asserting that a low position of the larynx should be maintained when singing (Hollinshead, 1924). A barrage of subsequent controversial arguments on larynx height flowed in the Musical Times from various vocal coaches and singers over a number of years (*e.g.* Aubrey, 1924; Abbott *et al.*, 1924; Aubrey, 1928; Field-Hyde *et al.*, 1928; Aubrey *et al.*, 1928; Hoban, 1928; White *et al.*, 1928).

This quite common occurrence of assertive and entirely contradictory comments on larynx position in vocal techniques highlights the vague understanding of voice science which was held into the twentieth century.

Hollinshead advocates the use of a lowered larynx, reasoning that correct vocal production should be the result of freedom, not control of the breath, 'So long as the larynx is allowed to assume a high position in the throat, breath control becomes a necessity, thus placing a restraint upon the lungs which should rightfully be borne in the diaphragm' (Hollinshead, 1924: 319). Aubrey, in one of the subsequent retorts, claims that although she too has studied the matter extensively over twenty years and agrees with him that the fault of bad singing lies in the position of the larynx, she continues 'where I totally disagree with him is in his statement that the larynx should be low in the throat.' She goes on to continue her plea for a high larynx technique in numerous letters to The Musical Times, clarifying 'that the raising of the larynx gives the most perfect breath-control...' (Aubrey, 1924: 450). Both these authors claim to be authorities in voice science and singing pedagogy and have the same basic principles of understanding: however, using the same knowledge they fabricate entirely opposing solutions.

It is evident from the above discussions that literature discussing larynx position is often based on sensation or perception rather than any actual measurement. As an accurate scientific measurement of larynx position is still not perfected it is very easy for current science to be manipulated to defend an individual's cause or belief, whether a singer or teacher. This misuse and misunderstanding of scientific knowledge illustrates the difficulties facing scholars interested in historical techniques. Without a full understanding of the role of the larynx in modern performance, comparative speculation on historical techniques becomes even more unreliable.

4.3 Expectations on Current Performance

Based on the information above it is very difficult to formulate a hypothesis as to the expected behaviour of larynx height between the two groups of singers studied. Without an established understanding of the behaviour of the larynx in contemporary female opera singers, it is problematic to assess the extent to which singers in the current study adhere to or deviate from established conventions of vocal techniques. However, considering the historical theories presented above which suggest that a lowered larynx is consistent with a technique established in the nineteenth century, the early music specialists in this study could be expected to utilise a higher larynx position than the opera singers if following the modern day theoretical ideal of the historical voice.

Early music singers also tend to be associated with specific timbres, often with reference to lighter / brighter or purer tone qualities than opera singers. The perceived timbre of the singers specialising in early music is considered in detail in chapter 5, however, may suggest that they do employ a higher larynx position than conventional opera singers, as lowering the larynx lowers the formant frequencies of the vocal tract creating a darker sound (see above). The distinct absence of specific vocal pedagogy for modern early music singers suggests that it is unlikely that early music singers today employ a significantly raised larynx position, in spite of current theories suggesting this would be historically accurate, as evidence of specific vocal pedagogy promoting this method would be expected.

4.4 Results

Chapter 2 outlines the results of all the parameters measured in the current experiment and explains that, due to various factors including the physiological makeup of the subjects, reliable electroglottographic data was not obtained for all subjects in all the tasks. For these subjects or tasks larynx position could not be tracked as the method being used was reliant on a strong electroglottograph signal.

The two-octave ascending scale sung to the vowel [ɑ] was chosen for analysis of larynx height in the subjects in order to assess changing larynx position with pitch reducing the influence of stylistic interpretation.

Figure 38 shows the fundamental frequency contour of the oscillator for subjects 1, 3 and 14 from the early music group and subjects 7 and 12 from the opera group. As chapter 2 explained, a downward movement of the larynx height contour represents a downward movement of the larynx. Graphs for all subjects analysed were also shown in figure 16 in chapter 2. Apparent extreme and rapid changes in larynx height, shown by long vertical lines in the fundamental frequency contour of the oscillator, are often the result of the singer breathing or pausing their phonation, and are therefore not a reflection of the larynx position of the singer at that moment because no signal was present in the electroglottograph. Poor electroglottograph data was obtained for the extreme top notes of the scale for a number of the subjects which prevents reliable judgment of larynx height for those subjects when singing those fundamental frequencies and is reflected in a sudden drop in the larynx height contour at the top of their range.

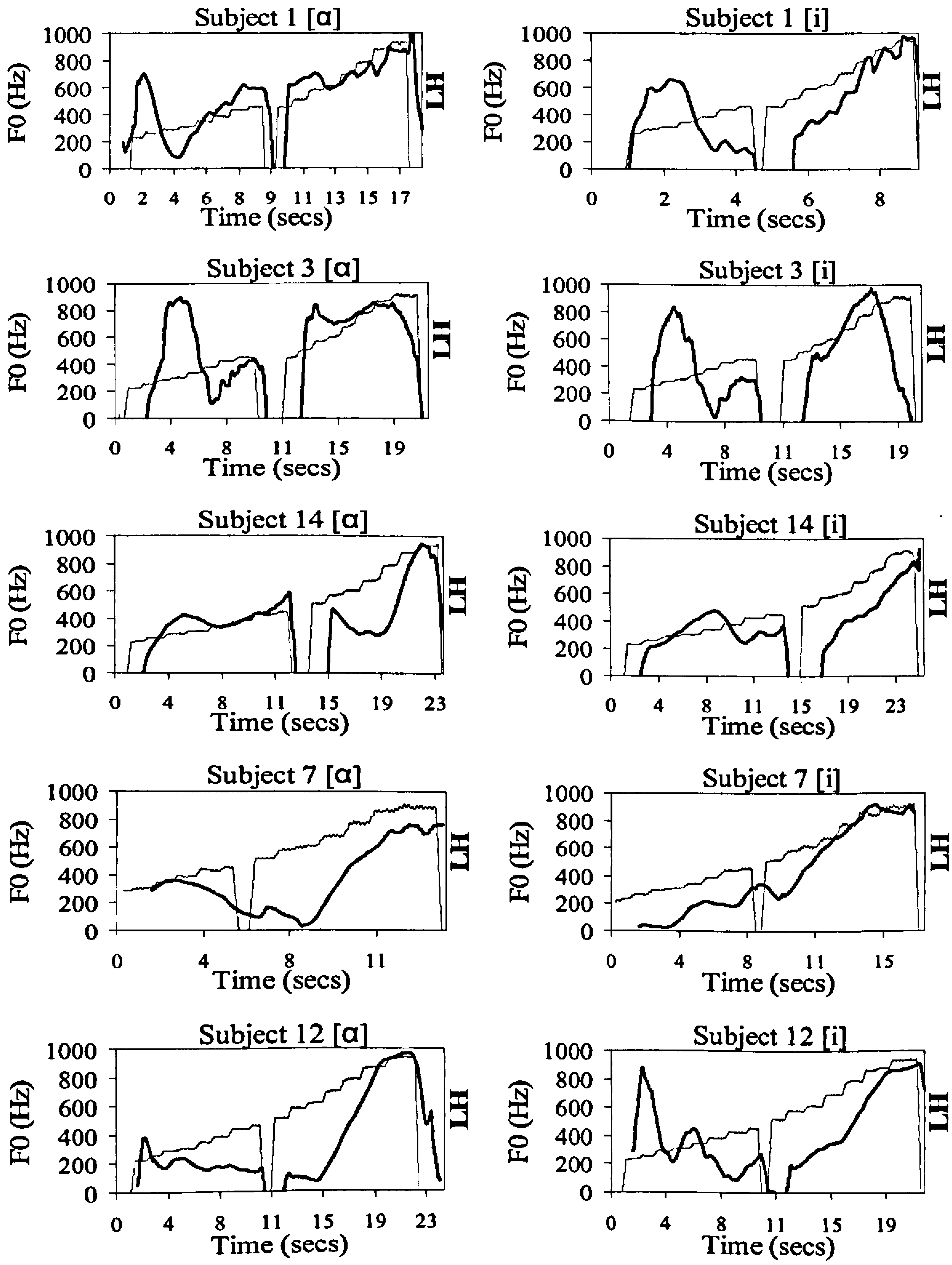
All the singers showed an overall increase in larynx height throughout the scale, with a gradual increase with pitch in the upper part of the second octave. However, the behaviour of the larynx in the first octave varied between singers, and the breath taken half way through the scale also seemed to have an effect on the larynx position of certain subjects.

There was a trend amongst subjects to either maintain a relatively consistent larynx position in the first octave or to gradually raise the larynx in the first few notes of the scale and then lower or maintain a relatively low position as pitch increased until they were two or three notes into the second octave, singing a note around an F5, above which the larynx rose considerably. Maintaining a lowered position of the larynx in the lower and mid-frequencies of the singers range could be indicative of resonance strategies such as singer's formant cluster type characteristics being employed by the singers. Raising the larynx with pitch in the upper notes of the singers' range could then be conducive to formant tuning as a further resonance strategy once the pitch exceeds that at which singer's formant cluster traits become useful.

A number of the subjects apparently lowered their larynx as fundamental frequency increased after raising the position slightly during the first two notes of the scale. This is particularly observable in subjects 1, 3 and 16 from the early music group. The inclination to raise the larynx for the first few notes of the scale could be connected to the very low part of their range they began the scale. In order to produce the Bb4 it is perhaps necessary to significantly depress the larynx and lengthen the vocal tract, the larynx then rising until the singer reached a more comfortable phonation frequency. The calibration procedure which produced marks on the thyroid cartilage whilst the subject sang three octave A notes (A3, A4, A5) to an [ɑ] vowel, showed for all subjects production of A3 (220Hz) below resting position, although this was noticeably reduced in subjects 12, 10,8 and 14 who were mezzo-sopranos. The A4 (440Hz) tone sung by the subjects again showed a common correlation in all subjects, in this case being just above rest position. The tracking of the A5 (880Hz) [ɑ] vowel was unreliable as for most subjects the larynx rose too high in throat to be observed, however, the calibration data does suggest that a rise in larynx position in the lower octave of the Bb major scale would be expected in all subjects.

The context of the sung tones is also likely to have an effect on larynx position, as are other factors such as the intentions or style of the performance or task being sung.This considered, the context of sung notes within the scale may not necessarily reflect the same larynx positions as tones sung separately an octave apart. However, when considering integral aspects of vocal technique, exercises which are commonly used by singers when practicing to improve their voice can be presumed to provide a sense of the overall technical objectives of the singers and intrinsic behavioural characteristics of larynx height. It also removes the factor of stylistic interpretation which could also have an effect on larynx height but be represented differently by the individual singers.

Figure 38. Showing the vertical larynx movement (LH – bold line) with fundamental frequency (F0 – thin line) in the scale task for subjects 1, 3, and 14 (early music) and 7 and 12 (opera).



4.5 Summary

The overall trend for the singers to increase their larynx position at the higher frequencies of their range is consistent with the research carried out by Johansson *et al.* (1982) and Pabst *et al.* (1992) which was described above. However, the relatively small sample size caused by the necessary discarding of the results of certain subjects makes any specific conclusions difficult to establish. The differences observed between subjects, such as the varied changing larynx position at mid-range frequencies, combined with the small sample size also indicate that larynx height behaviour changes with the individual and more research into larynx height in professional female singers is necessary before generalisations can be made.

The absence of any observed differences between the two groups due to the variety of results between the individuals prevents any inference on fundamental differences in their vocal technique. However, the overall similarities in the treatment of larynx height, particularly towards the upper notes of the scale, do imply that a technique is being used to prevent the raising of the larynx with pitch before the singer reaches their highest fundamental frequencies. This presumes that research which shows that in non-singers the larynx simply raises with pitch is consistent with untrained females as well as males (Shipp, 1975). A trend similar to that observed in subject 1 would have been expected in other subjects from the early music group if a method utilising tracheal pull or other mechanisms to maintain a lower positioning of the larynx is representative of a post nineteenth-century technique. This in turn suggests that a similar technique, in terms of general larynx position is being employed by most of the singers.

Further analysis of singers' acoustic strategies, particularly those that are thought to be connected to larynx position could provide further implications as to larynx height behaviour between the two groups and are detailed in chapter 6.

Chapter 5
Timbre

The quality of the sound produced is considered paramount to the overall impression of a voice. Subjective matters of like and dislike, as well as the categorisation of voices into genres, are based largely on the perception of quality or timbre of a voice. However, due to the intrinsic human nature of the voice and the subjectivity of musical matters, discussions of timbre often lead to ambiguities. This chapter considers the perceived defining vocal qualities associated with modern early music singers alongside those attached to theories of historical voices. Current understanding of timbre from an acoustical perspective is also appraised and is applied to current perceptions and the results of the present study. Ambiguities that arise from the terminology associated with timbre in both disciplines are also highlighted considering their impact on modern understanding.

5.1 Timbral Issues

When assessing the voices of early music singers, timbre is often highlighted as a key distinguishing feature with references being made to the suitability of specific tone qualities to particular genres; 'Her warmly coloured, clear-textured voice, with its sensitively controlled vibrato, is admirably suited to the Baroque and Classical repertory.' (Anderson in ed. Sadie, 2000). However, as 'there is no subjective rating scale against which timbre judgements can be made' (Howard *et al.*, 2006: 198) it is difficult to discuss timbre in an authoritative, collectively understandable manner.

Although there are common descriptors associated with timbre, including the use of various parameters within, for example, 'colour', 'warmth', or 'brightness', association of these terms with specific sounds is relative, and entirely subjective and idiosyncratic. When considered in context of its definition, the unavoidable ambiguity of timbre as a musical device is highlighted, 'Timbre is that attribute of auditory sensation on terms of which a listener can judge two sounds similarly presented and having the same loudness and pitch as being dissimilar' (ANSI, 1960 in Howard and Angus, 2006: 198). In the case of associating specific terms with specific sounds, due to the subjective perception and indefinable nature of timbre, it is difficult to attach particular jargon to sound quality that can be understood between individuals. It is due to this that, once music is discussed in terms of sound quality, or specifically timbre, meaning and agendas can become confused.

This is particularly true of singing, as the individuality of voices, and the characteristic that makes them unique relative to other instruments is the wide variety of timbres they create. Characteristically, instruments have unambiguous, identifiable sound qualities, although their timbre does vary depending upon the instrument and the player. The timbre of the clarinet, for example, allows us to identify it as a clarinet, and distinguish its sound from a violin. As well as the significantly different voice qualities that distinguish voices from each other and other instruments, individual voices also have the potential to alter their timbre considerably. This is just one characteristic contributing to the distinctiveness of the singing voice as a musical device and places a special importance on timbre. In turn this serves to increase the problem of ambiguous meaning when describing sounds through descriptions with no audio reference.

Whilst scientific explanations of sound should help to clarify artistic representations and explorations of different aspects of music, especially in the case of timbre, an absolute solution has not yet been reached. That is not to dispute that scientific clarification provides an invaluable contribution to knowledge, but to stress that attempting to quantify a subjective, and in this case aesthetic entity, is fraught with difficulty. Scientific understanding and explanation of timbre continues to alter as new methods arise to measure different aspects of sound. A comparison of the current definition of timbre that is presented above, with Seashore's definition in 1936 demonstrates some of the issues associated with describing sound that continue to give rise to ambiguities today:

'Timbre is that attribute of auditory sensation on terms of which a listener can judge two sounds similarly presented and having the same loudness and pitch as being dissimilar' (ANSI, 1960 in Howard and Angus, 2006: 198)

'*timbre,* representing the simultaneous presence or fusion of the fundamental and overtone at a given moment' (Seashore, 1936: 24)

The two statements agree in that the relative energy of the partials contributes to the timbre of a sound as opposed to the perceived pitch or loudness, however, the specific focus differs between the definitions. In a sense Seashore's earlier definition seems more finite as he assigns specific physical aspects of sound to the description, whereas the ANSI statement only specifies which physical parameters of sound are not connected with timbre. In doing so all other factors of acoustics become connected to the term. Harmonic structure, for example is indirectly implied to be essential rather than being labelled as an exclusive component. The article in which Seashore's assertion appears goes on to expand and justify this classification and is one of two that deal with 'tone quality', a term he uses to combine his definition of timbre quoted above with other aspects of sound. The other feature of 'tone quality' he describes in the second article as '*sonance,* representing the successive presence or fusion of changing timbre, pitch and intensity in the tone as a whole'. Seashore goes on to clarify that 'from an understanding of these two, we should gain a correct conception of tone quality' (Seashore, 1936: 24). This distinction between timbre and tone quality is important, especially the context of timbre within tone quality which is outlined by Seashore.

In the musical world the two terms often appear interchangeable. The following example from the article 'Operatic Characters and Voice Type' is a typical representation of the discussion of voices in the musical world,

> The voluptuous and alluring tone quality of the mezzo-soprano and contralto evokes the sensual seductive type of woman. The richer and earthier timbre of the lower female voice suggests the basically instinctive nature of such gypsy characters as Acuzena in *Il Travatore* and Preziosilla in *La Forza del Destino*
>
> Mitchells, 1970: 55

Even in the science world meaning can be less distinct: writing prior to Seashore, Helmholtz did not distinguish the two: 'By the quality of a tone we mean that peculiarity which distinguishes the musical tone of a violin from that of a flute or clarinet, or that of the human voice, when all these instruments produce the same note at the same pitch'

(Helmholtz in ed. Margenau, 1954: 10). The difficulties of Alexander Ellis when translating the German text into the term 'quality of tone' further highlights the difficulties of interpretation (Howard, 2005: 112). Seashore would likely argue the quality of tone is the result of the combined presence of various aspects of sound: the separate factor of sonance presented by Seashore accounts for the effects of changes of parameters within a tone. Under Seashore's definition which is quoted above, vibrato would be classed as a sonance, a separate factor from timbre but also contributing to 'tonal quality'.

5.2 Understanding Timbre

For over a hundred years it has been possible to obtain various pictorial and numerical measurements of sound, giving an insight into our perception of timbre. A firm understanding of acoustics, including the mathematical configuration of the harmonic structure of musical tones has been around for much longer – Pythagoras developed our understanding of the harmonic series in the sixth century (Kullman, 2001). The findings presented in Helmholtz's *On the Sensations of Tone* published in 1863 which explains the harmonic series, the construction of partials creating complex tones (Helmholtz in ed. Margenau, 1954: 22) and an understanding that the 'difference in quality of tone depends on different force loudness of upper partials' (Helmholtz in ed. Margenau, 1954: 25) has 'provided the basis for all subsequent theoretical consideration of timbre' (Cogan, 1969: 75). However, it is only recently, due to significant advances in technology and a new understanding of acoustics, that it has been possible to carry out quick and effective analysis of sound.

Seashore, in his article defining the term, when praising the new tools available in the 1930s to measure timbre (then an oscillogram and harmonic analyser), demonstrates the arduous task it was, explaining that, 'it is not necessary to discuss the intricate details of the measurement or to dwell on the fact that, even under the most favourable circumstances, it takes two hours to analyse a single wave with the best aids' (Seashore, 1936: 25). It is understandable, when the time and difficulties that faced scientists attempting to analyse timbre, that studies that expand on Helmholtz's findings were 'undertaken by acousticians, engineers, linguists, physicists, and psychologists (among others); rarely, if ever, by musicians' (Cogan, 1969:75).

However, there have been significant advances in technology since these explorations of Seashore and his contemporaries, and it is now possible to perform real-time analysis of sound by means of spectrographic analysis. As explained in chapter 2, a spectrogram provides pictorial representation of a sound showing the relative energy of all the partials within it on a grey or colour scale. It is the make-up of these partials which contribute to the perceived timbre of a sound. On grey-scale spectrograms which are used in this study, the relative darkness of each partial in the spectrogram corresponds to the energy of that partial.

Since such fast and relatively easy analysis became available, 'scientific' analysis has begun to penetrate musical academia, with discussions of acoustics and occasionally spectrographic images. Robert Cogan in 1969 highlighted the neglect of the available technologies and attempted to bridge the gap with his paper 'Toward a Theory of

Timbre: Verbal timbre and musical line in Purcell, Sessions and Stravinsky' intending to 'show that using timbral information now (and for some years) available, certain aspects of music can be significantly illuminated – that it is possible to make a beginning toward the musical analysis of timbre' (Cogan, 1969: 76).

Whilst spectrographic analysis at first seems an ideal solution to the issues facing those such as Seashore, for the musical scholar intending to begin exploration in the field of timbral analysis, the method does have restrictions. The process relies on filtering the sound signal using either a narrow or broadband filter, each of which has weaknesses, involving a trade-off between the frequency and time response of the analysis. The problems of narrow and broadband filtering are described in Howard and Angus alongside the scientific explanation of the production of spectrograms. They do not need to be discussed in detail here, beyond the acknowledgment that in spectrographic analysis you either sacrifice the time accuracy or the frequency resolution of the harmonics (Howard and Angus, 2006; 56 – 64).

5.3 Terminology

Seashore's two-part definition of tone quality as distinguished from timbre illustrates to an extent the confusion caused by the terminology that is associated with timbre and its discussion. However, problems of terminology are frequently less subtle than this example and potentially more confusing. Even when providing mathematical or diagrammatical representation of sound, describing, rather than hearing the sound being analysed is fraught with perceptual ambiguity.

5.3.1 Perception

Since the introduction of specialist 'classical' singers for specific periods of music which emerged from the early music revival (see 'Introduction'), timbre has become a prominent factor in distinguishing the specialism of voices. Consequently, comments on modern 'classical singers' often focus on vocal timbre and or tone quality as defining characteristics of a singer's suitability to a genre.

When considering literature that focuses on music, especially a performance rather than physiological aspects of vocal technique or quantifiable aspects of acoustics, perception becomes even more important and the margins for subjectivity expand. Associating certain terminologies with certain sounds can create a tenuous understanding and these associations may cause confusion. For example comments such as 'Vlasak owns a stunning and dark tone' (Petro, 2005) which is a comment taken from a review is entirely relative. Whilst it will evoke an association with everyone who reads it, the general sense of which is likely to be the same, the precise concept of darkness in a voice will depend on the relative associations of the individual reader. If the reader is used to listening to early music singers, their concept of a dark vocal sound is likely to be less extreme than a listener who absorbs themselves in the sound-world of Wagner.

Indeed, perceptual differences are not only relative to an individual, but are also likely to be effected by the knowledge and the education of the reader or listener. Taking the above quote as it stands, out of the context of its review, the reader must rely solely on their own relative scale of sound quality. However, once informed of various aspects of the performance the reader will form new parameters. For example, once informed that this review is of a performance of a duet from Rossini's comedy 'L'Italiana in Algeri' an informed reader will presume that the quality of the voices is being assessed within the usual parameters of that genre. Such perceptual parameters are dependent on the listeners' musical education and listening experience, in that only when aware (consciously or otherwise) of current trends of associating voice types with specific genres will such factors effect their interpretation of the review.

Reviews by their nature are subjective, the expectation being that the personal opinion of the reviewer will be expressed rather than an attempt at an objective description of a performance. Even within scientific and ostensibly objective research, however, personal opinion often shapes the scientific argument. Beyond necessary expressions of subjective terminology to describe a sound being analysed, in the case of multiple subject studies often the standard of the singer is a key variable that needs to be addressed. Whilst judgements can be made concerning the standard of the subject by considering their training, age and profession, the merit of the individual is dependent upon the personal view of the listener, and in the case of scientific studies, the experimenter.

In a study investigating physiological aspects of vibrato (Hirano *et al.*, 1995), the age and nationality of 23 subjects was stated, as well as an explanation that none of the singers were top-class performers, most being 'second class singers, teachers of singing, young singers to be expected in the future, or singing students.' The author goes on to clarify that 'The subjects were, therefore, heterogeneous in terms of singing skill and voice technique.' (Hirano *et al.*, 1995:18). As a result, the personal opinion of the experimenter is relied upon to make necessary conclusions as to the effects of the mixed ability group on the results. This leads to statements commenting on how 'good' or 'bad' the voice being analysed is; 'Her original voice was not bad but not well trained, not strong, and not rich' (Hirano *et al.*, 1995: 26). Even when using specific parameters to explain the quality of the voice, subjectivity occurs in the clarification; 'both had small extent of fundamental frequency oscillations, in other words, a small vibrato extent, and not very well trained rich voice.' (Hirano *et al.*, 1995: 22). Ambiguity is caused through use of the term 'not very well trained' as it comments on the quality of the training without qualification rather than stating the number of years training received by the subject (of course the quality of the training is yet another unquantifiable and usually unmanageable variable in such experiments). A common tool used to avert the biasing of discussions in experiments such as those above is to employ suitably qualified listeners to carry out a perceptual test on the recordings, removing the attachment of the researcher to the subjects.

When dealing with the analysis of timbre, creating an association for a reader is essential in order for them to grasp the results of the analysis; consequently, literature which is ostensibly dealing with a theory or scientific analysis necessarily contains frequent references to perceptions of sound. When describing the acoustic characteristic of the singer's formant cluster Howard explains that 'This is what gives the professional singing voice its characteristic ring' (Howard and Angus, 2006: 213). In such cases perceptual references are usually made in an attempt to clarify or identify a sound for the reader to associate with research outcomes that are almost exclusively represented as text – when reading a publication that deals with the voice there is rarely a physical sound provided to associate with the theory. Such descriptions are therefore understandable and in fact essential elements in any publication on the voice. Whether analysing how a sound is produced or the product itself, without descriptions of the sound the essence of the research cannot be retained – the investigation becomes irrelevant if the sound is forgotten.

5.3.2 The Musician vs. the Scientist

The advancement of scientific understanding of sound and the voice has added to problems of terminology, especially terminology associated with timbre, adding a new set of terms to an already confused catalogue.

There is a cross-over in the use of a large number of terms used by the musician and the scientist which do not share a common meaning. Duality of meaning is common in the musical world alone, particularly when dealing with terms such as 'tone' (a word in itself which has many musical meanings). However, once such ambiguous terms are combined with the 'authoritative' terminology of scientific fact, further confusion often occurs. Seashore is acutely aware of this in his 'Timbre' article, explaining in footnotes his intended meaning of terms such as '*harmonic structure*' as he explains 'it is unfortunate that the terms harmonic structure and harmonic analysis have two distinct meanings in music. For the present we must depend upon the context to know whether we refer to musical harmony or timbre' (Seashore, 1936: 25). If Seashore was hoping for a clarification of such terminology in the future, a distinction has yet to infuse the musical or scientific world, although attempts continue to be made to expound many musical expressions. The terms mentioned above are mainly theoretical in that they deal with academic discussion of physically identifiable components of music, either relating to acoustic structure or musicological analysis, and yet they still cause considerable ambiguity. Once focus moves on to the voice there is even less physical association to clarify the terminology because generally we cannot see the workings of the voice as the sound is being produced.

Research into the voice almost always includes descriptions of tone or sound. This is the case even in highly scientific work that deals primarily with a very specific physiological aspect of technique not directly associated with timbre. Donald Miller's book 'Registers in Singing: Empirical and systematic studies in the theory of the Singing Voice' which concentrates most heavily on physiological aspects of voice source and acoustic analysis, addresses the necessary problems of combining scientific findings with an aesthetic art-form. Miller's background, as a professional singer, singing teacher and later voice researcher, places him in an ideal position to identify the cross-disciplinary discrepancies of voice research. He allocates an entire section of the introduction to 'problems regarding the scientific study of the singing voice' and within that deals with the 'serious stumbling block for any scientific inquiry into the singing voice [which] is the arcane language employed by voice practitioners' (Miller, 2000: 25) with a subsection '*Terminology*'.

Providing an understandable reference to the reader is essential when writing about sound and the factors mentioned by Miller above highlight another obstacle to understanding in the terminology used by voice teachers. This issue adds a second perceptual problem for the reader as scientists have to describe what they find in a way that voice teachers will understand. When Sundberg explains the singer's formant cluster, rather than clarifying his meaning with an associated description of a sound like Howard does above, he attempts to relate the reader to a physical description of singing, 'Some singing teachers refer to this phenomenon as "head resonance" or "placement in the mask"' (Sundberg, 1987: 119). Of course in both cases it is presumed that there is a collective understanding of these terms, a particular danger being that two singers or teachers may not associate the same meaning with "placement in the mask".

The issue of language used by singing teachers has become a popular focus of research into the voice, the objective of the researcher being to discover or justify the acoustic or physiological meaning of certain expressions or terms used by singers and teachers. 'The challenge for the student is for the teacher's '*post-hoc*' verbal feedback to be interpreted and translated subsequently into an adapted singing performance' (Welch *et al.*, 2005: 227). This can understandably cause lengthy descriptions and justifications of terms, 'The voice quality "throaty", a term sometimes used for characterising speech and "non-classical" vocalists was examined with respect for subglottal pressure and formant frequencies' (Bjorkner, 2006: 3).

The musical scholar often falls into an opposite trap to the scientist or acoustician who creates ambiguity when finally trying to describe the sound. Unlike the scientist trying to humanise their often quantitative conclusions, the musical writer, which can include musicologists, performers and teachers, will make physiological or acoustic assumptions or allusions to try to clarify the sound manifestations of a performance. 'If the tone is placed at the edges of the upper or lower front teeth, the vocal folds are brought closer together' (Husler and Rodd-Marling, 1976: 69). 'In high notes, then the emission of the voice on the breath and 'dans le masque' is reflected in spontaneous intense vibrations, good timbre and ringing tone' (Celletti, 1991: 111). Between the two disciplines, both working in the same area and striving for clarity of understanding, there has been reached a plethora of confusion and ambiguity.

5.3.3 Purity

Primary source evidence shows that the quality of voices has been important to audiences and vocal theorists for hundreds of years. Although in writings on the voice from before the eighteenth century there tends to be a focus on text, in terms of enunciation and rhetorical declamation, there are also continuous references to the actual sound of the voice, whether it is good or bad, harsh or sweet *etc.*.

Since the early music revival the term 'pure' has been used as a defining quality of the early voice, both in terms of a probable historical sound and as a modern day ideal. Problems of the interpretation of terminology and the potential misguiding conclusions they can lead to, especially within musical rather than scientific literature; are easily demonstrated in the use of the term pure across the musical world.

Wistreich names it as 'one of the basic elements of baroque singing technique: purity of voice, precision of intonation and disposition itself.' (Wistreich in Potter ed. 2000: 190). This example refers to an academic historical ideal, in that, as the result of scholarly and performing research into historical vocal techniques, Wistreich is presenting his conclusions as to possible historical vocal sounds. Speculation into the historical voice and vocal practices and the sources on which they are founded are discussed in more detail in the section 'Historical Context' below.

The term 'pure' also appears regularly in current literature concerning modern day performances of early music, including dictionary entries, vocal tutors, reviews *etc.*. In these situations the 'purity' of the voices of modern 'early music' singers is often assessed and considered as an essential quality for the specialty. The Grove Dictionary of Music and Musicians article on Emma Kirkby, states, 'Her pure, light-textured voice and natural declamation have been widely admired by interpreters of early and Baroque music and have served as a model for many specialists in this repertory' (Anderson in ed. Sadie, 2001: 623).

From an acoustics perspective a 'pure tone' is a simple wave or sine wave 'more complicated waves can always be described in terms of these simpler sine waves' (Howard *et al.*, 2006:10). The best audio description of a sine wave would be the sound emitted by a tuning fork or whistle. As phonation produces a complex wave, it can be presumed that the true meaning of a pure tone is not a literal representation of the vocal quality. However, it has been used as a musical illustration of a desired sound. Timothy Day clarifies his description of a characteristic choral sound he is discussing as 'radiant whiteness, its silveriness, its sweetness, its resemblance to the pure tones of a tuning fork...' (Day in Potter, 2000: 125). Taking the acoustic association of the term pure in conjunction with its common connection with the singing voice, assumptions can be made as to the quality expected in a voice described as pure. The fact that the sine wave emitted from a tuning fork is a 'straight tone' in that there is no fluctuation of fundamental frequency, could translate into a vibrato-less tone in the voice.

That vibrato is a contributory factor in the association of purity in the voice also complements Seashore's definition of tone quality as a combination of timbre and sonance as discussed above. This also supports the consensus that early music singers tend to (and according to modern opinion should) employ less vibrato overall in their singing than singers of grand opera, even though the suggestion of a desired 'pure tone' is often not specified as being connected with expectations of vibrato production. As well as implications on vibrato, the acoustic meaning of the term could also influence the perception of the timbre in terms of the sound spectrum. As explained above, the voice cannot produce a sine wave; however, if there is any connection between the acoustic definition and musical description, a 'pure' timbre could be the effect of shaping the complex wave to produce a very strong fundamental, having the effect on the listener of picking out a single partial within the sound.

The reliability of the term 'pure' as a defining adjective associated with any specific sound comes into question when the persistent use of the term in literature until the current day is considered. Christine Nilsson, who sang a large varied repertoire of music from Mozart to Wagner, was complimented by Galignani's Messenger in Nov 1864 as 'possessing a voice eminently pure' (In Somerset-Ward, 2004: 150). In her book 'Some Memories and Reflections'. Emma Eames describes Patti's voice as having 'a tone of perfect purity' (Eames, 1920: 36) and New Grove describe Eames' own voice quality as being 'singularly pure and beautiful quality'.

There is nothing to suggest that any of these descriptions or ideals of voice qualities are untrue or unrealistic, even though opinions will always be subjective and therefore disputed. However, if significant reliability is to be placed on terms such as pure, in this case it would suggest that all the voices discussed above possessed a similar quality, and by implication similar techniques. If so, a logical conclusion would suggest that vocal techniques and the expected timbre of the voice has not changed much in the last four hundred years. Not only is that unlikely, considering environmental (performing environment) changes and compositional changes, it is also contrary to the common consensus that has already been discussed: that 'classical' vocal technique has changed significantly since the seventeenth century.

It is more likely that there is one aspect of the sound which is identified by the listener as having a pure quality; this could be a timbral feature, or another such as vibrato or clear enunciation of text. The identifying feature which characterises purity may alter depending on the voice or the listener.

5.3.4 Choral Music

Pure is often used as a complimentary term when commenting on choral music, particularly in the English choral tradition. 'Historians, journalists, critics and cathedral musicians themselves have been sure they can identify a style of singing peculiar to these [English Cathedral] choirs which they define by reference to purity of tone...' (Day in ed. Potter, 2000: 123). In a review in the New York Times entitled 'In The Pure Voices of Boys, A Chorus's Self-Renewal', King's College Cambridge are commended for their singing of Byrd, as being 'especially stunning in the purity of tone and compelling resonance...' (Oestreich, 1997). The attraction of the 'pure' sound is often primarily connected with the soprano line, and most probably a direct result of employing boy choristers to provide the upper parts.

Another explanation of the fixation with purity as a term to describe the choral sound could be a directly related to the religious roots of the choirs and the music rather than any acoustic significance. To associate 'purity' with the sound of the choirs in turn has a connotation as to the religious 'purity' of that choir and therefore the church. This theory is supported by the common analogy to angels in connection to singing, Anonymous 4 a vocal ensemble that often specialise in early music, described on their website as 'ethereal, pure voices that blend spectacularly well' (Napier, 2007). Bill Yates claims that 'Hearing Anonymous 4 is about as close as you're going to get on this earth to hearing angels sing' (Yates, Route 66 website). The label of heavenly or angelic is particularly used to promote early music and sacred choral music, often using the terms in the titles of the discs, such as 'Angelic Voices: The Best of The Vienna Boys' Choir', 'Angelic Voices' by the Oxford Girls' choir, 'Heavenly Harmonies' by Stile Antico, and 'American Angels' by Anonymous 4 to name just a few.

The sixteenth and seventeenth century polyphony which accounts for much of the repertoire being performed in churches, would originally have been performed by either boys or castrati. It is partly due to this tradition that cathedrals have shown a reluctance to allow female voices into their choirs. However, in the last 20 years some cathedrals have allowed girls to sing in their choirs, or have created additional choirs of girls to perform separately from the boys often in different services. A main objective for the acceptance of females singers into the church was to conform to the sound-world they entered; 'The girls' timbre of the Clerkes of Oxenford may not have been indistinguishable from trebles' – though it was often mistaken for it – but it certainly embodied the hallmark qualities of the cathedral choir's male voices' (Day in ed. Potter, 2000: 132). Studies have been carried out into the effects of the specific training and vocal development of both sexes (Barlow and Howard, 2002) finding that, depending on the choir, boys and girl choristers are easily confused and that this is 'a product of the particular traditions, expectations and cultural practices of the socio-musical environment to which choristers are inducted' (Welch and Howard, 2002). It is now quite common for certain choirs with roots in the English choral tradition to employ adult females to provide the upper parts, many of the Oxbridge choirs, for example, now take female choral scholars; in 2000 Clare College Cambridge was the first mixed Oxbridge choir to perform at the BBC proms in 2000. It is this change in convention to incorporate mature upper voices that is significant in the connection with the modern early music singer.

Whilst the physical make-up of the choirs has changed, the sound expected by England's purists remains the same. The essence of the perceived sound of the English tradition is shown in the reaction to Westminster Cathedral choir in the 1950s when George Malcolm took over and cultivated a sound from the boys that steered away from the typically desired 'flute-like' quality which was 'quickly dubbed continental' (Day in ed. Potter, 2000: 131). As Day points out, the choral sound Malcolm was using as his guide was actually from a Catholic church in Mayfair before the war, not Europe; however, the reaction still demonstrates the established fashion of the time. Even though apparent 'truth' or 'tradition' may be fictional, it is this snobbery which has placed pressure on the new adult female singers to emulate the 'pure' sound of the boys who preceded them. The singers who formed the core of the vocal facet of the early music movement originated from these choirs, first forming smaller often one-to-a-part ensembles and then venturing out to solo repertoire. The term 'pure' followed these singers and came to epitomise the then new solo style. The term as a definition may therefore be connected with the propaganda agenda of the church choirs from which they originated rather than conveying an actual representation of the sound being produced.

5.3.5 Historical Context

Whilst the above discussions consider modern performance practices and suggest an almost evolutionary inclusion of 'purity' to be associated with singing early music, there is also a strong academic interest and attraction to the concept of pure tone qualities being employed by singers of the past.

There is little direct association with 'pure' being used in conjunction with vocal qualities of the past However, when the language used in historical literature is considered, it is understandable that today's scholars place an emphasis on such terms in relation to the singing techniques and voice types of the past. Tone quality is an issue which is addressed in surviving literature from before the sixteenth century including scholarly texts such as treatises and informal comment such as letters and diaries (see for example, Toft, 1993). The recurring problem with relying so heavily on historical documentation, especially regarding timbre, is that any conclusions or theories that are formed are dependent on a collective understanding.

A basic drawback in making any examination from textual references is immediately apparent from the issues discussed above; it is very difficult to be confident of an accurate shared meaning when defining sound quality through descriptive language rather than audio reference. Nevertheless, the issue of timbre is of significant consequence in research and the study of timbre in any consideration of vocal technique is essential; however, it is important that its unquantifiable nature is taken into account especially when relying solely on textual references, which, in the case of the historical voice is necessary.

Considering the relatively sparse evidence available to scholars investigating historical vocal techniques, especially when contemplating changing fashions, descriptions are necessarily heavily relied upon. Unfortunately the use of written personal perceptions as solid fact is fraught with uncertainty and such evidence needs to be used in careful conjunction with any other material that can serve to objectify subjective data.

Whilst there is comment on the quality of the sound in the literature of the past, obsession with quality of tone clearly increases through the centuries to a point where the sound produced becomes more important than other aspects of singing. This presents in the literature as a change in the balance of priorities of features considered paramount to good singing.

Research into singing before the sixteenth century reveals the marked importance on text rather than quality of tone, Robert Toft's book 'Tune thy Musicke to thy Hart: The Art of Eloquent singing in England 1597 – 1622' focuses almost entirely on importance of text and its production, explaining 'The art of eloquent speaking in England during the sixteenth and early seventeenth centuries presupposed a knowledge of *elocutio* and *pronunciatio,* and in some quarters, speaking and singing were viewed as arts which were closely related' (Toft, 1993: 6). Other historical treatises of the sixteenth century that claimed to teach the art of song or singing were concerned only with the instruction of musical theory rather than vocal production: William Bathe's 'A Briefe Introduction to the skill of song: Concerning the practice, set forth by William Bathe' is an example of such a text, mentioning only to 'practice to have your voice cleer, which when thou hast done, learne the rules following' (Bathe c.1587 in ed. Rainbow, 1982).

Scholars and teachers continued to place much more emphasis on the music itself and which notes to sing, because their musical era was still heavily concerned with the 'rudiments' of music in terms of harmony, ornamentation, and, in song, a rhetorical declamation of text. Even as compositional style evolved into the seventeenth century with the introduction of opera, with arioso and eventually the aria, singers were expected to be learned musicians: scholars of the past emphasised in their treatises the importance for singers to be able to accompany themselves, and compose. Tosi explains, 'One, who knows how to compose, can account for what he does, and he, who has not the same Light, works in the Dark, not knowing how to sing without committing Errors.' (Tosi 1743, in ed. and tr. Galliard, 1967: 85). Due to this, when discussion came to the actual production of the voice, the focus remained largely on text and enunciation. It is when compositional priorities started to change and the career of the prima donna began to emerge with an emphasis on voice rather than musical intelligence that articulation of text became secondary to the overall sound produced.

Comments on timbre that do appear within historical treatises of this time, often discuss the aspect of the vocal timbre in an openly subjective manner without an attempt at clarification. It is common for references to mention how 'beautiful' or 'good' a voice is as passing comment, without any suggestion of the sound qualities that might be considered as such. De Bacilly provides an example of mentioning vocal quality in passing when instructing the importance of acquiring a good teacher, 'it is entirely impossible to arrive at the perfection in the vocal art no matter how beautiful the voice, fine the ear, or good the disposition of the throat may be' (De Bacilly 1668 in tr. Caswell, 1968: 18). Tosi in 1723 writes about vocal quality with a similar passiveness, 'that *Signor Lotti* strictly keeping to the same rules, with a penetrating Sweetness of Voice, gained the Hearts of all her Hearers' (Tosi in ed. tr. Galliard, 1675: 104).

It is when discussing 'voice types' that Bacilly goes further in an attempt to clarify descriptions of the sound produced by voices. When explaining the distinction between 'pretty' and 'good' voices he deduces,

> A single tone of a *pretty* voice is very pleasing to the ear because of its clearness and sweetness...The good voice on the other hand, may not have all this sweetness... but nevertheless is effective because of its vigour, strength, and its capacity to sing with expression, which is the soul of vocal art. The *pretty* voices are ordinarily not capable of this, nature having partitioned its gift in this instance as in all others
>
> De Bacilly in tr. Caswell 1968: 20

Bacilly goes on to explore all the 'types' of voice comparing them to each other, including 'big', 'small', 'light', 'strong', 'brilliant', 'expressive' and concludes,

> There is still one more criterion by which voices are differentiated. This factor is the *amount* of *tone* or *sonority* present in the voice. By these latter terms I mean that intangible quality which in some voices *fills,* or (to speak in musical language) *nourishes* the ear better than the more delicate voices. This is not to be confused with the phenomenon of *projection,* since delicate voices (the usual terms is *stringy*) are often capable of projecting their tone as far as the stronger ones
>
> De Bacilly in tr. Caswell 1968: 23

That 'intangible quality' could account for the lack of satisfying descriptions of tone in historical literature. Perhaps, rather than being unimportant, the quality of the sound was written about with less vigour than other aspects of singing because it could not be written about in an articulate, understandable manner. Suggestions of timbre can also be extracted from historical literature when it is not the actual subject matter of the author. Mancini made assumptions on the physiological workings of the voice based on its timbre; his belief that the sound is produced by the passage of air across the wind-pipe in a manner similar to the flute could be connected with the reference of the voice's 'flute-like' quality (Mancini, 1774 in ed. Foreman 1967). Whilst technically Mancini is entirely incorrect, the concept of a flute-like quality to the sound corresponds with the similar description of the ideal choir boy sound discussed in the section above.

References to vocal quality that do occur in historical literature often refer to 'beauty', 'sweetness' or 'clearness', and if the search for historical references to vocal quality is expanded beyond treatises to public opinion as recorded in letters and diaries further evidence of such terminology can be found. Comments such as 'she possessed a voice uncommonly clear, sweet and powerful' (Ian Woodfield, 2001: 136) can be found in abundance in literature of society throughout the seventeenth and eighteenth centuries. A tenor singing at the Vauxhall Garden in 1783 was described as a 'fine tenor voice, of great flexibility, extent and sweetness' (British Magazine and Review, 1783: 384). Charles Burney, the highly respected and well-travelled musical author also discussed voices using similar vocabulary, 'though by nature not perfectly clear and sweet toned, had been well directed in her studies and she sang with considerable agility, as well as taste and expression' (In Woodfield, 2001: 106). Such expressions could easily be translated into today's terminology as a concept of purity, especially when the other factors of current practices such as the church connections and commercial motives mentioned above are taken into consideration. Presumptions as to clear or pure tone quality being a historical ideal are also supported by evidence such as the comments above when the supposed change in technique at the middle of the nineteenth century is considered, with the 'new' lowered larynx technique being compared to an old 'voix blanche' (clear voice) (See Potter, 1998: 55).

A number of imprecise factors need to be considered here, including the reliability of the historical sources being used and their interpretation into modern day ideals. A significant amount of primary source material has been translated into English from its original language, which gives rise to immediate possibilities for discrepancies concerning the actual meaning of descriptive terminology. Even removing this level of ambiguity, the section written by Bacilly which is quoted above highlights the confusion and impenetrable nature of explaining vocal timbre through text. The origins of the interpretation of a desired 'pure' tone could be discussing vocal factors besides vocal timbre, such as vibrato or articulation. The importance of text in singing is evident throughout the sixteenth and seventeenth centuries and the learning of rhetoric in order to convey the true meaning of the text through song could be part of the issue when complimenting voices for clarity or clearness. Rather than referring to the overall sound being produced such allusions could be remarking on the success of the singer in conveying the words by way of good enunciation and using appropriate timbre for the text which was clearly desired.

Research which relies heavily on reviews of primary sources which are far more comprehensive than the one used as an illustrative tool above, clearly indicate changing vocal techniques over time, and therefore changing timbral qualities. However, the terminology used in that research does not prove to be any more rooted in singing of the past than it is a reflection of the modern vocabulary associated with voices. The use of the same terms to describe distinctly different singers in the modern performing circuit which was explored above serves to illustrate this. Whilst this demonstrates the infiltration of new terminology over time, there is undoubtedly a modern perceptual link between singers specialising in early music and a specific quality of tone, one often termed 'pure' or 'clear' in today's society. If the strong perceptual associations of specific terminologies to the specialist genres of modern performance which are considered within this study are connected to specific timbres, this would be reflected in the results. Acoustic analysis of the recordings of the early music singers would be expected to show noticeable differences between the two groups, perhaps with indications that the timbres created by the singers in the early music group are more indicative of perceived 'purity' than others. The following section carefully considers the findings of the study in light of the theories reviewed above.

5.4 Experimental Findings

The findings of the experiment outlined in chapter 2 demonstrate a number of distinct differences between the timbre produced by the two groups that were case-studied. The results show interesting compliances as well as discrepancies with current theories of historical vocal production considering the explorations of the terminology used above and comments such as 'any extraneous element in vocal sound, be it simply vibrato or perhaps other acoustical complexes which the modern ear might describe simply as vocal timbre or 'grain', would have been regarded as undesirable' (Wistreich in Potter, 2000: 185).

5.4.1 Spectrographic Analysis

Chapter 2 outlined the findings of the study identifying that although similar spectral energy is employed by all the participants, several differences in the use of this spectral energy over time were presented which could be characteristic of the subjects' performance specialty. These differences revealed by spectral analysis could account for distinctions in the perceived timbre of the singers' specialism, some of which complement the current theories of historical singing practices.

The spectrograms of the Puccini extract sung by all the subjects were shown in figure 10 in chapter 2 and illustrated that a band of high energy between 2kHz – 4kHz is utilised by all the singers. This result was expected in the opera singers as it is consistent with the current theories of the singer's formant cluster. The singer's formant cluster has been identified as high energy in this frequency band found particularly in opera singing which enables the singer to project over large orchestras (see chapter 2). The presence of this feature in the singers from the early music group suggests a similarity between their timbres, and is in turn suggestive of similarities in technique. Whilst this finding is discussed in more detail alongside the acoustic properties and physiological characteristics of the singer's formant cluster in chapter 6, it is important to mention here as it has a significant effect on the overall timbre. Increasing the energy of harmonics in the frequency band 2kHz – 4kHz contributes to the brightness of the sound, the singer's formant cluster being described as the 'characteristic ring' (Howard and Angus, 2006: 213) of a classical voice, and could contribute to what Wistreich describes as an extraneous element of timbre which he believes would have been undesirable.

In addition to the band of energy found in the expected region of 2kHz – 4kHz there are further areas of high energy in the spectra of some of the subjects. All subjects exhibit an additional band of energy to some extent above the frequency region of the singer's formant cluster, between 5kHz – 10kHz. The frequency of this second peak tends to occur at approximately double the frequency region of the first peak, and generally has more energy in the spectra of the singers from the opera group than the singers from the early music group. This acoustic effect could serve as a supplementary device to the singer's formant cluster, the possibilities of which are discussed alongside the singer's formant cluster in the next chapter. It would also affect the perceived timbre of the voice.

There is a noticeable difference in the use of this higher frequency energy between the subjects, and a general trend exists that singers in the opera group employ the use of this frequency band with more energy more often and consistently. The singers in the early music group tend only to employ this feature when reaching a 'climax' within a note. This characteristic is most noticeable in the treatment of spectral energy in the first note of the Handel extract which is isolated for analysis throughout the study and is considered in terms of timbre below (spectrograms of this note for all subjects were shown in figure 14 in chapter 2). The spectrograms for singers in the early music group show that there tends not to be any significant energy in the upper frequency bands at the beginnings of notes, and when it does appear it is not for very significant portions of a given note. Although this is most evident in the first note of the Handel extract, the spectrograms for the subjects singing the Puccini extract also present with this trait. Singers in the opera group also tend to add the high energy to this frequency region as the last spectral change within a note, however, the time delay between the note onset and the inclusion of this band is much shorter than that of the singers in the early music group which can also be observed in figure 14. Subjects from the opera group also often introduce this energy with the inclusion of the singer's formant cluster energy and sometimes (for example subject 9 figure 41) with the note onset itself. Changes of spectral content within notes are of important consideration illustrating significant features that contribute to the perceived timbre of the overall sound.

5.4.2 Timbral Consistency

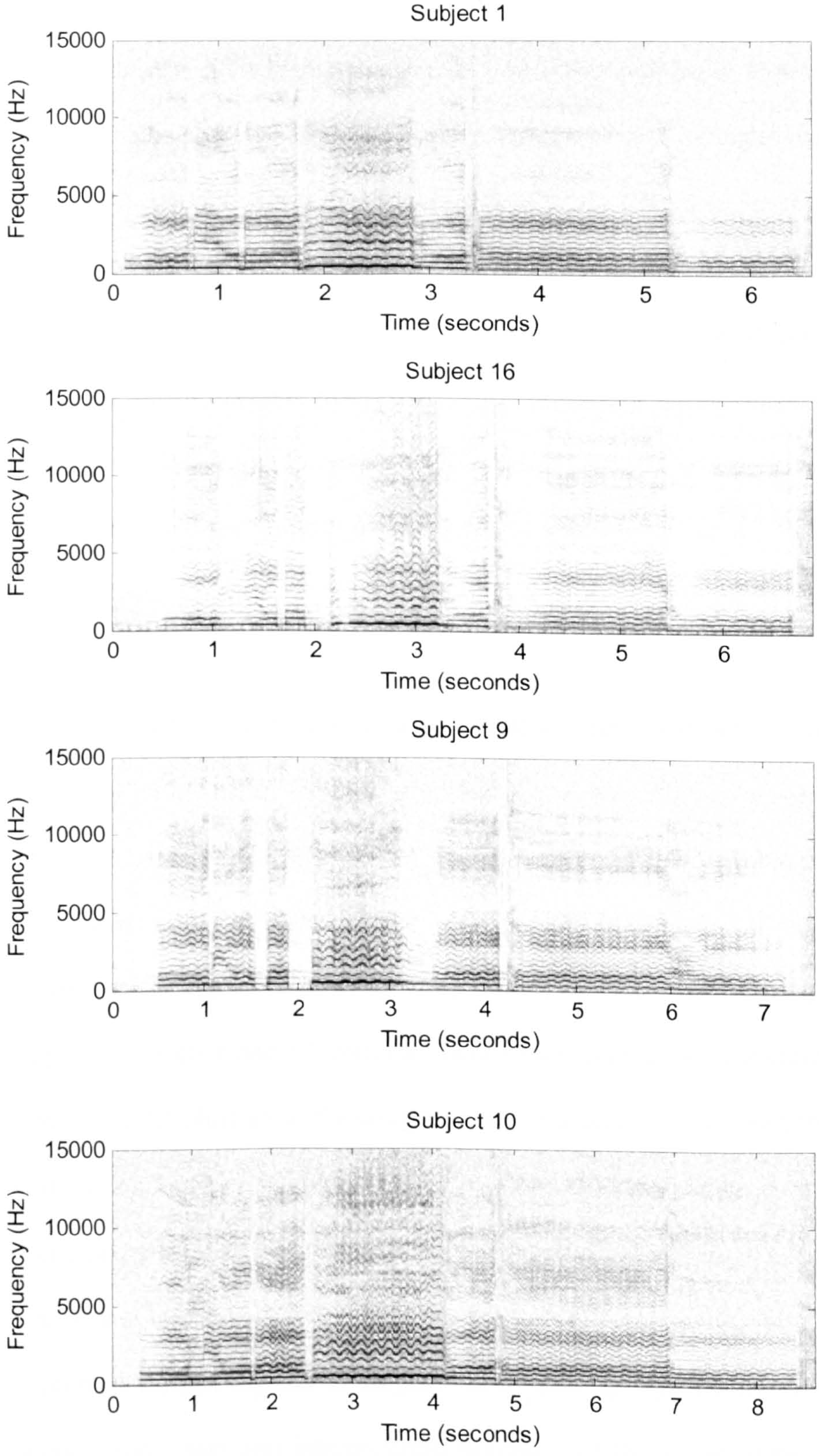
The consistency of tone expected of opera singers in contrast to the deliberate changing of timbre to clarify and express the words thought necessary of early music singers was mentioned above, alongside the opinion that it is thought that historically the voice would have been 'light' and 'clear' rather than 'heavy' as in modern opera singing. Whilst the presence of considerable energy in the singer's formant region in the early music singers suggests that they are not striving to apply the theories presenting an ideal of historical singing, there are other features of these singers which differ from the opera singers and conform with current theories of past techniques.

Considering consistency of tone, the singers in the opera group all presented, as expected, with similar spectral energy throughout notes, in that from the note onset to offset there was very little change in spectral energy, especially in the singer's formant region. Occasionally a slight delay is present between the note onset and the inclusion of high spectral energy; however, this delay is always very small, being difficult to detect on a spectrogram and often audibly imperceptible. Observing the spectrograms of the Puccini extract supports this theory. The first phrase of this extract sung by subjects 1 and 16 from the early music group and subjects 9 and 10 from the opera group is shown in figure 39 and reveals not only the much stronger use of the upper frequencies of the spectrum by the singers from the opera group, but also a delay in the inclusion of spectral energy at the beginning of phrases and notes by the singers from the early music group.

After each consonant (occurring with each change of note) there is a delay in the production of the upper frequencies for subject 1. In the singer's formant cluster region of the spectrum this is only noticeable in the first and final notes of the phrase and is very short, being just 0.2 of a second; however, spectral energy in the 5kHz – 10kHz frequency band is only employed for a portion of each tone, in total being employed for 74% of the sung phrase. Subject 16 shows this changing use of spectral energy throughout tones in lower frequencies in the spectrum, utilising energy in the 2kHz – 4kHz region 77% of the time with delays up to 0.3 seconds and 5kHz – 10 kHz frequency energy 46% of the phrase. Subject 10 however, once the consonant has been produced, exploits energy across the frequencies of the spectrum as soon as the vowel begins. The first note of this phrase is the only tone which presents with a delay in spectral energy which is very small in the 5kHz – 10kHz frequency region of just 0.1 seconds. A similar presence of spectral energy is visible in the spectrogram of subject 9, although the final two notes of the phrase utilise less energy in the 5kHz – 10kHz frequency band. Again this suggests that the singers in the opera group are used to producing a consistent tone, perhaps through necessity as considered below, whilst the early music singers are used to shaping notes to a point that even when not trying to make a stylistic affect the tendency remains apparent. This possibility of inherent technical differences being observed as a consequence of stylistic objectives is considered below.

Observable in subjects from the opera group when producing a crescendo through a note, as in the case of the first note of the Handel extract which is isolated below, the energy across the spectrum increases as the note intensifies, but notably the high band of energy between 5kHz – 10kHz becomes far more prominent. This suggests that the singers in the opera group maintain relative levels of intensity in the lower harmonics and singer's formant cluster region throughout tones independent of stylistic gestures, using the band of energy in the 5kHz – 10kHz frequency region to effect stylistic timbral and dynamic changes. Some subjects present with a third band of high energy within certain tasks which often seems to be treated as an additional device to the 5kHz – 10kHz band, observable in the Puccini spectrogram of subject 10 in figure 39 and the first note of the Handel in figure 41. This implies that when striving for a timbral or dynamic effect the singers in the opera group implement energy in the highest frequency region possible.

Figure 39 Spectrograms of the first phrase of the Puccini extract by subjects 1, 16 (Early Music Group) and subjects 9 and 10 (Opera Group)

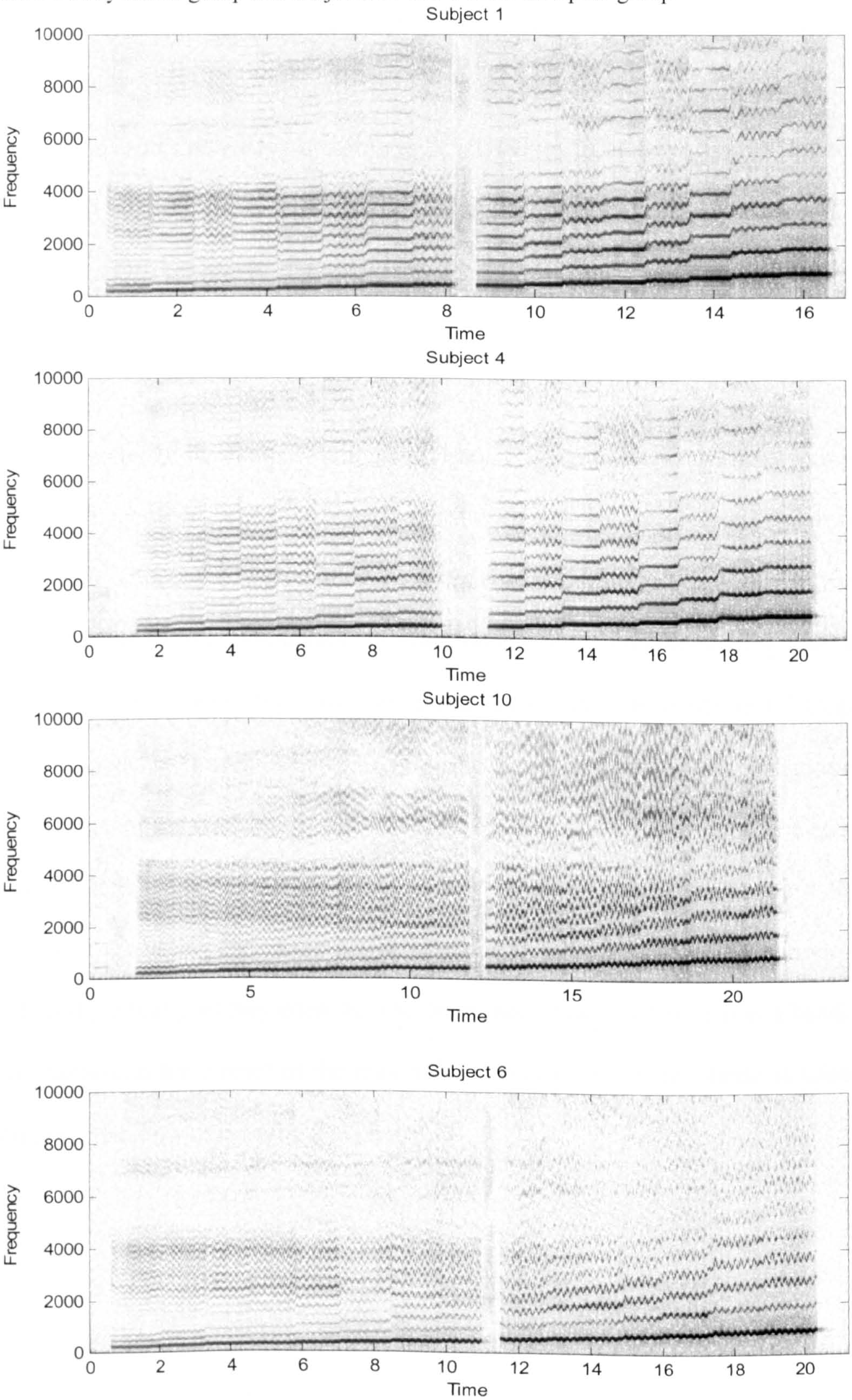


The subjects in the early music group displayed similar characteristics in that they increased energy in the higher frequencies when crescendoing or to produce a stylistic / timbral effect. However, the maximal energy employed at high frequencies by the singers in the early music group did not generally attain the same levels as the singers in the opera group. The spectra of the early music singers also altered much more than the singers in the opera group, in part due to the delay considered above, both within individuals and across the group. Whilst not present in all the singers from the early music group, it is more common for the singers in this group to vary their spectra throughout notes, particularly at the starts of phrases and at the beginning of notes within phrases.

Changes in spectral energy are more noticeable in both groups when singing the extracts from songs rather than the exercises. All the singers display a consistent spectrum throughout notes in all the exercises, including those which involve words, with only small changes in the levels of the very highest frequencies of the spectrum. The spectrograms in figure 40 show spectrograms of subjects 1 and 4 from the early music group and subjects 6 and 10 from the opera group singing the ascending Bb major scale to the vowel [i] illustrating the consistent spectral energy throughout the exercise. This could be indicative of the nature of vocal exercise, in that when practising vocal tasks rather than performing a piece of music the objectives of the singer change. Whilst in an exercise, a singer is concentrating primarily on vocal production and technique in order to optimise various aspects of singing such vocal agility, quality of tone *etc.*, when singing a song, text and interpretation become equally, if not more important to the singer. Changes in tone quality throughout or between notes within songs are often therefore necessary and deliberate traits of a performance. Another possible factor which could affect spectral energy, and particularly important in the present study, is the individual subject's familiarity with the songs. Whilst the exercises were likely to have been relatively simple to the singers, the songs were known to varying degrees which may have contributed to their timbral changes.

The first note of the Handel extract best illustrates the different use of spectral energy between the two groups in terms of the introduction of energy throughout a tone, and implications of stylistic influences on timbral features. This held C4 to the first syllable in the word 'Ombra' is treated quite differently by the two groups. As the singers dictated their own tempo the length of the note varied quite noticeably between individuals, ranging from just under 6 seconds to just under 3 seconds. Despite this difference in note length, for which there was no connection with subject specialism, all singers apart from subject 13 crescendoed through the note.

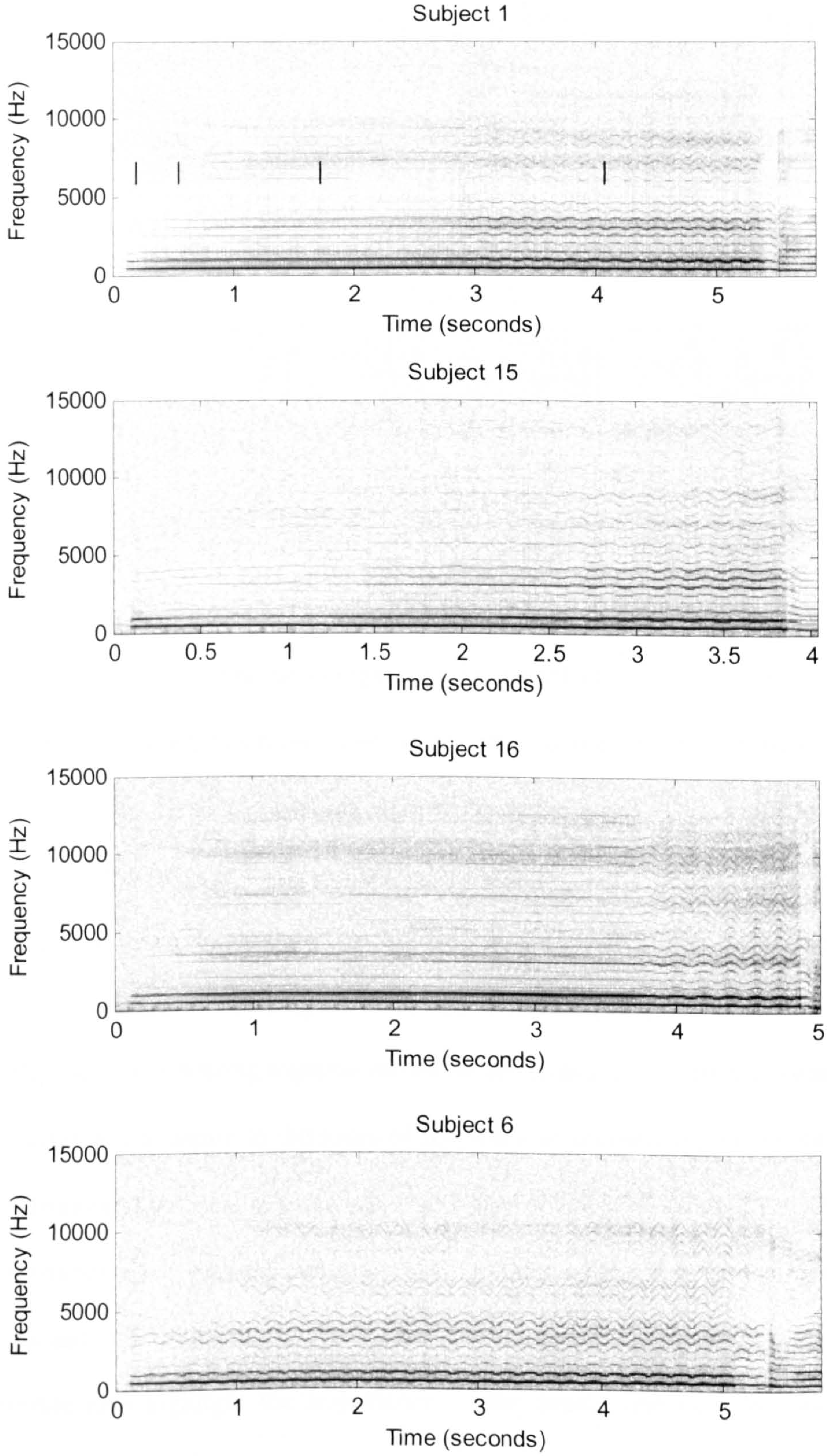
Figure 40 Spectrograms of an ascending two octave Bb major scale sung to [i] for subjects 1 and 4 from the early music group and subjects 10 and 6 from the opera group



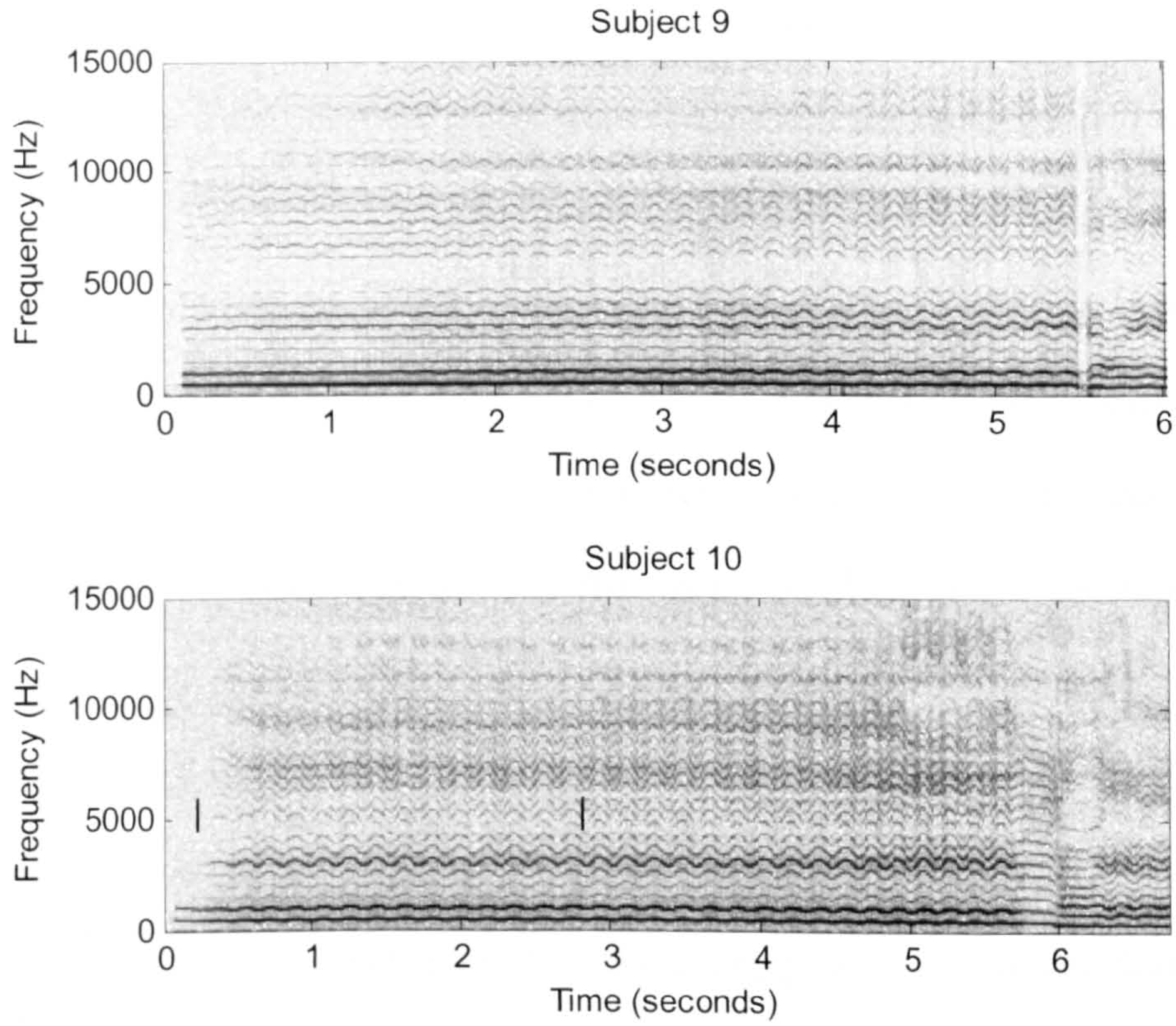
In addition to the singers' use of vibrato throughout this note which was highlighted in chapter 3, an interesting feature relevant in particular to the singers in the early music group is their changing spectral content throughout this note. Figure 41 shows spectrograms of this note sung by subjects 1, 15, and 16 from the early music group and subjects 6, 9 and 10 from the opera group as they illustrate the extreme treatments of the note between the two groups. Spectrograms for this note sung by all subjects are shown in figure 14 of chapter 2.

There is a tendency for subjects in the early music group to begin the note with a very prominent fundamental and second partial but with little or no other energy present in the spectrum. This onset could contribute to the concept of perceived purity or clarity in the sound due to the dominance of the fundamental, complementing the theory presented above of fewer high harmonics and high amplitude fundamental frequency contributing to a 'purer' timbre. Once the note has been established with a predominance of the first two or three partials, the singers begin to introduce energy in the higher frequencies of the spectrum, firstly in the region of the singer's formant cluster and then adding the harmonics in the upper frequency band. These harmonics are established gradually as they enter the spectrum individually rather than as a band. Once all the harmonics have reached the maximum energy of that note vibrato is added, the treatment of which was discussed in chapter 3.

Figure 41 Spectrogram of the first note of the Handel extract sung by subject 1, 15 and 16 from the early music group and subjects 6, 9 and 10 from the opera group



Lines indicate point of analysis for figure 44



Lines indicate point of analysis for figure 44

This treatment of spectral energy adds to the effect of the crescendo by changing the timbral characteristics rather than simply altering the dynamic of the note by increasing the intensity of all the partials equally from the onset. This acoustic handling of the onset of the note, introducing the harmonics gradually rather than forming frequency bands is comparable to the onsets of musical instruments. This has particular implication with relevance to the singers in the early music group as there are many historical references which bring together the voice and instruments, either encouraging particular instruments to aspire to the tones of the voice or encouraging the voice to behave more instrumentally: 'And who is not aware that singing is at all times the aim of every instrumentalist; because one must always approximate to nature as nearly as possible' (Mozart, ed. Einstein, 1951: 102). Current understanding of the psychoacoustics of timbre also highlight the importance of the onset, especially in connection with the timbre of instruments as research suggests that 'listeners cannot reliably identify musical instruments if the onset and offset phases of the note are removed' (Howard, 2006: 227).

The general treatment of this opening note by the singers in the opera group is indicative of the characteristics that were discussed above, in that, as they crescendo through the note the intensity of the energy throughout their spectrum, which is usually present from the onset, increases. Subject 6 in this group presents with a distinction between the inclusion of energy in the singer's formant region and the production of the band of energy above this region, with the higher frequency band appearing after the singer's formant band as the singer moves through the note (see figure 41). This trait, which is exhibited in only subjects 6 and 8 in the opera group, shows similar features to the early music group; however, the effect in both these singers occurs in the first quarter of the note's length, and very much as bands of energy rather than harmonics strengthening individually as is seen in the early music singers.

The evidence suggests that the staggered entry of harmonics used by the early music singers is a stylistic effect employed consciously by the singers. The implementation of 'growth' through the note by all subjects suggests a premeditated response to the style of the music they were singing. That the singers in the early music group increased the affect by employing techniques beyond the perceived loudness of the note complies with the current fashions of historical performance practices based on comments found in historical treatises, such as this quote taken from c. 1695 'Learn to fill, and soften as sound, as shades in needlework, in sensation, so as to be like also a gust of wind, which begins with a soft air, and fills by degrees to a strength as makes us all bend...' (In

Donnington, 1992: 487). It is likely that the effect is exaggerated most in those singers performing early music more often because it is their common repertoire and therefore a technique they are used to exploiting.

Figure 42 Spectrogram of Note 1 of the Handel extract sung by subject 12.

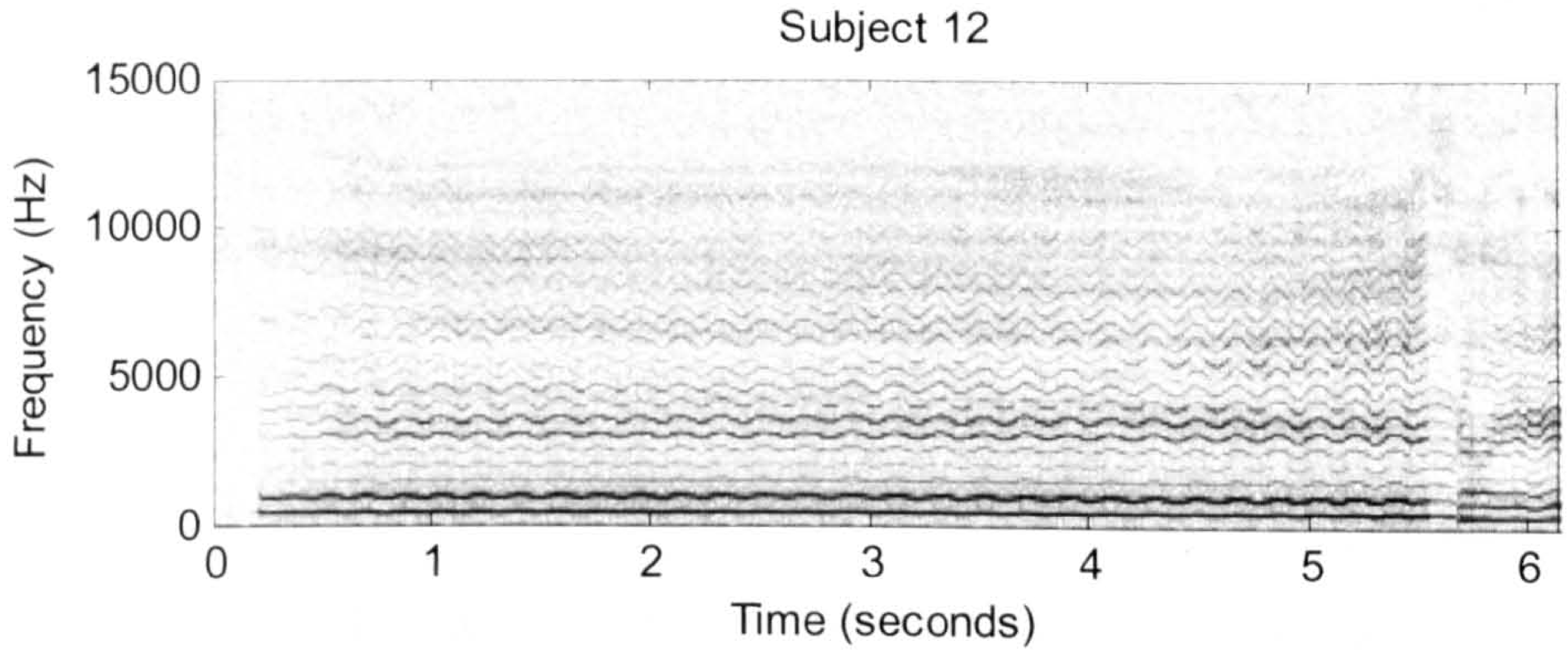
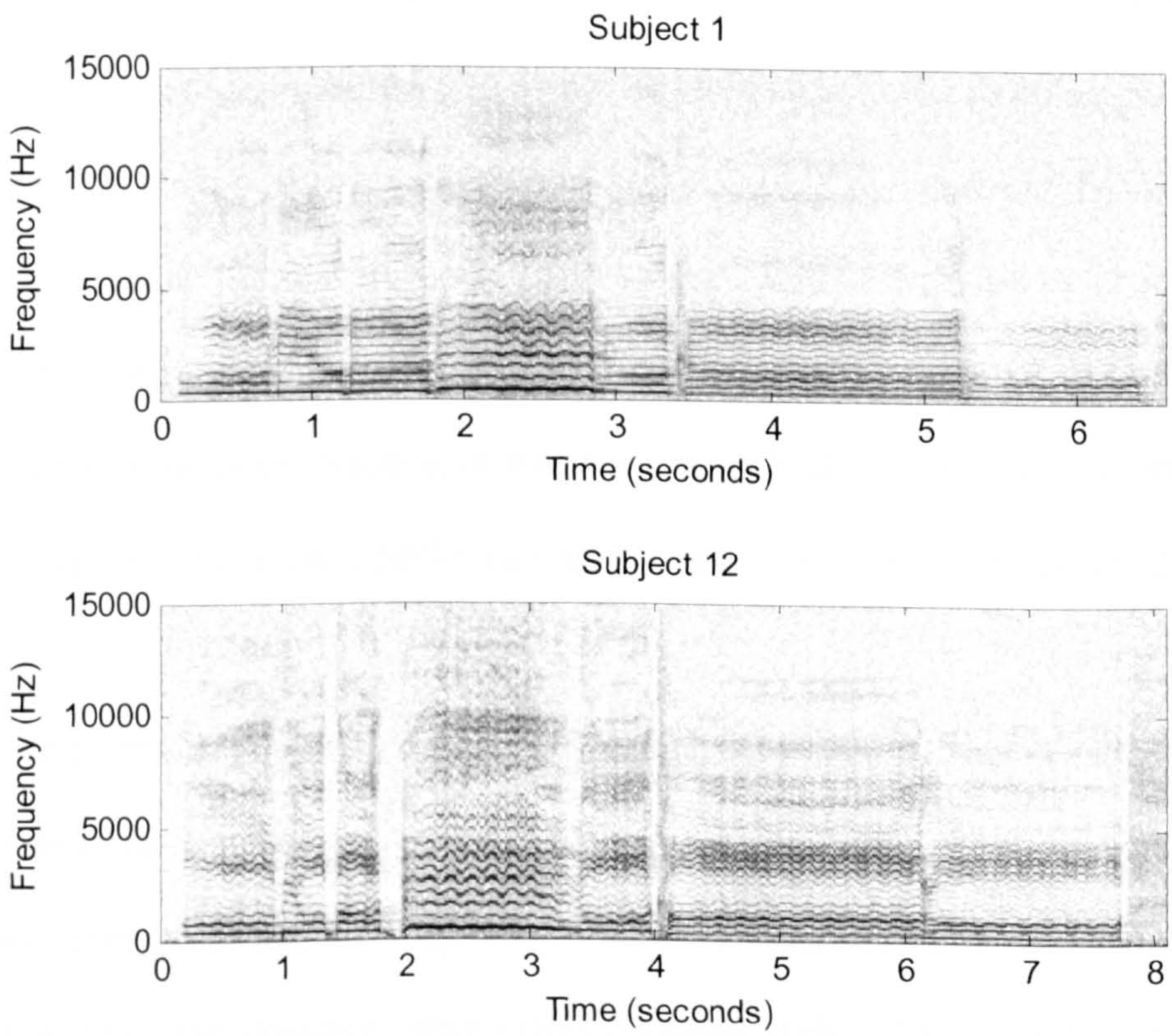


Figure 43 Spectrograms showing the first phrase of the Puccini extract sung by Subject 1 from the early music group and subject 12 from the opera group



This theory is supported when the case-studies are considered as individuals. Subjects 1, 15 and 16 present with this phenomenon most prominently and subject 1 and 15 are the only singers in the early music group that said they tended not to perform music written outside their chosen specialty, believing that they specifically wouldn't suit certain repertoire. Subject 13 who did not drastically alter the spectral content of the sound throughout the note, although she considered herself specialists in the early music field also regularly sang repertoire outside the early music canon and had been trained at a conservatoire.

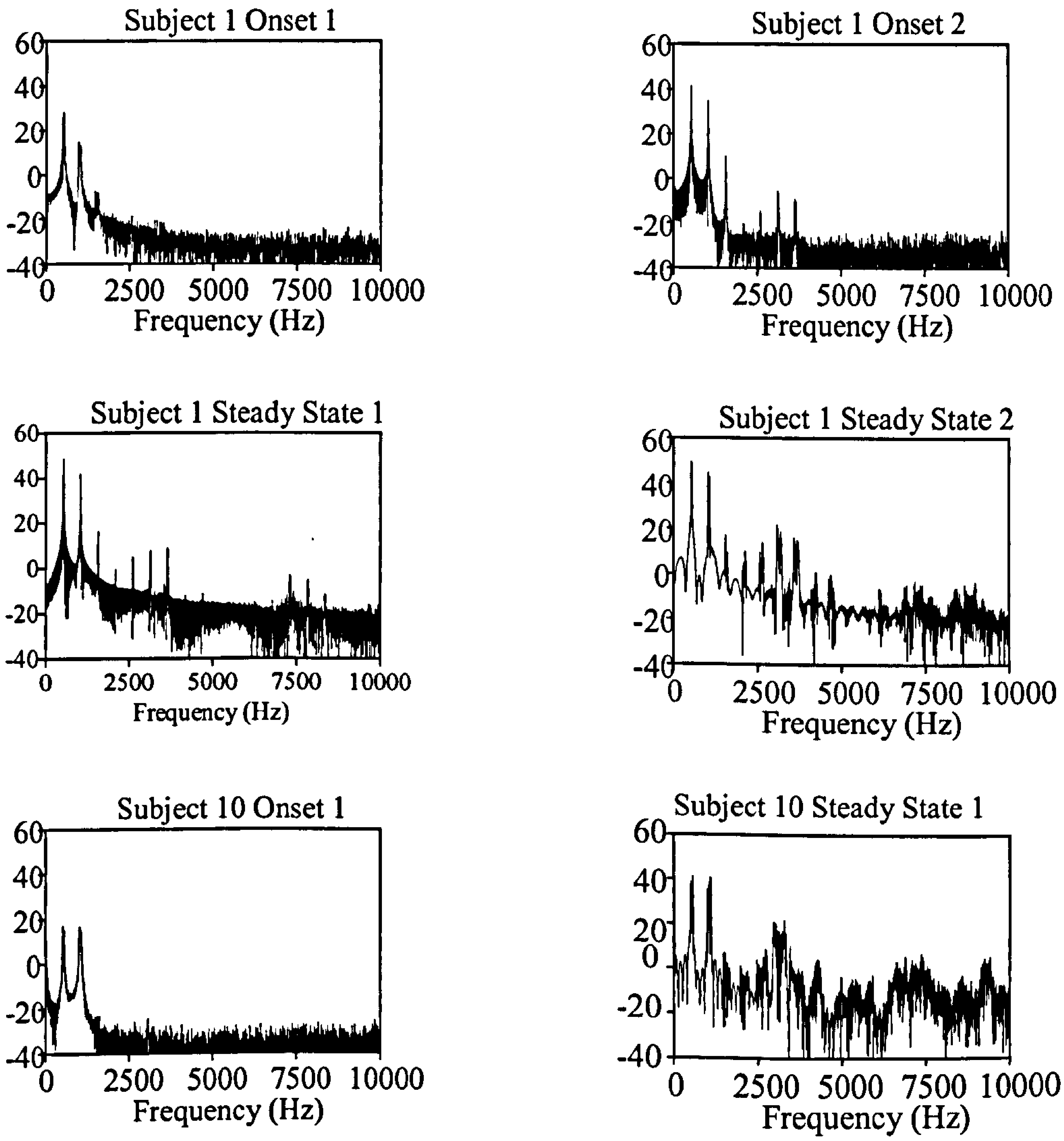
The environmental requirements of opera singers are of significance to findings such as these, in that the acoustic expectations of singers of grand opera necessitate specific vocal qualities. Considering the usual conditions in which the singers from the opera group perform, i.e. in grand opera houses with large symphony orchestras, it would be counter-productive for them to utilise the techniques seen to be employed by the early music singers as they would be too subtle to be heard over the orchestra. Environmental and acoustic factors are considered more closely in relation to spectral content and particularly the singer's formant cluster in chapter 6. However, it is important to note here as a likely explanation of more varied timbral changes apparent in the early music group, as in their usual performance set-up they are given more acoustic freedom.

The potential importance of a dominant fundamental during the onset of the opening note of the Handel extract as a particular feature in the technique of early music singers was mentioned above. If the intensity of the first few partials is considered throughout this note, the possible relationship between their relative energy and the perceived quality of tone can be assessed. Comparing the two subjects that displayed the most extreme differences in spectral development throughout this note (subject 1 from the early music group and subject 10 from the opera group) highlights several differences in timbral progression. Figure 44 shows spectral slices taken from moments of changing energy throughout the note by these two subjects. The points of the note that were analysed are marked on the spectrograms in figure 41. Four portions of the note were analysed for subject 1, two onset portions and two steady state portions representing the straight and vibrato portions of the tone once it was established. Only two portions of the note were analysed for subject 10 as there were no visible degrees of onset and the steady state of the tone was largely representative throughout the note. If the moment in the tone selected for analysis contained vibrato, a period of two vibrato cycles was selected.

Both singers produced note onsets with no spectral energy in the frequency region of the singer's formant cluster or higher. However the subjects differed in the relative strength of the fundamental and first harmonic. Subject 1 displayed a strong fundamental and weaker first harmonic, with a difference of 13dB. Subject 10 produced the onset with a fundamental and first harmonic of equal intensities.

Whilst this at first seems to support the theory of a strong fundamental being characteristic of clarity or pureness of tone, when all subjects are considered there is not enough consistency within the groups to suggest that trends between the relative strength of the first two partials is a defining feature of the singers' specialty. Considering the subsequent development of energy throughout this note, however, trends do appear within the groups, placing more significance on the importance of the first two partials on the perceived timbre.

Figure 44 Spectrums of the developing onset of note 1 of the Handel extract by subjects 1 from the early music group and 10 from the opera group



As the note develops the difference in intensity between the fundamental and the second harmonic diminishes in subject 1. However, it remains more dominant in the spectrum for this subject than subject 10, for whom the relative energy of the fundamental and second harmonic remains similar throughout the note.

Also important are the presence of the higher frequencies in the spectrum. This can be observed in the spectrums of the 'steady state' portions of the note shown in figure 44. Not only is it significant that there fewer energy peaks in the spectrum of subject 1, the much lower intensity of these peaks compared to the intensity of the first harmonics is striking when considered against the same comparison for subject 10. Based on the spectrums for the steady state of the tone (steady state 2 in the case of subject 1) there is a difference of 28dB between the intensity of the fundamental and the 2 – 4 kHz energy peak for subject 1 in contrast to a 19dB difference in the spectral slice of subject 10. Also, the energy above this frequency region is much stronger with considerable further peaks in the spectrum for subject 10, and the large frequency extent of vibrato for this subject increases the density of energy across the spectrum. The comparable strength of energy across the spectrum of subject 10 could contribute to the perceived difference in the timbres of these two singers; the clear bands that are present for subject 1 with a very dominant fundamental could be responsible for a perceived clarity of tone or 'purity'.

5.4.3 Impact of Text

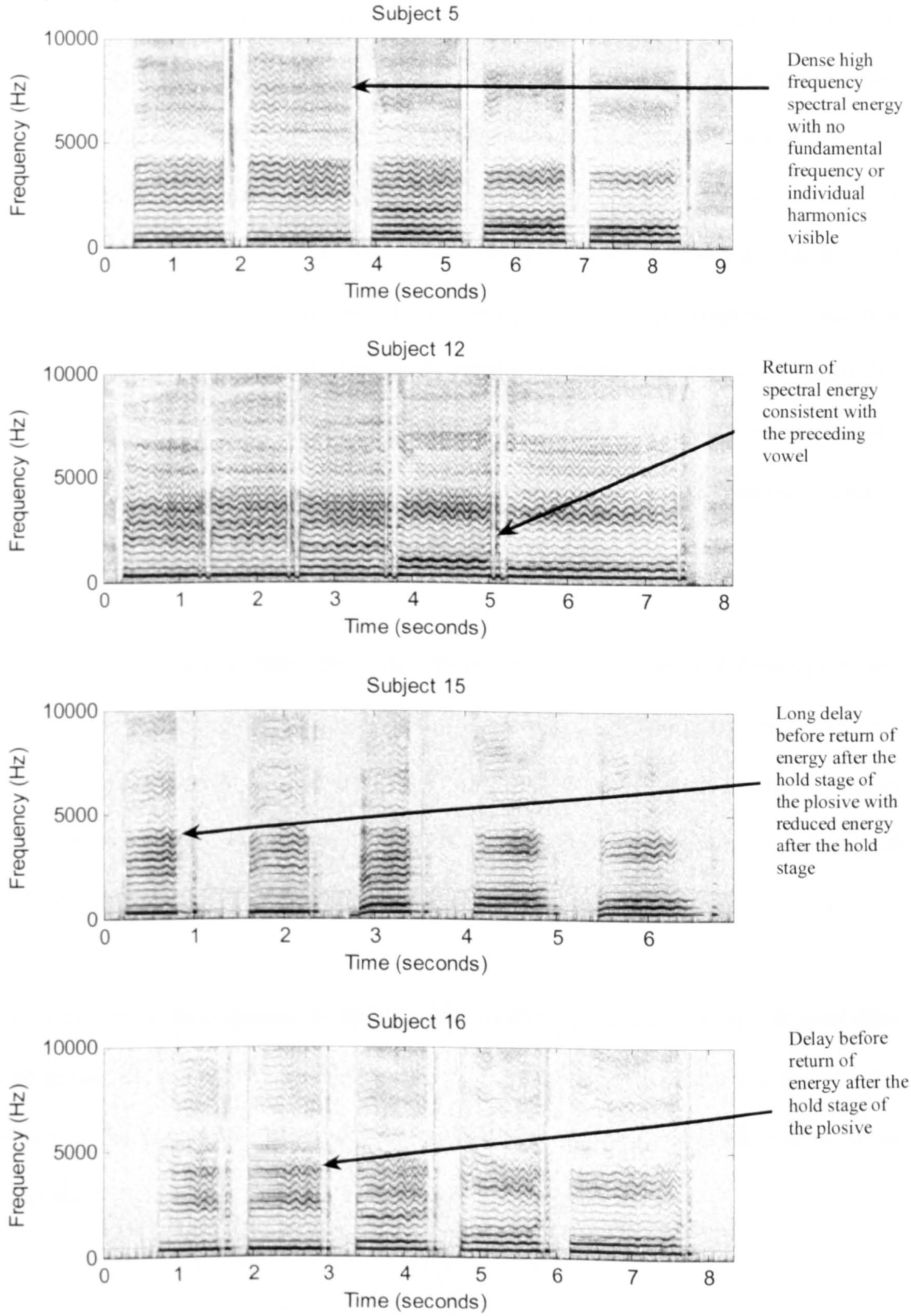
As mentioned above, current teaching of classical singing, and particularly opera singing, promotes the importance of quality of tone and the importance of the overall vocal sound. The production of text is often promoted by teachers as simply an interruption of this stream of sound, which should be kept to a minimum in order to allow continuity of tone: 'Now they [the vowels] can become the stream of sound on which the consonants sit lightly' (Salaman, 1989: 58). It is thought by modern scholars such as Potter and Wistreich that considering the evidence of the historical treatises, text was considered more important than overall tone production in historical techniques, not only in terms of clear enunciation, but also deliberately changing the tone quality as a response to the text in order to 'give every word its proper energy and pathos' (Corri 1810: 1).Previous research into consonant production has shown an increase in the time between the 'release of an oral constriction and the start of a vocal fold vibration' (Mccrea *et al.*, 2005: 423) in trained singers compared to untrained singers Mccrea *et al.*, 2005; Mccrea *et al.*, 2007).

Due to the nature of the experiment this study cannot provide a deep insight into the production of text in terms of altering timbre with meaning. The extracts chosen were not necessarily well known to the singers and the text was not in the native language of any of the subjects. Any musical devices they may tend to employ concerning specific text are therefore unlikely to be evident. However, intrinsic aspects of their technique concerning the physical production of text, such as time spent on consonants and continuity of tone production can be considered.

There were noteworthy differences in the text production between the individual singers that were case-studied. Particular differences can be seen in the third exercise they were asked to sing. Specifically this involved the subjects singing the words 'bid, bead, bed, bard, bored' to the notes of a D major arpeggio. Spectrograms for subjects 5 and 12, both from the opera group and subjects 15 and 16 from the early music group are shown in figure 45 illustrating the extremes of the differences that were observed across subjects (spectrograms for all subjects singing this exercise were shown in chapter 2 figure 17). These spectrograms illustrate the use and production of consonants of the singers. Especially considering the final 'd' consonant of each of those words, the singers display different methods of production.

Depending upon the singer, the 'd' is either produced almost as an Italian t or as an English d with a 'false vowel' occurring. The former is shown by a dark line of strong energy across the frequencies of the spectrogram, i.e. with an absence of any identifiable harmonics or fundamental, and is characteristic of an unvoiced, aspirate consonant. Subject 5 who uses this technique produces no energy in the lower frequencies of the spectrogram, suggesting that phonation stopped whilst the consonant is produced. The latter method of creating a 'false vowel' is characterised on the spectrogram by the presence of a fundamental and individual harmonics as illustrated by the spectrogram of subject 12. In these cases there is little energy present during the consonant or 'false vowel' that is not present when those singers are singing continuous vowels. This indicates that these singers continue to phonate throughout production of the consonant, the airflow being stopped by articulations of the sound modifiers to produce the consonant. In both cases these effects are seen after a complete interruption of energy in the spectrogram representative of a stoppage of airflow and therefore of sound indicating the point of the consonant.

Figure 45 Spectrograms of subjects 5, 12, 15 and 16 singing the text 'bid, bead, bed, bard, bored,' to F#4



Subjects 5 and 12 whose spectrograms are both shown above were both part of the opera group, and likewise, no consistency is apparent between the production of the 'd' consonant and the grouping of the singers. This implies that it is a matter of either personal taste or a result of certain teaching methods. One trend which is apparent between the two groups is that the 'gap' between the end of the vowel and the appearance of the 'noise' of the consonant (whether voiced or unvoiced) tends to be longer in the early music group than in the opera group as the spectrograms of subjects 15 and 16 illustrate in figure 45. This could support the theories of musical scholars that the singing of early music text is of more importance to the early music singer than the opera singer as the acoustic 'space' produced by this delay may be indicative of clearer perception of the consonant.

When singing extracts from the songs there were no consistent differences found between the two groups, although once again there was a wide range of results between the individual subjects. This could be due to the varying degrees to which the singers knew the songs they were asked to sing but could also reflect stylistic or pedagogical differences.

From this study there appears to be no specific intrinsic link between period specialism and actual text production in terms of the time spent over consonants and the acoustic effect of the consonant. However, this would need to be investigated further as an individual project for findings to be considered conclusive.

5.5 Physiological Implications

The spectral findings discussed above provide suggestive evidence pertaining to certain physiological factors of the technique of the singers. The previous chapter which considered the larynx position of classical singers discussed the various acoustic implications of lowering or raising the larynx, and explored the various theories of a lowered larynx technique being a feature of the modern operatic genre of singing. Considering the timbral tendencies of the two groups of singers discussed above, the presence of significance energy in the singer's formant region of the spectrum by all singers implies similar articulatory strategies between the groups, and is supported by the results of the previous chapter. However, the use of a wider diversity of spectral energy by the singers in the early music group suggests a more varied use of the positioning of the sound modifiers by these singers.

It would seem that singers in the opera group maintain a similar positioning of the sound modifiers throughout notes, perhaps with slight changes when intensifying notes and increasing the energy in the upper most frequencies of the spectra – although these changes could also be symptomatic of alterations in subglottal pressure which has also been shown to effect high frequency energy (Nordenberg, 2003; Sundberg, 2006). The results for the early music singers, however, suggest that they tend to adapt positioning of the sound modifiers throughout notes in order to change the timbre as well as the intensity. The higher frequency band which is exploited to a much larger extent by the singers in the opera group than the early music group could be an indication of a more extreme articulation strategy being employed by these singers although further research is be needed to confirm this.

To an extent, the singers' production of text is also suggestive of a more flexible movement of the sound modifiers by the early music singers considering the delay in returning spectral energy after a consonant is produced, and could also suggest that the singers in the opera group generally utilise a more extreme positioning of the sound modifiers. However, this is suggestive because of the evidence of the spectral energy throughout phrases rather than in the production of consonants. Whilst it is a common criticism of singers of grand opera that their words are lost, and it is thought that the lowering of the larynx will cause sluggish articulation because of restricted movements of the tongue (Potter, 1998: 53), there were little differences in the time taken over consonants or how they were produced between the two groups of singer. The differences that occurred were apparent in the energy of the vowels that followed the consonants as shown in figure 45 above, as the singers in the early music group tended to take slightly longer to return to their full spectral energy, even when not seeming to strive for a stylistic affect. It could be this subsequent 'space' in the spectrum following the consonant that allows the text to be heard more clearly by the audience, however rather than being connected with audibility of text it could also be another timbral feature of early music singing. The absence of this effect by the singers in the opera group is presumably due to the same environmental factor which prevents their text from being heard, as they are usually fighting for their words to be heard over the heavy textural lines of a large orchestra.

5.6 Stylistic Implications

The considerable differences seen, particularly in the consistency of timbre, between the exercises and the song extracts give an insight into the current stylist fashions of performing. Spectrographic analysis of the exercises implies that the singers are all striving for evenness of vocal tone throughout notes, indicated by the consistent use of energy across the spectrum by all the singers. This is apparent when singing with and without text, although when consonants are included there is a slight delay before the spectral energy returns. Stylistic influences on spectral content are revealed in the sung extracts, particularly considering moments that were discussed above such as the first note of the Handel extract. The use of a crescendo through this note by all singers demonstrates a stylistic understanding of current expectations of performance practice; however, the fact that this affect was utilised to a greater extent by the early music singers (employing more differences in spectral content as well as intensity) implies that they are more used to complying with the current conventions of music of this period.

Likewise, when the opera group sang the Puccini extract they produced higher levels of energy in the upper frequencies of the spectrum and were more successful at maintaining this spectral content throughout notes and across phrases than the singers in the early music group. This stylistic expectation for the later song is supported by the increased use of these traits by the early music singers, as, although not to the same extent, they mimic the spectral tendencies of the opera singers again being representative of a stylist understanding.

5.7 Summary

The findings discussed above indicate that the singers used in this study have different stylistic priorities, which in turn affects their overall spectral content, depending on their specialty. Whilst all the singers demonstrate an understanding of the assumed stylistic practices for each period, the extremes they use always favour their own area of expertise. Although all the subjects display spectral characteristics expected of 'classical singing' there are intrinsic differences between the two groups. Most notably these are the more significant higher bands of energy in the opera singers and the 'space' and flexibility in the energy utilised by the early music singers. These differences are likely to be the result of conscious stylistic priorities as well as environmental factors and training which have in turn impacted on the inherent vocal technique of the singers. The differences that were observed between the two groups, although those pertaining to certain features such as delay before high energy in the 2kHz – 4kHz region may seem very small, are likely contributors to modern perceptions of characteristic timbres being associated with the two specialties. However, the differences in overall spectral characteristics that contribute to perceived timbre were not as acute as would be expected considering the emphasis placed on timbral descriptions in literature concerning both modern early music practices and theories of historical techniques.

Chapter 6

Resonance Strategies

Part of the majesty surrounding the operatic voice is the perceived vocal 'projection' or 'ring' that opera singers achieve. Being able to hear a single voice over large symphony orchestras playing densely textured music makes the voice seem more powerful and imposing. Whilst this may appear to the listener to be the result of very loud singing, for an individual voice to compete directly with the overall acoustic intensity of the combined forces of an orchestra would be impossible. The techniques employed by singers to achieve these levels of projection have therefore long been a source of interest to singers, acousticians and voice scientists. A main feature which has been identified in classical singing as providing an acoustic tool for projection involves the manipulation of the sound modifiers to alter the spectral content of the sound from the voice source.

The term singer's formant or singer's formant cluster has been established to describe the acoustic phenomenon of clustering the upper formants to create a peak in the spectral envelope at around 3kHz (Sundberg, 1987: 121). This peak not only provides high energy in the frequency region at which an orchestra's spectral energy is decaying, but is also in the frequency region at which human hearing is most sensitive (See chapter 2 for an explanation of the singer's formant cluster and its acoustic features). Whilst the singer's formant cluster has been associated mostly with male singing, as chapter 2 explained, there is evidence of similar attributes in the spectra of female opera singers, although in female singers the band has been shown to be wider (2kHz – 4kHz) and less prominent than for male singers (Weiss *et al.*, 2001). Female singers are also thought to employ other acoustic strategies, particularly at higher fundamental frequencies, where the peak in the spectral envelope seems to disappear and other techniques take over such as tuning the first formant over the fundamental (Joliveau *et al.*, 2004). This chapter will consider the various resonance strategies employed by the singers included in this study, considering the recorded intensity and spectral content of the singers. Any differences between the two groups will be noted, and the significance of these differences in terms of the singers' performance specialty will be considered.

6.1 Loudness and Opera Singing

Whilst loudness is commonly associated with the perception of singing, loudness of a voice is very difficult to measure. Normally to measure sound energy a sound pressure level (SPL) in dB is used. However, as Sundberg explains, this is only a fair representation of perceived loudness for sinewave signals, causing a problem when measuring the voice: 'SPL mainly reflects the amplitude of quite a few or even one single spectrum partial' (Sundberg, 1994: 70). He goes on to explain, 'therefore, SPL values of voice sounds are comparable only if the sounds are identical with regard to fundamental and formant frequencies' (Sundberg, 1994: 70). Such problems in measuring differences in intensity will be considered within the analysis of the data, but in the absence of a more efficient and practical method, in this study intensity was measured in dBSPL using a decibel meter. It is also important to note that SPL measures the physical loudness and not the perceived loudness. Sundberg highlights the importance of distinguishing the two; 'while the perceived loudness of a tone may remain constant when its pitch is changed, its physical level may change by several dB' (Sundberg, 1987: 35).

In spite of these problems with measuring loudness, there have been studies which have compared the loudness in SPL between opera singers and untrained singers. Sundberg combines the findings of studies carried out by Bloothooft and Coleman *et al.*, measuring the mean maximum intensity the subjects could produce (Sundberg, 1987: 115-116). It was found that the trained singers produced much louder SPL values than the non-singers and this was attributed to the environmental necessity of opera singers performing with loud orchestras, Sundberg explaining that 'they simply have learned how to produce sound at exceptionally high levels' (Sundberg, 1987: 116). This trend was most prominent in female singers, in that professional sopranos produced much higher SPL levels than untrained females compared to the same two groups in male voices.

6.1.1 Current Perceptions

Since the discovery of various methods of projection employed by classical singers, discussions of vocal loudness often concentrate on intensity in relation to these factors, particularly the relative intensity of individual partials rather than analysing overall vocal loudness. However, amongst performers and listeners perceived loudness remains an important factor in the perceptual measure of a voice. When reviewing a 'family-friendly' version of 'The Magic Flute', Anthony Tommassini, writing for the New York Times, asked a number of children for their opinions. Their answers illustrate the comprehension of the audibility of the singers being justified by an abnormal loudness,

> The singing "was loud," Amitav said. Jonah added, "It was too loud." Kira more or less agreed....
>
> Amitav clarified their reactions when he said that the singing was "too loud for human voices," adding, "I never thought voices could do that."
>
> So their reaction was not a complaint about excessive volume, but rather an attempt to explain the awesome impression made by Ms. Miklosa's dazzlingly high vocal flights as the Queen of the Night, or Mr. Pape's unearthly powerful bass voice, or the amassed chorus in the temple scenes. It takes a while for young opera neophytes to adjust to such mind-boggling voices, to realize that this strange, unamplified "loudness" is actually amazing.
>
> Tommassini, 2007: New York Times

Although this statement is the reflection of children's views rather than an adult majority, this sort of attitude towards classical singing is also quite common in the mature spectator. Even amongst expert listeners of 'classical' music and particularly opera, matters of loudness can have a large impact on aesthetic values of a voice. In a profile of Cecilia Bartoli published in the Guardian newspaper, Nicholas Wroe explains that early in her career the size of Bartoli's voice was sometimes considered prohibitive,

> 'In 1986 at a mass audition for singers in Milan, Decca producer Christopher Raeburn was looking for a Rosina for a new recording of The Barber Of Seville. Raeburn had made the first Rossini recordings by the great mezzos Teresa Berganza and Marilyn Horne. When he heard Bartoli he instantly thought she would be ideal, "but what was interesting was that a lot of other people just weren't that impressed," he has recalled. "They thought the voice small. But while it's certainly not large,

> it had focus, and she was already such a complete musician. She phrased so beautifully.
>
> Wroe, The Guardian website, 2001

As with timbre and vibrato, matters of favourable loudness are entirely dependent on the individual assessing the sound. In an attack responding to criticism of quiet voices the author expounds his own view of small voices whilst also providing an insight into the common public opinion of opera goers in the 1930s,

> 'It seems to me that it is a far simpler task for a big singer to stand up and let out volumes of voice – to the great delight of a singularly short-sighted public – than it is of a little singer to win the appreciation of even a small section of that public, by the skill and musicianship needed to display her small voice to the best advantage'
>
> M.E.T, 1933: 536

Kimbell, the author of the article which promoted the retort above, when providing a further reply also supplies information on current perceptions of singers performing at that time, implying that although loud voices were favoured by the public they were less common than quiet voices even in opera,

> Big voices on the other hand, are rare; and I am sure that 'M.E.T.' will agree that they must be found and fostered if we are to have big oratorios and operas properly performed. And when I said that small voices were wheedling their way into grand opera, I stated facts.
>
> Kimbell, 1933b:635

Kimbell's comment on the 'proper' performances in regard to 'big oratorios' could be connected to the environmental conditions of the performances. Although not explicitly stated by the author, the singer competing with large orchestral forces and compositional textures in big opera and oratorio works could prevent the 'small' voices from creating an impact on an audience. In his article exploring the expectations of singers in modern music, Judd encourages this interpretation,

> Another disadvantage about modern accompaniment is that they are frequently so heavy that the singer has to yell to make himself heard.' there are only a limited number of singers possessing the tremendous volume required to dominate such accompaniments,...
>
> Judd, 1935:142

The evidence above illustrates the importance of perceived loudness in both everyday discussion and in more formal review. However, the perceived loudness that is considered could be as much to do with acoustic characteristics such as the singer's formant cluster as to do with actual intensity. Comments such as those previously considered which talk quite generally about loudness from a listener's and a musical perspective are not necessarily concerned with the parameters of intensity which can be measured. Such descriptions of perceived loudness could and probably do therefore include factors such as singer's formant cluster type characteristics.

6.1.2 Historical Theories and Environmental Necessity

Modern theorists investigating historical vocal techniques place an importance on loudness as part of the differences between old and new styles. This is partly because whilst historical sources must be treated with caution, especially when interpreting aspects of vocal techniques that were then unquantifiable, issues of perceived loudness can be universally understood. The general consensus amongst modern theorists is that, particularly in chamber rather than church music, a much quieter sound than is currently employed by 'classical' singers would have been favoured. Wistreich describes the necessity for quiet singing in renaissance and baroque music, drawing on a quote from Zacconi ,

> In intimate surroundings, vocal chamber music was often performed together with soft instruments like harps, viols, clavichords and lutes, and having as its overriding priority the clear, flexible and affective conveying of texts, loudness was not only unnecessary, but highly undesirable: "many learn to sing by singing softly and in rooms where loud singing is abhorred, and here sing those gentlemen and others who are not forced by necessity to sing in the churches and in the chapels where hired singers sing"
>
> Wistreich in ed. Potter, 2000: 182

Wistreich's deduction is based on Zacconi's account as well as consideration of the instrumental forces in use during the period in question. This again highlights the importance given to environmental factors in the investigation of historical techniques. Wistreich goes on to assume,

> Even allowing for the slightly more strident instruments such as violins, harpsichords and theobos, and for the increasing size of the mixed vocal and instrumental ensembles required to perform concerted music for the courtly opera and the chamber cantatas of the Baroque period, a dynamic level close to normal speaking allowed for the flexibility, subtlety and expressiveness in which text could remain paramount.
>
> Wistreich in ed. Potter, 2000:183

It most be noted that loudness is still relative to the individual and that this could effect the reliability of such sources, particularly as, for example, the standard loudness of speech could easily have changed. Uberti's earlier suppositions on loudness in historical vocal techniques agree with Wistreich, also explaining that dynamics within music would have been dealt with differently than today, 'One often associates dramatic intensity with loudness, but for Renaissance singing the equation has to be reversed' (Uberti, 1981: 494).

Considering the theories of modern scholars such as Wistreich and Uberti who suggest singing would generally have been quieter than it is today, alongside the environmental issues which seem to have increased the loudness of singing, it would be expected that the subjects from the early music group would generally have quieter voices than subjects from the opera group. Current fashions of performance which have established an expectation for modern singers specialising in early music to sing with period instruments performing as 'chamber' forces reinforces this hypothesis. Where differences are not found in intensity comparable differences would be expected in the various acoustic strategies which contribute to the perceived 'loudness' or carrying power of the singer.

6.2 The Singer's formant cluster and other Projection Strategies

An acoustic characteristic which has become familiar as a feature of western opera singing is the singer's formant cluster, although particularly in the case of female voices other resonance strategies are being identified. The spectral features of the singer's formant cluster were discussed in chapter 2, which explains that it presents as a peak in the spectral envelope at around 3kHz depending on the voice type. It was also explained that the singer's formant cluster has been promoted as a key feature in the success of hearing a singer over an orchestra and therefore is considered idiomatic of opera singing. As the phenomenon is mainly associated with male singers and low female singing, as well as assessing the energy in the region of the spectrum relevant to the singer's formant cluster, other potential acoustic strategies which would promote the singers' 'projection' also need to be considered. Any notable features will then be compared across groups to ascertain any common differences.

Although it was previously found that there were large differences in the maximum sound level of female singers and non-singers, it is noted that 'in reality, the singer's formant has a lower amplitude in female voices, particularly in sopranos, than in male voices' (Sundberg, 1987: 124). In order to account for these differences in maximum sound level which cannot be attributed to a singer's formant cluster, other resonance strategies of sopranos have been explored. The observed absence of a singer's formant cluster in some research has been attributed in part to the larger spacing of the harmonics in soprano singing due to the higher fundamental frequencies sung by this voice type (Joliveau at al., 2004: 2434; Barnes *et al.*, 2004: 530). Mendes *et al.* (2003) explains that increasing fundamental frequency 'would cause the singer's formant to decrease in amplitude because there would be no harmonic energy in the area of a formant peak to be maximized' (Mendes at al., 2003: 542). Sundberg identified the clustering of the third fourth and fifth formants, as forming the 'singer's formant' (Sundberg, 1987: 119). Supporting the argument against a singer's formant cluster in female singing, Sundberg observed two peaks in the spectral envelope in the frequency region of around 3kHz 'presumably reflecting F3 and F4, thus suggesting that they do not cluster these formants and do not have a singer's formant' (Sundberg, 2001: 186).

In spite of such evidence against a singer's formant cluster in soprano singing, research into this frequency range in females continues to be assessed as an important aspect of voice quality and projection and an increase of energy in the 2 – 4kHz frequency region has been associated with trained sopranos (See, for example, Weiss at al., 2001; Mendes *et al.*, 2003; Barnes *et al.*, 2004; Reid *et al.*, 2007). As 'females generally have a third formant located at approximately the same frequency as the singer's formant' (Mendes *et al.*, 2003: 542), and as the strength of the spectral peak is known to vary with vocal intensity, fundamental frequency, and voice type (Bartholemew, 1934; Sundberg, 1987) it is difficult to assess the significance of a spectral peak in this region in terms of identifying a 'singer's formant'. Bloothooft and Plomb found that, when the overall SPL is kept constant, the relative sound level of the singer's formant decreases as fundamental frequency increases (Bloothooft and Plomb, 1986: 2031). They also produced a quantitative parameter in order to assess the presence of a singer's formant concluding that 'when the relative level of the high-frequency peak exceeds a threshold of about -20 dB, we may refer to this peak as singer's formant; in other cases we may not' (Bloothooft and Plomb, 1986: 2032).

Barnes *et al.* considered the significance of spectral energy between 2kHz – 4kHz in the soprano voice, observing specifically professional operatic soprano voices (Barnes et al, 2004). Referring to the level of level of energy in the 2 – 4kHz frequency band as L_{HF}, they found that the operatic sopranos in their study produced a level in the region of 2kHz – 4kHz up to 10dB on the vowels '/a/ and /o/', concluding that 'hence those /a/ and /o/ vowels with L_{HF} between 6 and 10dB had HF [high frequency] energy equivalent to vowels with a singer's formant, a stark contrast to the Italian /i/ vowels where L_{HF} was always below zero' (Barnes *et al.*, 2004: 536). The lack of excess higher spectral energy in /i/ vowels was thought to imply that 'the normal articulation for this vowel is probably sufficient for good audibility' (Barnes *et al.*, 2004: 536). The above average energy between 2kHz – 4kHz was attributed to a probable reinforcement of the third formant, which naturally falls within this frequency range, by the fourth formant, implied by the 'the sharp drop of energy at the upper end of the boost' (Barnes *et al.*, 2004: 537). Conclusions of this study endorse Sundberg's findings, acknowledging that the 'double peak of most song task LTAS shows that there is no consistent clustering of F3, F4 and F5' (Barnes *et al.*, 2004: 537). The study showed a marked increase in high spectral energy with high performance level leading to the conclusion that 'while no evidence could be found to support the use of a soprano singer's formant, it was shown that HF energy is important to sopranos who sing opera' (Barnes *et al.*, 2004: 538).

An important method which has been identified in soprano singing is the technique to tune the first formant over the fundamental as an additional resonance strategy which could contribute to the high overall intensities measured for trained sopranos. Due to the fundamental frequencies common to sopranos being much higher than for other voice types, and often above 500Hz which is also about the frequency of an orchestra's loudest partial (Sundberg, 1987: 127), they are already at an acoustic advantage. To tune the first formant close to the fundamental frequency significantly increases the energy of that partial without demanding an extreme vocal effort of the singer (Sundberg, 1987: 126; Barnes *et al.*, 2004: 2434). This can account for both the significant increase in maximum sound level in trained sopranos reported above as well as the absence of a consistently identified singer's formant cluster. Unfortunately, this phenomenon of formant tuning is a particularly difficult feature to measure in the soprano voice as the fundamental frequency they are singing is often higher than the first formant frequency of the vowel they are producing. Due to this, Joliveau identifies that 'The problem is that it is difficult to determine reliably the resonance frequencies of the tract from the sound alone using either spectral analysis or linear prediction' (Joliveau *et al.*, 2004: 2434).

A number of methods have been employed to attempt to track the resonance frequencies of the vocal tract in females, including combining voice synthesis techniques with data obtained from live singers by placing an external vibrator against the neck of the subject whilst the subject silently produced vowels after first establishing the position of the sound modifiers through phonation (see Sundberg, 1987: 126; Barnes *et al.*, 2004). Johansson *et al.* used x-ray studies to investigate formant frequencies in two females (Johansson at al., 1982) whilst Joliveau *et al.* used broad band acoustic excitation at the mouth (Joliveau et al, 2004) and Miller used vocal fry to calculate formant frequencies (Miller *et al.*, 1997). Findings of all these studies support the theory of formant tuning in soprano voices.

6.2.1 Physiological Implications

It was mentioned in chapter 3 that the lowered larynx is thought to be the main factor contributing to the production of the energy in the region of the singer's formant cluster. Extensive investigation into the singer's formant cluster has produced theories as to its production based on acoustic findings. Sundberg explains that as a result of combining the acoustic features of the singer's formant cluster with models of the vocal tract it can be deduced that 'the larynx tube seems to be an important tool for obtaining the clustering of the higher formant frequencies needed for generating a singer's formant' (Sundberg, 1987: 121). However, Sundberg also explains that 'the individual shape of the pharynx and larynx may very well be such that there is no need for lowering the larynx in order to obtain a singer's formant' (Sundberg, 1987: 121). Drawing on previous research, Sundberg did signify that for the clustering of the third fourth and fifth formants it is essential 'that the pharynx be lengthened and the cross-sectional area in the pharynx at the level of the larynx tube opening be more than six times the area of that opening' (Sundberg, 1987: 121). Although, in females, due to the dissimilarities between their characteristic spectral peaks in the singer's formant region compared with the clustering identified in the singer's formant for male singers, different articulatory strategies may be employed.

A main physiological explanation for formant tuning which was explained above is connected to movements of the jaw (Sundberg, 1975; Sundberg, 1987: 128; Sundberg *et al.*, 1997; Sundberg, 2003; Joliveau *et al.*, 2004; Barnes *et al.*, 2004). Sundberg *et al.* conducted an experiment which measured jaw opening in sopranos using magnetometer equipment (Sundberg *et al.*, 1996) and found that when the fundamental frequency approached the first formant the singers consistently widened their jaw opening for the vowels /a/ and /a/. However, for vowels with low first formant values, such as /u/ or /i/, subjects only increase their jaw opening in the upper part of their ranges (Sundberg *et* *al.*, 1996: 304). This was attributed to other articulatory factors, particularly the sensitivity of vowels /i/ and /u/ to tongue constriction, in that reducing tongue constriction on these vowels will alter the frequency of the first formant. This strategy would not be employed on the /a/ and /a/ vowels because reducing tongue constriction on these vowels would have the undesired effect of lowering the first formant (Fant, 1960; Sundberg *et al.*, 1996: 305).

6.2.2 Historical Theories

There are a number of theories within current literature which consider historical vocal techniques in relation to the modern understanding of various acoustic devices. In terms of features such as the production of spectral characteristics of a singer's formant cluster, theories are formed through a de-construction of modern techniques based upon the current understandings of the scientific principles of voice production. As already mentioned, these findings are considered alongside current understandings of historical performing practices and primary source descriptions of voices in the past. Specifically concerning the singer's formant cluster, theories of its production in vocal techniques of the past are heavily connected to theories of larynx positions and particularly the well documented change in technique in the 1830s which is heavily associated with the teacher, singer and voice scientist Manuel Garcia.

Garcia and the theories concerning the new vocal techniques thought to have been employed in the early nineteenth century surrounding his treatise were discussed in detail in chapter 4. It is the implications of the supposed changes in the physiology of vocal technique that occurred as a result that provide suggestions of singer's formant cluster content in early voices. Working on the premise that the main physiological trait of the singer's formant cluster is the lowering of the larynx, and presuming that the use of a lowered larynx is the product of nineteenth century vocal techniques, theorists such as John Potter have concluded that the singer' formant would not have been a prominent feature of early singing (Potter 1998: 52-55; Uberti, 1981). The proposed characteristic 'loudness' of singing in the Renaissance as purported by Uberti could also be interpreted as evidence of the absence of a singer's formant cluster in early singing. This presumes that such acoustic factors affect the perceived loudness of the voice and therefore apply to discussions of loudness as a common identifiable descriptor in historical literature.

The absence of a singer's formant cluster in historical vocal techniques is also largely supported by the current acoustic theories surrounding the phenomenon combined with current understanding of historical performing practices, referring specifically to the performing environment of the singers, 'the singing techniques appear to reflect the acoustical working environment of the singer plus the importance of hearing his voice in the environment' (Sundberg, 1987: 124).

As the singer's formant cluster is highlighted as a feature which promotes a singer's audibility when competing with large orchestral forces, it would presumably be absent in singing before such orchestral forces became common to musical performances, especially in the Renaissance when instrumental accompaniment often took the form of a guitar or lute. When explaining the singer's formant cluster in current opera singing Sundberg asserts such a theory,

> We would not expect to meet the same technique in singing accompanied by other types of sounds; the vowels of a person singing with lute or guitar accompaniment no doubt sound more like those in normal speech than like those of opera singers.
>
> Sundberg, 1987: 124

6.2.3 Speculation on Current Fashions

If current theories of performance practice are being upheld by today's early music singers, or if their vocal objectives reflect current academic opinions of historical vocal techniques, in terms of spectral energy, it would be expected that they would display less energy in the region of the singer's formant cluster compared to opera singers. The spectral energy would be more likely to reflect that of speech, rather than producing a consistent timbre or singer's formant cluster characteristics which promote vocal projection throughout their voice.

Consideration of the origins of the singers in terms of their vocal training and backgrounds also has implications for the expected spectral content of their sound. Considering comments quoted in chapter 5 which refer to choral sounds popular in England as, for example, the 'Cambridge coo', would presumably be observable in the spectrum, particularly effecting the perceived timbre of the voice which was discussed in the previous chapter. The choral background and individual training of singers is therefore expected to be observable in their spectral content.

An experiment carried out by Howard case studied quantifiable aspects of vocal technique in a tenor singer performing in a modern operatic, modern early and Elizabthan style. The results for this study in terms of closed quotient were discussed in chapter 3. Another parameter analysed was the singer's formant cluster. According to current theory it would be predicted that the singer would produce stronger singer's formant characteristics in the operatic style of singing rather than either of the other styles. However, the findings showed 'a noticeable increase in energy in the frequency region between approximately 2.5kHz and 3.5kHz in all the singing examples compared to speech' (Howard, 1992: 53), although he did note that it 'is perhaps more dominant throughout the sung fragment for the operatic version' (Howard, 1992: 53). The absence of any significant difference in singer's formant cluster production in these results could be attributable to a number of factors. Howard identifies one such factor after explaining the unexpected presence of a singer's formant cluster in the styles which would involve the smaller accompanying forces of lute, guitar *etc*, 'after singing training, in which the development of a singer's formant plays a major part, it appears that John is not able to unlearn the technique for use when singing early music: indeed, this may not even be possible' (Howard, 1992: 54). If this is the case the background of the subjects in this study could be highly significant. It also suggests that the singers specialising in early music may produce more spectral energy in the singer's formant region than the historical theorists suggest would be appropriate due to the overriding conventional methods of 'classical singing'.

6.3 Experimental Findings

The following section outlines the results of the study that have implications for the perceived loudness and projection strategies of the singers case-studied. Significant similarities and differences between the two groups will be noted alongside the consideration of the historical theories of voice production presented above and the effects of the performance background of the singers.

6.3.1 Intensity

There were no significant differences observed between the overall intensity of the tasks between the two groups that were case studied. Figures 46 and 47 show the average intensity and maximum intensity of the Puccini and Handel extracts respectively. Although subject 1 from the early music group employs the lowest intensities and subject 5 from the opera group the highest intensity, there are only slight differences between the other subjects, and no general differences between the two groups. Considering the theories presented above, that early music singers do not have an environmental need to sing as loudly as opera singers, and that their perceived loudness would be less, these intensity results imply that the opera singers are using other resonance strategies to achieve a higher perceived loudness.

Figure 46 Average intensity of the Puccini extract sung by all subjects

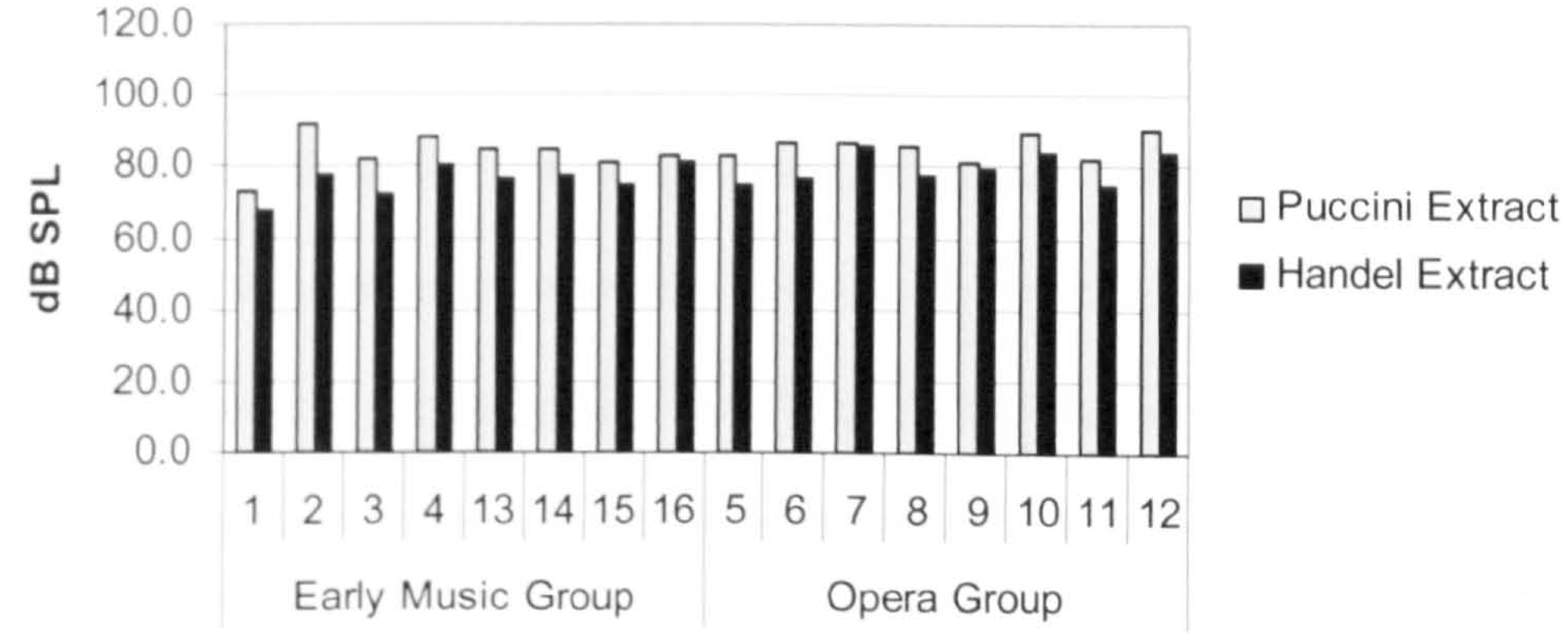
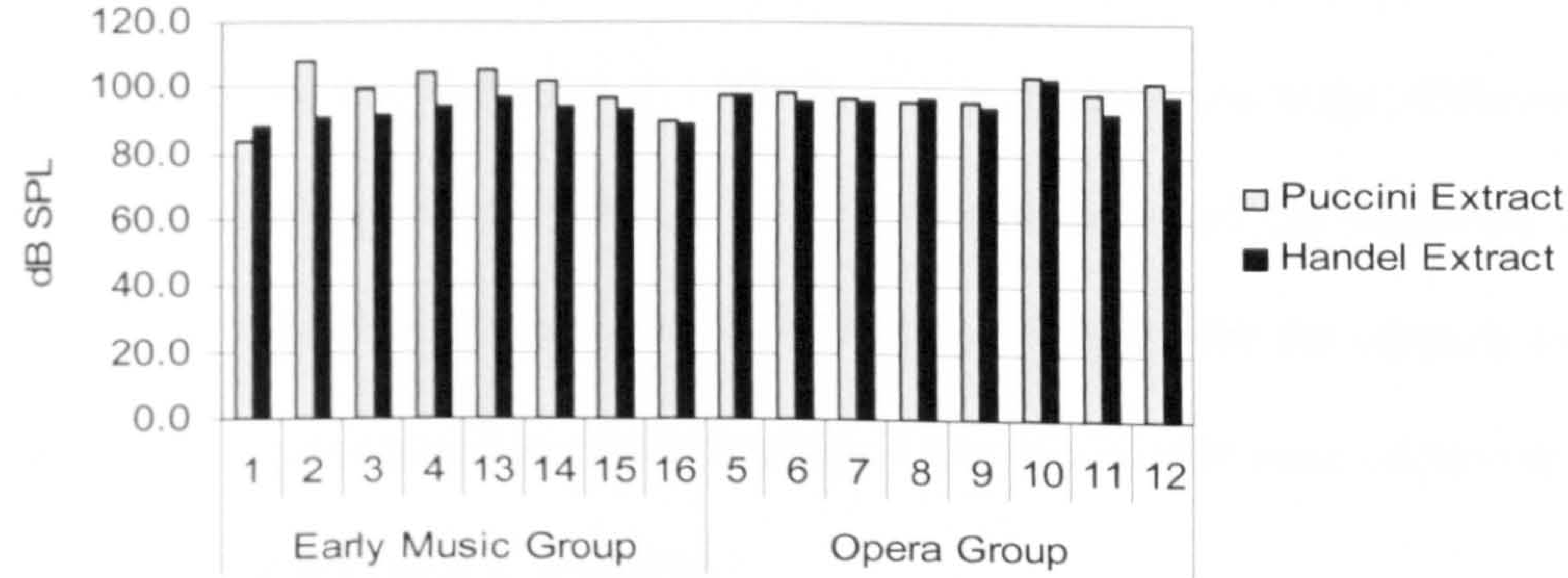


Figure 47 Maximum intensity reading in the Puccini and Handel extracts by all subjects



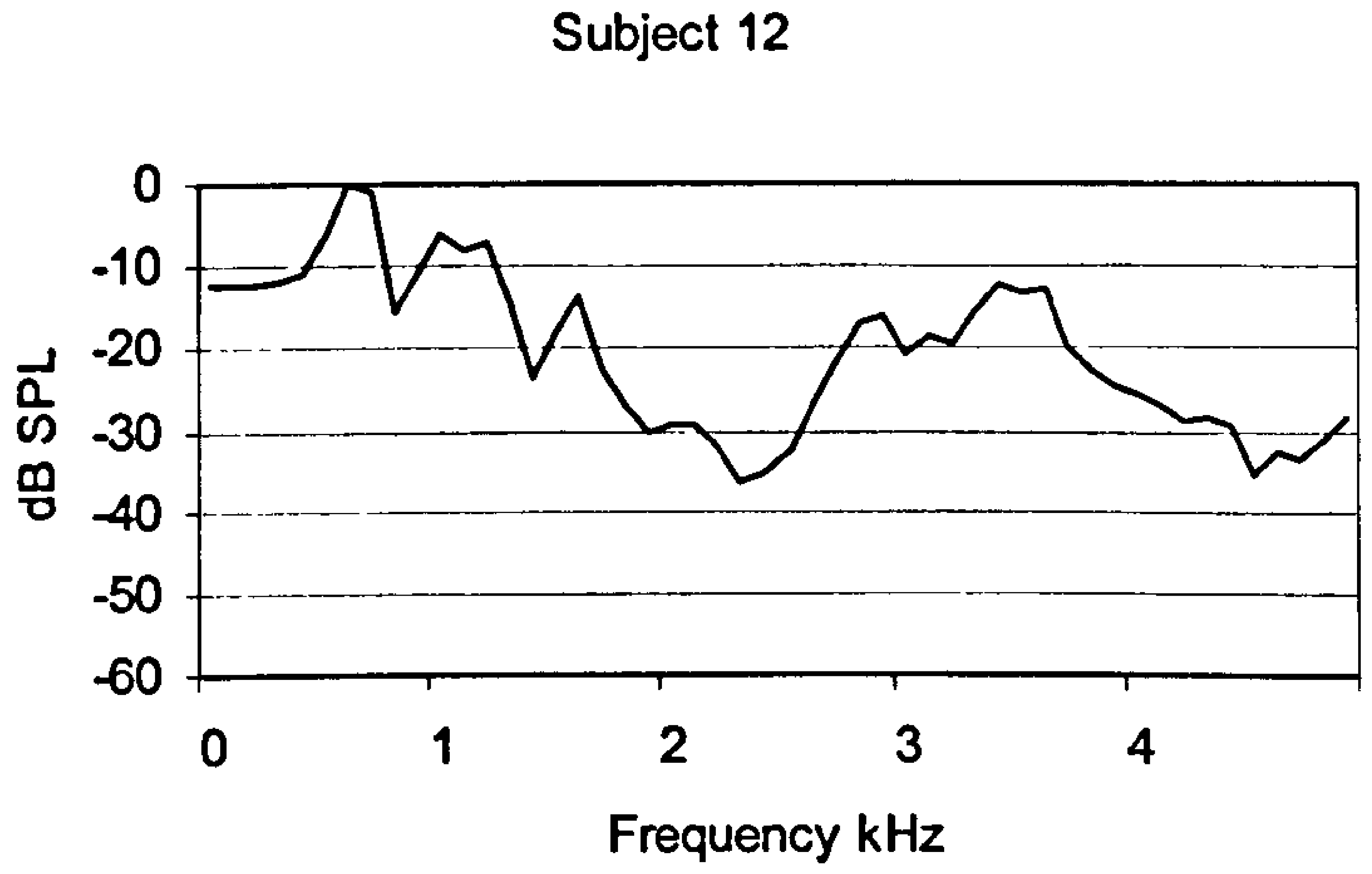
Lower average intensities were measured for all the singers in the early music group, apart from subject 1, in the Handel extract compared to the Puccini extract, whereas the results for the subjects in the opera group show very few differences between the songs. Consideration of the tessitura of the two songs needs to be noted for the comparison as the Puccini is higher than the Handel. However, the differences between the two groups could be representative of stylistic objectives of performance, as the early music singers could be consciously aiming to achieve a 'louder' sound when singing the extract of 'grand opera'.

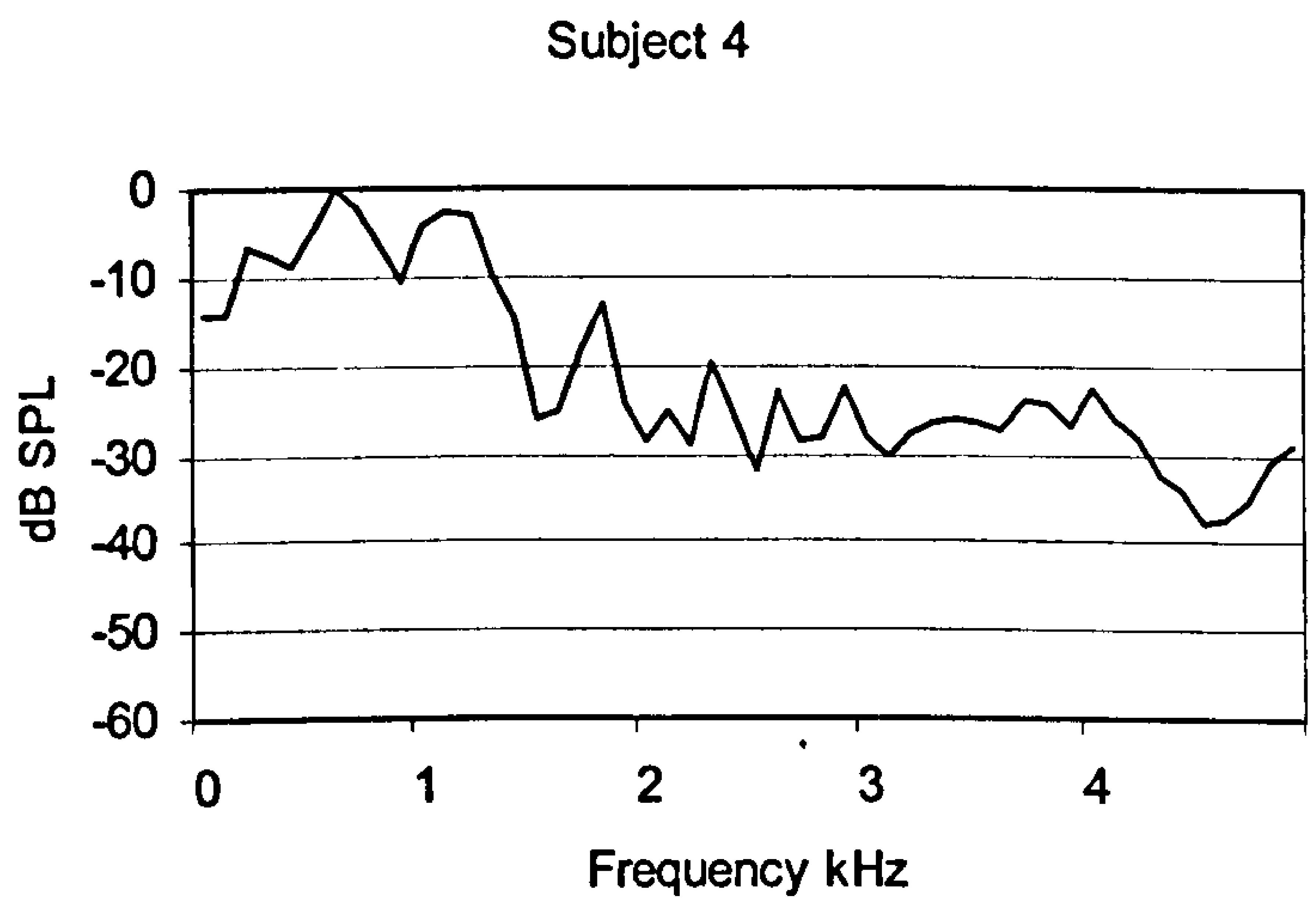
6.3.2 Singer's Formant Cluster Region

Although the presence of the singer's formant cluster in female opera singing is less prominent than in males, the energy in the frequency region of 2kHz – 4 kHz has been identified as an important frequency region in aiding projection in female opera singing and so was isolated for analysis in this study. As the Handel extract was over 20 seconds long for all subjects, this task was selected for LTAS analysis following the guidelines of Sundberg that between 20 and 30 seconds provides a stable representation curve (Sundberg, 2001; 181). LTAS graphs for each subject were shown in figure 21 in chapter 2. As chapter 2 explained, there were noticeable peaks in the LTAS curves of most subjects in the region of 2 – 4kHz, although there are large differences in the nature of this curve between subjects in terms of both the level and frequency bandwidth of the peak. A high but broad peak is commonly observed for the subjects in the opera group, with an indeterminate centre frequency due to a double peak occurring within the overall curve in the spectral envelope.

Figure 48 shows the LTAS of subject 12, who presented with the most notable double peak of all the subjects. This feature of LTAS in sopranos was previously identified by Sundberg who suggests that 'the divided peak in the LTAS for the sopranos probably reflects the averages of normal, that is, non-clustered F3 and F4' (Sundberg, 2001: 185). The subjects in the early music group presented with a larger variability in their LTAS curves. There is no significant peak evident in the LTAS of subjects 2 or 4 although their energy remains relatively high, whilst the peak in this region for subject 14 is more typical of the LTAS shapes from the opera group.

Figure 48 LTAS of subjects 12 from the opera group and subject 4 from the early music group singing the Handel extract





Figures 49 and 50 show the LTAS for each subject in the opera group and early music group respectively with the mean for each group plotted on the relevant graph. The mean curves of the two groups are presented in figure 51 and demonstrate that overall the peaks in the spectral envelope are similar between the two groups. The results for the mean LTAS of these subjects are similar to the LTAS results obtained by Sundberg for sopranos, the peak of which was just above -20dB (Sundberg, 2001:183). A difference which can be observed between the groups by the mean LTAS curves is the broader peak in the singer's formant region utilised by the singers from the opera group. The curve of the LTAS for the early music group falls steeply at around 3500Hz creating a further step in the envelope at around 4000Hz, whereas the high energy remains in the opera group until 3800Hz, removing the effect of the step. It is possible that this is reflective of an articulatory difference between the two groups such as the movement of a formant in the opera group to maintain the higher energy across the upper frequencies. It is clear from analysis of the individual subjects that a mean LTAS of the groups does not provide an ideal evaluation in terms of providing a detailed or finite differentiation between the singers, particularly considering the small sample size. Whilst it does provide a useful overall comparison, generalisations should be made with care.

Figure 49 Graph showing LTAS plots of each subject in the opera group with the mean of the subjects shown in bold

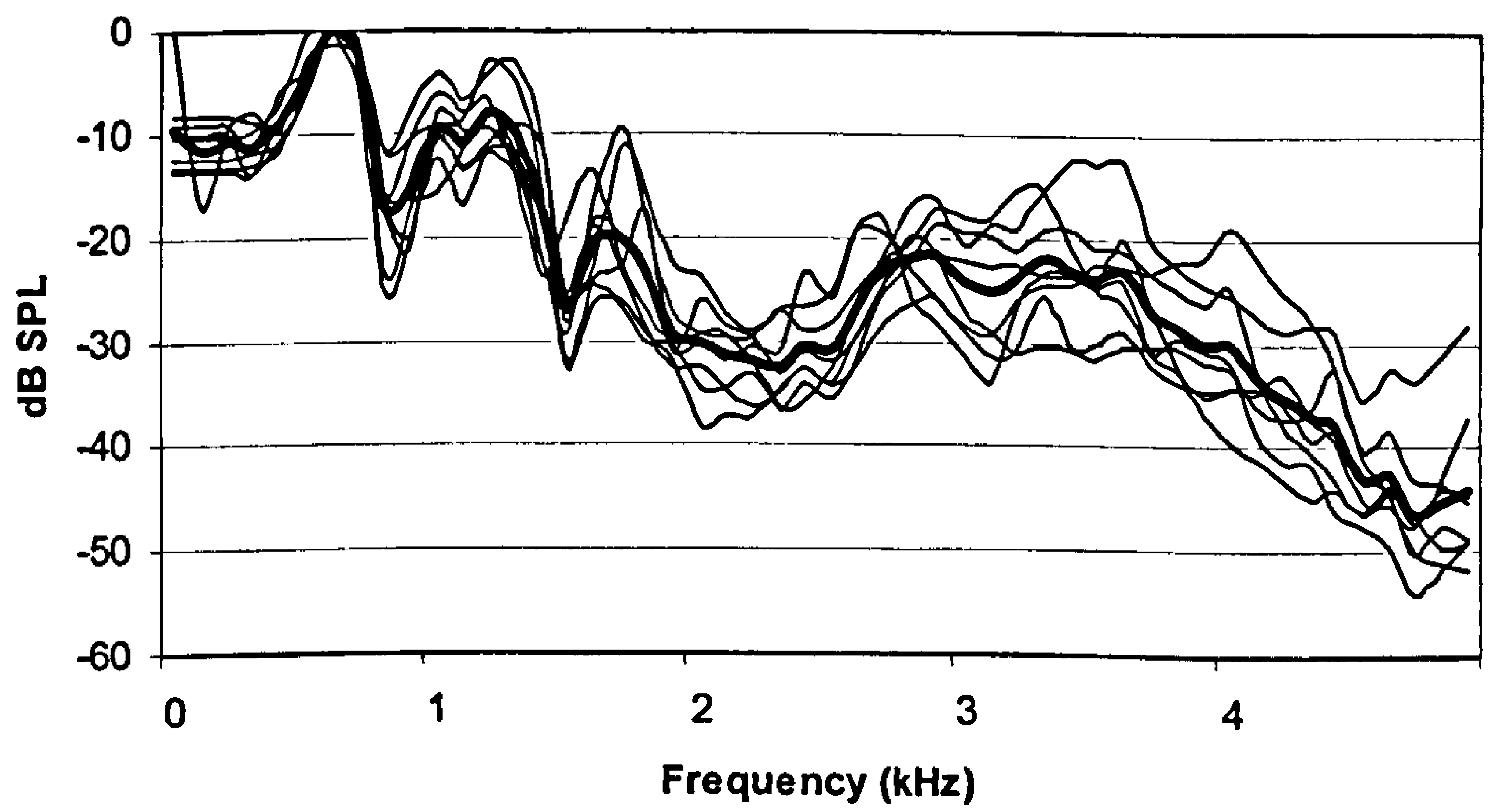


Figure 50 Graph showing LTAS plots of each subject in the early music group with the mean of the subjects shown in bold

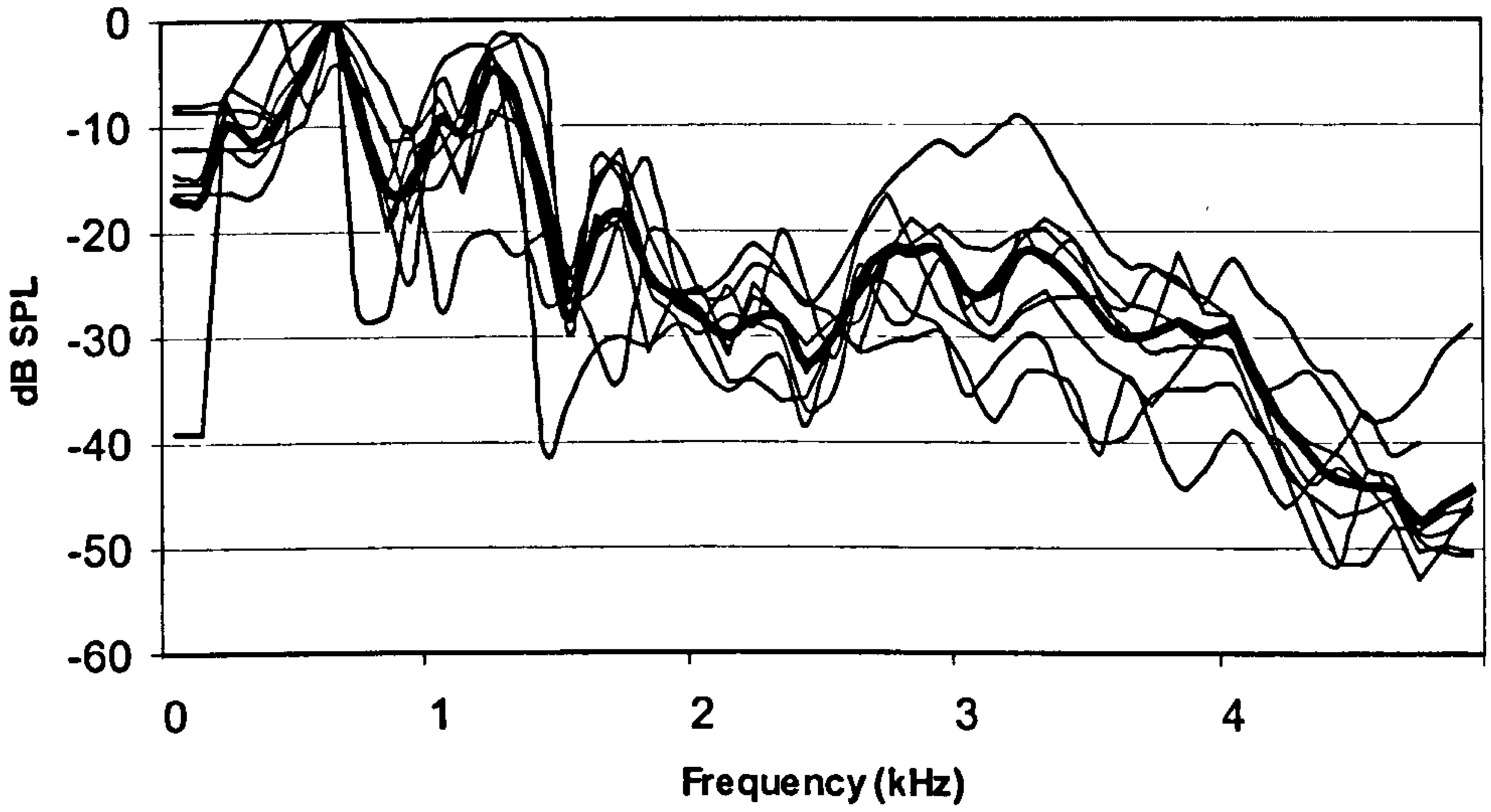
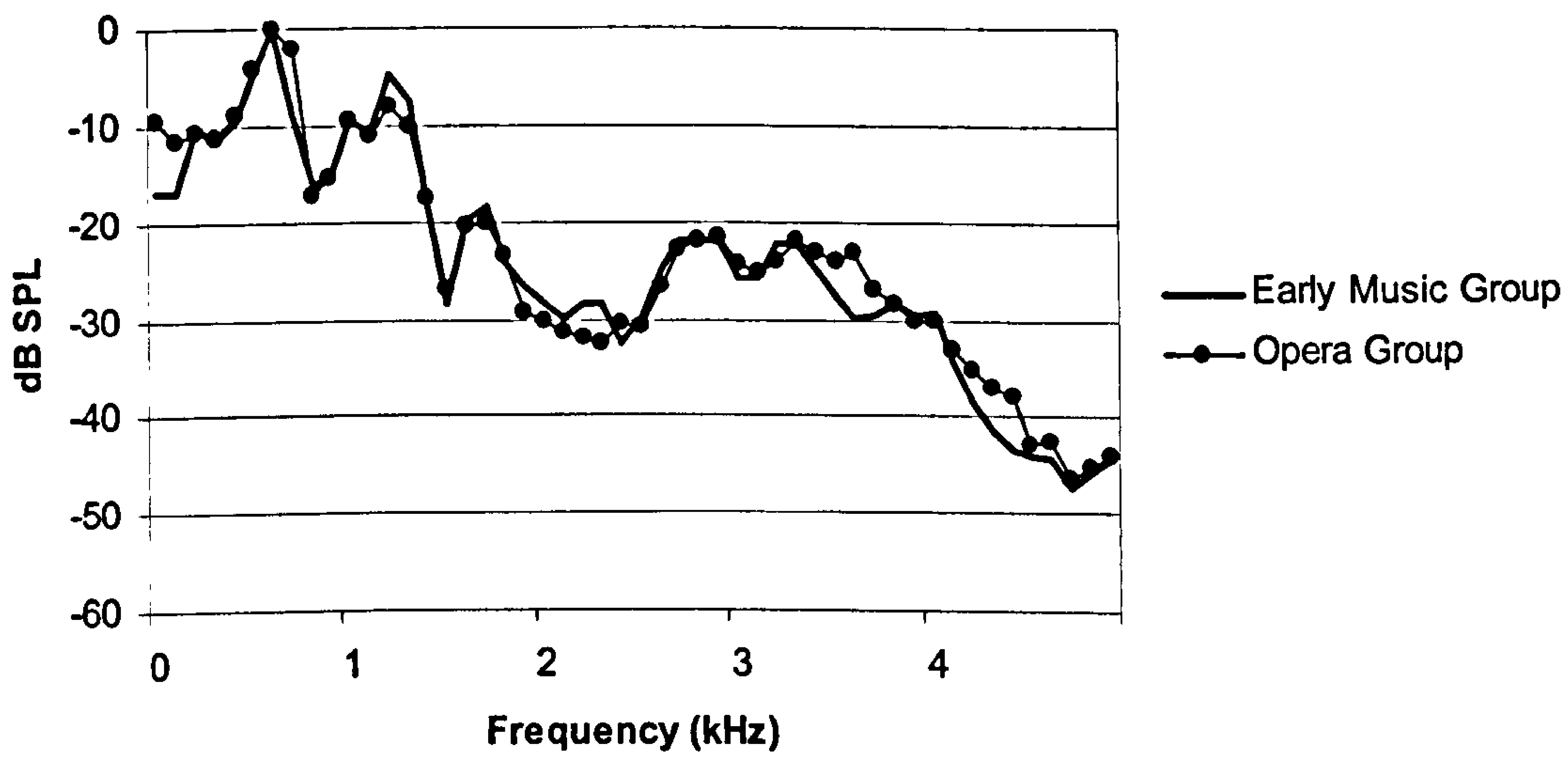


Figure 51 Mean LTAS curves of both groups singing the Handel extract



In order to assess the significance of the observed peaks, the Energy Ratio (EnR) and Singing Power Ratio (SPR) were calculated using the methods described in chapter 2 taken from Thorpe *et al.* (2001) and Omori (1996) respectively. The results for both EnR and SPR were shown in table 5 in chapter 2 and are presented as a graph in figure 52. A large variance is observed between singers, ranging from between 12 to 27 and between 13dB to 31dB respectively. The lowest EnR and SPR, which represent the highest energy in the 2kHz – 4kHz region were observed for subject number 14 from the early music group. This result is contrary to the expectation that opera singers would display higher energy levels in the 2kHz – 4kHz frequency band than early music singers and so have lower EnR and SPR values. However, the training and background of the subject could account for the noticeably lower values than the other singers. English was not the native language of Subject 14 who was trained in a conservatoire in Greece, and unlike all the other early music singers she had not been exposed to English choral training. The general trend for the SPR and EnR results for the opera group being lower than the early music group supports this theory. The largest SPR value was observed for Subject 7 in the opera group which is also unexpected, however, the EnR result is much lower at 24dB suggesting that the energy in the upper frequency region is more significant than the SPR suggests, being spread across frequencies rather than creating a high narrow peak as the LTAS for the subject illustrates.

A mean of the EnR and SPR calculations was taken of all the subjects in each group, and shows a small difference between the groups. As hypothesized the opera group have a lower EnR and SPR mean than the early music group, although the difference is much smaller than expected, being just 3dB and 1dB respectively. Figure 53 shows the EnR and SPR results of each of the subjects, illustrating the spread of results, and showing that taking a mean of each group is not necessarily representative of the individuals, particularly when such a small sample size is being averaged.

Figure 52 Mean EnR and SPR values for the early music group and the opera group

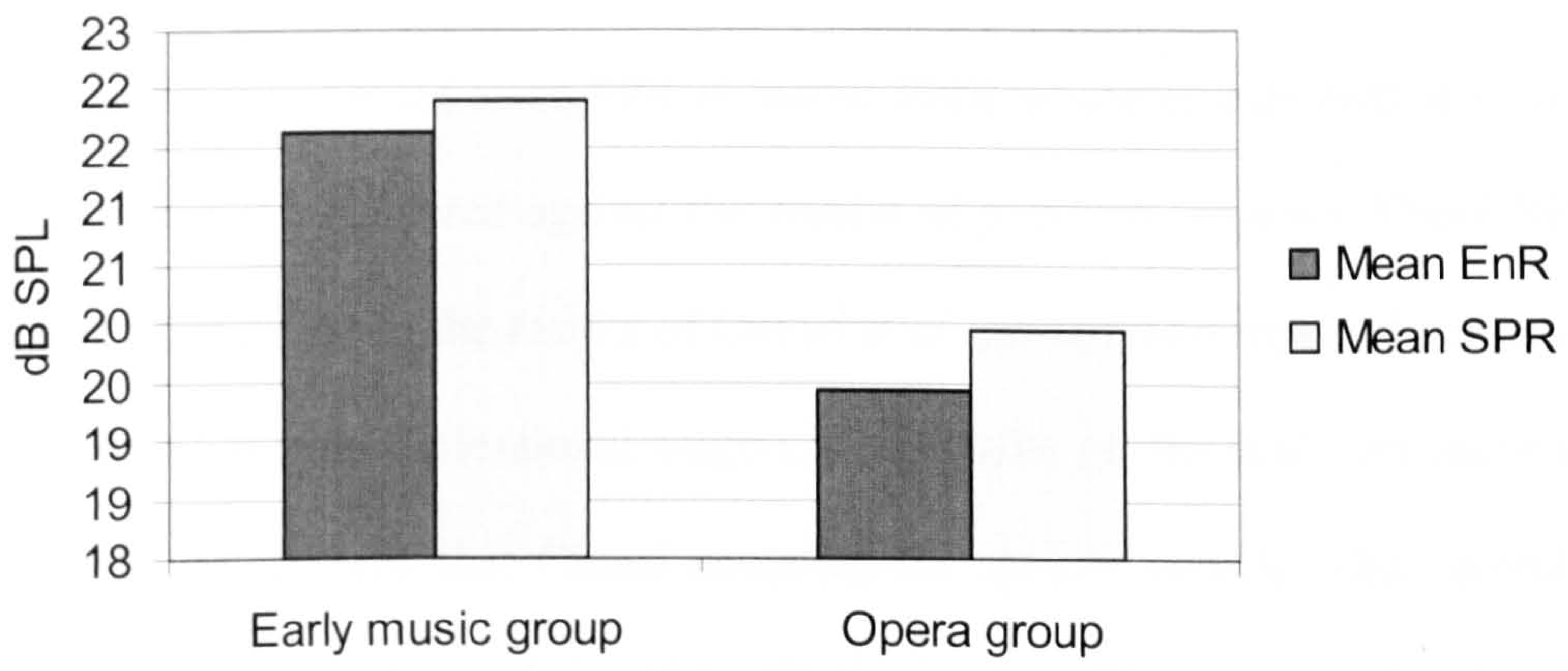
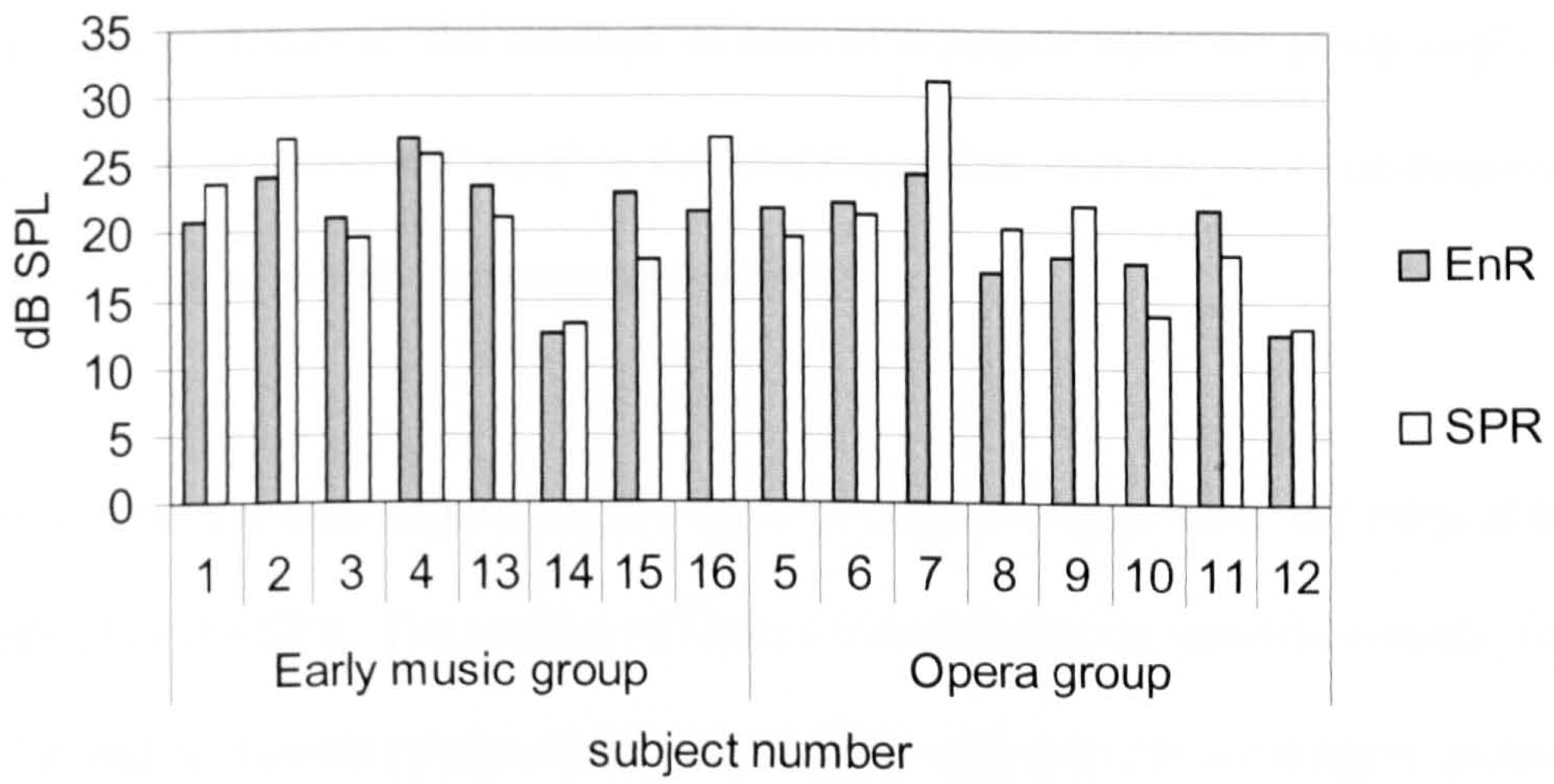


Figure 53 EnR and SPR values for all subjects in the Handel extract



Based on the findings of Barnes et al (2004), Bloothooft and Plomp (1986) and Sundberg (2001) an SPR value lower than 20dB is representative of high frequency energy which can be considered significant and therefore be classed as containing singer's formant cluster characteristics. Eight of the sixteen singers used in this study had SPR values of 20dB or lower, 3 in the early music group and 5 in the opera group. This is again unexpected as an SPR of below 20dB would be expected at least in all the opera singers if considered against the results of previous research. These SPR results are also incongruent to the results of Omori *et al.* (1996) who reported a mean SPR of -14 across 13 female professional singers. The results of this study are more similar to the results of -20.6dB that Omori observed for spoken vowels. The current findings reflect more closely those observed by Watts *et al.* (2005) who calculated a mean SPR of 22.6dBSPL across 12 female singers identified by external judges as 'talented'. Results of all these studies agreed that the lower the SPR the greater the perceived 'ring' in the voice. However, the absence of low SPR results does not alone imply that there will be a lesser perceived 'ring' to the sound as other strategies may be employed by the singers, some of which are suggested below.

A reason for the discontinuity of the results could be attributed to the method being used to calculate the SPR. The studies of Omori concentrated on specific vowels, finding that the /a/ and /u/ vowels produced the lowest SPR values in trained singers, presuming that other stratagems are used by singers for /i/ vowels, such as movements of the tongue and jaw to facilitate formant tuning. The SPR for this study was calculated from the spectrum of the entire song extract rather than for specific vowels, and therefore would expect to be affected by the overall vowel content of the piece as the relative formant positions will affect the SPR. The large range of fundamental frequencies in the song extract could also have an effect on the SPR, although Omori found that 'SPR had no significant correlation to fundamental frequency' (Omori *et al.*, 1996: 234).

The overall loudness has been shown to affect the steepness of the slope of the LTAS and therefore the SPR and EnR values and the apparent singer's formant content in the spectrum (Bloothooft and Plomp 1986; White and Sundberg, 2000). Consideration of the overall intensity of the Handel song task against the EnR and SPR values is therefore an important comparison with further implications for the vocal techniques of the singers. The average intensities of the song tasks were found to be similar between most subjects, usually between 70dB – 80dB SPL. It has been put forward by Sundberg and Bloothooft and Plomp that in male singers an increase in overall SPL of 10dB will yield a 16dB increase in the frequency region of the singers' formant (Bloothooft and Plomp, 1986).

As no established parameters are currently available for the calibration of spectral slope in soprano singing, only speculation on the effects of overall intensity based on the research findings that are available is possible. Calibration calculations were therefore based on the research using male voices discussed above, using the formula: *calibrated SPR = SPR – 1.6D*, where D equals the increase in overall intensity. The highest overall intensity was observed in subject 10 in the opera group, who also displayed the lowest value of SPR and EnR. This supports the theory of a decrease in spectral slope with increased intensity. The overall intensity for Subject 11 was approximately 10dB less than subject 10 at 75.4dB. Using the values which have been accepted for male singing, an increase of in the region of 10dB could lower the SPR by 16dB. For comparison between subjects 10 and 11, therefore, the SPR for subject 11 could be reduced to 2dB which is lower than subject 10 at 14dB. The other subjects in the opera group yield very similar overall SPL values, and the comparative effect on the spectral slope would be relatively small. Considering this possible process of calibration for the LTAS results, although using an untested method with approximate figures obtained from research into male voices, it shows that because the overall SPL levels are so similar for the opera subjects, only in one case would the calibration value effect the ranking of SPR values for the opera group.

The relationship between overall intensity and SPR results for the early music group, unlike the opera group, does change the SPR rankings of the singers revealing unexpected results. Whilst in the opera group the highest overall intensity yielded the lowest SPR result, the highest SPL value in the early music group also produces the second highest SPR reading. There is a difference of 18dB between the highest overall intensity produced by subject 4, compared to the lowest overall intensity produced by subject 1. If the calibration procedure for the slope was applied to these subjects and the overall intensity of subject 1 increased by 18dB, the SPR would be dramatically reduced to become lower than all other subjects in both groups. It also places more significance on the high SPR of subject 4, the higher level energy becoming less significant as it can be attributed, at least in part, to the overall intensity.

The lack of substantial research into the effects of loudness on spectral slope, particularly in female voices, makes any quantifiable judgment of effects of intensity on SPR highly approximate. However, it is clear that SPR values need to be assessed alongside intensity data in order make comparisons between high energy of the subjects. The heightened impact of SPR on the opera subjects with increased intensity, compared to the trend of lessened significance in the 2kHz – 4kHz spectral energy in the early music subjects with higher intensity could be suggestive of singer's formant characteristics being more prominent in opera voices than voices specialising in early music.

Although the analysis of the energy in the frequency range of 0 – 4000Hz revealed only slight differences between the early music group and the opera group in terms of singer's formant cluster characteristics, analysis of higher frequencies in the spectrum reveal more notable differences. LTAS were obtained for all the singers up to 15kHz and show that further peaks occur in the spectral envelope which could also contribute to the projection power and 'ring' of the singer's voice. Strong energy in the 8kHz – 10 kHz region has previously been identified in strong soprano voices and associated with resonance strategies (Weiss *et al.*, 2001:467). In the results of the present study this feature is most characteristic of singers in the opera group, although the frequency and amplitude as well as the number of the peaks are quite variable. The overall SPL is also likely to have an effect on this very high frequency region in terms of the effect on spectral slope which was discussed in terms of effect on singer's formant cluster above.

A higher overall SPL will presumably increase the upper frequency energy. This is reflected in the individual LTAS for subject 10 who displayed the highest overall intensity. The 5-10kHz peak for this subject is just 10dB less than the 2-4kHz peak, which is a much lower drop than most of the other subjects who also presented with lower overall SPLs. Similar to the results for the significance of 2kHz – 4kHz energy, the effect is not the same for subject 4 in the early music group, who does not present with significantly more energy in the 5-10kHz region even though this subject produced the highest overall SPL.

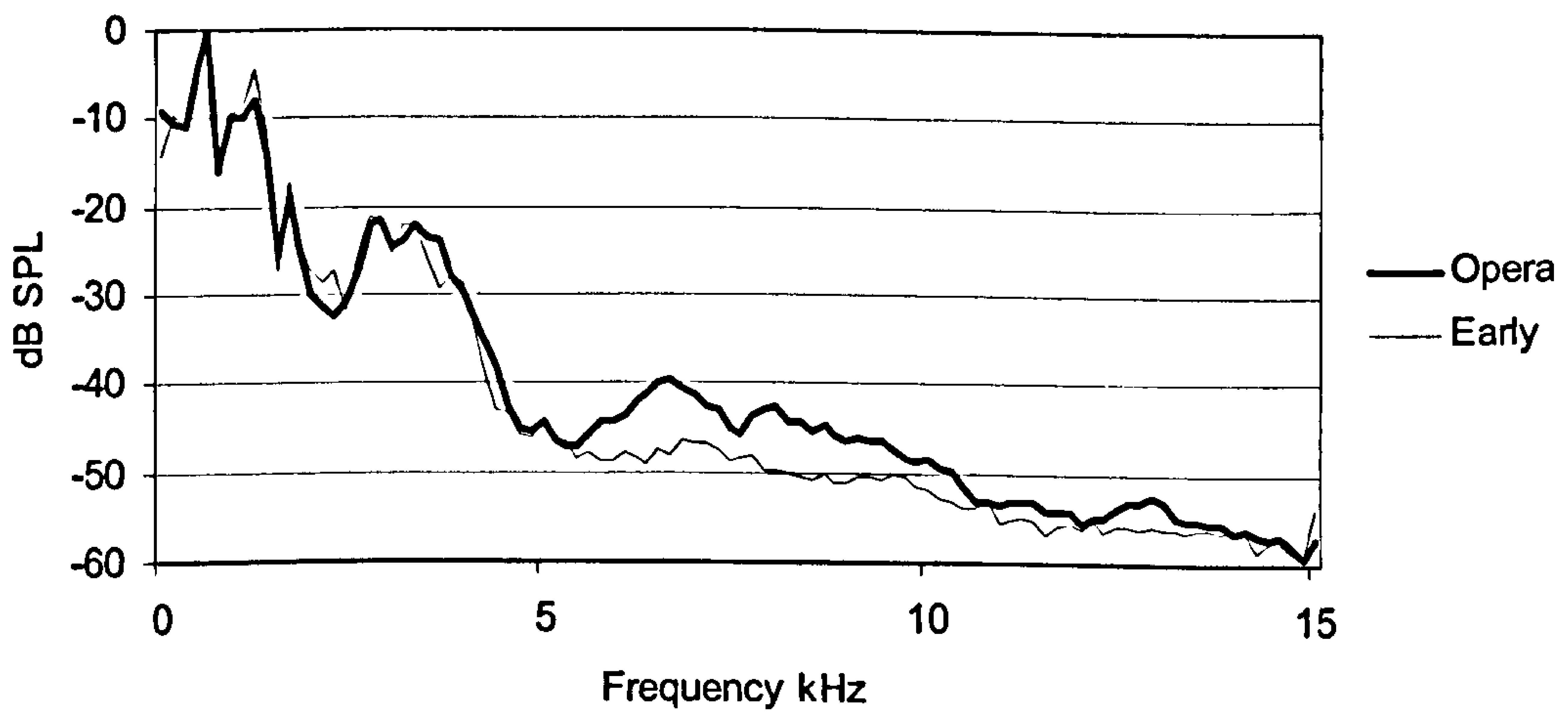
Figure 54 shows the mean LTAS up to 15kHz for the two groups of singers, and a higher energy peak is clearly observable in the frequency region of 5kHz – 10kHz with a further, less noticeable peak at around 13kHz. The increase in energy for the opera singers presents as a broad double peak with the highest energy points being at approximately 7kHz and 8kHz respectively. The higher overall mean intensity for the opera group could be a significant factor in this dissimilarity, however, the difference of 3dB between the intensity of the groups is unlikely to cause such a large difference in spectral energy. The higher energy present in the opera groups in this range can therefore be attributed to technical differences and not simply a higher overall SPL. These results suggest, for example that the singers in the opera group are using higher subglottal pressure considering the connection with subglottal pressure and sound level and the faster increase of higher partials than lower partials that it produces (White and Sundberg, 2000; Nordenberg and Sundberg, 2003).

The significance of energy in this frequency region is heightened by its relationship to the singer's formant cluster, in that the peak in the region of 5kHz – 10kHz usually occurs at around double the frequency of the peak observed between 2kHz – 4kHz, the mean frequency of the peak in the 2kHz – 4kHz region for the opera group being 3140Hz and the upper frequency peak mean 6894Hz. The data of the frequency of the lower peak corresponds with the recorded centre frequency peak observed in sopranos by Barnes *et al.* (2004: 536). The upper peak is generally broader than the 2kHz – 4 kHz peak which is to be expected considering the wider spacing of the harmonics at higher frequencies. The frequency distribution of the high frequency peaks was more dispersed for the singers in the early music group than in the opera group and so when averaged the same relationship between the frequency of the peaks in the bands 2kHz – 4kHz and 5kHz – 10kHz cannot be applied. The average frequency range for the peaks in the early music group is from 2898Hz – 6703Hz. This difference is largely due to the very high frequency observed for this peak in subject 1 of 8459Hz.

When the difference between the maximum peak in the 5kHz – 10kHz frequency range and the 2kHz – 4kHz peak are compared for all subjects the significance of energy in this region becomes an even more important factor. For the opera group the drop in dB between the two bands is either the same as or lower than the drop that was calculated between the 0 – 2kHz peak and the 2kHz – 4kHz peak (SPR), whereas for subjects in the early music group this drop was usually similar to or higher than the SPR. This is particularly noticeable in subjects 14 and 15 who presented with the lowest SPR values in the early music group, as there is a dB drop of 31dB and 28dB respectively, which shows a much steeper drop in spectral energy than for the other subjects.

This feature is not representative of singers in the opera group. Subjects 10 and 12 who had the lowest SPR values in that group had a subsequent drop of only 14dB and 10dB respectively which is similar to and, in the case of subject 12, lower than their SPR results. This could be representative of different strategies being used by the singers, in that although subjects 14 and 15 presented with lower SPR levels than expected they did not reflect the trend of high energy in the upper frequency region of 5kHz – 10kHz like the subjects in the opera group with comparable SPR values.

Figure 54 Mean LTAS curves of both groups singing the Handel extract (0-15kHz)

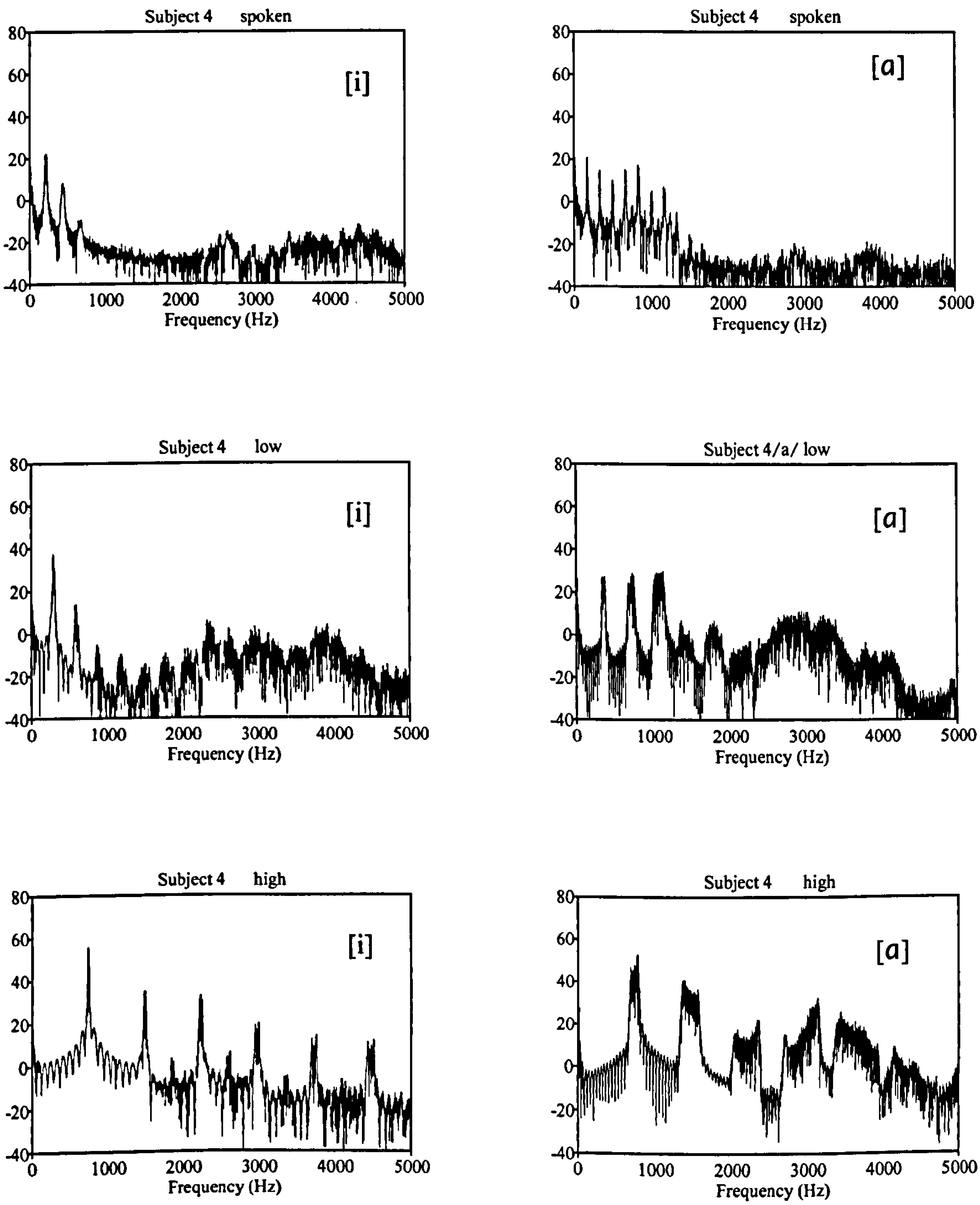


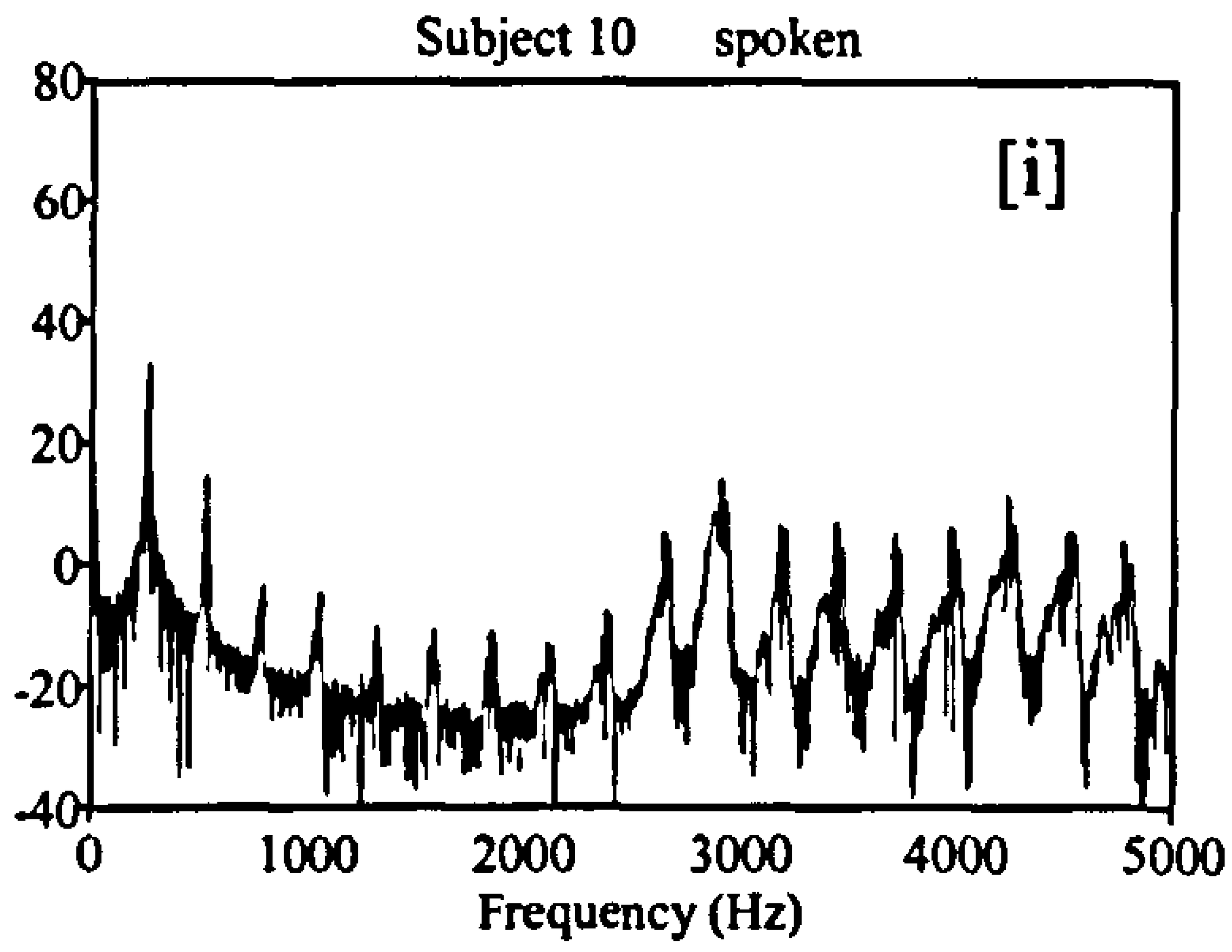
6.3.3 Other Resonance Strategies

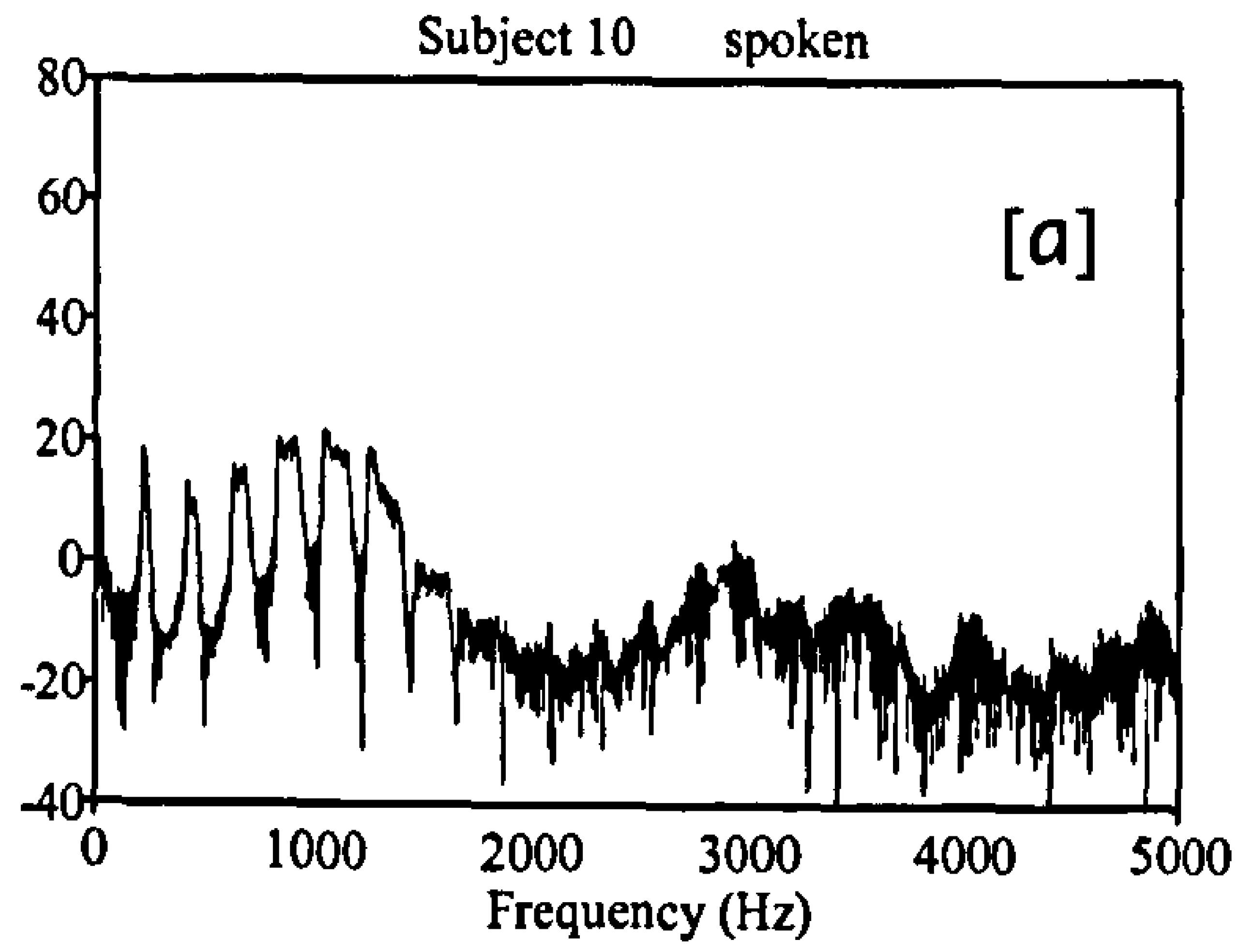
Although a clear peak can be observed in the LTAS of all subjects in the frequency region of 2kHz – 4kHz, as mentioned above, the intensity of this peak is not as high as would have been expected in trained singers to classify singer's formant characteristics. It was suggested above that this could be in part due to other resonance strategies being used on certain vowels and at certain fundamental frequencies affecting the overall envelope in the LTAS. Formant tuning is one of the main techniques which would be expected to be employed by trained female singers, particularly at high fundamental frequencies, and could effect the overall LTAS of the subjects. Without a specific methodology within this study to measure the formant frequencies, such as using an external vibrator or vocal fry as previous research has done, it is very difficult to obtain the necessary results to consider formant tuning from the data available. The frequency location of the formants is necessary in order to make assessment against the spectral energy and draw conclusions on the manipulation of the formants to amplify specific parts of the spectrum. Without this specific data any conclusions on formant tuning can only be speculative. The spectrum of certain vowels at different pitches can provide an indication of such strategies being employed by the singers, and as this is thought to be a principal projection technique in soprano singing an overall spectral envelope was considered rather than a formal formant analysis.

The two F#s (F#4 and F#5) were extracted from the arpeggio task for subjects 4 and 10 on the vowels [i] and [ɑ]. These subjects were chosen because they produced the highest overall SPL readings for their respective group. Figure 55 shows the spectrum of each vowel for these subjects when speaking and then singing the two pitches. The spectrum was taken from the steady state of the note in each case. The most obvious difference between the sung and spoken vowels for each singer is the expected increase in overall spectral energy when singing. The lower sung F# shows a more significant peak in the singer's formant region for both singers in the [ɑ] vowel rather than the [i] vowel. The high F# sung by subject 4 shows this to a greater extent as, in contrast to the [ɑ] vowel, the /i/ vowel no longer contains a peak between 2kHz – 4kHz. This is consistent with the findings of Barnes *et al.* (2001) and Bloothooft and Plomp (1984) who reported significant energy in the singer's formant region in /a/ and /u/ vowels but not in /i/ vowels, presuming that other techniques of projection are used for the latter vowel. Although this peak is also evident in the high F# of subject 10 there is a less distinct decay in the harmonics of the /i/ vowel with relatively consistent energy from 1000Hz to 3500Hz, making the difference between the vowels less dramatic for this subject. There is a noticeable increase in the level of the fundamental in the high /i/ vowel sung by subject 4 which could be characteristic of formant tuning. The high energy present in the first 5 harmonics of the high /i/ vowel by subject 4 also corresponds with the findings of Weiss et al (2001) who observed an increase in the first four or five harmonics for high-sung vowels with an absence of a singer's formant cluster (Weis *et al.*, 2001: 467). Without specific data for formant tuning any conclusions can only be speculative, however, it seems likely that a technique involving the movement of the first formant towards the fundamental in order to increase the overall SPL is being employed by the singers.

Figure 55 Spectrum graphs of subject 4 from the early music group and subject 10 in the opera group speaking and singing /i/ and [ɑ] vowels a low and high pitches




Subject 10 spoken
[i]
80
60
40
20
0
-20
-40
0
1000
2000
3000
4000
5000
Frequency (Hz)


Subject 10 spoken
[ɑ]
80
60
40
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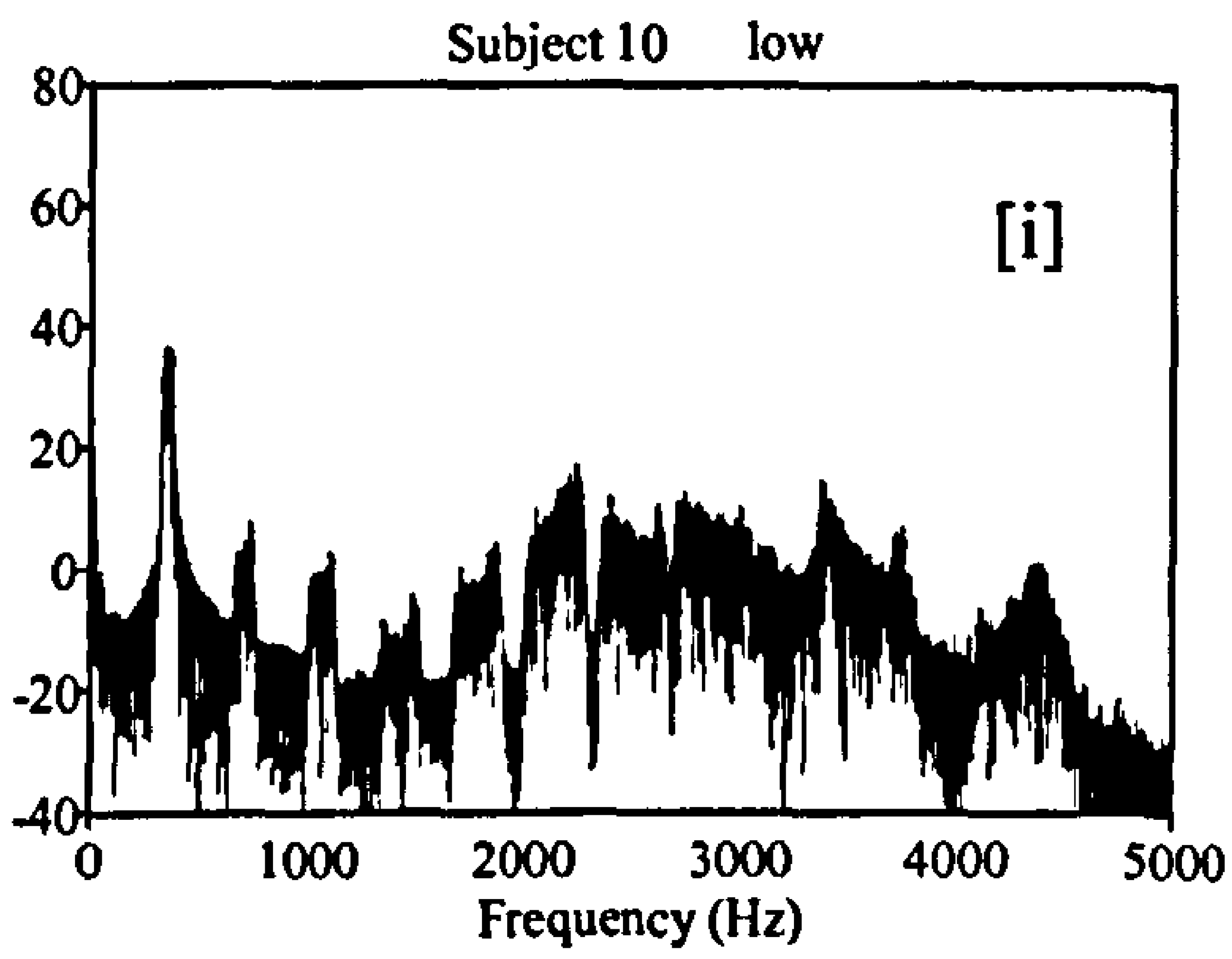
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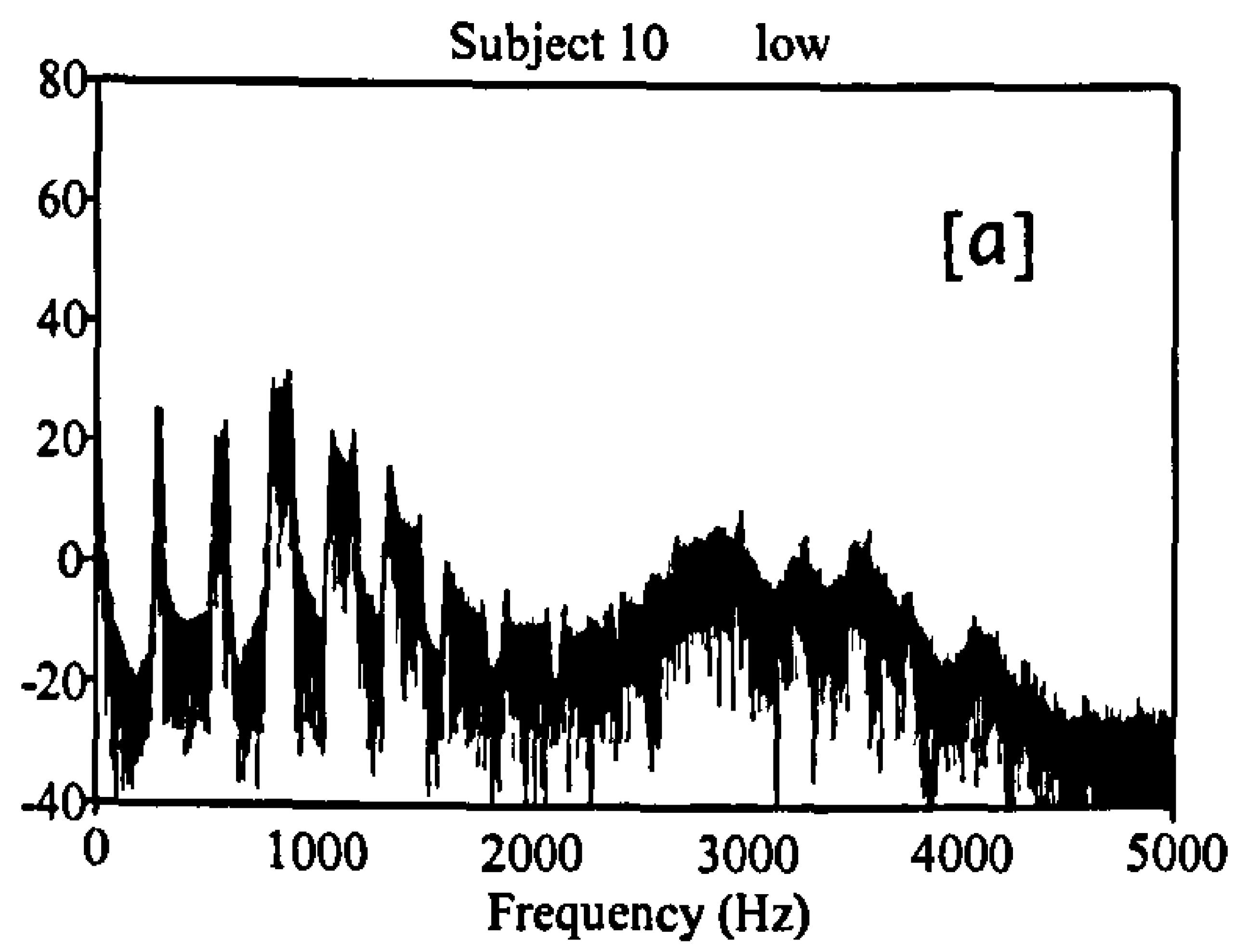
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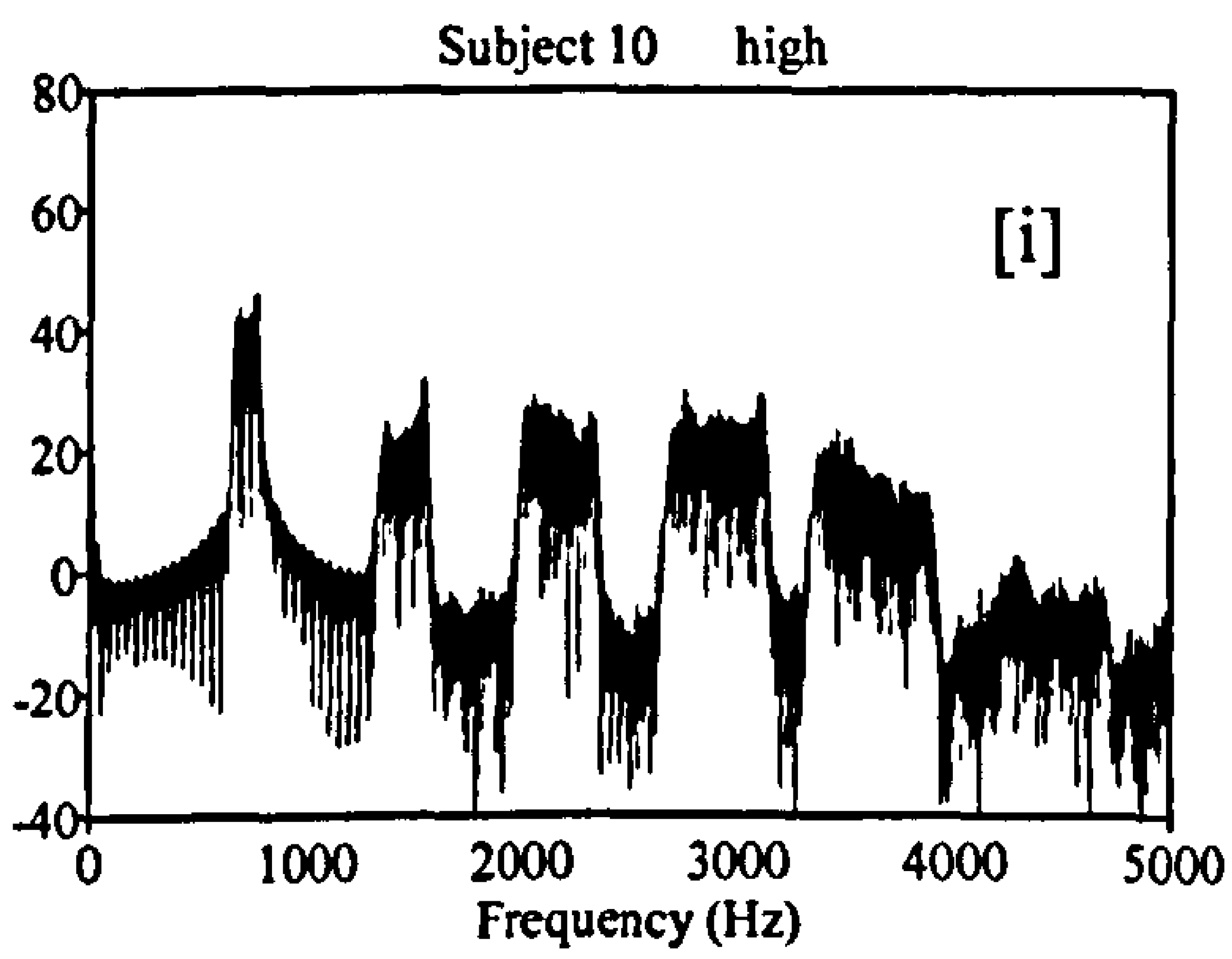
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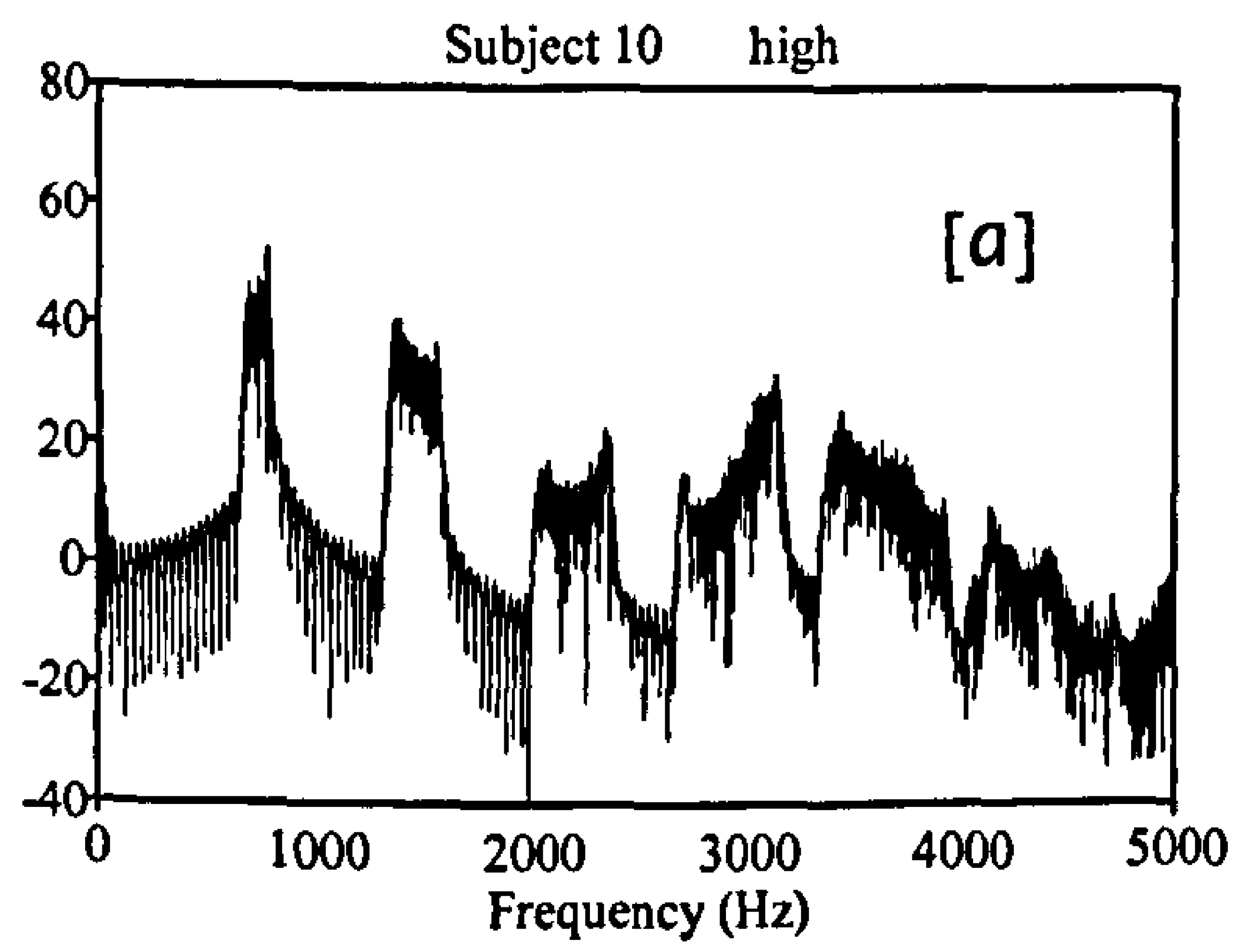
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6.3.4 Integral Use of the Singer's Formant Cluster

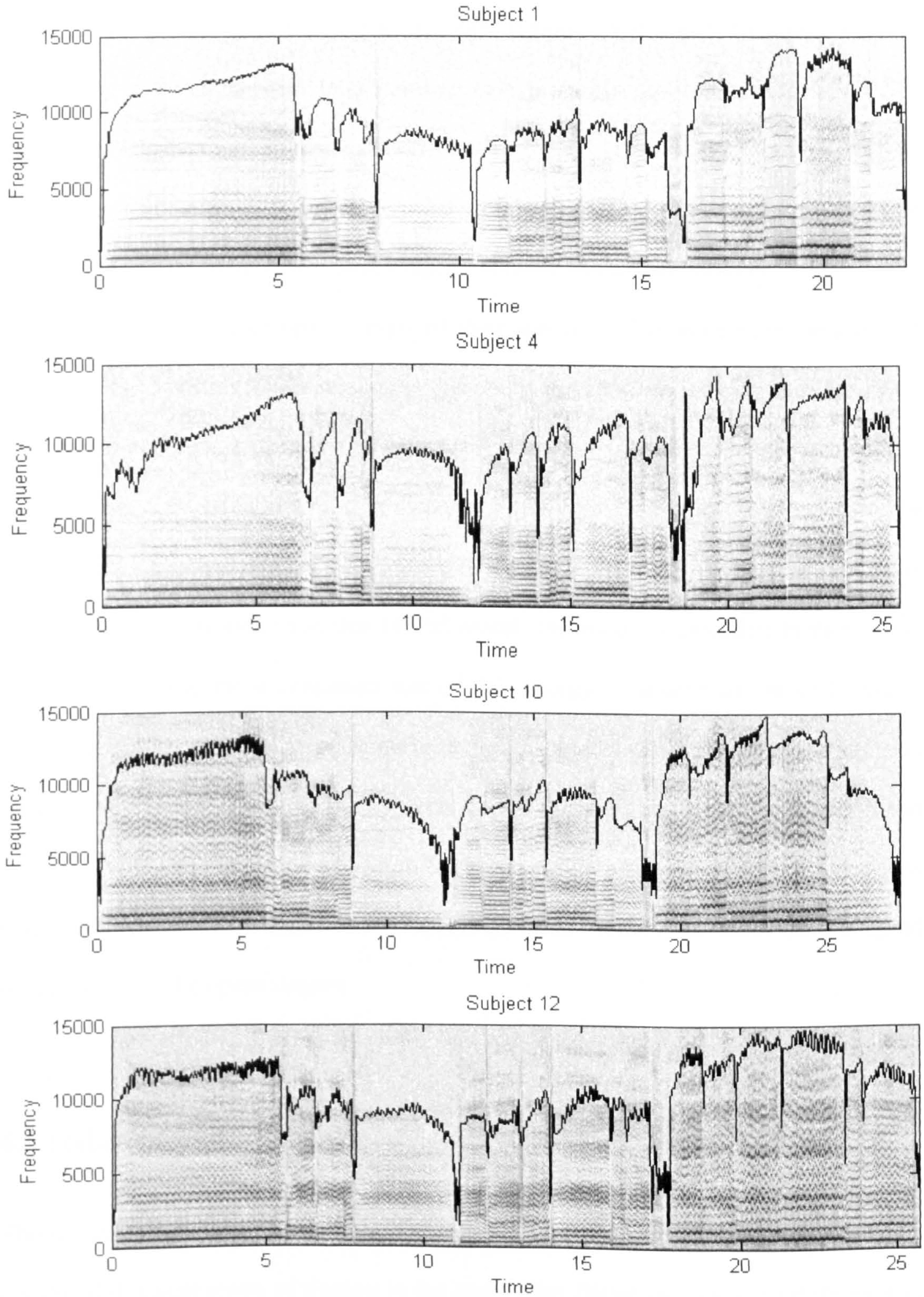
The results for energy in the singer's formant region support the data from previous research in that singer's formant cluster type characteristics were observable in all singers in the study, and all singers were 'classically' trained. However, the levels of this energy were not always found to be as high as thought necessary to be considered significant. Although there are small differences in the energy in the 2kHz – 4kHz region between the singers no significant generalisations can be formed between the two groups. This has a number of implications for the vocal techniques and objectives of the singers. It could suggest that the training received by the singers is similar, in that they are achieving similar projection methods. This implies that the singers specialising in early music use a technique with strong similarities to opera singers, and suggests that the desire for a certain 'resonant' sound is an objective of all the singers. Considering the environmental factors thought to promote the singer's formant cluster, the early music singers if performing with historical instruments and orchestral forces, do not have the same need as the opera singers to produce significant energy in this region. This implies that the inclusion of singer's formant cluster traits is the result of the current aesthetic associated with acceptable 'classical' singing, irrespective of specialty.

The notable inclusion of further peaks in the spectrum in the 5kHz – 10kHz frequency region by the opera singers suggests that certain differences in the projection techniques between the singers do exist. Although further research is needed to confirm the results of this study, it is likely that these higher peaks provide extra projection power for the singers adding further to the 'ring' in their voice. The lower energy in the upper frequency region in the early music singers is perhaps a reflection of the removed need for such extreme projection capabilities.

Although differences between the LTAS of the groups were not as significant as expected, spectrographic analysis reveals that energy within the spectrum and particularly the higher frequency energy is utilised differently by the singers over time. Figure 56 shows spectrograms up to 15kHz of the Handel extract sung by subjects 1 and 4 from the early music group and subjects 10 and 12 from the opera group. A striking difference between the subjects is the use of energy in the 5kHz – 15kHz frequency region. Although all subjects utilise energy in this frequency region, the two subjects from the opera group produce higher energy more continuously in this range, whilst the subjects from the early music group tend only to include this energy on certain notes, at high intensities. The intensity contour which is also shown in the spectrograms of figure 56 show that this high frequency energy is connected to the changing intensity throughout the note for all subjects. However, the very slight difference in mean intensity between subjects 4 and 10 compared to the quite large difference in high spectral energy observed in the spectrograms, implies that articulatory factors are affecting the energy content in addition to the effects of an increase in overall loudness. The absence of high energy in the majority of the spectrogram for subject 1, however, could be the result of the lower mean intensity for the extract compared to the other subjects.

There is also a delay observed in the inclusion of energy in the singer's formant cluster region for subjects in the early group which is not as prominent in subjects from the opera group. The second and third notes of the spectrograms of the Handel extract sung by subjects 4 and 10 illustrate this difference as the first half of each of these notes have much less energy above 2000Hz in the early music singers compared to the constant inclusion of high spectral energy throughout the notes by the opera singer. It was mentioned in chapter 3 in relation to the first note of the Handel extract, that the early music singers introduce vibrato within the note independently of spectral energy, whereas the onset of vibrato in the opera subjects is usually coupled with the production of high frequency energy. The same trend is observable in this example and could be representative of a link between the physiological traits of producing strong high frequency spectral energy and the production of vibrato. The importance of the use of spectral energy over time on the perceived timbre of the voices and potential connections between the results and performance specialty were discussed in detail in chapter 5.

Figure 56 Spectrograms of the Handel extract with Intensity contour for subjects 1 and 4 from the early music group and subjects 10 and 12 from the Opera group.



6.4 Physiological Implications

The use of high energy in the singer's formant region and at higher frequencies by all singers suggests that there are large similarities between the physiological techniques of the subjects. The overall similarities between the groups when considering the LTAS of song tasks, compared with the differences observed in the spectrograms in terms of changeable energy content over time suggests stylistic rather than intrinsic differences in technique between the groups in terms of their specialty. The more prominent use of energy in the 5kHz – 10kHz region by the opera singers does indicate that the opera singers are applying a different or enhanced technique compared to the early music singers. This is especially likely if the increased energy in this region is an extension of the acoustic and physiological significance of the singer's formant cluster. If this is the case, it could be an indication that the 'classical' technique is extended further in the opera singers. The more consistent use of this energy compared to the early music singers supports the theory of a more extreme physiological development of this technique by the opera group. The apparent connection between vibrato production and inclusion of higher frequency energy in the subjects from the opera group also implies that the early music singers are employing more variety in their physiological production than the opera singers.

6.5 Stylistic Implications

The results of this study seem also to correspond with those of Howard (1992) which compared different styles of singing in the tenor John Potter and found no difference in singer's formant cluster production. This further supports the current outcomes which suggest that the use of high frequency energy is integral to the singer's technique rather than a conscious stylistic tool. The results of Rothman *et al.* (2000) comparing historical and contemporary opera singing and Jewish cantors also support this theory as they observed peaks high frequency in both groups of female singers.

6.5.1 Environmental Suitability

The results for both intensity and projection characteristics are similar between the two groups, with all singers presenting with a large peak in the region of 2kHz – 4kHz which is expected of trained singers according to current research. When the significance of the peak was calculated by taking an SPR and EnR measurement from the Handel song task, the majority of the subjects produced values that were consistent with the parameters set to identify singer's formant cluster characteristics. However, that certain singers, particularly in the opera group did not reach the set parameter was unexpected and the data alone would therefore suggest less effective projection of these voices over an orchestra. However, considering the averaged method of analysing the data it is likely that other resonance strategies such as formant tuning and vowel averaging effected the SPR and EnR results.

The more prominent extra peak identified in the singers in the opera group between 5kHz – 10kHz could also be an additional projection technique being employed by singers. As it was observed in most subjects, further investigation is needed in this frequency region in research which attempts to quantify aspects of vocal quality. This feature could be particularly important as a possible additional strategy employed by females who are more likely to be able to utilise the energy of the harmonics at these very high frequencies than males. If this is the case, the higher energy additional peak between 5kHz – 10kHz combined with the broader peak in the 2kHz – 4kHz region observed in opera singers rather than early music singers could be representative of the environmental conditions promoting more significant projection features in opera singers.

The changing use of high frequency spectral energy over time, and particularly the delay of the use of singer's formant region energy which is observed in most of the subjects from the early music group, could be reflective of the different environmental conditions of the two groups. Whilst the absence of high frequency energy in the early group may be heard as a change in timbre throughout a note or musical phrase, use of this strategy by subjects in the opera group would restrict their audibility over an orchestra. It seems that it is therefore essential for the singers in the opera group to produce this energy consistently throughout notes, whilst, although the same basic technique characterises the early music singers, they are not required to produce this energy all the time.

Research into the acoustic differences between choral and solo singing suggested that choral singers will produce less energy in the singer's formant region than solo singers (Goodwin, 1980; Rossing *et al.*, 1984; Rossing *et al.*, 1985), although research in this area is limited with only few studies involving small subject groups having been carried out. The suggestion that singing solo music promotes use of energy in the 3kHz region has implications for this study in terms of the performance background of the subjects. All subjects involved in the study were choral singers in that they performed regularly with other singers in some capacity. However, the choral situation in which they perform is very different. The singers from the opera group perform as part of an opera chorus whilst the subjects from the early music group were performing mostly in small a cappella ensembles. The former are still therefore competing against large orchestral forces in grand concert halls rather than with the comparatively 'spacious' acoustic accompaniment of a continuo or perhaps baroque orchestra. Again the environmental implications for each group are therefore very different and are likely to have an effect on the appropriate vocal technique.

The expectation based on research into choral singing would be for the singers in the early music group to produce less energy in the 3kHz range. However, studies such as Rossing *et al.* compare solo and choral technique within the same subjects. As the subjects in this study were not asked to sing in a choral style the same comparison cannot be made. Only integral differences that may result from the regular use of a different choral technique may be present but not specifically identifiable. As only small differences were observed between the groups it can be assumed that either spectral energy in the region of 3kHz is not a factor in terms of the choral discipline they commonly sing in, or that they change their technique when performing with other singers and the current results are representative of their solo style of singing. The relatively low peaks observed in the 2kHz – 4kHz region of the LTAS for subjects 1, 4 and 15 could be indicative of their specific choral training at Oxbridge institutions, although further research is needed in this area for such theories to be confirmed.

The seemingly unnecessary inclusion of the 2kHz – 4kHz frequency peak in the LTAS of the early music singers could therefore be a reflection of the training of the singers, rather than the environmental enforcement of a technique.

6.6 Pedagogical Influences

The inclusion of significant energy in the singer's formant cluster region of the spectra of all singers case-studied is suggestive of similar techniques being employed by all singers. It seems unlikely therefore that the singers from the early music group are attempting to utilise an academic ideal of a historical vocal technique when these spectral features are considered. The training of the singers can again provide an insight into possible reasons for this acoustic feature of the singers in the early music group. It was mentioned above that the singers from the early music group presenting with quite low energy in the singer's formant cluster band were originally trained in Oxbridge choirs before becoming professional solo and ensemble singers (see table 1 in chapter 2 for the background of all participants). The singers from the early music group who tended to have similar energy as the singers from the opera group were those who had received conservatoire training after studying at undergraduate level at universities. This suggests that conservatoire training promotes a technique that increases the energy in the singer's formant region and corresponds with previous research into the effects of 'classical' training on the voice (Weiss *et al.*, 2001, Watts *et al.*, 2005).

The slight differences between the early music singers that went on to postgraduate study at music colleges and those who carried out all their training at colleges could be indicative of less time being trained in the music college discipline, or could be a refection of the different environmental or stylistic demands of the groups' performance specialty. However, as there is no specific training system established for singers intending to specialise in early music, the one-to-one tuition appears to be non-specific, the main differences in training therefore being between the choral origins of the groups. The similar findings of the comparison between historical and contemporary opera singers and Jewish cantors, which found differences between eras rather than singing style, also noting that the cantors were told to 'go out into the community and find themselves a teacher of singing' (Rothman *et al.*, 2000: 212) further implies that no specific vocal technique is expected for their singing specialty.

Lundy *et al.* (2000) found little differences in observed SPR values between singing graduates and undergraduates, observing no significant differences between the groups they tested or between the speech and singing of the vowels they used (Lundy *et al.*, 2000). Results such as these must be considered alongside the outcomes of the current study both in terms of expected differences between the two groups and in considering SPR as a reliable measure of quantifying aspects of voice quality. Other studies have shown an increase in the SPL of the 2kHz – 4 kHz frequency range with training (Mürbe *et al.*, 1999). Brown *et al.* (2000) found that the presence of singer's formant cluster energy and vibrato contributed most to the perceived differences between trained and untrained voices which is backed up by similar findings of Watts *et al.* (2005) when measuring LTAS and SPR. The inclusion of singer's formant cluster characteristics by all the subjects in this study therefore implies the perceptual reflection of their status as professional 'classical' singers. Bloothooft and Plomp also stated that 'it is likely that not for all voices is the presence of a singer's formant a necessary requirement for good voice quality' (Bloothooft and Plomp, 1986: 2032).

6.7 Summary

Although all subjects presented with high energy in the 2kHz – 4 kHz frequency region, which suggests that the singers in the early music group are not employing a vocal method indicative of current theories of historical singing practices, there are notable differences between the two groups. Particularly important is the use of energy above 4kHz in relation to lower frequency spectral energy. The reduced spectral tilt observed in the singers from the opera group suggests an extension of the 'classical' technique that is seemingly being employed by all the singers in the study. The significance of this additional feature in the spectra of the opera group, alongside the consistency in their spectral energy could reflect their environmental need to project over larger forces than the early music group.

The results of this study corresponding to the resonance strategies of the singer subjects perhaps represent the effects of the different training and backgrounds of the singers, the consequent acoustic suitability in terms of projection and the subsequent aesthetics of timbre then dictating their specialty, rather than the observed differences being reflective of different objectives of performance.

Chapter 7
Conclusions

The purpose of this study was to combine musicological theory with scientific investigations to consider modern performance conventions of 'classical singing', specifically considering the specialist performance of early music. These investigations have led to a new awareness of vocal characteristics which contribute to the performance specialism of the two genres and demonstrate the potential to advance research into performance practices through interdisciplinary means.

The various elements of vocal technique that were isolated within this study provide valuable insights into modern performance cultures, particularly those associated with early music singing. Results relating to certain areas of vocal production were of greater consequence than others to the overall study due, in part, to the considerable variability of contemporary understanding of the individual factors assessed. There are clear indications that the fundamental technique used by all singers involved in the study was similar to and based on contemporary ideals and methods of 'classical singing'. Consideration of the training of the individual singers supports this consensus. Variations that do occur between the two groups tend to reflect the current aesthetic of performance styles within their specialism. Based on the findings of current research, compared to the singers in the opera group who mostly conformed to modern expectations of western opera singing, the singers in the early music group displayed more diversity between individuals. The tendency for the singers in the early music group to present with a wider variation in their results in a number of aspects of technique is perhaps explained by the differences that exist between their singing backgrounds, as well as the environmental demands of the two performance specialisms.

A summary of the results pertaining to each parameter investigated is presented below. The importance of the results is then considered, with particular trends and relationships between factors and groups highlighted. The significance in modern performance practices is also explored in light of the overall findings and the various social / political influences of the early music revival, which were discussed in the introduction.

7.1 Summary of Findings

- Closed quotient data was similar for all subjects, with patterns connecting closed quotient and fundamental frequency emerging for most singers. There were no noticeable differences between the two groups in their closed quotient values or the trends of changing closed quotient with fundamental frequency.
- Vertical larynx position was found to increase with fundamental frequency in all subjects across a two octave ascending scale. Treatment of larynx position at mid-range fundamental frequencies altered between subjects as some lowered their larynx or maintained lower larynx positions until the upper part of the scale. These trends were not group dependent.
- The rate of vibrato employed by all singers was very similar at approximately 6 oscillations per second. Vibrato was the element displaying most variability between subjects in terms of both peak to peak extent and use of vibrato within

tones and revealed notable trends between the groups. Overall, singers in the early music group employed vibrato within fewer tones and for a smaller portion of tones than the singers in the opera group who generally produced vibrato consistently throughout most tones. The singers in the early music group also utilised a smaller vibrato extent overall and utilised a less consistent extent of vibrato throughout tones than the singers in the opera group.

- All singers utilised high energy in the frequency range 2kHz – 4kHz within most tones. The overall SPR and EnR results for the two groups suggest that differences in the relative energy of the 2kHz – 4kHz band between singers were not particularly important. However, considering the higher spectral energy and the effects of SPL on spectral slope, this resonance strategy is more pronounced in the opera group than the early music group.
- Subjects often produced a further frequency band of reinforced energy between 5kHz – 10kHz. This second band of energy was more prominent and consistent in the singers from the opera group, for whom it was usually present.
- Notable differences in the onset of spectral energy were apparent between singers with trends occurring within the groups. This was highlighted in the use of spectral energy in the first note of the Handel extract in chapter 5. The singers in the early music group tended to introduce the tone with a prominent fundamental and very little higher spectral energy, gradually introducing prominent frequency bands independent of the introduction of vibrato. Singers in the opera group showed this tendency to a lesser degree, employing both high spectral energy and vibrato much sooner within a tone.

- There was a strong connection between vibrato production and high frequency spectral energy in singers in the opera group: both elements were introduced simultaneously within a tone. In contrast, the early music singers tended to treat vibrato and spectral energy independently, introducing higher frequency energy gradually within a tone and producing vibrato as a separate musical component.
- Overall there were more variations in vocal technique in the early music group compared to the opera group.

7.2 Significance of the Results

Previous research that has produced quantifiable parameters in opera singing provided a model against which to consider the results of this study. Extensive studies have been carried out investigating projection techniques and vibrato providing reliable evidence against which the results of the current study can be compared (chapters 3 and 6). The less conclusive findings in previous research concerning larynx closed quotient and larynx positions in females make the significance of conclusions in these areas less dependable (chapters 3 and 4).

The volume and authority of previous research pertaining to the various aspects that have been quantified in this study also contribute to the significance of the findings of this experiment, particularly to how these results impact on theories of overall differences in vocal techniques between the two groups. This existing research therefore provides an authoritative base on which to compose theories of current practices.

A reduced sample size for both closed quotient and larynx height data in the current experiment reduces the authority of the conclusions drawn concerning both these factors. However, this data still provides an indication of techniques employed by singers, especially given the similarity between the results.

7.3 Intrinsic Technical Characteristics

The various tasks which were performed by the subjects were purposefully compiled to involve a variety of vocal activities, including isolated vocal exercises and musical excerpts from two different periods. These tasks were chosen in order to gain an indication of intrinsic technical aspects of the singers' techniques, as well as stylistic alterations that may be made depending upon the performance specialism of the singer. It is presumed that when performing the exercises the singers would be concentrating on their vocal production as a main objective, the scales therefore presenting results indicative of the singer's intended overall technique.

An indication of intrinsic characteristics present in a singer's technique is particularly authoritative where results associated with an aspect of technique are the same across vocal tasks. Where results differ, depending on the activity being performed, possibilities of conscious or subconscious changes in the singers' objectives must be considered, particularly in light of contemporary stylist expectations depending on the task being analysed. There are strong similarities between the two groups as a whole in terms of the results concerning most aspects of technique analysed which indicates that the method being used by most singers is inherently similar. The inclusion of resonance strategies and larynx height movements previously identified as being representative of western opera singing by all singers in the study also suggests that the main qualities of their vocal technique are intrinsically based on the current aesthetic of classical singing.

Considering the professional success of the singers in the opera group (they are all employed full-time in highly competitive positions at The Royal Opera House in London) their vocal technique represents that of current expectations of opera singing. The strong relationship of most factors of technique analysed between both groups therefore suggests that the early music singers are complying more closely with contemporary attitudes and methods of 'classical' or operatic singing, rather than applying a technique inspired by theories of historical techniques.

Once the subtle differences that emerged between the two groups across the vocal elements are considered, such as high frequency spectral energy and the employment of this energy over time, factors that could contribute to perceived differences in voice quality in spite of similar general techniques being employed by the singers become apparent. Although these differences, particularly the delay of spectral energy after consonant production, are quite subtle, they comply with the expectations of the groups' specialties and environmental constraints.

The evidence suggests that whilst the basic characteristics observed in all subjects are rooted in the same intrinsic technique, the singers in the opera group have developed these characteristics to a greater extent than the singers in the early music group. In particular, for example, the increased relative use of spectral energy in the 5kHz – 15kHz region by the singers in the opera group could be representative of their extending the basic techniques identified beyond that of the singers in the early music group. Although not a topic of current research in the same way as the singers' formant, this high frequency spectral energy could provide further strategies for projection and contribute to the characteristic timbre of the operatic voice which the singers in the opera group represent.

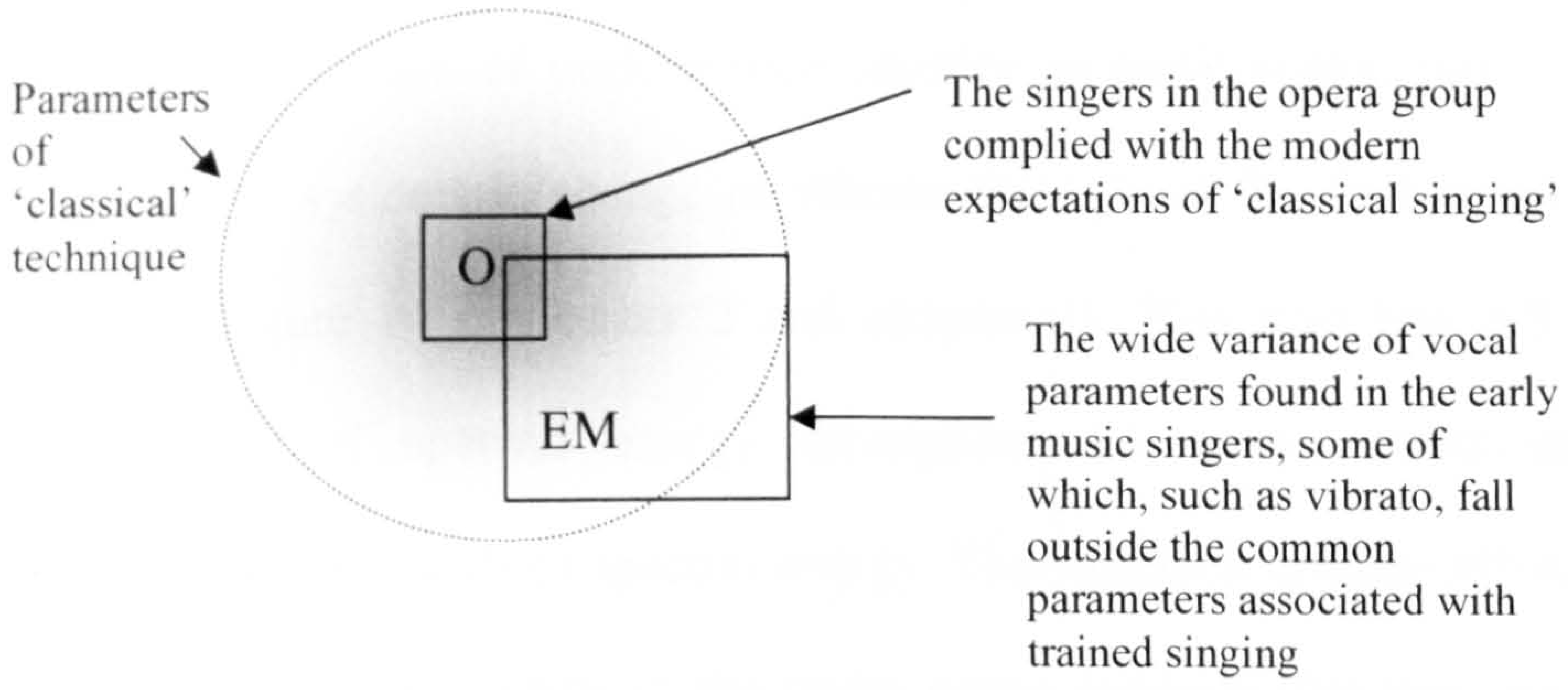
Consideration of individuals within the groups reveals quite dramatic differences between the groups overall. Once all factors are analysed, the extent to which the individual subjects adhere to the operatic parameters varies quite considerably, creating a noticeable difference between the groups and providing an insight into the contemporary perceptions of the acceptable parameters of their performance specialties.

There are clear indications that whilst the singers in the opera group all conform to modern expectations of a 'classical' or 'opera' technique to similar extents, there is a wider diversity of results for the subjects in the early music group. The results for vibrato showed the widest diversity across subjects in this respect. Often the subjects presenting with the least vibrato production also display fewer characteristics associated with opera singing, becoming further displaced from the opera group in terms of complying with all the parameters discussed. Therefore, combining the individual factors of technique that were analysed, in spite of similarities which identify both groups of singer as utilising a modern 'classical' technique, there are indications of innate differences identifying the speciality of the groups.

The subjects in the opera group conform to relatively tight parameters compared to the early music group, who display a much wider diversity of results across aspects of technique. It is apparent from this observation that the acceptable boundaries of the various facets of technique are different for each group, but remain fundamentally within the perceptual boundaries of classical singing. The possibility is explored below that this could be due to the specific training and background of these subjects and also a consequence of the stylistic objectives of the subjects infiltrating the intrinsic qualities of their technique.

Figure 57 shows a diagrammatic representation of the overall findings in terms of the extent to which the results of the present study reflect the current quantifiable aspects of vocal technique associated with trained classical singing. The opera group is represented by the small box which is central to the overall boundaries of a classical singing technique which is symbolised by the shaded circle. The larger box representing the early music group shows that they display mainly features of technique pertaining to a classical method, sharing the extent of some of these features with the singers from the opera group. However, certain subjects in this group presented with results outside the expectations of modern classical singing in certain aspects of technique especially in the use of vibrato, or the independent use of spectral energy.

Figure 57 Showing a diagrammatical representation of the overall findings of the study



Examination of the extent to which the stylistic incentives of the performance speciality impact on the overall results can also provide an insight into the singers' main objectives. This can give an indication of the origins of some of the qualities that seem to be intrinsic characteristics of the singers' techniques.

7.3.1 Stylistic Effects on Voice Production

The results of the different tasks revealed certain stylistic tendencies. The song tasks were particularly useful in identifying conscious or subconscious stylistic features, some of which seemed to be inherent in the singers' techniques whilst others seemed to be controlled in addition to intrinsic vocal characteristics.

The song tasks revealed that vibrato was the feature most changed by the stylistic intentions of the singer as well as producing the largest overall differences. Conforming to current expectations of performance practice in early music, most of the singers demonstrated a systematic change in vibrato throughout the first note of the Handel extract (see figure 14 in chapter 2 and chapter 3). This trait was reflected in their distinctive use of spectral energy throughout this note, introducing harmonics individually to form bands of spectral energy. The inclusion of these effects, though to a lesser extent, by some singers in the opera group suggests that they are aware of the stylistic expectations especially connected with vibrato in the performance of early music. However, the considerably reduced effect of this feature by singers in the opera group also suggests that either their technique does not regularly utilise this feature of performance and so restricts their ability to execute it as an ornament, or they are less concerned with the stylistic notion of vibrato than they are with its production as an essential component to classical singing.

The tendency observed in a number of the subjects in the opera group, and some singers in the early music group, to produce small, irregular fluctuations in pitch before establishing their full vibrato usage suggests that, in spite of a stylistic awareness, intrinsic physiological factors are preventing the exact effect of the desired musical expression.

The vibrato production and spectral energy in the Puccini extract supports the theory of a stylistic awareness. There are clear indications in the results of all subjects that there is a change in stylistic objective between the two pieces as all singers utilise a more consistent vibrato and spectral energy in the Puccini extract. The results for these two aspects are strongly connected in that the subjects with the largest extent and overall use of vibrato also tend to produce high relative energy levels higher in the spectrum observable from the onset or close to the onset of the tone.

Consistency of spectral energy, particularly across notes, could also be representative of an overall stylistic attitude considering legato phrasing and, more specifically, portamento. It is a common expectation in the modern performance of early music for notes to be 'attacked cleanly' and for portamento to be avoided (Potter, 2006). This could partly account for a delay in spectral energy in the early music group across notes, as this is avoided by the singers in the opera group by sustained legato singing. This involves continued phonation between tones with consistent 'resonance' and, therefore, the effective production of a portamento, although not to the extent that an audience would perceive this strategy as a specific vocal feature or ornament.

The overall results of the study therefore indicate that the stylistic objectives of the singers impact on intrinsic qualities of their technique. Those singers showing extremes of results in either of the song extracts did not achieve results representative of the opposite extreme of the other stylistic expectation, although there are strong indications within the results that specific stylistic objectives are being attempted by most singers.

The extremes that were observed represented the expectations of modern performance practices within the subjects' specialism. The subjects in the opera group produced the most consistent use of vibrato and high spectral energy throughout the Puccini extract, however, presented with the least alteration of these traits in the Handel extract. In contrast, the singers in the early music group demonstrated the most abundant use of straight tones and graduations in high spectral energy in the Handel extract. In spite of showing tendencies more similar to the opera group in the Puccini extract, the early music group continued to present with the tendencies that were observed as stylistic features in the Handel extract within the Puccini excerpt.

In terms of stylistic objectives and performance specialism, there are two probable explanations for the observed stylistic characteristics in vocal technique, both of which relate to the intrinsic vocal techniques employed by the subjects. The regular performance of early music as a specialist repertoire by the singers in the early music group, and the modern expectations of performance style and specific vocal qualities associated with that style presumably result in the employment of technical characteristics fulfilling these criteria. The opposite is true of the singers in the opera group as the principal objective of their usual performance speciality involves the consistent use of characteristics commonly associated with opera singing.

This in turn suggests a difference between intrinsic techniques being employed by the singers with additional vocal objectives providing characteristics which alter the overall findings of a certain speciality. In the case of vibrato for example, it seems that some of the singers in the early music group utilise a technique with relatively little vibrato compared to the other subjects, consciously adding vibrato as an ornament when it is deemed stylistically appropriate, as in the case of the Handel extract. A technique intrinsically related to vibrato production is indicated in the subjects in the opera group, with the suppression of vibrato being the stylistic change, rather than its addition.

Therefore, even with an understanding of the stylistic expectations of the styles for each speciality it seems expected that the regular employment of the stylistic traits associated with their own specialism impact on overall technique. The diversity of results in the early music group supports this theory as those presenting with characteristics most similar to subjects in the opera group were also the subjects who regularly perform music outside their performance speciality of early music. Presumably therefore, they necessarily need to employ traits more highly associated with the opera group in order to satisfy the expectations of vocal and stylistic qualities when performing this later repertoire.

Relationships between performance speciality, musical style and intrinsic techniques also appear to be connected to the training and singing background of the singer, particularly considering their choral experience the possibilities of which are explored below.

7.3.2 Effects of Training and Singing Background

There are clear indications within the results that the training and background of the individual subjects impacts upon their overall vocal technique. Although there were important similarities between the two groups in all aspects of technique, differences that were identified, particularly across the early music group, appear to represent the choral background and training of the singer rather than necessarily indicating factors which dictate the subject's performance specialism. A table outlining the backgrounds of all subjects was provided in chapter 2 (Table 1), but the specific relevance of their various training paths to the results of the study are considered below.

Consideration of the inherent technical characteristics of the subjects and the extent to which the individual singers achieve the characteristics associated with classical singing revealed especially pronounced similarities within the opera group, with a much more diverse range of parameters for various aspects of technique in the subjects of the early music group. Considering the training of the individual subjects could account for this variety within and across the two groups.

All subjects in the opera group carried out their post-eighteen education at conservatoires, some continuing onto postgraduate (or equivalent) study at other performance institutions such as the National Opera Studio. The similar objectives of these institutions, particularly in London (which is where all subjects in this sample studied), to focus on producing solo opera singers, is represented in the similarity of the results between the singers and the conformity of these results to current quantifiable parameters of the classical voice. Considering this trend, the divide between the results of the singers in the early music group are traceable to the different paths of training pursued by the individuals compared to the subjects in the opera group.

All singers in the early music group apart from subjects 13 and 14 undertook their post-eighteen undergraduate education at academic institutions rather than music colleges. Of all the subjects in the early music group these two subjects produced the highest extent of characteristics symbolising an operatic technique, particularly considering the large use and extent of vibrato by subject 13. These subjects also regularly perform music composed later than the nineteenth century, although still classifying themselves as 'early music singers'. These factors combined suggest that their training at music colleges developed a specific vocal technique representative of the modern 'classical voice'; however, they also show that modern performance culture still accepts this sound in the performance of early music. The Greek nationality of subject 14, her professional career and Music College training in Greece must also be taken into account, as the results for this subject are likely to reflect the performance culture of her background.

Of the subjects that studied at universities subjects 1, 3, 15 and 16 went to Oxbridge colleges, subject 16 being the only one subject out of the four to study music. These subjects displayed results expressing the qualities of modern opera singing to the least extent once all parameters are considered. Of these four subjects, subjects 3 and 16 went on to study at performance institutions obtaining post-graduate qualifications from the Guildhall in early music performance and the Royal Academy of Music in Vocal Studies respectively. These subjects produce qualities more similar to the subjects in the opera group than the subjects which did not continue studies at music colleges, particularly considering vibrato production and spectral energy (See chapters 3, 5 and 6).

Of the two subjects who attended universities other than Oxbridge, both went on to post-graduate study at music colleges and the results for these subjects fit a similar trend to those subjects from Oxbridge colleges who went on to performance institutions; although certain factors of technique are not employed to the same extent as the opera singers, their characteristics are more similar to the opera group than those who did not attend these institutions. This not only supports the suggestion that a music college environment promotes vocal techniques fundamentally associated with opera singing, but also suggests that the time spent singing in certain environments with specific objectives has a lasting effect on vocal techniques.

Whilst the place of study varied between subjects, especially within the early music group, all singers had received prolonged periods of regular individual vocal lessons, although subject 15 was already fulfilling professional engagements before she began individual tuition. It is also important to note that vocal tuition in classical music remains essentially based around the same objectives which are concerned with the modern aesthetic of a classical voice, which are essentially operatic (Wistreich, 2002).

Even the introduction of specific 'early music' courses at music colleges, such as the Guildhall course attended by subject 3, have not had a significant impact on the expectation of vocal techniques at these institutions. Vocal tuition continues to be carried out mainly by the same teachers that produce the opera singers at these institutions, the 'early music' element illustrating an emphasis on the repertoire performed and performance practices associated with that repertoire rather than specific vocal techniques. Considering the generalised vocal tuition of classical singing and the training received by all subjects in this study, it therefore seems likely that factors other than vocal tuition are affecting the results which imply differing intrinsic techniques between the subjects.

In particular, the Oxbridge connection between certain characteristics of subjects' vocal techniques, the choral background of the singers seems indicative of specific vocal characteristics within the groups. Whilst all subjects in the study had choral experience, the type and extent of choral background was quite diverse between the singers. Most of the singers in the study sing in ensembles as a predominant aspect of their career, the singers in the early music group singing as part of professional early music ensembles and all subjects in the opera group being part of the Royal Opera House Chorus. However, there are noteworthy differences between the objectives of these ensembles in terms of both the overall sound and the objectives of the individual within them.

These differences are largely environmental in that the early music ensembles usually perform music with significantly reduced accompaniment compared to the opera chorus, often performing music a capella or with small continuo forces. Whilst the objectives of the singers in the opera chorus, therefore, necessarily mirror those of opera soloists as they need to project above large symphony orchestras in large performing venues; the early music singer is not forced to conform to the same parameters.

The evidence obtained in this study indicates that the Oxbridge background and particularly the choral training involved in that background has a large impact on the intrinsic characteristics of vocal technique in the singers. In terms of an identifiable vocal quality or qualities associated with the modern performance of early music, the results pertaining to the individuals in the early music group, particularly considering the diversity of these results, seem to suggest that their speciality is representative of their choral background rather than any specific execution of historical vocal characteristics.

The terminology commonly associated with early music ensembles reflects that often used to describe the Oxbridge choral sound. This is to be expected when the origins of the directors of these ensembles is considered, as Oxbridge tends to have been their place of musical training (Potter, 1998: 113 – 132). It is therefore another natural progression in this evolution of sound-worlds that modern perceptions of early music voices also mimic those of their own Oxbridge origins. Potter explained the commercial success of the Oxbridge elite during the early music revival and their tailored early music niche, 'Groups with singers who do not make the accepted Oxbridge sound were consistently marginalised' (Potter, 1998: 116).

The parallel terminology used to describe the specific sound associated with Oxbridge and contemporary perceptions of ideal 'early music voices' are also reflected in the results of the subjects who studied at these institutions. The various characteristics of vocal qualities associated with the early music and opera and representation of various facets of vocal technique accounting for perceptions of tone quality were discussed in chapter 5.

Of particular significance to the choral and specifically Oxbridge background of the singers is the concept of purity associated with early music voices. The presence of a prominent fundamental in certain tones, especially when stylistic features of performance are being expressed (see for example the first note of the Handel extract chapter 2), could in part account for the perceived purity of tone in these singers. Although this feature is not consistent throughout tones, introducing spectral energy more closely to the spectral content of the opera singers, it will change the overall perception of the quality of sound. Onsets are known to have a notable effect on perception of timbre, a matter which has been highlighted in the identification of instruments through their onset phase (Howard, 2006: 221 – 227). This implies that the different onsets employed by the singers in the study, and particularly between the two groups, could be an important factor categorising them within their speciality, especially considering the important part timbre plays in the pigeon-holing of the two groups.

An important feature contributing to the use of the terminology and perceptions of early music singers is also the reduced use of vibrato compared with conventional classical singing, a feature which represents the most noticeable differences between subjects. A predominant factor associated with the Oxbridge choral tradition which has infiltrated the early music phenomenon is the perception of choral blend which also seems highly connected to vibrato use (see, for example, Day in Potter, 2000: 128). Vocal timbre and vibrato are thought to be important factors contributing to choral characteristics of vocal techniques. In terms of spectral energy it has been found that a choral singer will reduce energy symptomatic of the singers' formant, as its presence would have the opposite effect to a 'blending' sound (Sundberg, 1987: 141). The results for all subjects showed high energy in the singers' formant region of the subjects' spectra, implying that they do not fulfil this criterion. However, research considering the solo and choral styles of an opera chorus found an increase in spectral energy in choral mode, which is supported by the results of this study (Reid et al., 2007). Previous research considering aspects of choral voices has considered the same subjects performing in a soloistic and choral manner; because this was not asked of the subjects in the current study it cannot be quantified from the data available.

The soloistic nature of the careers of all subjects, in that they all also perform solo music regularly and are required to sing as soloists within their ensembles, combined with the objectives of the experiment, provides a possible explanation for this discrepancy. When asked about their choral experiences and the ways that the singers changed their objectives when singing in an ensemble, all subjects commented on the additional consideration of choral blend; however, when asked what this involved most of the subjects could not clarify which specific aspects of technique. Some of the singers mentioned the conscious restriction of vibrato in ensemble singing, commenting that this was sometimes a specific instruction from the ensemble's director. 'Loudness' was also commented on as a factor involved in choral blend which could have implications on the spectral energy, especially the relative energy of the singers' formant frequency band. The lack of specific conscious changes in singing technique juxtaposed with an awareness of choral blend implies that incentives of choral blend are achieved by way of acute listening, the singer achieving subtle subconscious changes in vocal behaviour. It is also possible that modern perceptions of professional vocal ensembles need to adhere to modern perceptions of 'classical singing' as a method of distinguishing between amateur choirs and those which are professional choirs made up of 'trained soloists'.

Specifically concerning the issue of vibrato and choral blend, consideration of the results alongside the views of the subjects provides further insight into the modern expectations of early music performance and their origins. All singers that mentioned vibrato as an important element of choral blend were part of the early music group, apart from subject 9 from the opera group who had previously had a career specialising in early music, implying that a specific choral blend is desired for their speciality. The reduced use of vibrato by this group overall supports the singers' incentives in ensemble performance of using less vibrato as this trait is reflected in their solo techniques which are represented within this study. Returning to the educational origins of the singers in the early music group, the institutional origins of the early music revival and the musical directors which emerged from its success, the amalgamation of all these factors contribute to the modern perceptions of early music today.

Considering the modern incentives of early music performance, especially regarding vibrato in ensemble performance which was mentioned above, the individual training of the singers in a modern operatic style seems to contradict the objectives of the early music singer. All subjects were asked whether they consciously change any aspects of their technique when performing solo compared to ensemble music, and early compared to later repertoire. Whilst most of the singers in the opera group claimed to maintain the same intentions in terms of technical objectives of voice production between early and late repertoire, the singers in the early music group were more aware of a conscious change in technical objectives, particularly concerning vibrato usage. Subject 1 identified the conflict between the individual vocal tuition she received and the sound desired by the conductors of the early music ensembles she sang with: 'I can do lots of fast stuff or I can smooth [my voice] out a bit but my singing teachers tell me not to do that so its impossible... It's a constant battle to straighten it out and make it all long line...' (Subject 1).

The evidence of differences between the subjects' techniques combined with modern perceptions of their specialist singing style, the training backgrounds of the subjects and their own attitudes towards their specialism highlight a number of factors concerning the modern performance of early music. Whilst the basic technique of all the singers complies with the characteristics associated with 'classical singing', the current objectives in the specialist performance of early music include traits which directly contradict those characteristics. The large diversity of results in the early music group suggests that the acceptable parameters of vocal characteristics are larger in the performance of early music than in the performance of opera, for which group the results were quite similar. This also conforms to the model of the rise of the early music singer constructed by modern theorists which was explained in the introduction: their origins in Oxbridge institutions and their commercial success as satisfying a need to sound different to conventional opera singers, whilst still maintaining a connection with identifiable 'classical' characteristics (*e.g.* Wistreich, 2002).

7.3.3 Significance of the Results in Modern Performance Culture

The main differences observed between the two groups reflect the background and training of subjects alongside the employment of stylistic attributes which comply with modern performance practices. The characteristics identifiable to the specialist performance of early music also reflect the performance environments of the two groups.

The early music revival, which saw the resurrection of certain historical performance practices and in some cases the creation of entirely new ones, provided a performance environment for the classical singer which created opportunities for voices with different characteristics to work under that category (Potter, 1998: 122). The subjects in the early music group demonstrating the use of a technique most displaced from modern opera singing, though still fundamentally based upon it, would be unlikely to succeed in the performance environment of the opera group without adapting their technique to conform more fully to the operatic characteristics. As the modern early music singer often performs in relatively small performance spaces compared to opera singers, with much smaller accompanying forces, the environmental incentives which are thought to be the reasons for many of the characteristics associated with the operatic voice are removed.

The early music singers generally sing in more varied situations than opera singers especially in terms of performance space. It is due to this that stylistic features such as changing use of vibrato and spectral energy throughout notes and phrases can be employed to a larger extent by the singers in the early music group than the singers in the opera group. If the subjects in the opera group were to delay the onset of their optimum spectral energy when competing with large symphony orchestras, they simply would not be heard. Subtleties of performance in terms of vocal characteristics are therefore more diverse for the early music singer for whom projection characteristics are not so important.

The use of more consistent energy and vibrato in the Puccini extract by singers in the early music group shows that these subjects have an awareness of the need, or fashion, to produce consistent vocal qualities throughout tones and musical phrases in this repertoire. In spite of this apparent intention, the singers in the early music group that express the early music traits to the greatest degree continue to produce a notable delay in spectral energy and vibrato, implying that their vocal technique is not developed to a point at which these features are consistently sustainable.

The demonstration of the opposite effect by the opera group, in that they show an inclination toward the stylistic features of the early music group when performing the Handel extract but not to the same extent, also implies that these singers have cultivated a technique which meets the demands of their environment. Therefore, perhaps due to the extreme exercising of specific laryngeal mechanisms, these singers do not produce the same subtleties in spectra and vibrato as the singers in the early music group. The presence of a more noticeable use of energy in the 5kHz – 15kHz region of the spectra by the opera singers supports this consensus, as, although this is not yet an established phenomenon associated with opera singing, if representative of further projection strategies being employed by these singers, it is another feature being dictated at least in part by their performance environment.

7.4 Historical Theories Revisited

The divergence from certain aspects of an operatic technique by modern singers of early music does, in some respects, reflect modern theories of a historical technique. Due in part to the different environmental controls on the two groups, the singers in the early music group do not always produce consistent vibrato and spectral energy, because it is not essential. This natural emergence of a technique based on the use of period instruments, or its transference from Oxbridge choirs, could therefore inadvertently bring the modern early music singer closer to the realities of a historical voice. Although not based on the scholarly exploration or recreation of historical techniques, a number of the features do comply with modern theories of historical methods. For example, the concept of purity of tone which was discussed above and in detail in chapter 5, and a reduced vibrato compared to contemporary operatic voices, are purported to be characteristic of pre-nineteenth century voices (Wistreich in ed. Potter, 2000: 184). That these features also reflect the qualities attributed to Oxbridge voices from which the early music singer emerged perhaps theoretically diminishes the authority of the connection of these traits as a representation of a historical sound-world, but may still in practice represent them.

Whilst noticeable differences were observed in a number of the singers in the early music group compared to the opera group and these differences conform to some extent with modern theories of historical vocal sound-worlds, it is evident that all singers in the study utilise a technique essentially based upon the modern conventions of opera singing. This is indicated most significantly by the use of energy peaks in the spectra for all singers in the 2kHz – 4kHz frequency band and the evidence of a low larynx position being maintained in the mid-low pitch range of most subjects (see chapter 4). There are popular theories in current literature which have been reported throughout this thesis which assert the use of a lowered larynx position in singing only after the nineteenth century (See chapter 4). A modern technique of singing early music which conformed to this theory would, therefore, produce a characteristically different timbre to conventional opera singers obtained through the use a raised (rather than lowered) larynx.

The results for subject 1 seem to express these theories to a greater extent than the other subjects and suggest that this subject conforms most closely to theories of a historical vocal technique than the other subjects. However, once the objectives of this subject are considered, it is revealed that rather than an execution of an historical ideal, her objectives of technique are driven by the motives of her employer, which are almost certainly more strongly connected to the Oxbridge aesthetic which turned into a contemporary early music sound than any scholarly revival. It does seem that the modern vocal performance of early music ostensibly complies closer with theories of historical vocal techniques than the modern singing of grand opera; however, this is due mainly to the reduced execution of the operatic technique by the early music singers rather than any reconstruction of historical practices.

7.5 Categorisation of singers

It became apparent throughout the central chapters of this thesis that more variations in technique were apparent in the early music group compared to the opera group. The singers in the opera group produced consistent results as expected of them in all the aspects of technique that were analysed. The singers in the early music group, however, although they all displayed characteristics of a modern classical technique, produced them to different extents.

There was a clear relationship between the results pertaining to the individual singers in the early music group and their perceptions of their own techniques and categorisation. The subjects that presented with features of an 'operatic' technique to the least extent were those who considered themselves most categorically as early music singers. Subjects 1 and 15 categorised themselves very specifically as early music singers when asked about the repertoire they perform. Although willing to perform lieder repertoire of later composers such as Strauss, both these singers received professional engagements performing music written before the mid-eighteenth century. Subject 15 deemed that her voice was not always suited to the later repertoire she was engaged to sing, stating for example that her voice was 'too small' for certain performances of Mozart for which she was sometimes engaged. The singers from the early music group that were more willing to perform later repertoire conformed more consistently to the results common of the singers in the opera group, although still to varying degrees.

It seems, therefore, that where differences are greatest between singers in the early music group and opera group, vocal speciality is determined by vocal qualities probably reflective of intrinsic technical characteristics, whether formed by the specific training and background of the singer or dictated by the physiological makeup of the voice. However, when similarities between the singers in the groups are strong, specialism is apparently chosen through a preference of repertoire. This suggests that whilst there are strict parameters which must be adhered to in conventional opera singing, the acceptable margins for the same characteristics in early repertoire are much more variable.

7.6 Changing fashions

Whilst this thesis has focussed on the modern performance of early music after the early music revival, there is no doubt that styles of playing and singing have continued to change throughout the domain of 'classical music'. The fashions of the specialist performance of early music continue to be moulded by the continuously changing understanding of historical practices, and, perhaps more importantly, the ever-changing aesthetics of society.

The consideration of two voice types within this study represents only a fraction of the vast compass of the 'classical voice', as, 'early music is only one of the many varieties of singing which have evolved alongside what we think of as classical singing' (Potter, 1998: 122). The 'classical voice' continues to evolve as perceptions, attitudes and tastes also change.

This thesis therefore provides insight into the current aesthetics associated with 'classical music', and through musicological study and scientific investigation has shown the characteristics and parameters which determine the singer's discipline and how the early music voice has evolved to be defined by those characteristics.

7.7 Hypothesis Revisited

Hypothesis:

New scientific understanding demonstrates that modern singers of early music exploit a technique which is founded on the same basic principles as modern singers of grand opera, which doesn't necessarily adhere to current theories of early singing practices.

The results of this study support the hypothesis, in that the findings indicate a similar intrinsic technique being employed by singers from both specialties. It also demonstrates that a multidisciplinary approach to research is a valuable tool in furthering knowledge in musical performance. Although differences were identified between the groups, the characteristics specific to the early music voices were not representative of a scholarly revival or reconstruction of historical techniques, but rather reflected the training and particularly choral background of the individual singer. In the case of the subjects involved in this study, categorisation of the singer was based on the predominance of the various characteristics of a classical technique which again seemed mostly connected to the vocal education of the subject. Considering the changing fashions over time, particularly with the commercial incentives of the early music revival and the relatively cursory interest in historical vocal techniques by today's singers, the modern aesthetic of the early music singer therefore seems more an issue of the nurture of both the performer and their audience in terms of exposure to modern pedagogy and contemporary fashions than a representation of a historical sound-world.

7.8 Further Research

- The substantial data collected in this study provides indications of vocal techniques in the current performance practices of early music compared to opera singing. To gain further insight into techniques and to explore in more detail some of the theories presented as a result of the data collected, additional recordings of a larger sample size would be valuable.

- The differences observed within the early music group and the possible reasons for these differences, including objectives of performance and intrinsic vocal characteristics resulting from variations in the paths of training, were particularly important to the study. From a musicological perspective these results provide evidence of the different objectives and motivations behind current performance practices of early music and also contribute to current research which considers the effects of training on the classical voice. Based on the implications of the current results, therefore, of particular interest in further studies would be the origins of the singers in terms of their choral background and vocal training, and using a large enough sample size based on this information.

- Whilst this thesis concentrates on the results of the experiment in juxtaposition with contemporary theories of historical singing and modern performance practices, supplementary information concerning modern perceptions of 'early music voices' could be obtained by carrying out perceptual tests using a panel of listeners identifying the vocal qualities of recordings and assigning performance specialties to the singers. Whilst this was beyond the scope of the current study it would provide an additional dimension to the research and have further implications on the changing perceptions of vocal performance over time.

- This study concentrated on the recordings and electroglottograph data from subjects to compile theories of the techniques being employed by the singers. In order to assess the extent to which differences found in this study are the result of the physiological makeup or training and background of the singer, further studies quantifying various physical parameters of the singers could be insightful. For example, endoscopic images assessing laryngeal features, tests considering lung volume and MRI imaging of oral cavities could all prove useful to assess the extent to which a singer's specialism is connected to the physical possibilities of the voice.

- Although this study focussed on a comparison between modern singers of early music and opera, a valuable comparison to consider the qualities of specialist vocal performance of early music in more detail would be to compare these singers with other performance genres. Considering theories of historical techniques and their supposed removal from modern operatic techniques and closer connection to speech, a similar study using folk singers could provide a particularly interesting comparison.

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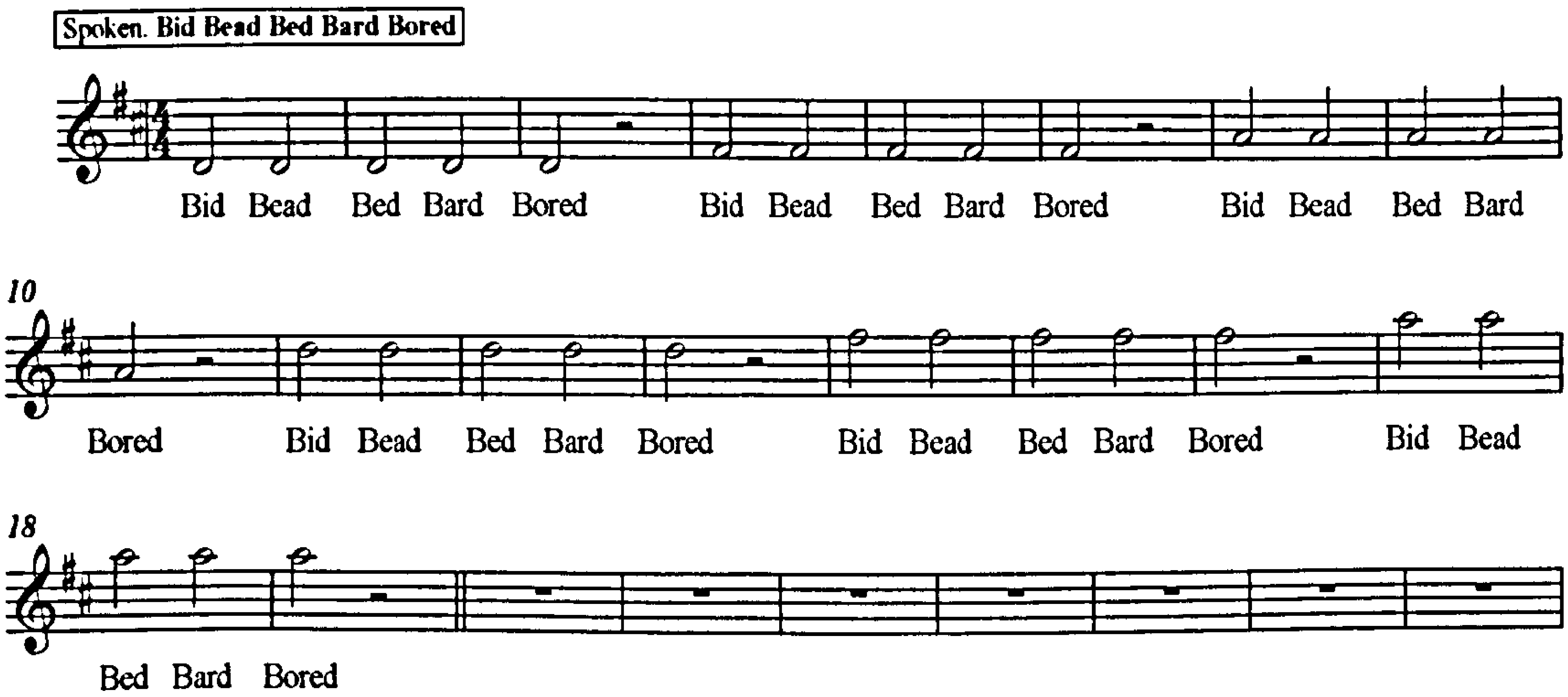
Appendix I

Musical Tasks

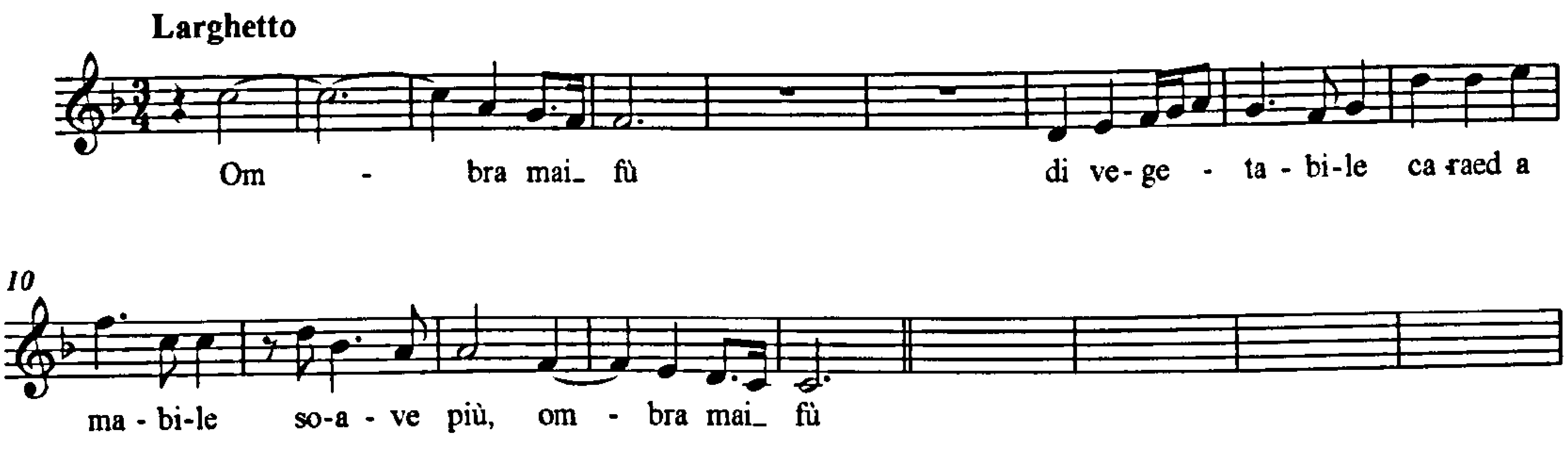
The Following vocal tasks were performed by each subject:

- Spoken text 'The North Wind and the Sun'
- Siren to 'ng' (glissando from the lowest to highest part of the singer's range)
- 2 octave ascending scale sung to [i] and [ɑ]

- Short text repeated on the notes of a D major arpeggio



- Extract from 'Ombra Mai Fu' (Handel)



- Extract from 'O Mio Babbino Caro' (Puccini)

Appendix II

Interview Questions

The informal interview with all subjects was structured using the following questions to structure the conversation,

1. Age

2. Vocal Range

3. Did you know the songs from which you were asked to sing extracts?

    3.1. Had you sung them before?

4. When did you start having regular singing lessons?

5. Formal musical education (e.g. Music College, University)

6. Choral experience

7. Small vocal ensemble experience

8. Do you sing differently when singing in a choir / vocal ensemble compared to solo singing?

    8.1. What do you change and why?

9. What period of composition do you sing most regularly?

10. Are there any periods of music or specific composers whose music you wouldn't sing?

11. What do you think makes your voice suitable for early music / opera?

12. Which factors affect the suitability of a voice to a specific field? (e.g. vibrato, loudness, timbre...

    12.1. Do you think those vocal characteristics are due to natural tendencies of the voice, training or some other factor?

13. Considering the tasks you performed in the experiment and the conversation we just had are there any other comments?

APPENDIX III

International Phonetic Alphabet (IPA) symbols

Table of the IPA symbols used within the thesis

IPA symbol	English word	Placement
[ɑ]	Calm	Back vowel
[i]	Bee	Front vowel
[d]	Do	Dental Plosive
[t]	Tea	Dental Plosive