The male passaggio in classical singing, with reference to the [a] vowel and vocal pedagogy

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There may have been a moment of foolhardy madness when I decided to commence this research project and dissertation, given that I was also in a position of responsibility as Head of Vocal Performance at RCS supervising and also teaching some students within a department of approximately 120 first study singers.
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The Voice Foundation Annual Conference, Philadelphia
Dunedin University Seminar, New Zealand
Singing Voice Science and Workshop, Montclair University
Annual Conference of Singing Teachers of New Zealand
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Abstract

The male passaggio presents a challenge in vocal technique, especially when the [a] vowel is sung. As the bridge to the upper range of the voice it is especially important to the voice types which have to traverse that zone frequently. For both professional and student singers the management of resonance of the [a] vowel in the passaggio and above can result in a multiplicity of responses, affected by aesthetics, voice-category, vocal acoustics and physiology as well as specific musical requirements.

By adapting principles from Post-Positivist methodology this thesis explores the issues outlined above in the real-world ecology of two groups of singers: established professionals, and Conservatoire undergraduate students. Sung examples gathered from both groups is explored and analysed in order to understand in more depth the challenges, problems and possible solutions for resonance of the [a] vowel in the passaggio and upper voice. The software programme *VoceVista* is used to present spectrographic and electroglottographic views of the sung examples, providing thereby a means of making reasonably objective observations.

The data emerging from examples is related to vocal pedagogy and professional-student material is interrelated. The professional examples demonstrate a hitherto unreported distinctive resonance strategy used by one particular group of tenors. The student examples make it possible to observe developments over time in student resonance management, as well as elucidate some of the common facets of student singing.

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List of abbreviations

In order of appearance in text.

CQ: Closed Quotient or Contact Quotient. (The length of time, expressed as a percentage of a glottal cycle, that the vocal tract is effectively closed to the air flow from the glottis. Where the term 'closed quotient' is discussed in Chapters 1 – 3 this is explained, but for the following chapters the abbreviation CQ stands for 'contact quotient'.)

NATS: National Association of Teachers of Singing. (This is the well-established professional association of singing teachers in the USA, publishers of the peer-reviewed Journal of Singing.)

MRI: Magnetic Resonance Imaging. (Used by some voice researchers to see physiological details during singing.)

LTAS: Long Term Average Spectra. (An analysis of vocal timbre achieved by providing spectral information averaged over time.)

EGG: Electroglottogram/Electroglottography. (A non-invasive method using an electronic device for monitoring the contact between the two vocal folds. The recorded or printed signal is called an electroglottogram.)

SF: Singer's formant. (More properly described as the singer's formant cluster, referring to the clustering together of formants 3,4, and 5. Especially important to male classical singers.)

dB: Decibels. (The unit used to measure intensity of sound by comparing it with a given level on a logarithmic scale.)

MS: Milliseconds. (A unit of measurement of time.)

ICR: Initial Closure Rate. (A measurement of the initial closing speed of the glottis over time.)

Chapter 1: Introduction

1.1. The concept of the 'passaggio'

The motivation for this study was originally practical. As a singer and pedagogue it had long been apparent to the author that mastering the zone of the male voice referred to commonly as the 'passaggio', and the range extending higher beyond that zone, was a vital skill for any aspirant professional singer to address. There is general agreement amongst both singers and teachers of singing that this is so. Such a view is easy to sustain in several ways. Conversations and reported opinions from singers constantly emphasise the importance of this aspect of the male classical singer's craft. Though by its nature much of this material is anecdotal, the frequent recurrence of the topic in such sources, (and the importance that it is accorded), conveys how crucial this aspect is considered to be 'in toto'.

One clear illustration of this occurs in the glossary provided by Hines (1982) for the non-specialist reader. The book is a series of conversations with some of the most notable singers of the twentieth century. In the majority of the discussions offered between Hines and male singers it is not surprising that there is some discussion of the 'passaggio'. However, the glossary perhaps best illustrates the importance of this topic by providing an explanation of the term which is longer, more complex and detailed than any of the other thirty-eight specialist terms offered.

This is not to imply that there is some kind of general agreement about the role of the 'passaggio' in male classical singing, or even its existence. An internationally successful Heldentenor who visited the Royal Conservatoire of Scotland in 2008 to give masterclasses, was asked about the ‘passaggio’ by a student of singing, (who was studying in the opera school there). The response was, ‘There is no such thing. I keep my voice completely open from bottom to top and simply sing the vowels’. He then gave an impressive demonstration, singing a scale of Ab major commencing on Ab3 and ascending to Ab4 sung on an [a] vowel, thereby traversing the zone of the ‘passaggio’ (which for this robust type of tenor is commonly thought to be from around C4 – F4). However, it was noted that there was an obvious change of the vowel which occurred around Dd4, which may be described as, ‘rounding of the vowel’ away from the [a] towards [o].

Such occasions illustrate the potential for confusion – especially for students, when a major artist uses words to describe their own singing which somehow do not match the acoustic reality then offered as example/demonstration. There is no guarantee that highly successful artists understand the physiological and acoustic detail of how they sing, other than in a personalised proprioceptive set of concepts and language. This fact is one very important reason for arguing that those who teach singing should have better grounded knowledge than that of the successful executant. Obtaining such knowledge is challenging and requires multi-disciplinary skills and background knowledge. A degree of empathy and insight in interpreting what is really meant by successful singers is needed (when they speak of their craft, describing perceptual elements), along with an ability to discern what is practically relevant and useful amongst the vast amount of physiological and acoustic serious research material extant. The best pedagogy should be able to combine and reconcile these two seemingly conceptually opposed modes of knowledge, one perhaps appropriately called ‘instinctive and practical’ (or perceptual) and the other ‘physiology and acoustics based’.

In singing teaching, describing and demonstrating things which actually help a singer to coordinate better may involve a semi-personalised access to imagination as much as in imparting factual knowledge. There has been considerable research published in the last ten years which discusses two seemingly opposed approaches to teaching singing, one termed 'declarative' and the other 'procedural' (e.g. Harrison and Abbot, 2014). These seem in some ways to mirror the 'factual knowledge/descriptive' component of knowledge about classical voice production as against the 'practical/doing' type of knowledge. It is interesting to note that when this discussion about 'declarative' versus 'procedural' methodologies was first mooted, there was a tendency to be somewhat dogmatic about the differing approaches. However, more recently (Helding, 2016) there has been some acknowledgement that even 'procedural' teaching requires some 'declarative' assistance in order for concepts to be understood and subsequently activated in practical work. This area (how to teach singing effectively) is well beyond the scope of this dissertation. It is also beyond the scope of this dissertation to offer judgements about the anecdotal discussions of the 'passaggio' (and the higher pitch range beyond) which abound in the world of classical singing, though this writer believes that there is a wisdom concealed and partially obscured within the sheer quantity of such material.

Some of the books available on vocal instruction for the male singer, which have a more scholarly background (not alas, the majority), also assert the importance of the 'passaggio' zone and the higher vocal range beyond. Achieving the required skill to meet the repertoire demands and sing in a manner that is generally perceived as both aesthetically pleasing and vocally healthy is clearly seen as essential. Amongst others such as Vennard (1967), Appelman (1967) and Doscher (1994), the prominent and influential American singing pedagogue, Richard Miller, in his articulate and thorough series of books on vocal technique (1986; 1993; 1996; 2000; 2004; 2008) has made this clear by advocating that the 'passaggio' and upper voice requires intensive study, special skills, and consolidated physiological and acoustic coordination, in order to achieve the required sophisticated artistry of classical singing.

There is a long history of attempts to understand the physiological and acoustic basis of how the classical voice functions. Information about the physiology and acoustics of the classical singing voice began to be published and disseminated from approximately the middle of the 19th century, with Manuel Garcia II (1805-1906) being one of the most significant figures. However, it is reasonable to say that there has been an explosion of activity in serious singing voice research in the last fifty years, fuelled by several factors. The National Association of the Teachers of Singing (based in the USA but with wide international circulation and influence) and that organisation's academic *Journal of Singing* was founded in 1944. The Voice Foundation (again USA based but international) was established in 1969 with its own attendant *Journal of Voice*. The British Voice Association (and its associated journal *Logopedics Phoniatrics Vocology*) was formally established in 1991. These three organisations with their emphasis on multi-disciplinarity in studying the singing voice, exponential growth in medical science, together with extremely rapid development in computer-based technology for voice analysis, has led to intensive work to further understand the issue of 'registers' in singing and, arising from that, the male 'passaggio' and higher range in male voices.

1.2. Registers in the singing voice

It may well be helpful to an understanding of the context of this study to say a little more about 'registers' in classical singing here, though the relevant literature is discussed in more detail in the literature review.

There continues to be some debate and disagreement in the voice community about 'registers' in the human voice. Some of this apparent controversy occurs because it is assumed that registers exist and function in a consistent way in humans, without reference to the aesthetic context in which they may exist. This goes some way to explaining why there exist differing views concerning the physiological, acoustic and perceptual basis for recognising the existence and functioning of registers. Henrich (2006) has pointed out,

> One major issue is to define a vocal register before labelling it. Another major issue is to be precise about the means which are required to identify a vocal register (p.12).

Since this study is only concerned with one very particular zone of pitch in males and the prevailing international aesthetic standards which are commonly sought and accepted in that zone, a great deal of the debate about registers is not relevant. For example, we are not concerned here with the speaking voice and its registers, nor with female voice registration. Henrich also states that, '…vocal registers have an acoustic and perceptual reality for singers which cannot be ignored' (p.6). One could go considerably further than this and say that some aspects of registers have an acoustic and perceptual reality for all of those concerned with the classical voice profession, which would include audiences, agents, opera houses and concert organisations, and the classical part of the recording industry. A singer whose registration practices do not accord with 'industry norms' may have a limited career.

The first challenge here then is to state clearly what the male passaggio zone and higher range are in relation to the subject of registers.

Most of the authoritative information about registers argue for the delineation of four (and in the case of female voices, five) possible registers, based on each register being defined by each register using a specific laryngeal mode. These registers are: pulse (or vocal fry), modal chest (dominated by thyro-arytenoid activity, thicker vocal fold mass and stiffening of the vocalis muscle), modal head (dominated by crycothyroid activity with thinner vocal fold mass and less vocalis muscle activity), falsetto (no vocalis muscle activity) and in females a very high register often called 'whistle' or sometimes 'flute'.

This study is not concerned with the pulse, falsetto or whistle registers but solely with the modal register. The modal register is that which classical basses, baritones and tenors use. In giving such a bald description of the known existing registers, (described in more detail by Hollien, 1983; Thurman and Welch, 2004; and Henrich, 2006 pp.7-12), there is a crucial point missing. The registers of whom? There is an underlying implicit assumption here that since all human beings have the same musculo-skeletal design and the laws of acoustics do not change between different individuals, it follows that registers are consistent in all males and females. This is not true when one considers registers in singing. A register cannot be said to exist until some coordinated activity causes it to sound, (and arguably only exists in the medium of sound). It is therefore necessary to take into account how the differing variables in coordination of physiological, acoustic and perceptual areas lead to differing outcomes in terms of registers.

In this study, this aspect is important. Singers train for specific skills in how physiological, acoustic and perceptual characteristics function. An untrained person may experience a sudden, unintended ‘break’ or discontinuity in gradually ascending or descending pitch which crosses the ‘passaggio’ zone. However a trained singer learns how to negotiate this area so that in classical western operatic/concert singing voice usage the upper range is attained whilst still using the same voice source (the particular vocal fold function) as in the preceding range. Thurman and Welch (2004) state that,

> ‘Some trained singers are able to produce this register with a CQ [closed quotient[1]] that is slightly above 0.5.’ (p.29.)

One notes that this was based on the work done by Howard (1995) looking at CQ levels in trained and untrained female singers. The present study will show that for male singers (even for those whose formal training is relatively short), it is common to find CQ levels exceeding 0.5 (50%) in upper voice, and that for professionals this is the norm for operatic and most concert singing. (Specialist Baroque and Early Music aesthetics sometimes produce different results.)

Trained male singing in the upper range, in modal head register (named ‘Upper Register’ by Thurman and Welch), employs a degree of thyro-arytenoid activity remaining relatively strong, rather than giving way to crycothyroid dominant activity in the balancing of laryngeal agonist/antagonist forces. This interrelates to the intriguing remark offered by Henrich (2006) that,

> ‘…the problem of identifying the mechanisms related to singing voice registers has been partly solved, at least at the laryngeal level.’ (p.7.)

Such a remark seems an invitation to open *Pandora’s box* to investigate the concomitant issue(s) of identifying registers further, in relation to both acoustic and perceptual levels.

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[1] The closed quotient [CQ] is the length of time the glottis is effectively closed to the passage of air within each glottal cycle, expressed as a percentage of the whole cycle from the point of closure of the glottis until the subsequent point of closure in the succeeding cycle.

Miller, D. (2008) explains that when males sing in full voice in the upper range (the Italian term used for this in operatic/concert singing is ‘voce piena in testa’) the vocal folds continue to function basically in the same way as they do in the middle and lower range (pp.59-69). The vocalis muscle remains significantly engaged, facilitating a similar or even higher closed quotient level than in the lower voice. Miller mentions CQ levels in excess of 70% for singing in the upper male range, sometimes even exceeding 80%. Unlike other registration events (for example a change from full voice to falsetto) this means that the change(s) required in the ‘passaggio’ and for upper voice are primarily acoustic adjustments in the vocal tract, and not a significant change of the mode of the vocal folds.

Miller (2008) also describes the two most common resonance strategies for traversing the passaggio zone and singing in the upper range of male operatic voices (pp.79-86). Since understanding this is central to the investigations undertaken in this project it may be worth summarising the basics here.

1.3. The [a] vowel and male classical singing

The challenge in seeking optimal resonance in the passaggio and above is at its most demanding when the sung vowel is the Italianate [a], one of the vowels commonly used for training classical voices and which is required constantly in repertoire. This is because that vowel has the highest first formant (f_1) value of vowels which are sung with the classically desirable low resting position of the larynx[2]. The frequency range of this formant is often between 620 – 750 Hz for males, depending on the exact pronunciation of the vowel, and other physiological factors

[2] The [æ] vowel has a yet higher first formant value, but is not accepted for sustained singing in classical styles and is avoided by modification when it occurs in the passaggio or upper range in male voices. It is not generally used in vocalises intended to train classical voices, though it does have valuable pedagogical uses.

such as dimensions of vocal tract, and jaw/lip position. (Peterson and Barney, 1952; Ladefoged, 1962; Sundberg, 1987; Thurman and Welch 2000.) McCoy (2004, pp.43-45) provides a clear summary of typical male formant frequency values for all vowels, (based on Peterson and Barney, 1952) with associated saggital views of the articulators and simple spectrum diagrams. The first formant for the [a] vowel is given as 730 Hz, and second formant 1,090 Hz, though McCoy also points out that sung values 'will almost always be somewhat different (p.43)'.

If a singer has an f_1 value of, for example 740 Hz, when he sings F#4 at 370 Hz the second harmonic of this pitch will be reinforced by the proximity of f_1. If his f_1 value is somewhat lower at 720 Hz it will likely effectively give an acoustic boost to his sung F4 at 349 Hz. This can cause a strong ringing quality in the radiated tone of the voice. However if pitch then rises (as it may in a musical phrase) the sung pitch may pass beyond the influence of the acoustic boost available from f_1. An inexperienced singer, having heard and sensed the strength of tone on the pitch boosted by f_1, may either accidentally or instinctually allow f_1 to continue to rise in order to boost the rising pitch by constriction somewhere in the resonance tract, or by allowing the larynx to rise (thereby raising all formant values). This is referred to by Miller (2008, pp.65- 66) and Bozeman (2013, pp.21-23) as a 'register violation'. This term is in general use amongst vocal pedagogues to describe singing which in some way fails to make appropriate adjustments that preserve quality of timbre and vocalism not potentially injurious to the singer.

This action may facilitate the continuance of brightly sounding strong tone but, as it is accomplished by constriction or laryngeal elevation, some freedom of vocal production is compromised; with further rises of pitch there would be a point at which such an approach would not be feasible. The singer may also experience discomfort in using such a strategy. For these reasons, those being trained to sing classically are not encouraged to use such strategies. However the loss of the engagement between f_1 and H2 on pitches beyond the easily established link causes a potential perceptual loss of resonance and fullness in the timbre of the voice. For this reason it is necessary for a sophisticated classical singer to find a 'replacement' resonance for the f_1/H2 factor. The commonest 'replacement' is for the singer to situate f_2 so that it resonates H3 (Miller, D., 2000). Alternatively, some voices which have very strong resonance in the region of the 'singer's formant'[3] can use that vocal quality to create a sense of seamless, well resonated tone.

These events are of prime importance to any aspirant male classical singer. Without the necessary skills to negotiate the zone in which H2 passes beyond the influence of f_1 a singer may not realise that he potentially has access to an extended upper range. He may find it difficult/impossible to sustain singing in that range without undue strain and effort. Or he may be unable to produce the timbre which is considered to be professionally desirable. It is therefore a matter of crucial importance to those who train male classical singers.

To summarise the above description of the 'passaggio': it is reasonable to assert that the male classical passaggio commences where H2 of a sung [a] vowel is significantly strengthened by the proximity of f_1 (Miller, R., 1993, refers to this as 'primo passaggio'). At the point where in gradually ascending pitch H2 rises above the influence of f_1 the end point of the passaggio is reached (Miller's 'secondo passaggio). Therefore this zone is commonly around C4 – F4 or F#4, though this may shift by as much as a semitone either way depending on voice type. It does not shift as

[3] A band of spectral strength where formants 3,4, and 5 may cluster to boost high harmonics in the timbre around 2700-3400 Hz creating brightly ringing timbre which projects easily This is usually referred to as the singer's formant cluster, abbreviated hereinafter simply as SF.

dramatically as might be expected by the voice-type name designations such as Baritone or Tenor. It may be thought somewhat curious that singers speak of ‘the passaggio’, when in fact this is an area of pitch in which resonance balancing is actually mostly concerned with the [a] vowel. As already stated this is because of the high f_1 position of the [a] vowel: all other vowels have passaggio points which are therefore lower and therefore less stressful to manage. Subtle adjustments to other vowels are required to traverse the passaggio and extend the range beyond; but this study examines the issues related to [a].

1.4. Context

Since the context for this study has shaped its content it seems appropriate to address it more directly. Arising from this, we need to consider what biases might be thought to exist because of the context. Having been a professional singer was a facilitating background for the writer, because singers tend to trust other singers to ‘understand and empathise’: many professional singers are reluctant to expose themselves to analytical processes with which they are not familiar and which they do not understand. Professional standing is zealously and understandably guarded. Nearly all of the professional singers approached for this project, however, readily agreed to assist in providing example material.

In addition, since the writer is head of a large UK Conservatoire classical vocal department and has taught singing in Conservatoires for nineteen years, access to student cooperation has been easy and direct. Perhaps even more significantly, through direct experience as a performer and subsequent pedagogue, ideas have been shaped by extensive practical experience. This generated almost unique possibilities to explore two major questions. First, to what extent are the currently published theoretical models for passaggio skills reflected in the reality of singers working in operatic contexts at high professional levels? Secondly, and of crucial interest to all vocal pedagogues who teach male singers, what are the characteristics of student voices in passaggio management and is progress over necessarily limited time audible? It was very obvious from the outset that it would be valid and interesting to compare these two areas through a number of case studies.

It also became clear as time passed that there could be no definitive moment in the acquisition of example material that would enable a conscientious observer to conclude that the process of observation was complete. This is because there were many moments of highly individual interest and variety demonstrated in the example material, so that it must be acknowledged that this project can aim only to signpost some trends and to illustrate some potential answers to the posed questions. That there have emerged some clear and new findings, of importance to both singers and pedagogues, could not have been predicted or expected at the outset.

Some biases shaped by the author's experience must be admitted. Even prior to commencing the project, like the vast majority of classical singers, the writer believed that when vowels are optimally adjusted this results in best aesthetic, acoustic and physical resonance outcomes. Effort levels are minimised by maximised skill. The writer's own extensive exploration of formant tuning had repeatedly shown that the proximity or otherwise of a formant to a particular harmonic could create better, easier timbre in accordance with the classical tradition. The area in which such skilled vowel adjustment was most demanding was the passaggio zone and the writer's association and work with other professional colleagues constantly reinforced this view, with a small number of easily-explained exceptions. Awareness of these beliefs meant that the exploration of available example material needed a mode which would facilitate an accurate and transferable way of describing the characteristics of a sung sound, not reliant on the somewhat vague traditional language with which singers and most pedagogues describe singing - hence the use of computer based spectrographic analysis and the (limited) use of electroglottograms.[4]

1.5. The longitudinal aspect

The reasons why studies of the development of student voices over time are so rare are discussed in Chapter 7.1 and 7.2 (Discussion of Student Examples). The most significant ones are the inappropriateness (in this context) of the prevalent medical model for studies over time, together with the impossibility of achieving an insulated group which could be regarded with any reliability as the control group. However for vocal pedagogues student progression over time is an area of obviously prime interest. There is an assumption that students do make progress from an initial level of limited technical coordination towards a more developed level of sophistication, which enables their singing to achieve potentially professional characteristics. As with so many other areas of classical singing, this is often claimed without any really clear evidence of what has actually been achieved. The language used often seems obscurely vague, lacking in precise meaning which can be discussed constructively, since terms such as ‘forwardness’ or ‘chiaroscuro’ to describe tone quality may easily mean different things to different people.

In this project the working context provided the opportunity to observe in some detail how student voices progressed over specific periods of time. It is acknowledged that caution must be exercised in the interpretation of the accumulated data, but it will be

[4] For further details about this aspect see Appendix 1, Glossary of Terms: Electroglottography, p.313.

argued that there is sufficient evidence to be of significant interest. The observations and conclusions point to very important pedagogical issues, which are new and valuable. Not only is it possible to state which aspects of vocal technique are susceptible to development and why, but there are important implications in deciding the order in which various skills for vocal coordination should be tackled. Further, there are significant conclusions about voice categorisation arising from the accumulated student case studies. For example, since it is possible to show that training resonance management can alter the characteristics of a voice, an extremely important issue is the appropriate balance between allowing any voice to adhere to so called 'natural' characteristics and deliberately training it to achieve different characteristics. The discussion of student examples and the conclusions reached in this submission provide valuable insights, which have not hitherto appeared in publication.

1.6. Fach, voice categorisation and vowel modification

The German operatic tradition uses the word 'Fach' to denote differing voice categorisations. Agents and opera houses in the classical singing world place voices in a 'Fach' and offer work on that basis, so this is of great importance to professional singers and those who aspire to become professional. For auditions, the appropriate 'Fach' of a singer needs to be established, and thereafter she/he is expected consistently to demonstrate qualities appropriate for that voice type. Entire books have been devoted to this subject, (McGinnis, 2010) and singers spend a great deal of time considering where they fit best into the 'Fach' system. One of these books (Shepard, 2007) has even been popular enough to merit being published in Kindle format. The Germanic operatic world is considered to be of very great importance because of the sheer number of opera houses (approximately 95 professional opera houses in Germany, Austria and Switzerland) and the consequent quantity and variety of professional work.

Of the many factors which are influential in determining 'Fach'[5], the resonance characteristics of the voice are regarded as extremely important, indeed arguably pre-eminent. For example a tenor whose physical stature could be appropriate for 'Heldentenor' roles, but whose instrument sounds more like a light-voiced 'Spieltenor', will be categorised according the timbre of his vocal instrument and so not placed in the 'Heldentenor' category.

Some studies of passaggio registration do take into account the fact that male singers can choose to manipulate the position of the secondo passaggio moment by how they treat resonance factors. The study by Sundberg, Lã, and Gill (2013) only divides singers into classical and non-classical, and is therefore rather limited in the conclusions which it can draw. The examples gathered for the present study, on the other hand, have offered a rich source of detail about Fach determination; but a constant awareness has been needed of how aesthetic decisions concerning the characteristics of Fach may determine the way available resonance strategies are employed. This is a complex area, and the current project opens many questions for further research in this respect. It is extraordinary, however, in attempting to relate the observed characteristics of resonance in the passaggio with Fach designation.

The change in timbre at the secondo passaggio point as H2 ascends beyond the boosting influence of f_1 clearly depends on the pitch of these two components. The pitch of harmonics is not a matter of choice for the performer; nonetheless vowel

[5] These factors may include age, appearance, previous experience/career, range, flexibility, perceived loudness. Timbre is generally the word used to refer to coloration of the tone as created by the voice's distinctive resonance. In male voices, some audition panels/agents regard the audible change of timbre which occurs at the top of the passaggio as an indicator of 'Fach'.

modification can change the pitch of a formant, including f_1. As will be seen later, some performers can change the location of passaggio points at will, by the deliberate manipulation of formant(s) according to desired aesthetic.[6] Some of the changes over time observed in student voices will result in very different Fach designations, and are likely to have a major influence on the type and level of a possible professional career.

There is, therefore, an intriguing interplay between three elements which this study seeks to investigate. The first of these is the passaggio and resonance proclivities of an individual voice. By this we mean an individual's natural passaggio characteristics prior to formal training, or as relatively unchanged by formal training. Secondly, there are the influences exerted by precedents and expectations established in the profession, and perhaps most appropriately termed professional aesthetics. Thirdly, there is the manipulation of passaggio events by sophisticated and deliberate control, achieved by training.

[6] See Chapter 4.3 Professional Singers: Examples, p.108 and following, (re Tenor 9).

Chapter 2: Literature Review

Classical singing has a very large hinterland of associated literature dealing with various aspects of performance, teaching and science. Much of the literature is anecdotal about performing and teaching. It may be argued that the sheer bulk of such material and the commonality of some of the views expressed should be taken into account by researchers on singing, since it may represent truths which have not yet been fully explored by more scholarly methods. Singers and pedagogues place some value in such material, which in itself makes it relevant to those who wish to understand the classical singing voice. Conversely it is also probably at least partly true to assert that much of the published scientific exploration of the classical singing voice has not connected efficiently with singers and pedagogues. Callaghan (2014) observes that the ideas embodied in the oral tradition of teaching 'bel canto' singing have been endorsed by voice science, though she also discusses the confusion in vocal pedagogy (persisting to the present day) caused by, 'fragmentation of sources of knowledge about voice, and new information about vocal function and vocal health….' (p.9).

Discussion of the male passaggio figures in both traditional approaches to vocal pedagogy and in voice science. Some discussions claiming to offer the wisdom of the oral tradition do not offer anything other than unsupported personal opinion. Occasionally a book appears which looks as though it may tackle the issue of the male passaggio as a main topic, such as Striny (2007). However the whole book is highly subjective and mostly a sequence of reminiscences about the author's relationship with Birgit Nilsson. Chapter 7 (pp.59-63), entitled, 'The Passaggio: To What? From What?', begins with, 'Oh, that dreadful word "passaggio" !'. The various unsupported assertions and stories of famous artists cannot be considered for serious consideration here. All such material has been excluded from this review.

This review of relevant literature seeks to show how serious discussion of the male passaggio has emerged in the literature. Part of this has been to illustrate the relationship between the topic of registers in singing, and the passaggio which exists in order to unite what have been thought of as two registers in the male voice – commonly referred to by singers and pedagogues, (and some scientists[7] also), as 'chest' voice and 'head' voice (though there are many other terms which refer to the same zones).

After the Second World War the establishment in the USA of The National Association of the Teachers of Singing (NATS), and its highly respected Journal of Singing, brought together singers, singing teachers, medics, phoneticians and voice scientists regularly and effectively. One of the most influential books to appear in the latter half of the twentieth century on classical singing was Richard Miller's, *The Structure of Singing* (1986), which is described by the author as, 'a detailed system of technical studies', (p.xix). It represented a milestone in an emergent trend in American singing voice instruction (see Callaghan, 2014 pp.8-12) which attempted to integrate and synthesise traditional vocal instruction, with the growing body of knowledge and research on vocal physiology and acoustics. There had been other earlier books which had a similar goal, though the physiological and acoustic information available to earlier authors was less extensive. The most prominent of

[7] Simply because the term seems to be in such ineradicable use by singers and pedagogues.

these would include Vennard, *Singing, the Mechanism and the Technic* (1967) and Appelman, *The Science of Vocal Pedagogy* (1967). Vennard gives a thorough description of the mechanics of the larynx, vocal folds and air flow in achieving register changes, which description is as up-to-date as was possible at the time, including the results of Van den Berg's scientific investigations in the late 1950s, with whom Vennard had cooperated. Appelman offers extensive advice on what he calls 'vowel migration' (pp.270-377). This is fundamentally the same approach as what is now more often termed 'vowel modification', i.e. the subtle colouring of one vowel with another nearby vowel in order to achieve an acoustic advantage. Appelman offers saggital diagrams derived from X-rays to show the position of tongue, lips and jaw in attempting to describe precise vowel formation. But neither of these authors had easy access to the computer-based analytical tools which subsequently became readily available and which showed more clearly and precisely how formants could be related to acoustic advantage.

Though Miller (1986) is very well known in Britain and is on the shelves of most Conservatoire and University Music libraries, as well as many public and private libraries, the earlier books are less well known here in Britain – probably because they were until the advent of the internet less easily discovered and obtained. Subsequently Miller published a further sequence of books also aimed at helping singers to achieve good technique based on tradition and science in combination. These include, *Training Tenor Voices* (1993), *Training Soprano Voices* (2000), and *Securing Baritone, Bass-Baritone and Bass Voices* (2008). Miller brought to the attention of his readers issues of registration in classical singing, and more specifically the role of the 'passaggio' in achieving a voice which had access to its full, necessary range and which sounded unified. Chapter 9 of *The Structure of Singing*, (pp.115-129) in using terms such as ‘Primo passaggio’ and ‘Secondo passaggio’, attempted to identify points at which the passaggio zone commences and finishes. Miller had visited many Italian voice studios and stated that these terms were in regular use there. In addition he discussed ‘chest’ voice and ‘head’ voice. Though his discussion of these various terms was presented logically and with some corroborative scholarly material, Miller then offered definitions of the registers which relied almost wholly on laryngeal mechanisms as the defining factor, and the subsequent instructional advice does not appear to be clearly related to the physiological information proffered. Both may be correct, but we are not told why doing certain things as exercises will achieve the desired change of registration. Such an explanation was indeed not possible at that stage of singing voice research. Though Miller (1993) offered some spectrographic analysis of resonance, particularly in the volume dealing with training tenor voices, this was not related specifically to issues of the male passaggio, nor to registration management.

This situation is not surprising because it is only recently that it has become possible to identify formants in the vocal tract without attempting to guess their probable pitch simply by inspecting the strength of harmonics. This latter method can only give a general impression of the whereabouts of any particular formant. It is clear from the discussion of vowel modification that Miller (1986) believes that the mechanical changes in registration are best achieved via vocal tract changes caused by gradually modifying vowels (pp.150-159). This implies that the answer as to how to achieve desirable graduated changes in registration is an acoustic one. However one notes that there is a gap in the supporting explanatory information. According to Miller, changes in registration are marked by mechanical changes at laryngeal level and to achieve this the singer needs to modify vowels. But no explanation of cause and effect in this relationship is given, but simply an assertion that it exists. There is a subtly different element offered twenty years later by Miller (2008, p.56) when he asserts that building the even scale is, ‘best explained not as a mechanistic event but as modification of the sound that occurs during pitch ascent’, and he subsequently proceeds to a discussion of vowel modification.

This is important because it characterises much of the discussion of the male ‘passaggio’ in the literature. It also encapsulates a discontinuity which for many years has characterised the work of voice scientists who work in the field of the classical singing voice. A great deal of excellent and undeniably careful and accurate work has been done to discover how the singing voice works. But much of this observatory activity has not suggested a means by which a singer might benefit from such knowledge. There has been a gap between the traditional assertions of singers and pedagogues and the growing body of established scientific knowledge about how the classical singing voice is produced.

In Miller (2008, pp.56-85) there is in Chapter 5 a thorough rehearsal of how to use vowel modification for lower male voices to achieve a smoothly successful ‘passaggio’. Also in Miller (1993, pp.38-70), there is a similar chapter specifically for tenors. However a close reading of these chapters clearly implies that the author believes that carefully graded vowel modifications cause gradual changes in mechanical registration events which result in the voice emerging smoothly into the ‘head’ zone. Subsequent research on the interaction between acoustic and mechanical events have shown this to be only partly accurate. (See below)

Titze (2018) in discussing ‘mixed registration’ succinctly points out that the source of the sound (ie the vocal folds chopping up the air stream) and the resonance filter (the vocal tract) are inter-active. This means (which is significant for this study) that perceptual changes in timbre may be caused not by a mechanical change in the sound source but because of the influence of the acoustic filter of the vocal tract. The changes in timbre may be sufficient for singers, listeners, and pedagogues to label such a change a register event, even though there may not be a change in the mechanics of the sound source. A further complicating factor is that such changes in timbre may occur accidentally or deliberately and may be influenced by aesthetic/artistic considerations as well as factors to do with vocal efficiency and health.

There has been discussion about the existence and nature of vocal registers, (and the need to accomplish smooth changes between such registers), for centuries. Stark (1999) helpfully provides a good overview of the discussion of registers from before the twentieth century which goes as far back as Lodovico Zacconi’s, *Prattica di Musica* of 1592 (pp.57-90) , but Stark does not adequately summarise the contribution of such important texts as *The Science of the Singing Voice* (Sundberg, 1987) which describes in detail the mechanical and acoustic events of registration, even though there is a section specifically entitled ‘Register Theory and Modern Voice Science’ (Stark 1999, pp.81-85). Manuel Garcia (translated in, Paschke, D.V.A., 1984) has become one of the most oft-quoted earlier writers on the concept of the 'register' in the singing voice, though he does not specifically mention the word 'passaggio', which was not in general use in that period. Garcia's definition of register is cited by others such as Appelman (1967, pp.87-88), Miller, D., (2000, pp.30-31), Miller, R., (1993, p.1) and Stark (1999, pp.68-73).

A most useful summary of research on registration is given by Henrich (2006) in her article and again Garcia's definition is used as a starting point. Henrich summarises the findings of the committee formed by the Collegium Medicorum Theatri as reported by Hollien (1984). Of the five recommendations made by the committee, three were unsurprising. The committee confirmed the existence of registers, stated that registers for singing and speaking needed to be treated differently, and that it was desirable to eliminate or conceal registers for classical/western, concert/opera mode of singing. More interestingly the committee accepted that there were probably two sources for registers, - the larynx mechanism and the vocal tract, but considerable debate was raised by a minority who argued that the source of a register was laryngeal and that other events only caused 'register-like' phenomena and were 'quality/timbre events'. Lastly the committee rejected traditional terms such as 'chest' and 'head' as being based on singer's sensations, and suggested other alternative terminology.

Whereas Richard Miller's body of work typifies the best and most informative singer/teacher/pedagogue combination approach to matters of the male passaggio, voice science has continued to explore the acoustic and mechanistic properties of the passaggio. Sonninen, Hurme and Vilkman (1992) presented a paper which reported changes of vocal fold length with, ‘special reference to register transition and open/covered voice’. However this study only dealt with three male singers, and there is no information about the level of skill or experience which these singers offered. Two were tenors, aged 32 and 47 and the third was a 70 year old baritone. The conclusions reached would not be surprising to most vocal pedagogues in that it was found that vocal cord tension increased with increasing pitch and loudness, and that above a certain point this could become potentially injurious. It was reported that the group of singers managed to avoid this in their upper range by partly relaxing the vocalis muscle (inner muscle of the vocal cords) and stretching the vocal ligament more. Singing in the upper range with ‘covered’ voice (of which there is an incomplete discussion) was found to be less potentially damaging to the vocal cords than remaining in ‘open’ voice. It was reported that the group of non-singers did not present this manoeuvre. Leaving aside whether such a group of singers could be considered helpfully representative of best practice in male classical singing, this kind of interesting study, (aimed at explaining the detail of how a part of the voice works), does not attempt to go beyond observation and offer advice on how to achieve the changes which are considered healthier, (and therefore more desirable?). As such it typifies much of the work done by voice scientists in relation to the classical singing voice.

Other recent analytical studies, such as the pilot study made by Echternach et al, (2008) on vocal tract and register changes analysed by real-time MRI (Magnetic Resonance Imaging) in male professional singers, seem to offer some more promising indications that with much further investigation it would be possible to show data concerning lip and jaw opening, jaw retraction, tongue shape and uvula position from which it might be possible (with a sufficiently substantial body of information) to draw conclusions as to what constitutes better or less good strategies for the male singer in managing register transitions – i.e. the passaggio. This particular study was only able to establish that it is possible to observe these aspects. Subsequent more recent articles by Echternach et al, (2011, 2017), established that perturbation measures were less when tenors descend from above the passaggio, and that there is some evidence of constriction of epilaryngeal structures as tenors ascend through the passaggio and beyond. However these studies were not examining the effect of particular vowels during the passaggio zone and in the higher range. This type of study exemplifies much of the excellently thorough work investigating the male passaggio in voice science, but seems of very limited further use to pedagogues and singers because, a) the chosen subject singers do not necessarily represent 'best professional practice' and, b) because trained singers can change the factors being investigated according to required aesthetics and artistry and this, very awkward, aspect is not considered.

Sundberg (1987), a voice scientist working on the singing voice, describes many important aspects of how the singing voice functions and his book has become regarded as a seminal work for many aspects of singing voice research. His work included a study of formants in singing voices – particularly differentiating between male and female formants. At the end of Chapter 4, 'The Voice Source', (i.e. larynx, glottis, air flow – the basic production of vibration) he comments,

> Singers often experience difficulties in the continuity of phonation; the voice timbre changes automatically, as it were, just because the pitch or the vowel is changed, or, in other words, just because the frequency relationship between the fundamental and the formants changed.

This perceptive comment looked forward to the investigation of the role of acoustic phenomena in causing/assisting changes in the vibratory mechanism, as such it hinted at reversing the hitherto common emphasis of explaining the detail of changes in the vibratory mechanism as though this might help a singer achieve such changes. At the very end of this chapter he asks perhaps the most crucial question, ‘Do registers originate from physiological or acoustic phenomena, or both?’ Sundberg makes a fairly extensive study of the functioning of the so-called ‘singer’s formant’, (which he points out is actually an acoustic gathering of formants three, four and five). He was clearly aware that there existed the possibility that register change was at least partly affected by vocal tract formant/vowel tuning and possibly controllable by this aspect of the singer’s craft, which in male singers would be mostly the province of the behaviour of the first and second formant, (though this is something of a generalisation).

In an earlier study Sundberg (1977) had demonstrated how sopranos tune the fundamental frequency to the first formant in their upper range, though he did not go so far as to claim that this coupling could be used as register defining. Nevertheless this looked forward to the most recent research. Subsequently both Wang (1983) and Estill et al, (1983) presented further convincing though limited studies which connected registration events with vocal tract formant strategies.

The most important studies in recent years which have changed substantially our understanding of registration and consequently the crucial area of the male passaggio are those of Schutte and Miller (1986) and Miller (2000, 2008). The article published in 1986 was the result of a collaboration between Harm Schutte and Donald Miller, the results of which were presented initially at a conference in Sweden organised by Sundberg in 1984. For the first time it was clearly established, using miniature pressure transducers, that with the fundamental frequency tuned to the first formant (as Sundberg had shown in 1977) there was a remarkable acoustic back pressure, even to the extent that the pressure across the glottis actually reverses during the open phase of the glottis. The significance of this is that it showed that physical changes in the vibratory mechanism could, at least in part, be caused by acoustic events in the vocal tract resonator system. Miller (2000) further argued that the registration events of the male passaggio and 'head' voice, as well as the concept of 'cover' were primarily an acoustic adjustment of the vocal tract, rather than an adjustment of the intrinsic muscles of the larynx (pp.125-147). Miller shows convincingly that on open vowels in the passaggio zone male singers 'tune' the first formant to the second harmonic. As pitch ascends, at some point the second harmonic becomes too high for the first formant, and at that point either an unacceptable register 'violation' occurs or the singer successfully tunes a different harmonic and formant – most often the third harmonic is linked with the second formant, (though that is not the only possible strategy). This enables the desirable 'standing wave' in the vocal tract to work efficiently and the vocal folds adjust as required. The chapter headed, 'Male Passaggio' (pp.125-147) concludes with,

> While not denying a secondary role to adjustments in intrinsic musculature of the larynx, our argument bypasses the common theoretical explanation of the passaggio from 'chest' to 'head' as an (ideally gradual) reduction in contraction of the vocalis muscles combined with increased contraction in the crycothyroids. Aside from the fact that electromyographic data is inconclusive from the most experimental investigation of this question (Vennard, 1970; Hirano 1970), we submit that the 'registration event' of passaggio is primarily about a change in the

> position of f_1 with respect to H2, rather than a change in the balance of the intrinsic muscles of the larynx.

By stating this Miller (2000) makes a link with the earlier assertion (p.136) that, '…the singer's control mechanism for these events is primarily auditory'. Singers and voice teachers work primarily with sound, not with muscle mechanics.

These ideas are of major importance because first, they have practical applications for performers and secondly, because they reversed the view that had developed in voice science in the latter half of the twentieth century which tended to analyse register changes as originating at the level of the vibratory mechanism, instead now viewing the process as one which is controlled by events which are supra-laryngeal in the resonator system. Much of the literature about how the singing voice works starts with the motor (breath), then moves on to the vibrator (larynx) and then, (literally upwards through the body), to the resonator system (pharynx, mouth, naso-pharynx, all mostly controlled by vowels). The notion that this neatly ascending system may not be actually how the system functions, (on an interrelated basis), for at least one area of technique was one that can be seen slowly developing towards the end of the twentieth century.

Neumann et al (2005) made a further study using eleven classical singers, (from Frankfurt Opera – a German category 'A' house), which confirmed the findings of Miller (as described above), and others who had commented on the relationship between formants and the consequent behaviour of the vibrator mechanism including Hertegard, Gauffin and Sundberg (1990), Titze (1988), and Sundberg and Askenfeld (1983). Neumann, in common with Miller concludes that the f_1/H2 and f_2/H3 relationships (also adding further information about the consequences for H4), 'provide objective parameters for the definition of the two registers' (p.326). As Miller had also done, Neumann uses closed quotient results which are able to show that the classical upper male voice range uses essentially the same vibrator source mechanism, with slight changes being occasioned by the resonance strategy employed.

Miller (2008) subsequently sought to make these theories more readily available and accessible to the community of singers and voice pedagogues, though most voice pedagogues would nevertheless find the material challenging in its complexity. This book attempts to condense and explain the necessary science of the resonance factors, and offers a potential approach for performers and teachers, (who would nevertheless need to have access to spectrographic and electroglottogram equipment, and be reasonably skilled in its use).

It should be clear from the above that spectral analysis, (either in combination with other measurements, such as closed quotient levels, or alone), has for many years been accepted as a means of examining closely some aspects of the singing voice which remove the discussion from the sphere of subjective description. It could of course be argued that the skill required to interpret the data leaves some room for manoeuvre, but importantly the measurements themselves are factual and as long as it is understood how and what is measured we have consequently a useful language for communication. Most importantly, this remains true even where singers themselves or (some/most) pedagogues remain unaware of the underlying basis of their craft.

Mitchell and Kenny (2008) as part of a sequence of studies examining the concept of the 'open throat' in classical female singing concluded that, '…acoustic analyses such as LTAS (Long Term Average Spectra) do not reliably match perceptual judgements by expert listeners'. There are so many problems with this sequence of studies that this conclusion cannot be regarded as accurate. The authors do not investigate the science of what actually occurs in either physiological or acoustic matters pertaining to the 'open throat', and definition of terms is highly subjective. The claimed 'panel of experts' apparently have no background in relating LTAS to audible voice qualities and remain anonymous. Worse still the results, on which much of this research relies, uses a group of singers who are required to deliberately try to sing less well than their own individual norms, and the results are treated as though such a vocal manoeuvre would affect only one element of the singing. Even if perceptual judgements by listeners did not reliably match LTAS results, it would not mean that LTAS results are either misleading or wrong. Facts cannot be changed. Howard et al, (2005), and Nair (1999) both strongly support the view that information derived from spectral analysis and closed quotient (derived from glottograms) measurements is extremely valuable in understanding the nature and behaviour of the singing voice. This view is clearly also that held by such eminent figures who have spent a lifetime specialising in the field such as Sundberg (1987) and Titze (1994).

The emergence of a new approach to examining the process of registration in the singing voice, with particular reference to the male passaggio, has made possible the scrutiny of prevailing professional strategies in this particular zone of the male voice. Bozeman (2013) offers a well-informed discussion for management of the male passaggio which shows easy familiarity with the acoustics of formants and physiology having assimilated the ideas and information established in voice research since around 2000. The book manages to combine instructional advice for singers with clear summaries of the acoustic causes of some of the challenges faced especially by male singers traversing the passaggio (see Chapter 7, Male Passaggio Training, pp 37-48). There is some explanation also of why the open vowel [a] poses a particular challenge at the 'secondo passaggio' point (pp.22-27). This book, and Miller (2008) explain clearly the hinterland for exploring the examples in this study gathered from professional and student singers.

To date there have been no published studies which seek to show how the most renowned operatic artists proceed in traversing the passaggio zone and singing into the higher range when the open [a] vowel is required. Vocal science in the past has often taken scholarly care to explain exactly the nature of the equipment being used and methods employed to establish results, but for obvious reasons it has not been possible to use the world's most renowned artists for study. At last now it seems that vocal science has made it possible to learn from the example of great singers without needing physically invasive techniques, (which most singers would reject even if they were willing to take the time out of busy international schedules which would otherwise be needed for such research). Schutte, Miller and Duijnstee (2005) showed a possible approach in their study which looked at the resonance strategies for the important and often climactic pitch of Bb4 in the tenor voice as shown in spectrographic information using eighty different examples of thirty-four different tenors. Their conclusions arguably form a guide for those who wish to learn how to conquer such territory. If we are to improve the precision of what we attempt to teach young male singers seeking to join the ranks of professionals, then clearly we must have an informed view of what such professionals actually do in performance.

The writer made a pilot study[8] of strategies employed on pivotal pitches in the passaggio as exemplified in Donizetti's well-known tenor aria *Una Furtiva Lagrima*, which exposes such pitches clearly. To obtain really certain conclusions several such studies would be needed, but it is already clear that the information yielded has direct pedagogical applications, which it could be argued make a significant contribution to the current state of knowledge.

The developments in voice science and vocal pedagogy over the last fifty years as reflected in the relevant literature create a challenge for all serious teachers of singing. If vocal tutors are to offer properly grounded advice to trusting students and professionals seeking advice, then we must be able to see what is important and relevant in the scientific work available and seek to advance that understanding by creating and exploring the relevant issues for best practice.

The concluding remarks of Callaghan (2014 pp 166-172) should not be discouraging, but rather the opposite, a source of inspiration.

> 'It is no longer adequate for practitioners to base their teaching solely on the directives that were used in their own training, or that they have heard used by famous singers in masterclasses, or on the personal imagery that has worked for them in their own singing (pp.166-172).'

[8] See Appendix 4, p.324.

Chapter 3: Methodology

3.1. Introduction

Much of the extant literature about classical singing divides into three main types: anecdotal personal experience; quantitative scientific investigation; and qualitative interpretive research, often based on interviews or surveys. However, the ideas and approaches which underpin post-positivist research were helpful for this study in that they suggest possible combinations of more traditional approaches with empirical work, and the view that research can be about problem-setting rather than problem-solving (Hammersely, 2000). This is not a rationale for directionless, poorly founded research - '….empty-headedness is not the same as open-mindedness (Wolcott, 1990, p.36)'.

Post-positivism is not simply a reaction against positivist research epistemology, it is rather a development of it. Its origins lie in social science research and the concepts that research should not always seek to negate/remove the formed experience and opinions of the expert researcher, but conversely via reflexive discourse seek to incorporate the views and skilled, informed judgements of the researcher. There is an emphasis on research as an exploratory activity rather than an attempt to prove a particular outcome. Ryan (2015) identifies post-structuralism, critical psychology, anthropology, ethnography, feminism and developments in qualitative research as some of the main areas which have been sources of critical opposition to positivism. One main tenet of post-positivist epistemology which was attractive to the writer was the idea that complexity and 'thoughtful guidelines' (Ryan, 2015) may be the result of post-positivist research, rather than deductive, narrower answers. It seemed logical that any exploration of the [a] vowel in the male passaggio and higher range would demonstrate varied aspects, since voices differ through artistic and technical choices and physical differences in morphology. Hammersely (2000, p.456) remarks that, 'Discovering the right way to formulate a problem is often as important in the advance of knowledge as hypothesis-testing'. This seemed particularly apposite in the context of this study since it is clear to the writer, via experiences in the professional singing world and pedagogy over an extended period, that the [a] vowel in the passaggio and higher range presented a special challenge, or 'problem', for many male singers. What was sought was a qualitative approach to discussing this area of vocalism which could help to elucidate the complexity of the topic, rather than reduce it to simpler answers.

The ideas of post-positivism have helped to solve specific challenges. The use of spectrography, the electroglottogram, and discussion of formants, partials, and closed quotients could give the impression that this is a primarily quasi-scientific research project. These elements provide a vocabulary for investigation, comment, discussion and evaluation which is essentially qualitative, rather than being a means for quantitative measurement. We were aware at the outset that we were investigating an important aspect of an art and craft, and that the setting and context of these elements would need to be included if the project was to be valid in its findings. From this sprang the concept that, rather than asking a singer for spoken opinion and a description of their singing, taking example recordings would make it possible to have a body of material that directly demonstrated how each singer was responding to the requirements of the moment. Subsequently it seemed far better to discuss this material using specific techniques for articulating some particular aspects of the singing offered, rather than simply using words to describe what was audible. At least then a reader would be able to follow the logic of what was being asserted (or to disagree) with some transferable clarity available about the processes of observation. Simply describing sound using the traditional singer's language, with such vague terms as, bright, forward, dark, back, constricted or free, would have resulted in highly personalised variability of meaning. However, totally excluding additional elements which might be important to how a singer sings a particular vowel/phrase, just because such elements needed to be described in words, seemed to be too limiting.

It seemed that post-positivism, therefore, suited our purposes well. The emphasis on permitting the expertise and experience of the researcher to be part of a reflexive process of the research was attractive (providing of course that this is fully acknowledged).

> Understanding rather than explanation is sometimes regarded as the objective of post-positivist enquiry, and this is often further constrained by the acknowledgements of context and contingency. Furthermore, in post-positivism the role of the researcher as interpreter of data is fully acknowledged, as is the importance of reflexivity in research practice (Fox, 2008).

It was expected that there would be a range of differing approaches to the [a] vowel in the passaggio and therefore it was important to remain open-minded during all aspects of the research. The idea was to try and 'discover' what professionals and students were actually doing in this area of their vocalism, rather than prove any one thing. The notion that research discovers something rather than seeks to prove one thing is a distinguishing aim of post-positivist research (Hammersley, 2000). Ryan (2015), discussing post-positivist research, aptly articulates what is appropriate in this project,

> Many of the problems that we wish to investigate do not lend themselves to ready answers, but are more appropriately addressed by research outcomes that offer thoughtful guidelines, principles and acknowledgements (p.30).

The initial impetus for commencing this work was the author's experience working as a vocal tutor over a long period at Conservatoire and higher professional levels, having previously sung professionally. A recurrent theme for all pedagogues who claim to be serious and professional must be the nature of the basis of their pedagogy. This and the more specific, known challenge of the male passaggio zone, led to the formulation of questions. The resulting determined curiosity eventually distilled the main research question posed here of how male classical singers sing the [a] vowel in the passaggio zone and above that area of pitch in the higher range.

Arising from this it was necessary to ask, how could we capture this information, understand it, and convey it clearly to others? Singers themselves tend to describe what they do in terms of highly personalised language born from proprioceptive experience and training influences. The 'training experiences' include all components, such as listening and observing, in addition to more direct training. This creates a 'gestalt' in each singer's mind encapsulating what that singer conceptualises as 'good' classical singing, which tends to guide that singer both consciously and subconsciously. In order to avoid discussions and conclusions becoming entangled in the labyrinth of such personalised 'gestalts', it was necessary to find a way of commenting on singing in the passaggio zone which made observations usefully transferable amongst people. Descriptors were needed which were not dependent on imaginative personalised language.

This sounds like an argument for a quantitative study but our approach needed to be broader than that. The sounds and qualities of living classical singing are part of a tradition of that singing which is a specific aesthetic. One would only need to examine the professionally accepted parameters for the rate and pitch of vibrato (Ship et al 1980; Sundberg 1987, 1994; Imaizumi et al 1989; Horii 1989) to start to see that classical singers adhere to a particular set of values. There are parallels for other aspects of classical singing which make it recognisable as such including, timbre, resonance, vowel definition, range, agility, dynamic variety, sostenuto and legato. Singers who work within the broad category of western classical singing are able to make choices about such things even whilst they remain within the boundaries of the tradition. Such choices may also be affected by a singer's voice type, their 'Fach' designation, and imaginative/aesthetic issues arising from the repertoire and performance situations. In seeking to establish 'truths' about what and how classical singers do what they do, if we were to ignore the fact that they are able to make choices according to context it is possible that conclusions concerning the singer's craft would be misleading.

Therefore, this study did not seek a gradually narrowing answer to questions about the singing of the [a] vowel in the passaggio. Rather it investigated the possible width of responses, outcomes and qualities which may exist. Several of the singers (both professionals and students) showed that they were able to sing the same particular pitches and vowels in differing ways. To discuss what the demonstrable characteristics are of the singer's sound without some contextual acknowledgement of why it is thus might lead to limited or misleading truths about the coordination of acoustics and physiology of the voice. This would be a poor basis for both research and any pedagogy which is informed by research.

There have been very many qualitative research projects which use interviews with singers and vocal pedagogues, with subsequent analysis of those interviews as the main research tools. This seems problematic. Using the spoken or written word to describe how or what a singer does is already a significant step away from what actually occurs during singing, since singing is a sound (in the form of music) and not text (though of course it may have sung text). The sound of the singing needs to be the starting point for the researcher.

In this study therefore, the material is the actual sound which each singer makes. The recorded examples from singers are then subjected to a critical assessment and processes of observation which are appropriate to the material. The sound of the singing captures the 'opinion' and coordination skills of the singer in the medium which singing inhabits, rather than converting the sounds used by a singer to a verbal description at an early stage (ie as may be attempted in a conventional interview, or written survey of some type). Subsequently employing computer software to uncover and make explicit the components of the sounds provides a reasonably clear mechanism for making qualitative observations and comparisons. This qualitative study investigates the topic but has not sought to use quantitative analysis in articulating the emerging ideas. The use of computer-based software has simply provided a reasonably clear and consistent way of encoding the aspects of the examples discussed which are thought significant. Since the computer programme does not have an opinion, apart (importantly) from that which is buried in the programme encapsulating the background standpoint of the designer of the programme, all further comment and analysis can be clearly seen as additional and interpretative. The assumptions, background, and 'opinions' of the designer of the software programme can be identified and stated. This is because the software programme is a static and continuously existing artefact, which has remained constant throughout this project.

These reasons seemed a powerful basis for transferring the ideas associated with post-positivist research in social science to singing voice research. It was not expected that one overall ‘truth’ would be arrived at. Rather that the complexity of behaviour and variety of responses to the ‘problem’ of the [a] vowel in the passaggio and beyond would be explored. The collection of data here explained and discussed was not offered to close a question, but rather to attempt to elucidate it (similar to the approach discussed by Ritchie and Rigano, 2001).

3.2. The spectrogram, electroglottogram, and *VoceVista*

The advent of rapid processing in modern computing equipment made possible accessible, portable equipment, for observing aspects of singing which had hitherto mostly been discussed using descriptive language open to differing interpretations. The preceding literature review has already mentioned the emergence of the spectrogram and electroglottogram as tools for assisting clarity of description. Schutte, Miller and Duijnstee (2005) asserted that,

> ‘The spectral measurements give an important objectivity to qualities of sound that have been traditionally available only subjectively to the more or less expert ears of practitioners (p.306*)*.’

Titze (1994) considers the spectrograph, ‘A basic tool of analysis of vowels (p.156).’ This particular study and the work of others such as Baken (1992), Sundberg (1977, 2013), Neumann et al (2005), Miller, R., (1986, 1993), Miller, D., (2000, 2008) and Bozeman (2010, 2013) have given authority to the view that spectrographic observation is of value and can contribute valid information which can be clearly conveyed to others (who understand spectrographic material).

Whilst care needed to be taken in interpretation of information derived from electroglottogram (EGG) signals (coordinated with the audio signal), the current view is that when singing is firm in phonation, using an operatic timbre, it is likely that the

EGG signals and calculation of the resulting contact quotient[9] will be broadly accurate (Hampala et al, 2015). These measurements have been included when the signals were clear and stable, and the results have potential relevance and interest.

For these practical reasons the decision was taken to use an appropriate software package to assist in making recordings of the empirical example information which would form the basis of the study.

Of the various software packages available at the outset of the project, *VoceVista*, (having been designed from the outset to be of use to both pedagogues and vocal researchers) offered the most sophisticated features, combined with easy portability and rapid, straight-forward set-up suitable for varying circumstances. The version used in this project is *VoceVista-Pro*, version 3.2. The introduction to this version states,

> Intended for researchers and voice-science-savvy teachers of singing, this is a program for scientific analysis of the voice, including voice waveforms, glottal waveforms (via the electroglottograph), voice spectrogram, and voice power spectrum (VoceVista, version 3.2., 2002, VoceVista introduction, p.3).

This qualitative study uses the facility of *VoceVista* to provide a clear and consistent tool for articulating and interpreting aspects of the sung examples. The range of options within *VoceVista* for adjusting how the sung sounds could be viewed and encoded exceeded those of similar software packages (such as, Sing&See, YMEC Singing Software, and SingPro). The addition in *VoceVista* of the facility for coordinating EGG and audio signal was not available with other systems. The software also makes retention and storage of materials simple and reliable. This made

[9] The term contact quotient is preferred to the term closed quotient, since the EGG measurements cannot be certain to indicate complete glottal closure, but can indicate contact between the vocal folds which results in the resonator tube above the glottis reacting as a tube closed at one end.

it the most robust yet practical tool for encoding, preserving and observing the examples of singing which were to be collected. Indeed, the existence of such a package to some extent governed the process of what could be observed and discussed, but advantageously so.

The designers of *VoceVista* recommended the use of the *Logitech H110* simple headset with microphone, selected for its flat response and studio practicality. The microphone has a frequency response from 100 Hz – 16,000 Hz, appropriate for the recording task. The manufacturer states the input impedance as 32 ohms and sensitivity as -58dBV/µBar, -38dBV/Pa +/-4dB. The same microphone was used for all recordings. For all participants the fitting of the headset microphone was achieved, by explaining that the purpose of using the headset was not that the participant would be using the headphones but simply that the microphone was easily held in a consistent placement, close to the mouth (thereby helping to minimise the effect of the room acoustics on the quality of the recording). If it was observed that the participant changed the position of the headset/microphone during the recording session this could be seen in the relation between EGG and audio signal in *VoceVista* and the consequent delay setting for the EGG adjusted accordingly[10].

The strap which holds the EGG electrodes in place either side of the thyroid cartilage was adjusted so that the singer felt that it was comfortable and did not interfere with, or impede, their normal vocalism. This required some patience since

[10] The writer conducted a series of experiments using higher quality microphones such as the Sony ECM-909A and other microphones made available by the recording department of the Royal Conservatoire of Scotland. Recordings of scales were made sung by the author in a variety of rooms, including in an anechoic chamber. Once recording levels were appropriately adjusted so that signals were not over or under recorded, no appreciable differences were found in the spectrographic information displayed by VoceVista. A total of 51 VoceVista sound files were accumulated in the course of these tests which are available from the writer. These tests cannot be regarded as 'fool-proof' but gave a reasonable level of confidence about the recordings made in a variety of rooms with the Logitech H110 microphone.

the elasticated strap with *Velcro* fixing needs to hold the electrodes reasonably snugly and securely in place in order to obtain clear signals, but at the same time the singer must not sense any constriction or pressure which could interfere with their normal vocalisation. Many student singers wanted to see the resulting signals and some were able to stabilise the quality of the EGG signal by a light touch on the electrodes once they had seen what a clear signal looked like. (Some of the professional singers who nevertheless did provide completely clear signals did not wish to look at the screen to check this aspect.)

The output from the microphone and the EGG unit were connected to the two inputs of a Tascam US-122 MKII USB audio interface, (without using phantom power for either of the inputs) which made possible the adjustment of signal levels so that they could be optimised for use with *VoceVista*, as recommended by the software designers.

3.3. *VoceVista* screen views

In addition to the accompanying video presentation (CD) of *VoceVista*, the following examples explain the views of bitmap screen captures taken from *VoceVista* which are presented for information and discussion in Chapters 4,5,6 and 7.

Figure 3.3.1: Waveform envelope, colour spectrogram and power spectrum

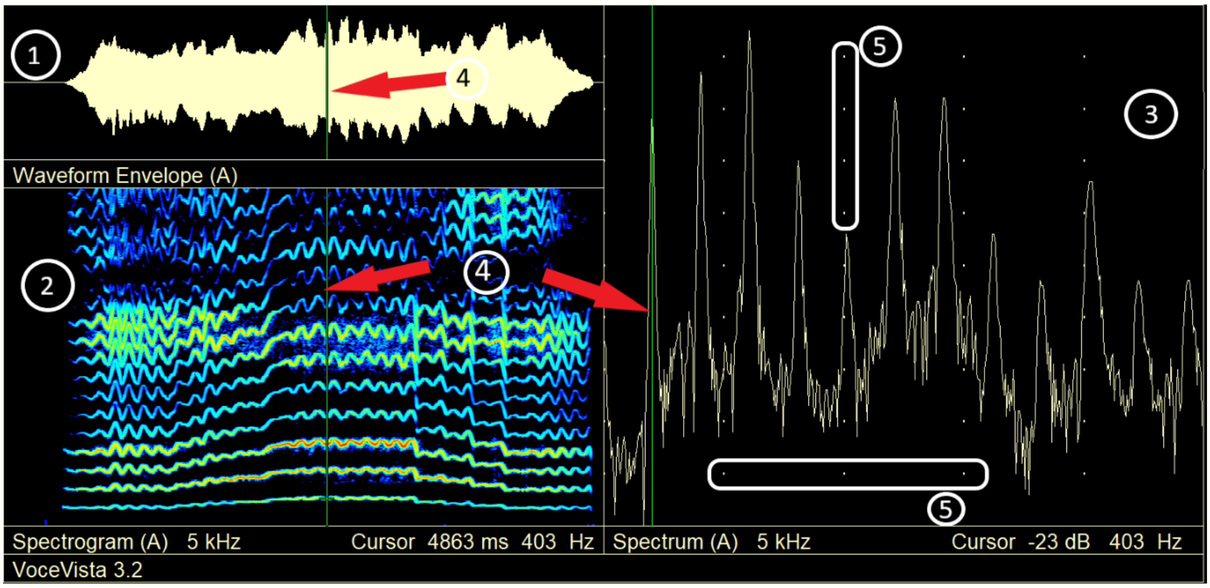
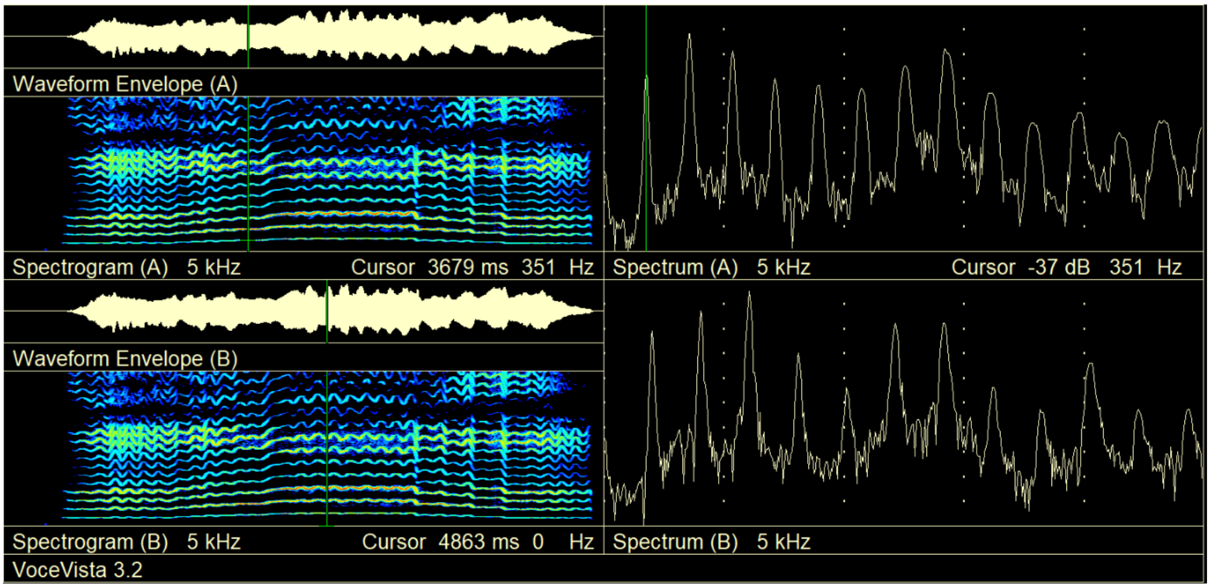


Figure 3.3.1 (above) shows a saved bitmap view taken from *VoceVista* of a recorded file sung by the writer of a major scale to the fifth from Db4-Ab4 on the vowel [a]. This is typical of the material collected from both professional and student singers. The view shown is one of the most useful, (and herein frequently used), views within those offered by *VoceVista*. The screen is divided into three main sections, two on the left hand side (encircled numbers, 1 and 2) and one on the right (encircled number 3). The *VoceVista* label for each part of the screen view is shown in the bottom left hand corner of the relevant view.

1) This upper left portion of the screen view, (shown with an encircled 1), is labelled Waveform Envelope (A). The (A) is shown because it is possible within *VoceVista* to divide the screen so as to show two sets of differing signals simultaneously. When this setting is used *VoceVista* automatically labels one set of screen views (A) and the other set (B) to avoid confusion. In such screen views the boxes for containing each sub-view are compressed, as in Figure 3.3.2 shown below. In this example the moment

selected for the Power Spectrum (marked with an encircled 3 in Figure 3.3.1) using the vertical green cursor is different in (A) and (B), though from within the same recording. The lower part of the screen shows the same moment as in Figure 3.3.1, but the upper screen shows an earlier moment from the same recording. This is sometimes useful in showing how different harmonics are strengthened when sung pitch moves (because the relationship with formants is changed), or when making comparisons between differing recordings.

Figure 3.3.2: Comparison mode (showing two sets of signals)



Returning to Figure 3.3.1 (encircled 1), the Waveform Envelope shows the audio envelope as generated by the sound pressure received by the microphone. The constantly shifting frequencies of harmonics associated with vibrato can cause a complex interaction with formants as harmonics move in and out of the influence of formants. Consequently, the audio envelope may show some asymmetries caused by the very rapid changes in input created by this interaction (Schutte et al 1991, and 1995). For adjusting sound recording levels, showing maximum detail without the possibility of distortion by over-recording, the white shape of the waveform envelope should not overlap the edges of the provided box in which it is presented. A good recording level would be one which shows that approximately half - two thirds of the available space is occupied by the white oblong of the audio signal. If the audio signal is recorded at a level which is slightly too weak (showing a thinner, erratic sideways oblong) there will be less detail easily seen/revealed in the colour spectrogram and associated power spectrum.

2) The lower left view (encircled 2) of Figure 3.3.1 is labelled Spectrogram (A) and shows a colour spectrogram view. The vertical y axis is frequency, and the horizontal x axis is time. Cursors can be used to measure either of these aspects with precision. The colour spectrogram gives a useful overview of an entire sung example and it is possible to see immediately which partials are emerging as stronger by referring to the colours. Though this can only ever be a rather approximate guide to relative strengths of partials within a particular recording, it can also efficiently and rapidly help to identify moments of particular interest. For example, by looking closely at the colour of any one partial as it fluctuates in frequency with vibrato it can be seen if it remains consistent or whether it appears to strengthen or weaken as pitch ascends or descends within the vibrato cycle. The ‘cold’ colour dark blue represents the weakest sounds and the ‘hot’ colour bright red represents the strongest. With familiarity it becomes possible to interpret the colours with useful accuracy, though it is always possible to see far more precise detail by referring to the power spectrum (marked with encircled 3) which can be synchronised with the colour spectrogram using the green vertical cursors. Where any partial is stronger than the prime, (alternatively referred to as the first harmonic or fundamental) it must be because it is being strengthened by the proximity of a formant. So, one can see for example, in Figure 3.3.1 that

the initial moments of the first note of the scale have less vibrato than subsequently. During this initial pitch it is clear from the colour spectrogram that the fourth harmonic is being strengthened. Once the sung pitch has ascended to Ab4 the third harmonic is strong (shown in mostly evenly distributed/consistent red). This could only be explained by the influence of a nearby formant, in this case the second formant (f_2). The fourth harmonic of Db4 would be the frequency of 1,108 Hz and the third harmonic of Ab4 1,245 Hz. It can be seen that the fourth harmonic of Db4 is not as strong as the third harmonic of Ab4, which would therefore suggest that the second formant is lurking somewhere nearer 1,200 Hz than 1,108 Hz, though this remains an approximate guess. In any case, such a guess would only have validity if the vowel remained consistent, as any change in vowel quality would move the frequency position of f_2.

3) The right-hand part of the screen shown in Figure 3.3.1 (encircled 3) is labelled Spectrum. The *VoceVista* programme uses the Fast Fourier Transform mathematical formula to almost instantaneously display the components of a complex sound-wave. The vertical y axis in this view shows the comparative amplitude of the partials (harmonics), and the horizontal x axis the frequency of the partials. Again, these can be accurately established using moveable cursors. The vertical green cursor (indicated with red arrows and marked with encircled 4) can be coupled in synchronicity to the spectrogram. Whenever the green cursor is moved forward or backwards in time along the x axis of the spectrogram, the view of the detail shown in the power spectrum shifts to the position of the linked green cursor. In this way, the power spectrum shows the detail of partials

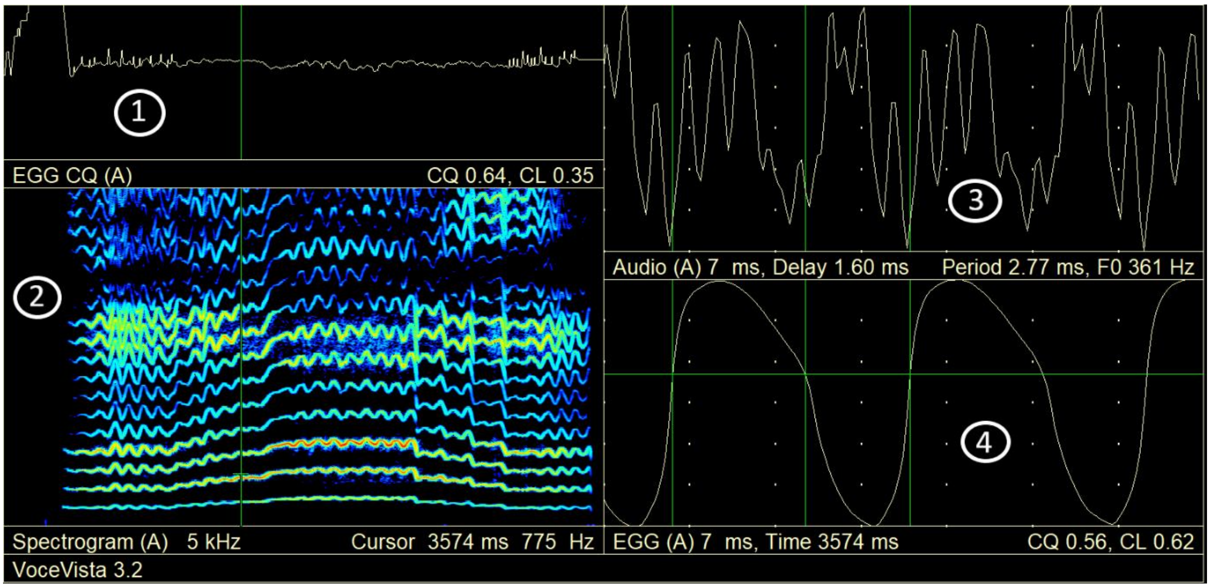
within one moment of time selected from the much longer duration of the recording. That moment of time for averaging can be set within *VoceVista* to a minimum of 100 milliseconds and a maximum of 10,000 milliseconds. The setting of 100 milliseconds is nevertheless sufficiently long to capture many glottal cycles (eg A3, 220 Hz, 100 milliseconds would capture 22 glottal cycles; A4, 440 Hz, would capture 44 cycles). This minimum average setting shows maximum detail and is therefore the setting mostly used within this study. Using the green cursor within the power spectrum view, it is possible to scroll over a particular partial and in so doing see the dB level of that partial which is shown in the lower right-hand corner of the screen, along with the frequency at that point in Hz.

4) As mentioned above the green cursors (indicated by red arrows and encircled 4 in Figure 3.3.1) have various functions. These can be coupled together to move in synchronicity between the various views, or, uncoupled so that they can be used independently within the different parts of the screen. They are used for making accurate measurements of time, frequency and amplitude.

5) The vertical series of dots shown in the power spectrum window (marked with encircled 5) are for quick orientation of amplitude. Each dot is -10 dB apart from the next. Similarly, the horizontal dots are for orientation of frequency. These are each 1000 Hz apart. This enables the experienced user to quickly estimate these aspects even before making more precise measurements of them.

Figure 3.3.3 shows a different set of screen views from *VoceVista*, with only the colour spectrogram (encircled 2) the same view as in Figure 3.3.1 discussed above already.

Figure 3.3.3: Contact quotient history, colour spectrogram, audio and EGG



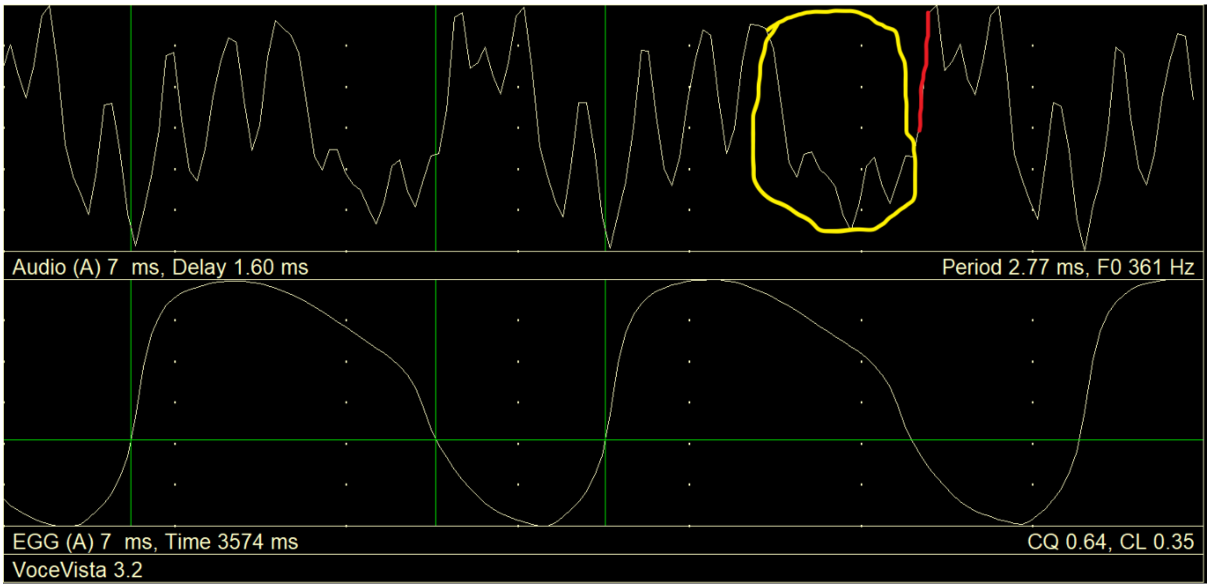
1) This view shows the EGG contact quotient history. The trace of the line moving along the horizontal x axis can show the stability of the signals being received by the EGG. In simple terms, the steadier the line, the better the stability of the EGG information. So for example where the line appears somewhat jagged (above the encircled number 1) this probably indicates that

contact between the EGG electrodes and larynx was unstable and signals will not be of useful quality from such a section.

2) The colour spectrogram (encircled 2), as discussed above in relation to Figure 3.3.1.

3) The voice source waveform as received by the microphone (encircled 3), not yet adjusted so as to be synchronised with the EGG signal (shown in panel marked with encircled 4). It is possible to see (in Figure 3.3.4 below) within the repeating cycles of the signal where the audio dies away during the opening phase of the glottal cycle (marked with yellow circle), which is followed by a sharp rise in the signal (marked with red line) denoting the rapidly closing phase of the glottis.

Figure 3.3.4 Shows enlarged Audio and EGG from Figure 3.3.3

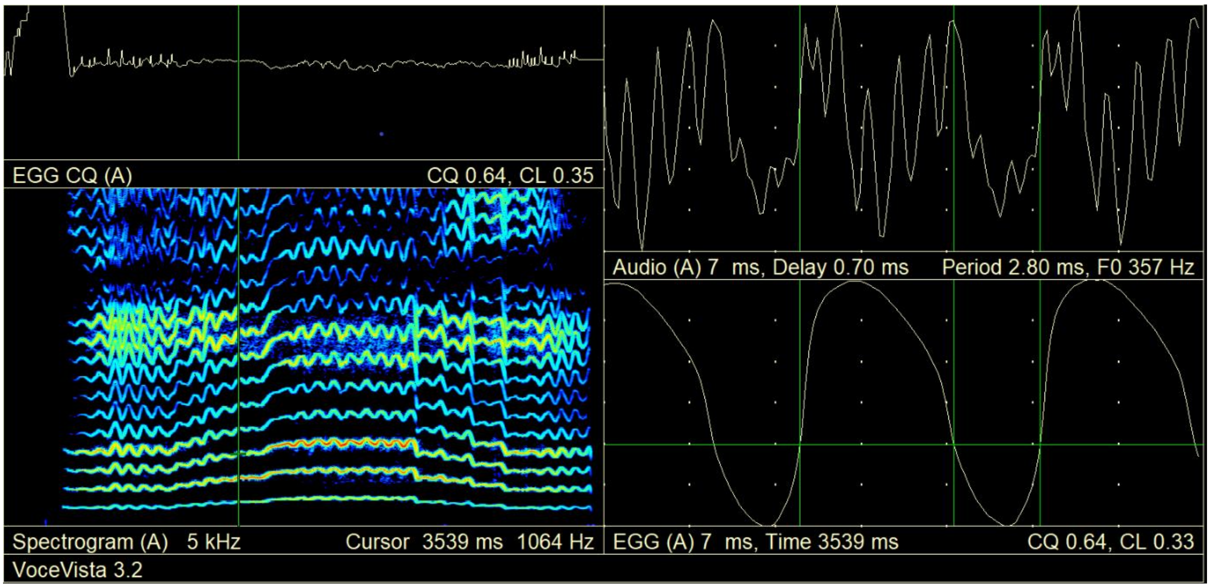


If it is necessary to see more glottal cycles this can be achieved by resetting the audio segment length (here set to 7 ms). The current setting is shown at the base of the upper left quadrant of the screen.

The delay setting shown of 1.60 ms is too high for the position which the headset/mic employed for the recording would normally cause. A distance of approximately 30 cm between glottis and microphone would create a delay of c.1 ms. This basic information is useful in the initial judgement of adjusting the delay setting.

4) Returning to Figure 3.3.3 the EGG signal is shown in the lower right quadrant of the screen (marked with encircled 4). The polarity of the signal is evidently correctly already set, since the rapidly rising slope of the glottal closure is seen to the left of each glottal cycle, followed by the gentler descending slope showing the gradual opening of the glottis. In order to set the correct delay between audio and EGG signals it is necessary to align the rapid, steeply rising slope of the initial closing of the glottis and the sharply rising moment in sound pressure in the audio which follows the visible slow fall in pressure. The correct adjustment is shown below in Figure 3.3.5

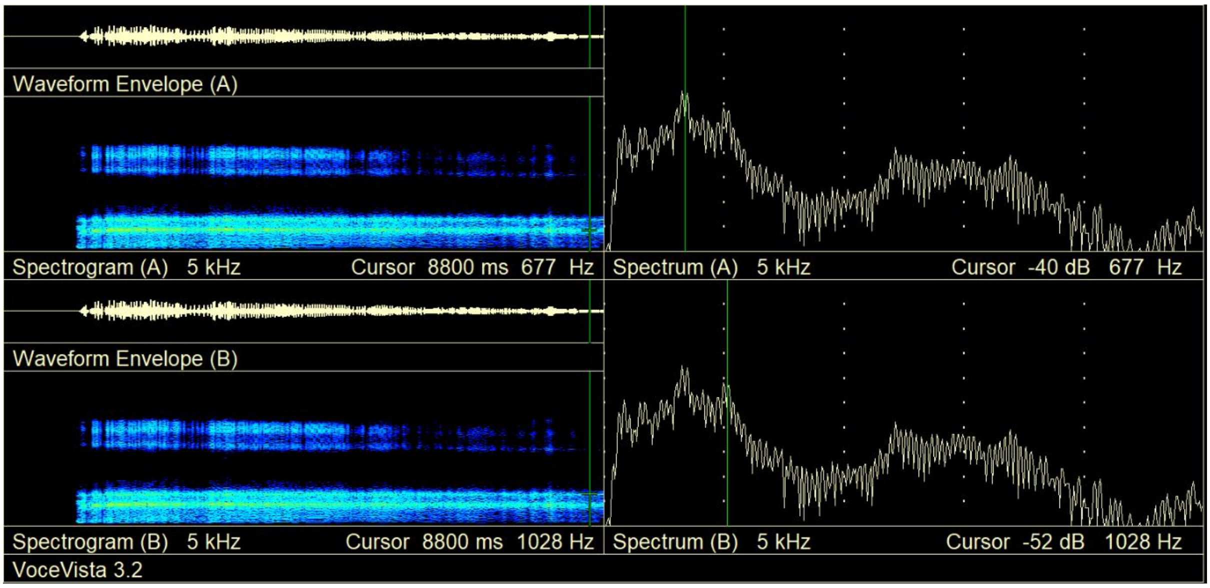
Figure 3.3.5: Showing corrected delay between audio and EGG signals



The green horizontal cursor can then be adjusted for fine tuning of the contact quotient using the detail of the glottal cycle to help arrive at the best possible setting. This aspect requires experience and skill on the part of the user.

Figure 3.3.6 below, shows the very different appearance in the spectrogram and power spectrum views when the recording is of non-periodic 'vocal fry', sometimes referred to as pulse register/phonation or creaky voice (see Miller 2008, p.23). This occurs when the phonation is loose and is devoid of periodic phonation. Figure 3.3.6 shows the writer using vocal fry with the vowel [a].

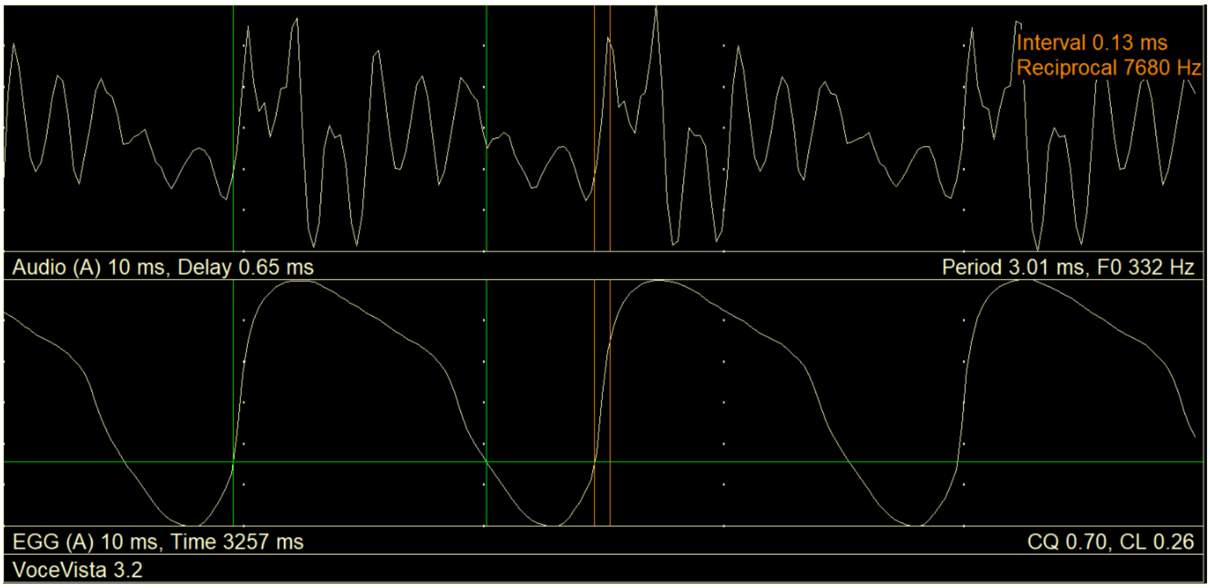
Figure 3.3.6: Vocal fry, using comparison mode



There are no partials/harmonics visible in the spectrograph or power spectrum. The irregular series of audibly separate 'clicks' made in this way make it possible to see which frequencies the vocal tract tends to amplify (the formants of the tract) and is a useful, sufficiently accurate way to establish the first two formant frequencies of vowels. This is only useful if the tract and laryngeal position retains the position which the desired vowel uses when actually singing. Not all singers are able to easily produce this type of phonation, though most can with familiarity/practice. In Figure 3.3.6 the screen view is divided to show, using the green cursor in the power spectrum, that in (A) f_1 is c.677 Hz. In the (B) view the cursor has been moved to show that f_2 is c.1028 Hz.

It is also possible within *VoceVista* to measure the initial closure rate of the vocal folds. This is done using by measuring the steep part of the rising slope of the EGG signal, at which point the vocal folds are closing. Figure 3.3.7 is taken from a recording made by the writer showing two complete EGG glottal cycles occurring during the frequency of a sung E4 on the [a] vowel (lower part of screen, which has been expanded for clarity).

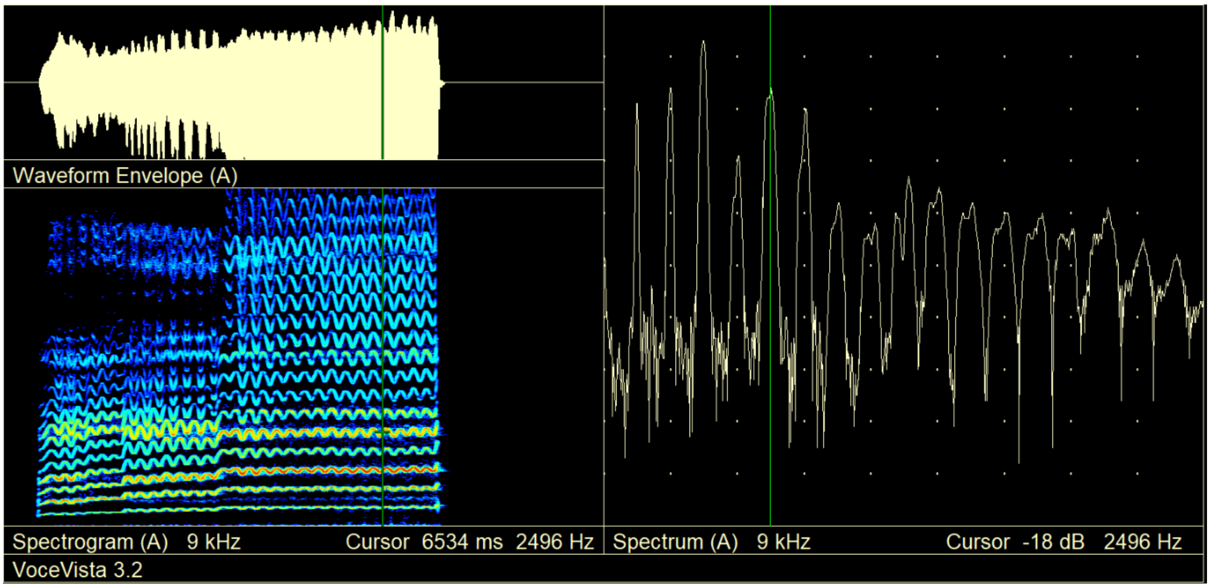
Figure 3.3.7: Audio and EGG expanded for clarity



The left orange cursor is positioned to coincide with the commencement of the steepest part of the glottal closure slope and the right orange cursor is placed at the point in the upwards slope where the steepness begins to become less marked. The programme provides an automatically calculated measurement of the time taken by this rapid rise and displays this in the top right-hand corner, shown as ‘Interval 0.13 ms’. Training and experience is needed to use this feature.

As mentioned above in the explanation of the Audio Envelope view, the white shape representing the audio waveform envelope should not overlap the edges of the provided box in which it is presented. Where this does overlap the edges this could potentially indicate over-recording. It is possible to check that the signal in any one individual recorded example is usefully valid for consideration by examining the higher harmonics beyond the usual 5000 Hz upper limit. If there were serious distortion present because of over-recording it would be probable that there would be inexplicably strengthened high harmonics in the extended range of 5000 – 8000 Hz. Within *VoceVista* it is possible to perform this check by raising the upper frequency limit shown in the spectrogram and power spectrum views. Figure 3.3.8 shows a recording (Professional Tenor 5, singing a scale on [a] from B4 – E4) where the sustained B4 appears to be over-recorded. In this view the upper frequency setting in the spectrogram and power spectrum has been extended to 9000 Hz, but there is no sign of higher harmonics having been strengthened by distortion in the recording. This pitch (B4) in a ‘heroic/spinto’ tenor voice is very strong, often used as a climactic note in repertoire. The signals show a marked increase in amplitude once the B4 is attained, but this is not surprising for such a pitch. The higher harmonics become more visible between 5200 Hz and 7600 Hz but there are no inexplicable levels on particular harmonics which would might indicate distortion from over-recording.

Figure 3.3.8: Professional tenor (5) B4 – E4 scale [a]



3.4. Method and field techniques

The methods and field techniques used in collecting examples for this study developed as the study proceeded. The 'participant observation' element (as discussed in Wolcott, 2009), required decision making which called upon the writer's background as singer and vocal pedagogue. That this is so again underlines the qualitative nature of the project.

Having become accustomed to using spectrographic information for pedagogical underpinning it seemed an easy and logical step to develop a library of examples from the Conservatoire students who were both available and willingly enthusiastic to contribute to such a library. This led to a more orderly and developed method for collecting source material and for dealing with the arising ethical issues. This was already in place when the current project was conceived. Once the project was in progress students were selected so as to provide a reasonably varied overview of undergraduate activity. The sung examples were collected sometimes during lessons, but more usually during specifically arranged appointments which were devoted to the recording of examples. These sessions were normally no longer than one hour in duration and often shorter. Where it seems relevant or important that the reader knows the chronology of recordings, this is described in the case studies of the students.

Post-graduate example files were also collected. The range of these was very wide in vocal technique attainment levels, experience, and prior training (with ages ranging from 22-36) and accessibility was also more complex for those students. It was therefore decided to exclude this group from the current project. (It is hoped that this material will become the focus for a separate future study.)

The examples garnered from professional singers was enabled by a period of three months study leave from the Royal Conservatoire of Scotland. It was decided that only singers who were working in 'A' category Germanic (ie Germany, Austria and Switzerland) opera houses and in equivalent opera houses in Holland, Italy, Spain, France, USA and the UK would be approached. (In Bunch and Chapman, 2000, these singers are in category 2.) This was to ensure that the example material was at a high level of experience which could be defended as professionally successful and worthy of serious consideration. Singers with whom the writer had professional links were initially approached via email and subsequently by telephone to establish whether they would be willing to participate. Some of the singers have extremely distinguished international careers of note extending over more than twenty years duration. (More detail about this is given in the relevant sections later.) This material led to the publication of an article in the Journal of Singing (Robertson, 2014), entitled ‘Using the Second Formant to Achieve Professional Classical Quality in the Male Singing Voice’.

All files of examples have been stored electronically in folders and subfolders. These are stored on two private personal computers and in two separate back-up systems, all of which are only accessible to the author and protected by passwords. Even in that context the name of the individual concerned was reduced to initials. A separate key file was created only accessible by the author, which listed the names of participants.

For each participant the project was described fully and all arising questions were answered before any examples were recorded. All participants were required to sign an ‘Informed Consent’ form (See Appendix 2 p. 316.). The form covered the purpose of the study, procedures, risks/discomforts, benefits, confidentiality, publication and the right to withdraw. A copy of each was retained and the participant was offered a copy.

3.5. Protocols for recorded examples

These needed to be flexible if the main research question was to be truthfully served. Whilst it seemed tempting to devise a sequence of vocal exercises (whether scales, arpeggios, other specially composed or repertoire derived material) and ask each singer to sing exactly the same material this would have been unlikely to have provided material which would have valid integrity for comparisons to be made and representative conclusions to be established. This is because what one singer would find tiring and taxing, which might result in significant effects on the quality of examples (caused for example by tightening pharyngeal muscles), another might find far more vocally congenial. The singers were not all of very similar voice type and Fach, with similar tessitura comfort zones and similar vocal stamina. Therefore, requiring each singer to work through the same vocal sequence of material could provide seriously misleading results. As the aim of the study was to understand better how singers deal with the challenge of the [a] vowel in singing through the passaggio and beyond that in pitches which ascend to the higher range, it was essential that each singer felt that what they were offering was, in their opinion, representative of their usual vocalism.

All singers were asked to sing at a level which they considered to be their comfortable mezzo-forte level. Singers were asked to conceptualise the short scales and arpeggios as though they were moments occurring in an aria. It was emphasised that the aim was to record what the singer would normally sing if such material was required as part of a composition. This was important, since singers were being asked to sing on the [a] vowel. More explicitly, and to make the point clearer, it was explained to each singer that if they would usually modify the [a] vowel in any way as they sang through a particular part of the range they were to continue to do whatever they thought ‘normal’, rather than attempt to stick rigorously to the requested [a] vowel.

In the recording sessions with professional singers each singer was asked if they would be comfortable to sing through a sequence of short scales or arpeggios (usually covering the range of a fifth) ascending and descending, which traverses the passaggio zone and enters the upper voice range. Mostly the focus was on the [a] vowel in making the recordings. Many of the singers commented that they felt this was the most challenging vowel to manage in the passaggio and upper voice and were keen to offer examples on other vowels, especially the [e] vowel.

Each session with the professional singers began with a general description of the project and an explanation as to why the writer was undertaking it, and what it was intended to achieve. The 'Informed Consent' form was read, discussed as necessary and signed. Thereafter the equipment was explained, with headset, the EGG neck strap and *VoceVista* briefly demonstrated. Most of the professional singers were interested in what *VoceVista* could display, but this could only be briefly discussed. It was interesting that when asked if they wished to watch the display whilst singing, none of the professional singers wished to do so. Some singers wanted to briefly warm up if they had not had an opportunity to do so, but this generally only took about 2 – 4 minutes. Once the singer was fitted with the equipment, including establishing whether it would be possible to obtain EGG signals, a few short trial recordings were made so that the singer could acclimatise to the equipment and appropriate levels were set for optimum audio and EGG using the Tascam US-122 MKII USB audio interface.

The singer was then given a key and initial pitch from a piano, which in most venues was available, but where one was not available (or the piano was not at A=440 Hz) an electric piano was used. The requested short major scales and triads, ascending to the dominant and then returning to the tonic were each recorded separately. Tempo was decided by the singer, though if advice was requested, the writer advised a moderate pace which made the task comfortable for the singer. For those who wanted more specific direction a tempo of crotchet = metronome mark of 100, (where each note in the scale/triad was a crotchet) was suggested. The vowel requested was the

Italianate [a] vowel, (written by phoneticians as [ɑ]). The dynamic level was suggested as a comfortable mezzo-forte, The examples commenced in a range identified by the individual singer as middle voice, so for tenors this meant commencing on a pitch around E3 or F3 and ascending from that point. Each recorded example was visually inspected as it was recorded to check that levels were appropriate. After each example the singer was asked if they were satisfied with the quality of the example. If they were not, multiple versions were recorded until the singer was content with their quality in the sung example. Examples were not replayed to the singer, but the singer was able to decide if they judged their singing representative of their vocalism. Singers are generally very self-critical and highly self-aware so this seemed a relatively ‘normal’ procedure for the singers who are all professionally reliant on their own self-perception. Subsequently a new key/starting pitch for the next example was established, a semitone higher than the previous one, and the recording process re-started. In this way multiple short examples were recorded until the singer reached the top of their professionally viable range. The atmosphere in recording sessions was relaxed and where a singer preferred to sing a longer scale to the octave or ninth, this was accepted, as were arpeggios to the octave. A few singers, especially Tenor 4, tended to give multiple versions of the same scale/triad within one recording, making some of those recordings slightly longer than the average recorded length of examples (usually c.5-10 seconds including the brief silence before and after phonated example).

Though for most singers the position of the headset and microphone remained static, some singers moved the headset slightly between examples, and occasionally took the headset off entirely before replacing it to be ready for the next recording. All examples were recorded separately rather than in sequence within one recording. This was necessary so that the delicate synchronisation of audio and EGG could be individually adjusted within each recorded example. It also meant that the recordings do not include hearing the pitch given, nor chat surrounding the recordings. Each file was labelled with the pitches sung and the date of the recording and then immediately stored in a file dedicated to the individual singer.

The author visited each singer in a location chosen by the singer. This meant that recordings were made in music studios, rooms provided by opera houses, and the singer's own home music room. It was important that each singer felt as comfortable as possible in these sessions. Consequently, singers were allowed/encouraged to comment upon their own examples, and re-record any with which they were dissatisfied. If a brief rest or drink was needed or requested this was of course permitted. Some singers sang phrases from repertoire which illustrated how they treated the [a] vowel in that context. It was noted that singers were often quite judgmental about their example recordings. Where their comments seem important they are remarked on in Chapters 4-7. To exclude such material would be to offer a deliberately less complete view of the work of the singers.

It was found that unfortunately a number of the professional singers were not comfortable to offer vocal non-periodic phonation (Miller et al, 1997), 'fry', on vowels and tended to prefer not to attempt that. Also, many of the opera singers had substantial beards extending down the neck-line, or substantial subcutaneous insulation making it not possible to get clear EGG signals. If the singer felt that the neck strap and EGG electrodes externally touching each side of the thyroid cartilage seemed to impede the sense of singing 'normally', these were not used. Where it was possible to use the EGG with clear resulting signals this is referred to in the appropriate sections.

In general, the student group seemed more familiar with electronic feed-back and computer-based interaction. They were all able to provide both audio and EGG examples, though it may be noted that some of the oldest examples which were taken in 2008 and 2009 did not have EGG. These are still interesting sources since they show clearly aspects of the resonance aspects of the singing in the spectrographic information yielded. Unlike the professional group of singers, some of the examples from the student group were selected from material which had been recorded in the flow of their regular singing lessons. Being able to access this material made it possible in some instances to witness changes over time in vocalism and resonance management skills. However, most of the material was recorded at arranged meetings in teaching studios in the Royal Conservatoire of Scotland. Some students were comfortable using non-periodic phonation ('vocal fry') and where this provided useful relevant information it has been reported and discussed.

During the specifically arranged recording sessions the project was explained (as described above for the professional singers) and the 'Informed Consent' form was read, explained and signed. If a student singer was unfamiliar with the equipment and *VoceVista*, this was introduced and explained, with the writer giving a short demonstration to show how each aspect functioned. The student was then fitted with the headset/microphone and the EGG neck strap, taking time to ensure that both were comfortable, and that the student did not feel that their normal vocalism was impeded in any way. The instructions and procedures for collecting the individual examples were the same as for the professional group of singers. Each of the examples was recorded separately. The student was asked to sing a short scale to the fifth, and/or a major triad, using the long Italianate [a] vowel. The suggested tempo was simply 'moderate', but in practice any tempo chosen by the singer was accepted. A starting pitch and key for each example was given, then the *VoceVista* recording activated. At the end of each short sung example the recording was stopped. Again, as with the professional group of singers, if the student wished to make multiple versions of the same material this was permitted. In all cases, where a student volunteered a slightly different version of a scale or triad these were accepted. Also, where students sometimes said they felt more comfortable/familiar singing a full scale (to the octave or ninth) or full arpeggio, these were also permitted. The area of pitch explored was from middle voice into the upper range, with students offering suggestions for starting pitches. It was an over-riding aim of the these recording sessions that the student should feel relaxed and not as though taking some kind of examination. The writer encouraged the students to chat freely about whatever they wanted to mention. In this sense the sessions with the students were slightly more interactive than during the professional singers recording sessions. Some very interesting and worthwhile material was offered when students made suggestions themselves about trying out sung material which was not simply a scale or arpeggio. Similarly, the students were often very aware of using vowel adjustments/modifications and were uninhibited about expressing their self-assessments. Where such material has been used in the relevant chapters it is explained and discussed.

Collecting the examples of sung scales and arpeggios on the [a] vowel through the passaggio and upper voice range was similar, but in only a limited way, to conducting a series of interviews. There were sung equivalents of the ‘ers’ and ‘ums’ which occur in speech. Some examples commenced, stopped, and recommenced as the singer coughed, cleared the throat of phlegm, or simply wished to re-start. ‘Opinions’ (ie the sung examples) were revised on the spot in that singers asked to repeat recordings if they thought that they had sung in an unrepresentative manner.

No judgement or comment of any kind of the singing was offered or implied by the author during the recording sessions, beyond the repeated question, ‘are you happy with that recording?’. Only once a recording session was completed was there any further discussion about the characteristics of what had been recorded.

It was impressive that even the most well established and internationally famous artists were curious to explore what the signals displayed in *VoceVista* revealed. The time available meant that such conversations were generalised, especially as most of the professional singers were completely unfamiliar with spectrographic displays.

3.6. The process for scrutiny

All the short, recorded files of scales and arpeggios were examined in a number of ways. Some of these required more background skills for the observer than others.

It was important that the files were listened to so as to discern if there were changes in the target vowel during the particular example/recording. Formants filter the spectrum of partials produced by the voice source and in so doing produce differing vowels. If a vowel change is audible this must be related to changes in formant position, especially formants 1 and 2. As this study was very much concerned with the way in which singers coordinate formants and pitch when singing the [a] vowel, this issue was important. Even when using the International Phonetic Alphabet symbols to describe vowels, describing vowel qualities with words or symbols remains one step away from the actual sounds produced. Though there will always remain the possibility that some will disagree with observations about vowel quality, the author can claim over forty years of experience as a vocal tutor and singer working at high professional levels.

In some cases, though the perceived vowel remained an [a] and would be understood as such by an audience, it could be heard that the vowel was either slightly rounded towards the [ɔ] back vowel, or towards [ʊ]. There were some moments where a singer 'leaned' the [a] towards a frontal vowel such as [ɛ] and even [e]. Any such audible changes of vowel are mentioned in the presentation of the examples from both professional and student singers.

The colour spectrogram was carefully inspected for each sung example. This was a very useful way to see quickly and clearly the relative strengths of partials within one example, since it showed the entire length of the sung scale or arpeggio. As it is a natural human tendency to focus on what is first noticed, it was necessary to return to further observation of each colour spectrogram on many occasions rather than just once. This proved valuable in finding significant details.

It is possible within *VoceVista* to choose a setting which displays only the colour spectrogram rather than multiple screen displays. Using this setting and a large display screen enabled observation of detail which might otherwise have been missed. Remarks offered about comparisons concerning the relative strengths of partials derived from observations shown by the colour spectrogram and the power spectrum are only valid within one recorded example and never between examples. (The absolute recording levels in the differing examples vary significantly from one to another.)

The frequency range setting chosen for the colour spectrogram and power spectrum was usually 0 – 5000 Hz. The upper limit is shown in the lower left side of the screen in views when either or both the spectrogram and power spectrum are in view. For a few recordings the waveform envelope window showed that a file could be slightly over-recorded, with the possibility therefore of some distortion or 'clipping' in the signals. This was suggested when the white area of colouration occupied by the waveform envelope in the upper left window appeared to extend to the edges of the box provided. In such cases, the file was examined carefully with the upper Hz level changed to 8000 Hz. Were there to be significant distortion in the signal one would have expected unusual, and otherwise inexplicable, spiking of high partials beyond the 5000 Hz range. This was not found to be the case in any of the recorded examples offered. It was therefore concluded that the information shown by the relative strength of partials in such recordings still had validity.

Inspection of the colour spectrogram often prompted the need for the second stage of looking to see the detail of the relative strengths of partials visible in the power spectrum. Placing the green cursor available anywhere in the colour spectrogram brings a detailed view of that instant of the sound in the power spectrum. The usual default setting for this was with the power spectrum set to 100 milliseconds for averaging. This gave a detailed view for further observation using the cursors which are provided for measuring pitch and strength of partials. In addition, every recording was observed with the power spectrum averaging set to 300 milliseconds (PS300ms) which provides a more realistic representation of how the sound would be perceived by the human ear in real time (Miller, 2008, pp.8-9). At this setting the averaging encapsulates at least one complete vibrato cycle and gives a more realistic representation of the comparative strengths of frequencies which the ear hears in real time. It is not possible with such a setting to retain the power spectrum scrolling facility enabling the user to halt at any instant and retain a view of the power spectrum at that moment. It was therefore necessary to view each recording many times to watch the power spectrum in real time and form a reasonably accurate opinion on what to present in a screen grab representing the relative strength of partials when averaging was set to the higher level. This is referred to each time it is used in the chapters on the professional and student examples.

Where the strength of partials is compared using decibels these were measured using the cursors within *VoceVista.* In all instances the aim has been to select moments which illustrate an important point, rather than simply the most contrasted levels detectable.

The coordination of the electroglottogram (EGG) and acoustic signal needed to be set up individually for each recording session and checked also for each scale or arpeggio recorded. This is necessary because the arrival of the signal from the electroglottogram in the computer processor is almost instantaneous, whereas the accompanying acoustic signal has had to travel up from the glottis, through the length of the vocal tract and arrive at the microphone before it is then passed electronically to the computer processor. There is therefore a micro-delay involved[11]. This is a skilled process which requires experience[12].

Once the delay setting for the coordination of the EGG and acoustic signal is established, *VoceVista* shows the likely resultant contact quotient. The amount of time the glottis is closed to the passing of the air stream is expressed as a percentage of the entire single glottal cycle. Where clear signals were obtained these figures are mentioned and discussed.

[11] The delay setting needed repeated checks because if a singer inadvertently adjusted the positioning of the headset microphone, the delay setting would be affected.

[12] The rising slope of the initial sound from any one cycle being generated from the glottis is coordinated with the rapid rising slope of the moment where the vocal folds contact one another, thereby closing off the air flow for an instant. The writer received extensive training in making this judgement over a period of several years, dating back to 2008.

Using a screen which shows only the EGG (therefore visible in more detail) it is possible to establish the probable speed of the initial closure rate. This is calculated by *VoceVista* by placing the two orange cursors at the commencement of the initial rapid rise in the EGG signal, and the second cursor at the point where this rise begins to level off slightly, as shown in Figure 3.3.7, above. Where the closure rate seems faster than is usually encountered this has been pointed out. Sundberg states (1987, p.79) that, '…when the closing rate increases, the dominance of the higher overtones is increased in the spectrum'. It was therefore thought worthwhile including relevant data from examples, especially since this is an area of current research (being undertaken by Miller and Rizterfeld, as yet unpublished). It was necessary to examine the EGG and acoustic signal in conjunction with the spectrographic views for the whole length of each example in order to establish whether there were points of interest arising. Though in practice this was a very time-consuming procedure it was central to the observation and process of scrutiny which was employed for this study in order to address the main research question, using a method which offers some objective information for interpretation.

3.7. The selection of examples

It will be apparent from the fore-going information that one of the challenges of the study, since it intended to enquire about the variety of responses in professional and student singers to the [a] vowel in the passaggio and higher area of the voice, was the need to achieve a certain 'critical mass' in terms of sheer quantity of examples. Such a large quantity of raw data needed selective distillation based on criteria serving the research questions for presentation in the chapters on the professional and student examples, to avoid excessive length and lack of focus. Yet at the same time it was necessary to avoid the temptation to present examples which could make conclusions seem neatly narrow. If the real answer to the research question were to be partly or wholly foggy, the project would need to show and state that, rather than offer an answer which achieved a sense of clarity which was warped by the selection of data.

In response to this, some questions were borne in mind whilst detailed observation was undertaken for each recorded example file.

- Did the example exhibit characteristics consonant with already known and reported classical voice coordination?
- Were there characteristics which appeared unconventional and which are thus far not reported. What were they?
- Did the characteristics of the example relate in some way to voice-type and/or the repertoire base of the singer ('Fach')?
- Did formants assist the aesthetic and functional aspects of the voice in the example? How?
- Was there evidence of the singer having chosen to use particular characteristics in the coordination?
- Was there any aspect of the example(s) which could suggest further research areas for future exploration and which would inform the current research question?

3.8. Motivation and design

It might be useful here to recapitulate something of the motivation which generated this project and consequently the design for it. What was sought was clearer knowledge about singing the [a] vowel in the passaggio zone of male classical singers. It is clear from the acoustic facts that this zone of pitch presents coordination challenges for the male singer, because the [a] vowel has the highest first formant value of all the vowels[13]. Some common resonance management characteristics for this zone had previously been reported, most notably by Miller, D. (2000, 2008). This study set out to see how consistently professional singers deal with the passaggio [a] vowel challenge, and secondly how this may relate to the development and coordination observable in student singers at Conservatoire level. To make a useful contribution to this field of knowledge it was necessary to deal with acoustic facts, finding a way of reporting those facts which was reasonably clear, keeping in mind the context of the singer and voice type. These were the driving considerations which generated the design here reported.

It has to be acknowledged that by far the biggest assumption which lurks behind this project is the acceptance of the expertise, integrity and probity of the author in guiding the many small decisions which had to be made in collecting the recorded material and subsequently making innumerable choices about what was significant for reporting and discussion. The post-positivist researcher would argue that ultimately it is never possible to present solely factual objective material shorn of the prism of the human minds which have devised the process of observation and analysis. The only comfort which can be offered to assuage any doubts in the reader is the existence, in their raw state, of the recorded examples. Individual examples could be made available for further scrutiny if the relevant singer were willing to permit this.

The use of *VoceVista* and the discussion and assessments of the acoustical aspects of the sung examples which *VoceVista* facilitates should not disguise the fact that this study is fundamentally qualitative. As subject anonymity would have been

[13] See Chapter 1.3, pp.8-9.

potentially compromised by offering the recorded examples in their raw state, *VoceVista* has offered a sophisticated set of tools which enable the study to discuss important aspects of the examples with a helpful level of precision which can be communicated to anyone who understands the nature of the information offered. It is hoped that the information offered above in section 3.3 and in the accompanying recording will assist the reader in the following chapters.

Chapter 4: Professional Singers:Examples

4.1. Introduction

A total of 286 recorded files was accumulated from 12 professional singers. These recordings were taken using the software programme *VoceVista* (VV). All recordings have clear spectrographic information and some had simultaneous electroglottograms (EGG), which this programme can coordinate with the spectrographic material. The quality of the EGG signals varied with differing subjects mostly as a consequence of beards and/or optimal/less optimal subcutaneous insulation. Where information is discussed which is derived from EGG signals, the quality of EGG signals was good, unless otherwise stated.

TABLE 1: PROFESSIONAL SINGERS

Singer 1. Tenor	Age 40-50	Jugendliche Heldentenor
Singer 2. Tenor	Age 50-60	Charaktertenor (Character Tenor)
Singer 3. Tenor	Age 50-60	Lyric tenor
Singer 4. Tenor	Age 60-70	Lyric/Spinto tenor
Singer 5. Tenor	Age 50-60	Lyric/Spinto tenor
Singer 6. Tenor	Age 40-50	Lyric tenor
Singer 7. Tenor	Age 60-70	Mature Heldentenor
Singer 8. Tenor	Age 30-40	Lyric tenor
Singer 9. Tenor	Age 60-70	Charaktertenor (Character Tenor)

Singer 10. Tenor	Age 30-40	Charaktertenor (Character Tenor)
Singer 11. Bass-Baritone	Age 40-50	Lyric-Helden Bass-Baritone
Singer 12. Bass-Baritone	Age 50-60	Lyric-Helden Bass-Baritone

In considering this large amount of information in relation to the main research question (of how male singers manage the passaggio and higher range with special reference to the [a] vowel), three main areas emerge.

1) The area of pitch in the passaggio zone in which f_1 engages strongly with H2. ('Primo passaggio'[14].)
2) The area of pitch towards or at the top of the passaggio zone, where the influence of f_1 on H2 begins to weaken. ('Secondo passaggio'.)
3) The area of pitch in the upper voice which is likely to move beyond the easy coupling of f_1 and H2. (Beyond 'Secondo passaggio'.)

The tenors who provided examples represent a wide variety of 'Fach' types, ranging as they do from the heaviest and most heroic type of tenor, through the middle ground of big lyric voices to the rather lighter lyric voice type. The other group of tenors referred to by the German title 'Charaktertenor' cannot be appropriately labelled either heavy or light in vocal quality since they perform some of the most demanding repertoire, often competing with extreme orchestral forces and dynamic levels and with busy texts which have a relatively rapid syllabic change rate, compared with the

[14] The terms 'primo passaggio' and 'secondo passaggio' are explained in Chapters 1.3 p.10 and 2.1 p.20.

more sustained melodic writing of the lyric vocal category. (Since the classical voice is loudest when singing vowels, as compared to consonants, the more a vowel is prolonged the easier it is to be heard in auditoria. Rapid text changes the ratio of vowel to consonant time and may require voices which are 'brightly' projected in tone so as to be audible.) The big Heldentenor roles require both highly effective declamatory skills and sustained singing at loud levels. Overall, the tenor singers cover a very wide range of operatic and concert repertoire.

The two baritones in the group are both of the virile 'Helden Bass-Bariton[15]' Fach, singing demanding roles with wide vocal range and voices which are perceived as powerful with a complimentary balance of what is termed 'bright and dark' tone, ('chiaroscuro' in traditional Italian vocal descriptive terms). Both have sung substantial roles in Wagnerian repertoire as well as a wide range of Italian repertoire.

These vocal types are relevant to keep in mind, since the events of the male passaggio can be manipulated by skilled performers. In part at least, characteristics which can be identified may be the result of deliberate choice rather than the enforced result of physiological and acoustic laws.

4.2. 'Primo Passaggio'

This term is borrowed from Miller R., (1993), and is used here for convenience to cover the area of pitch in the passaggio zone where f_1 becomes highly influential on H2. The [a] vowel has the highest first formant value of all the vowels[16]. In classical singing the value of f_1 is generally lower than in everyday speech, because of the low resting laryngeal position adopted for classical singing. However, as will be seen

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[15] German spelling of this voice type.
[16] See Chapter 1.3 pp.8-9.

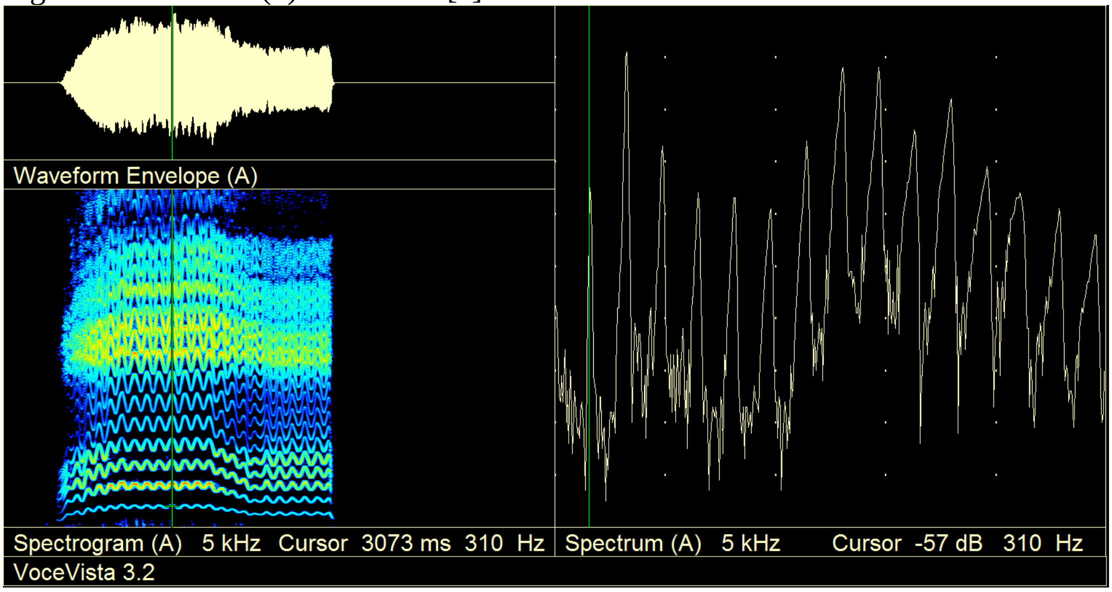
later, the Charaktertenor voices seem to employ a higher frequency location for f_1, which enables them to achieve qualities which are to some extent unique to that voice type.

Tenors numbers 1, 5 and 7 comprise one discernibly distinctive group in which the repertoire they sing appears to be linked to how the interaction of f_1 and H2 function in their voices. These voices sing the roles which are described as either Helden (literal meaning, heroic, for the German repertoire), or Spinto (literal meaning, pushed, in the Italian repertoire). Examples of roles would be the major tenor roles of Wagner such as Siegfried, Tannhäuser, Tristan, as well as Beethoven's Florestan and Strauss' Bacchus. In the Italian repertoire, example roles include Andrea Chénier, Ernani, Manrico, Don Carlo, Des Grieux, Radames and Otello.

In tenors 1 and 7 the [a] vowel is audibly slightly modified towards the [ɔ] vowel. This is less noticeable in tenor 5. The effect of this relatively subtle change is that the location of f_1 would be somewhat lowered. This group of three tenors show the earliest engagement (in terms of pitch as the voice ascends) of the fundamental (perceived pitch, also referred to as H1 as the fundament is the same as the first harmonic), with f_1/H2 tuning.

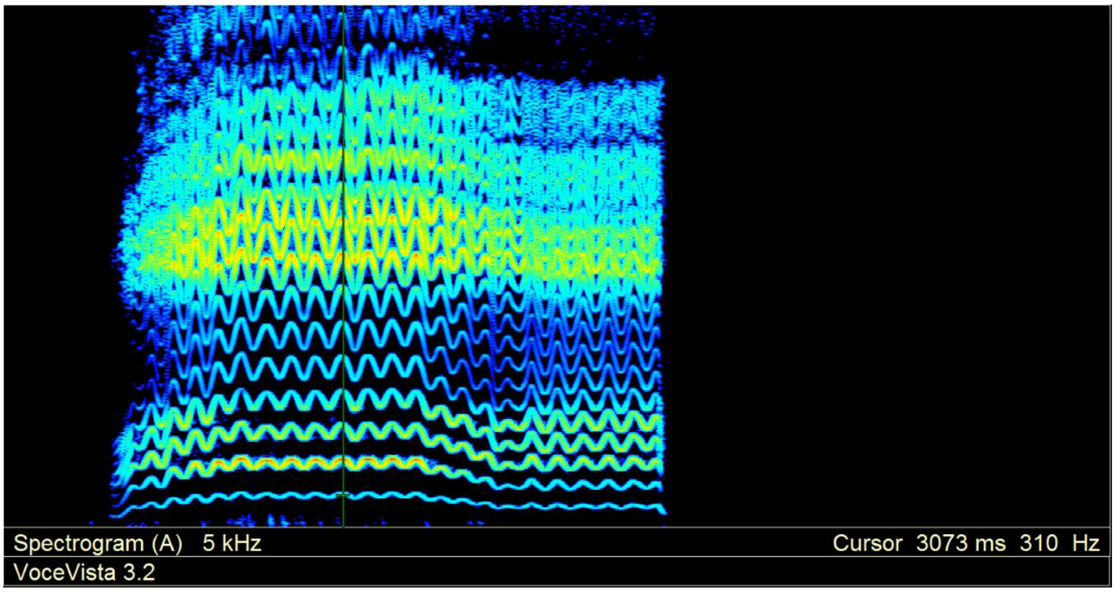
In Figure 4.2.1, Tenor 7 ascending from Ab3-Eb4 on [a] shows strengthening of f_1/H2 tuning from around 277 Hz (Db4) onwards, reaching maximum strength at 311 Hz (Eb4). It can be seen (Fig 1, vertical green cursor) that there is a large difference between H1 and H2, which is c.26 dB. Also clear is the very strong activity in the 'singer's formant' (SF) zone, especially here H8 and H9, which are only c.4 dB weaker than H2.

Figure 4.2.1: Tenor (7) Ab3 - Eb4 [a]



The colour spectrogram (enlarged view in Fig 2) shows that H2 is maximally strong when at the top of the vibrato pitch cycle, suggesting that the location of f_1 is somewhere slightly higher than the centre of pitch of Eb4. (Figure 4.2.2)

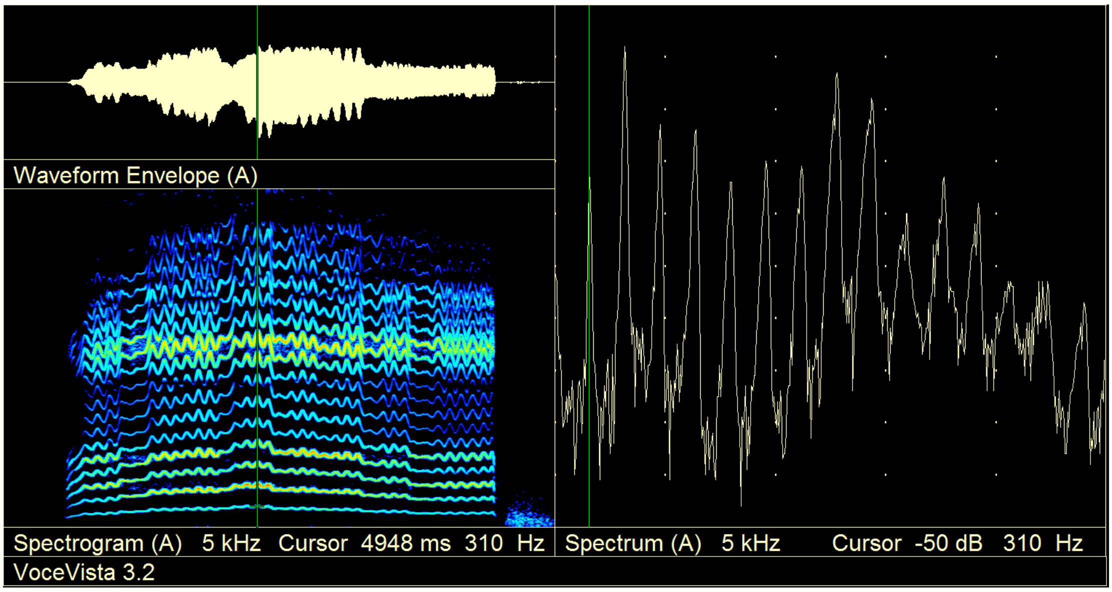
Figure 4.2.2: Tenor (7) Ab3 - Eb4 [a] enlarged



This could indicate a location for f_1[17] of somewhere between 650-c.680 Hz.

In Figure 4.2.3, Tenor 1 shows a very similar maximal strengthening of H2 being reinforced by f_1 on Eb4. At this point there is a c.25 dB difference between H1 and H2. As with Tenor 7 the [a] vowel in the recording sounds modified towards a more central, rounded vowel with aspects of both the [ɔ] and [ʌ] vowels. Again there are also strong partials in the SF zone.

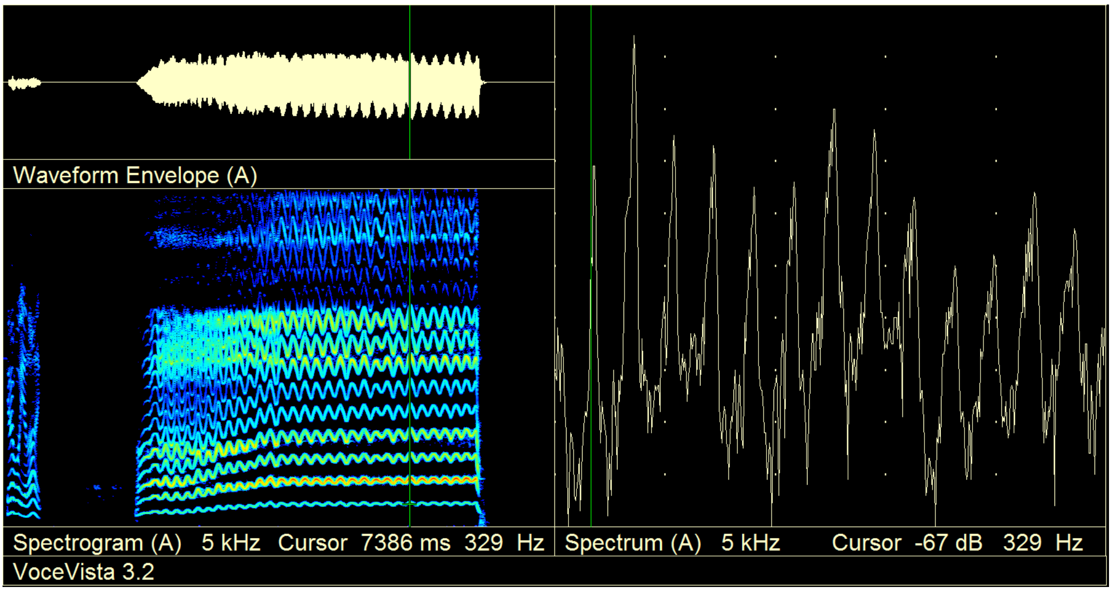
Figure 4.2.3: Tenor (1) Ab3 - Eb4 scale [a]



Tenor 5 (who sings the Spinto/dramatic Italian repertoire but has not been so active in German Heldentenor repertoire) shows his strongest moment of f_1/H2 coupling on E4 (Figure 4.2.4) a semitone higher than the two more ‘Germanic’ voices (so called because they sing more of the German repertoire).

[17] It is not possible to establish accurate formant values from inspecting strengths of partials. The strength of partials may indicate the approximate zone in which a formant lies. Where partials are closely packed and vibrato causes further pitch-sweep, it is sometimes possible to witness at what pitch a formant is most influential on a partial, but this does not necessarily indicate the accurate position of the formant itself.

Figure 4.2.4: Tenor (5) A – E4 scale [a]



The green cursor in the Power Spectrum is slightly to the left of H1 since it is placed at a high point in the pitch cycle produced by vibrato, rather than the exact pitch of E4 which would here be more towards the middle of the vibrato pitch fluctuation. Since the strength of H2 is changing as the vibrato moves up and down in pitch, any measurement of the dB difference between H1 and H2 is a little arbitrary, but at the point at which H2 is strongest (top of pitch cycle vibrato cycle) it is 25 dB stronger than H1.

Considered together these very substantial strengths of H2 give these pitches a very strong ringing sound which is described by singers and pedagogues as ‘open’. The necessary virile strength and powerful ring of tone which these operatic roles require is at this point provided in significant part by this resonance strategy. We shall see later that even though none of the singers who provided source material had either been trained in the use of formant tuning, nor knew of the theoretical basis for formant tuning in singing, they were very aware of the timbre which details in vowel choices could create. This suggests that a singer who does not couple f_1/H2 to this extent on the [a] vowel in the middle passaggio zone will not have the timbre in the voice necessary for the Helden/Spinto repertoire.

Similarly both of the baritone voices (who sing major Wagner roles in addition to the more demanding Italian ones) exhibit very strong f_1/H2 tuning in the passaggio with a differential between H1 and H2 in excess of 25 dB. For both singers 11 (Figure 4.2.5) and 12 (Figure 4.2.6) this occurs on the pitch of Eb4. The vowel [a] is not noticeably rounded or modified.

Figure 4.2.5: Baritone (11) Ab3 – Eb4 triad [a]

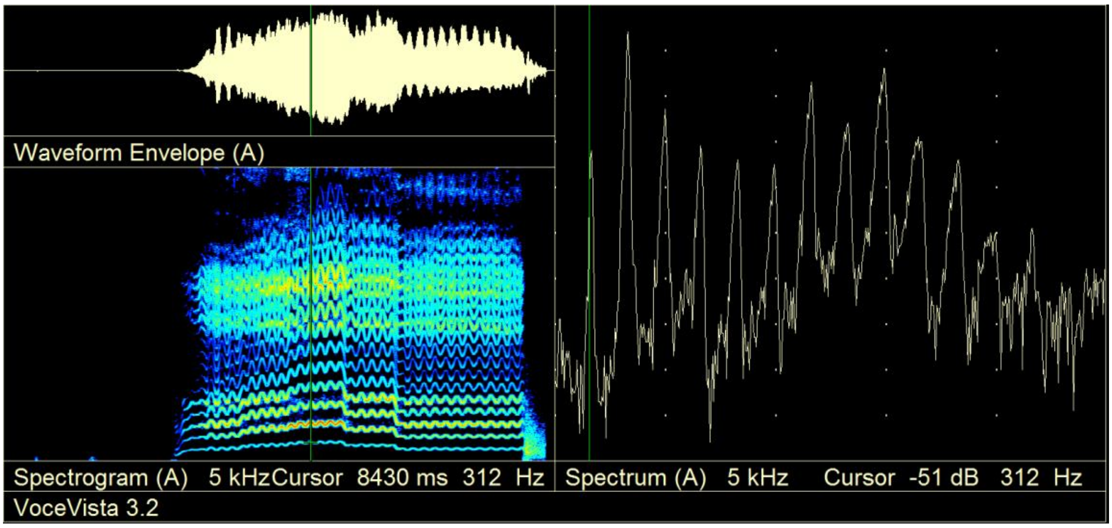
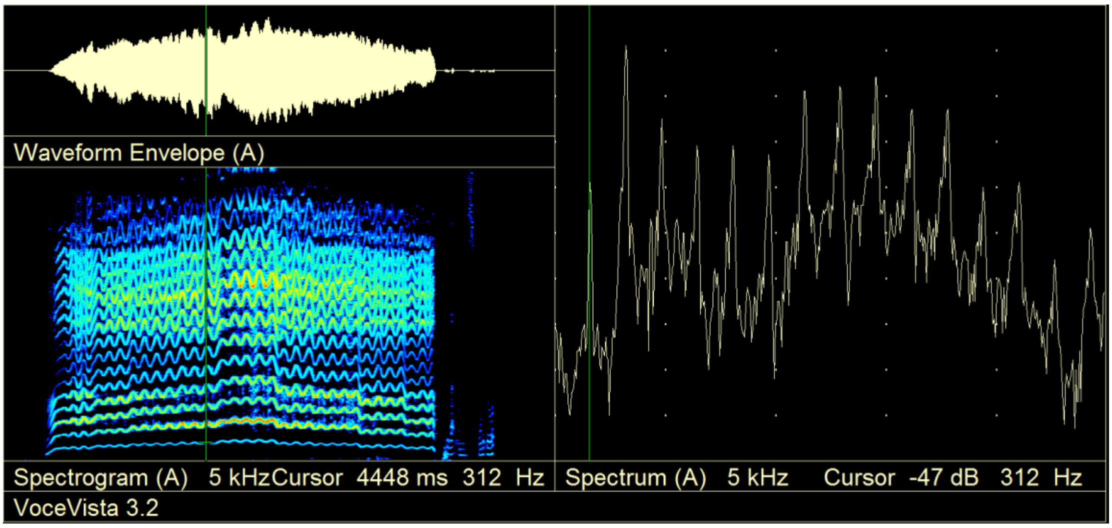
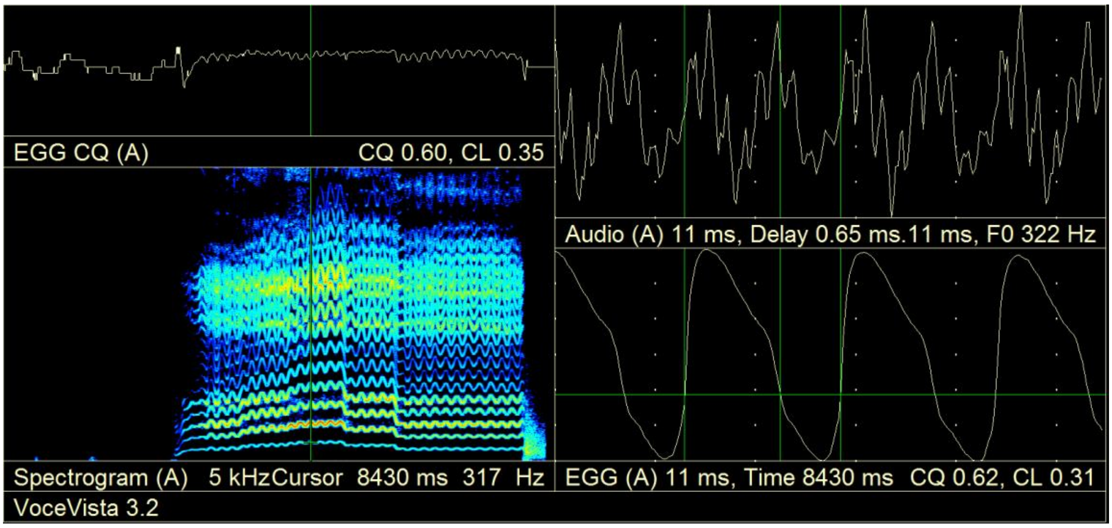


Figure 4.2.6: Baritone (12) Bb3 – F4 scale [a]



Singer 11 had very clear electroglottogram signals (EGG) and these when adjusted appropriately suggest a contact quotient of around 62%. (Figure 4.2 .7)

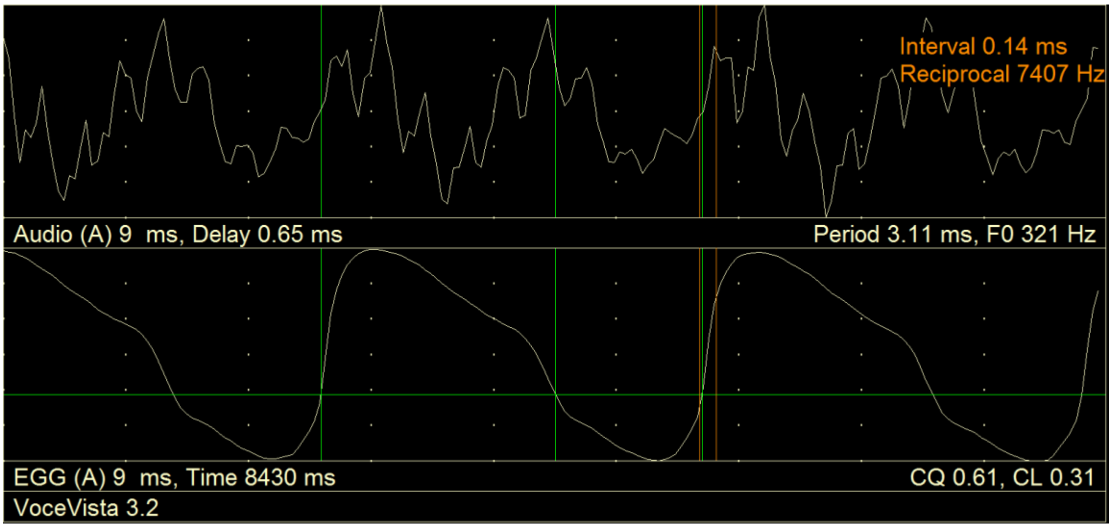
Figure 4.2.7: Baritone (11) Ab3 – Eb4 triad [a] with EGG



This is of interest since it will be possible to see if this figure remains stable, increases or decreases on subsequent pitches. Conventional voice teaching frequently refers to the upper range as ‘head voice’ and this is sometimes thought to be produced by a differing voice source. Any information which throws light on whether the voice source changes substantially or not may well have valuable pedagogic implications.

Also of interest is the apparently extremely rapid initial vocal fold closure rate of this singer. (Figure 4.2.8; the orange cursors shows how this measurement is judged.) Looking at the EGG signal at the same moment already described on Eb4, it is possible to see that initial closure is c.0.14 msecs, which is extremely fast. Though there is more research to be done in this area, there is emerging in current research some evidence which may link this rapid behaviour of vocal folds to elite professional classical singing.

Figure 4.2.8: Baritone (11) Ab3 – Eb4 triad [a] with EGG showing detail of EGG

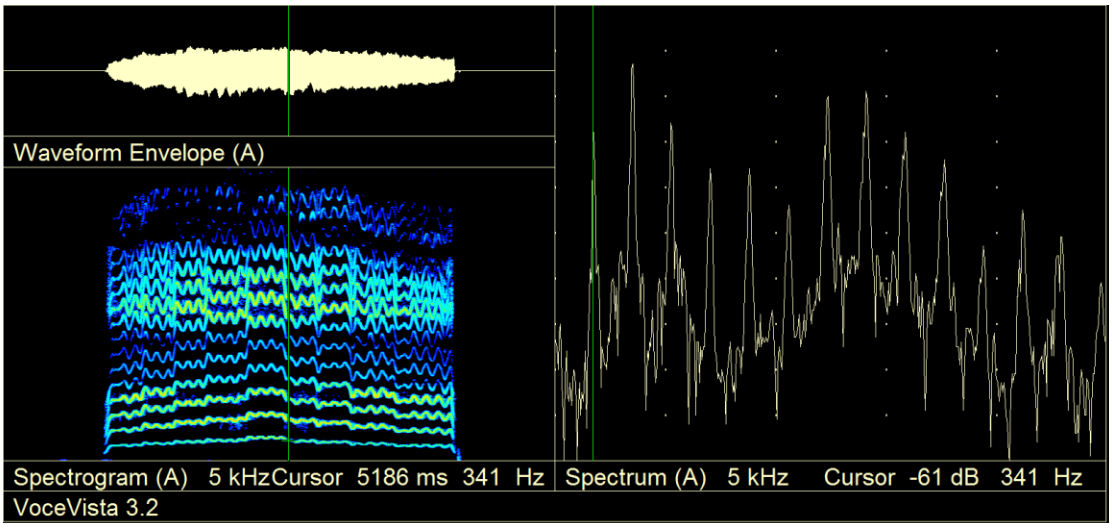


Tenors 3, 6 and 8 represent the 'lyric' Fach tenors. Tenor 4 is a highly renowned (and recorded), internationally well-known tenor who is particularly interesting since though he mostly sang the mid lyric repertoire, he was also very successful in some of the 'heavier' more dramatic Italian repertoire (eg the role of Radames). The information below which can be seen in relation to f_1/H2 tuning, shows a strong correlation with these career/Fach details.

With the lyric tenor voices though there is still clearly a strong engagement between f_1 and H2 on the [a] vowel around the centre of the traditionally-defined passaggio zone, the differential between H1 and H2 is markedly less than in the more heroic voices. In addition it can be seen that often H3 is not far away in strength from H2. In the more heroic voices H2 could be found as a more isolated peak of resonance in the region of the lower harmonics/partials.

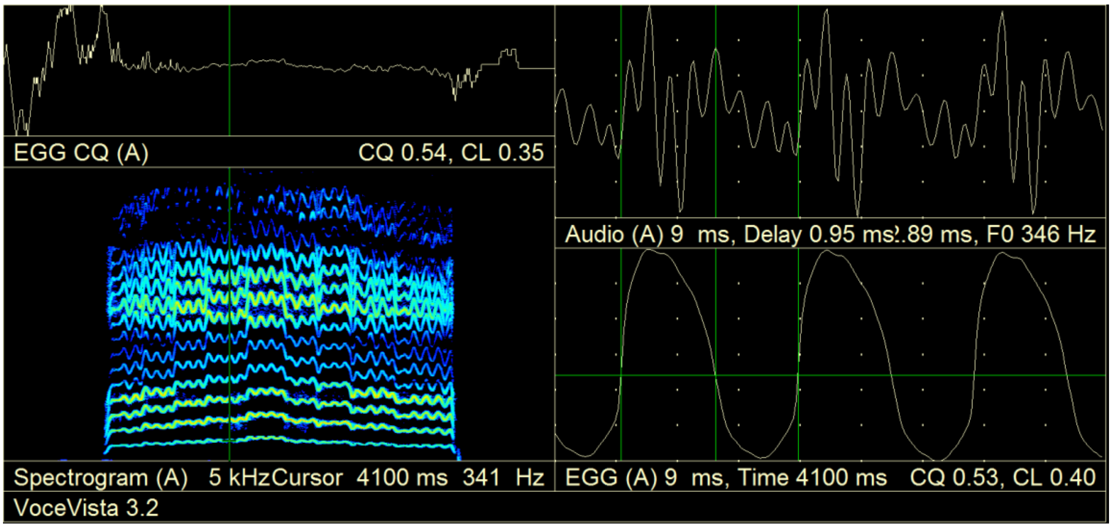
Tenor 3 typifies the group of lyric tenors and also had the advantage of very clear EGG signals. This view (Figure 4.2.9) of the strongest moment of f_1/H2 interaction shows a difference between H1 and H2 of 15 dB on the pitch of F4.

Figure 4.2.9: Tenor (3) C4 – G4 scale [a], green cursor at F4



The EGG signals suggest a contact quotient of c.53% (taken from an earlier but comparable moment of f_1/H2 interaction on F4, Figure 4.2.10). This is a fairly modest contact quotient compared to the much higher levels reported as frequently encountered in more robust voices singing the heavier repertoire (Miller, 2000, 2008). The figure of 53% makes sense for the repertoire which this particular tenor undertakes.

Figure 4.2.10: Tenor (3) C4 – G4 scale [a], green cursor at F4 with EGG



Similarly Tenor 6 exhibits the same differential between H1 and H2 on his F4, of 15 dB (Figure 4.2.11) even though his contact quotient appears to be markedly higher (Figure 4.2.12) at around 74% as compared to 53% for Tenor 6.

Figure 4.2.11: Tenor (6) Bb3 – F4 scale [a]

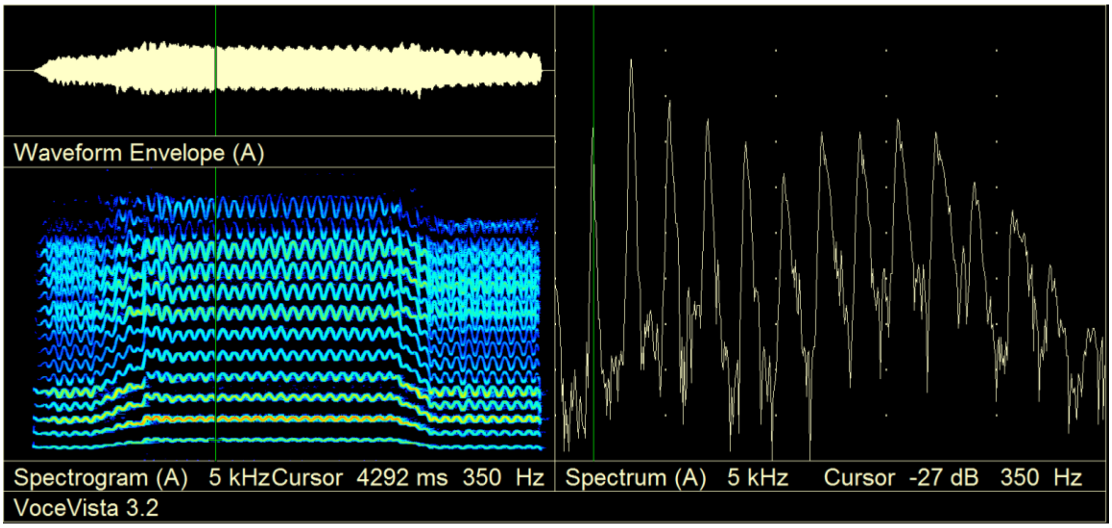
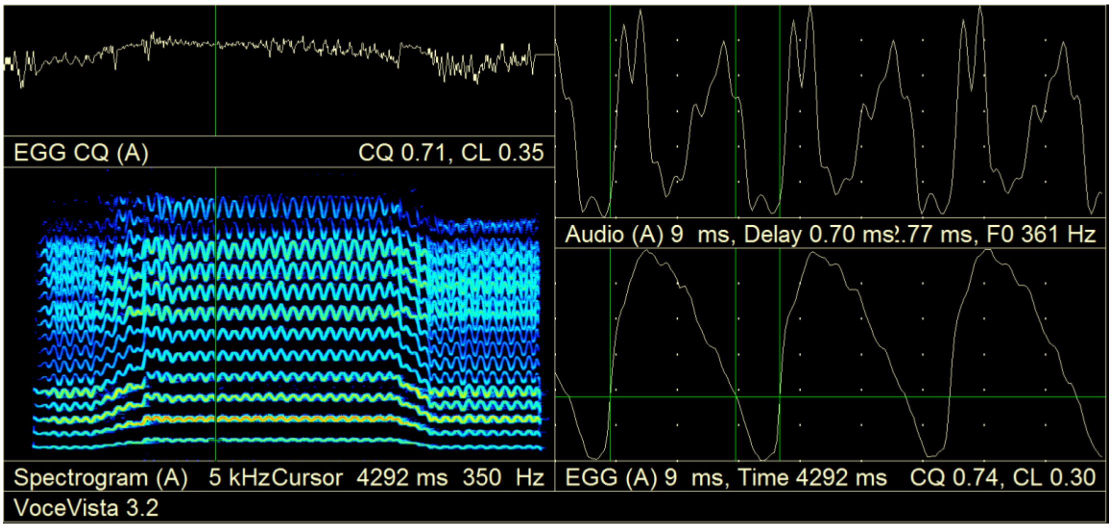


Figure 4.2.12: Tenor (6) Bb3 – F4 scale [a] with EGG



For both of these tenors, when H2 is at its strongest, H3 is not more than 5-9 dB away in strength[18]. This is in marked contrast to the substantial isolated strengths of H2 shown in the more heroic voices. This may in part be explained by the fact that the maximal engagement with f_1/H2 interaction in this second group of tenor occurs at the somewhat higher fundamental pitch (F4 as opposed to Eb4 or E4) which may mean that H3 would be nearer the position of f_2 in the [a] vowel. It will be seen shortly that the character tenors manage an extension of this aspect, which at first sight seems surprisingly extreme to anyone who has worked mainly with lyric or heroic voices**.**

Tenor 8 also shows the most effective interaction between f_1 and H2 on his F4, (though he retains this strength on H2 for F#4 and as high as G4, which will be discussed later). This voice is a little nearer the heroic/spinto category in repertoire and timbre. The H1 – H2 differential peaks at c.22 dB. (Figure 4.2.13)

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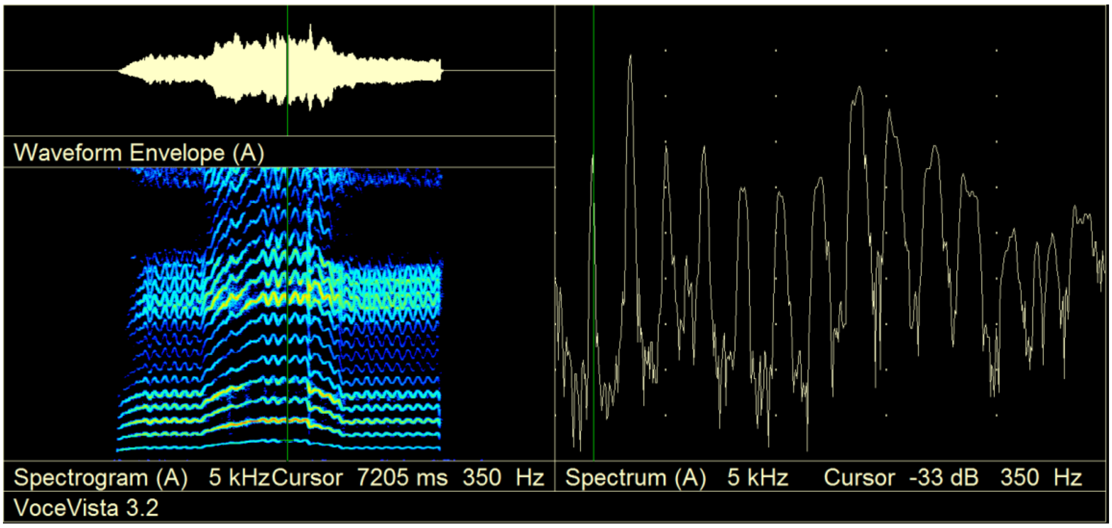
[18] This may partially explain why these tenors are perceived by listeners as being 'softer-grained' in timbre than the more heroic voices.

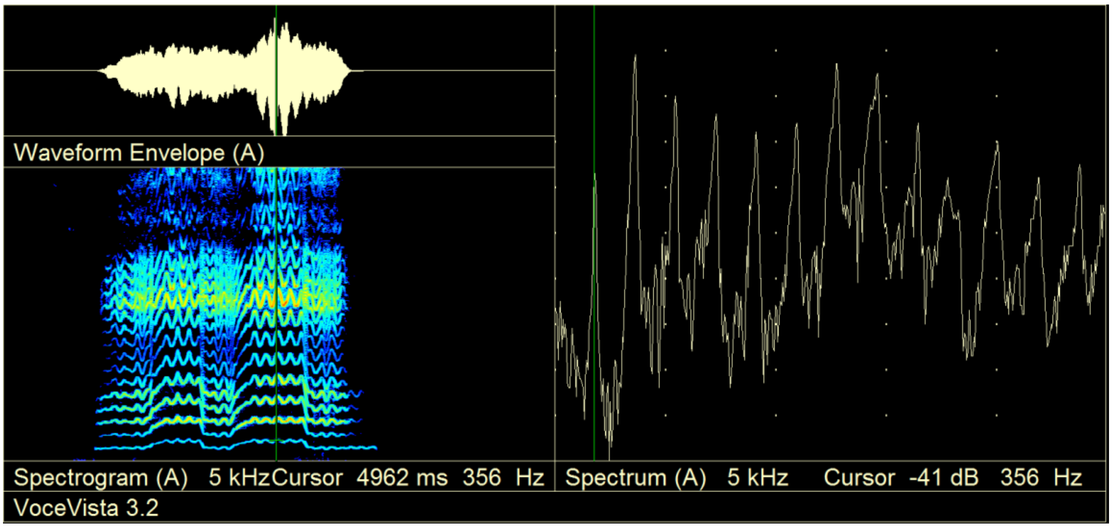
Figure 4.2.13: Tenor (8) Bb3 – F4 scale [a]



The voice categorisation system (Fach) may seem somewhat rigid to anyone who is professionally unfamiliar with it but it is often the case that artists cross over the Fach system categories, and many voices do not neatly fit into one category.

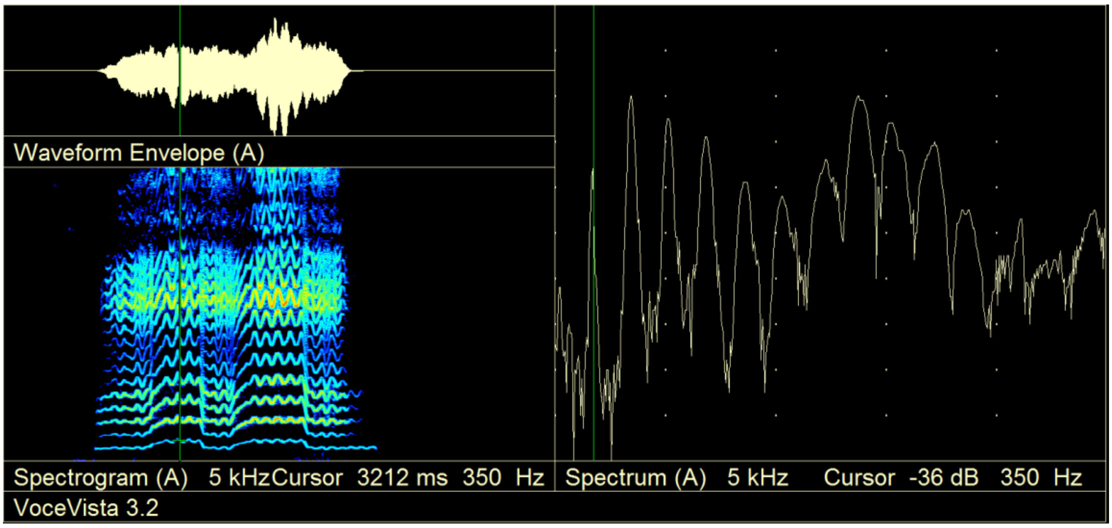
Tenor 4 is a good example of an internationally acclaimed voice whose career spans the mid lyric repertoire and also some of the 'Spinto' (or dramatic) repertoire. For example he sang roles such as Nemorino, but also Radames. This is pertinent here since his recorded examples show evidence of how this may have worked as regards his treatment of the passaggio zone, and most particularly (at this point in discussion), the f_1/H2 interaction. He does attain similar H1 – H2 differentials as the heroic voices, but these are slightly higher in fundamental pitch (on F4) and tend to be momentary. (Figure 4.2.14)

Figure 4.2.14: Tenor (4) Bb3 – F4 [a]



Mostly he offers a more modest differential between H1 and H2 that seems similar to the lighter lyric voices already described. In this example (Figure 4.2.15) the H1- H2 difference was c.16 dB.

Figure 4.2.15: Tenor (4) Bb3 – F4 [a]

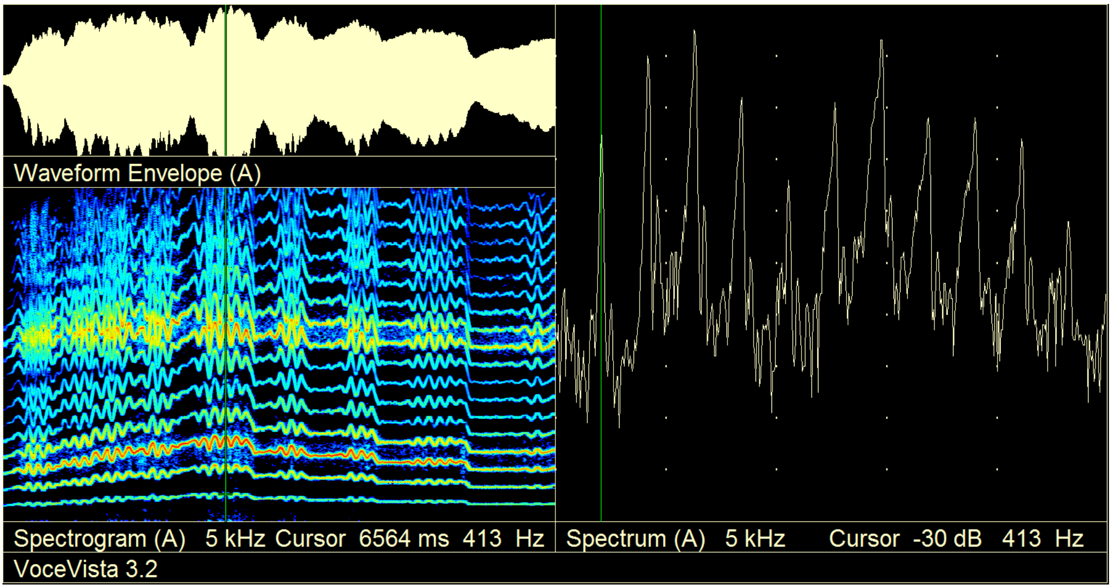


The resonance characteristics of the passaggio zone of the group of tenors (tenors numbered 2, 9 and 10) who have been prominently successful in the Charaktertenor repertoire is strikingly different to that of the other tenors.

Tenor 2 shows a clearly strengthened H3 on Bb3 which is then maintained throughout the passaggio zone into the top of the voice. This is very unusual and a very marked contrast to the characteristics shown by the entire group of Heroic and Lyric tenors. It seems most likely that this is achieved by a proximation of first and second formants, creating a strong broad-band formant, comparable to the way that formants tend to cluster in the higher zone of partials referred to generally as the 'singer's formant'. The signals suggest that the first formant in particular is allowed to rise. The other, unlikely, possibility is that for this voice the second formant is stronger than the first formant.

Figure 4.2.16 (a scale from C4-G4) shows in the colour spectrogram the clear progress of H3 as it ascends and is continuously the strongest partial.

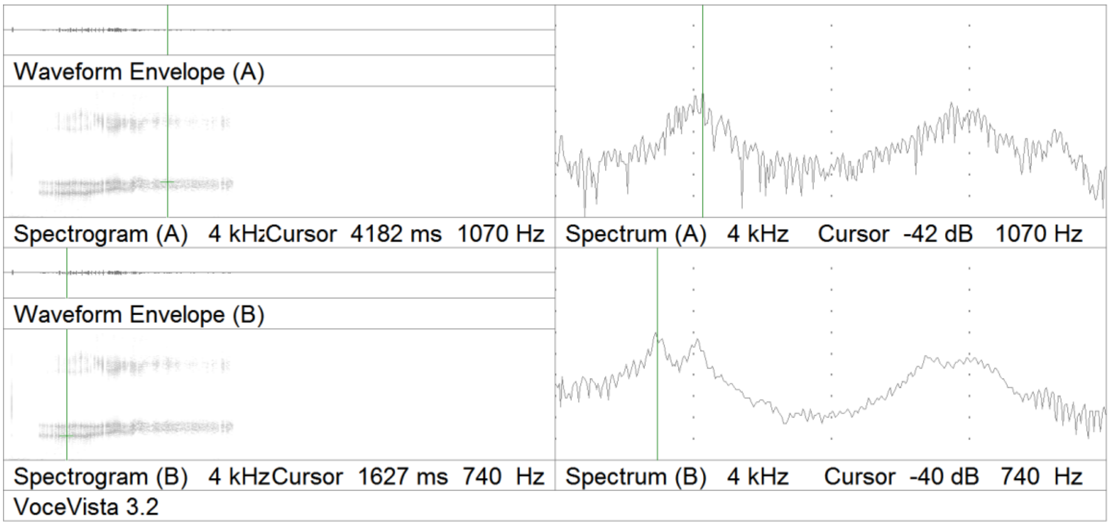
Figure 4.2.16: Tenor (2) C4 – G4 scale [a]



It could be that the smaller peak shown slightly to the right of H2 in Figure 4.2.16 in the power spectrum view shows the approximate location of f_1 (at 925 Hz). If so, this is a very high value.

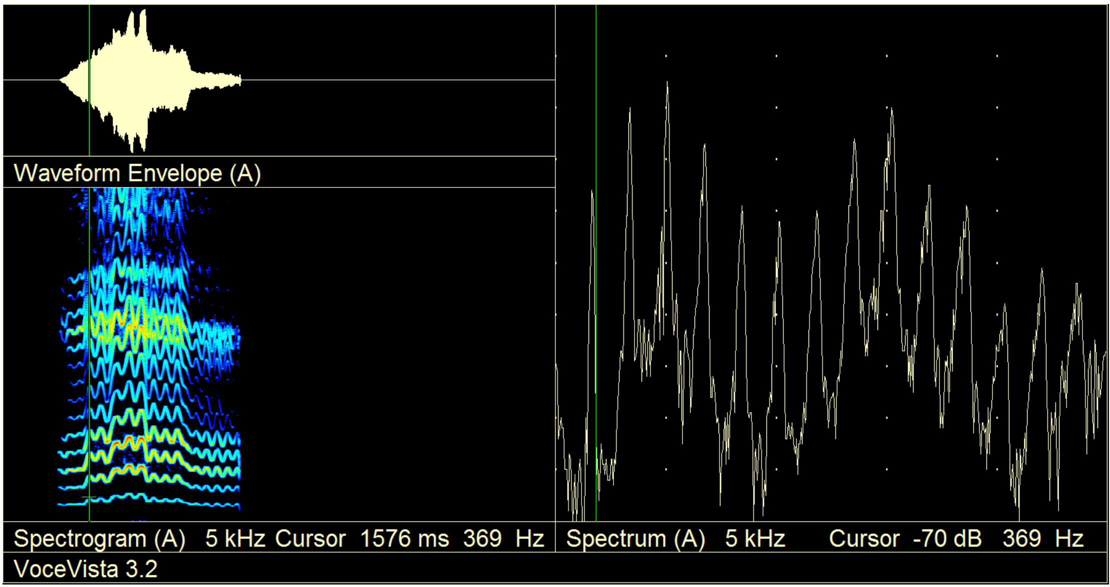
The author experimented, using vocal fry to indicate the approximate position of formants, to see if it was possible to bring f_1 and f_2 together. The following grey screen-grab (Figure 4.2.17) shows the position of conventional positions for f_1 and f_2 (lower screen) and in the upper screen f_1 and f_2 'clustered' together making one broad band formant. (These examples were made at the same recording session.) This demonstrated to the writer that clustering of formants 1 and 2 is to some degree possible.

Figure 4.2.17: Vocal fry on [a] showing formant positions



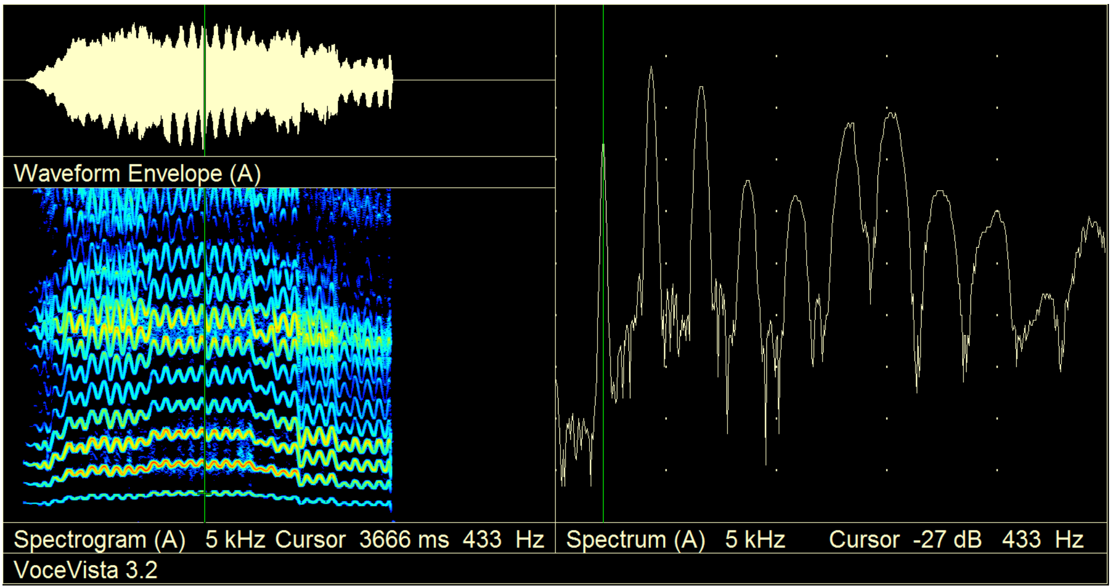
At some points Tenor 9 seems to use a similar resonance quality to tenor 2. In Figure 4.2.18 it can be seen that on E4 H3 is strengthened and this remains the case for the highest note in that triad, G4.

Figure 4.2.18: Tenor 9 C4 – G4 triad [a]



However, this is not consistently so in this tenor's examples. In a scale ascending from D4 – A4 f_1/H2 resonance tuning is prevalent throughout the scale (Figure 4.2.19). This could only be achieved by some manipulation of the position of f_1, possibly in order to retain a very strong quality for projection, which prioritises volume and projection, rather than the 'chiaoscuro' blending of elements desired in other tenor Fachs.

Figure 4.2.19: Tenor (9) D4 – A4 scale [a]

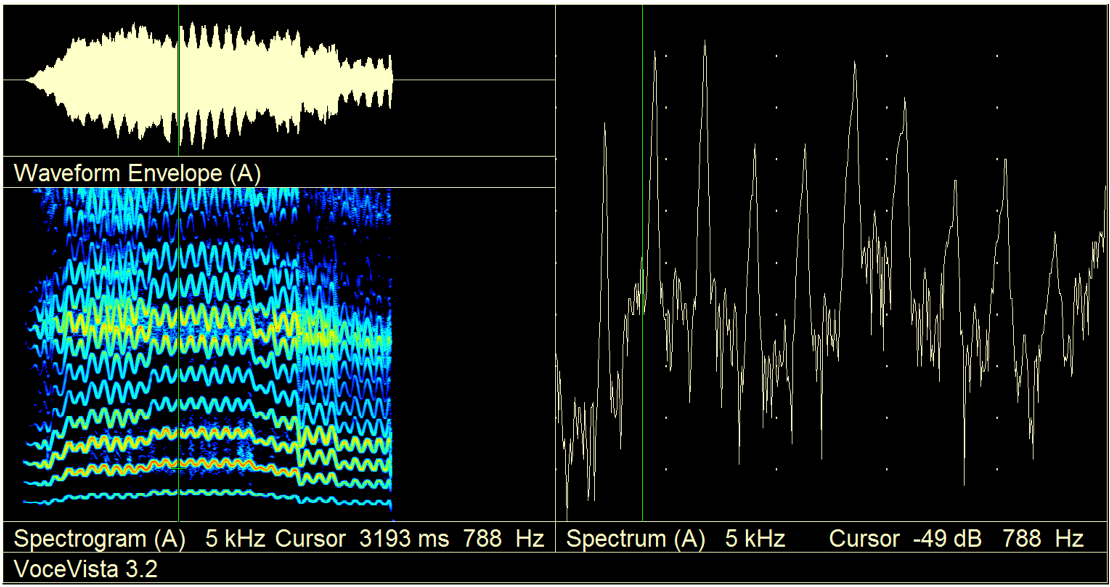


In the scale shown in Figure 4.2.19, H2 is clearly dominant for most of the scale. On the uppermost pitch (A4) when the pitch is at its highest point within the vibrato cycle H3 appears to briefly be stronger than H2 (Figure 4.2.20). Viewing the example with the Power Spectrum average set to 300 milliseconds[19] shows that H2 is the strongest harmonic throughout the sustained A4. If the small peak shown to the left of H2 in Fig 20 (see position of green cursor in Power Spectrum screen) suggests the possible position of f_1 at nearly 800 Hz, it is close enough to H2 at 880 Hz to still be

[19] This is sometimes desirable in order to be able to better judge how the sound would be perceived by the human ear, which does not hear things in the detailed way that a computer using VV can.

enhancing it. Coupled with the evidence of H3 strengthening as pitch rises to 1320 Hz, it seems that both f_1 and f_2 are somewhat unusually high.

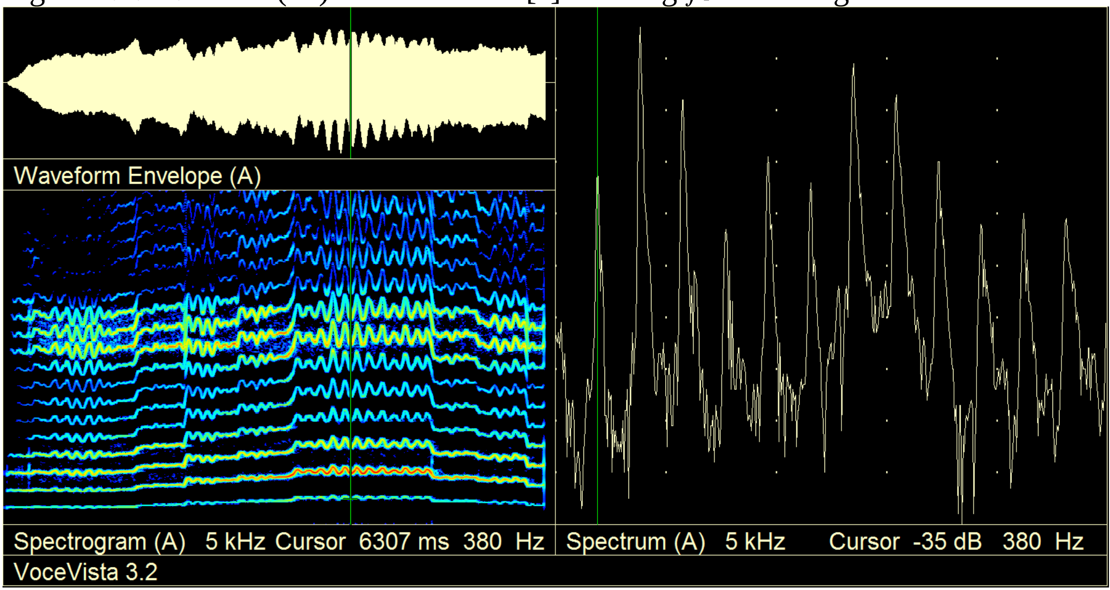
Figure 4.2.20: Tenor (9) D4 – A4 scale [a], possible location of f_1 (green cursor)



(It may be worth reporting here that when this tenor was first approached with a request for his participation, he responded saying that he was aware that his passaggio treatment was unconventional. It will be seen later that this awareness extended to the ability to sing the same scale figures traversing the 'passaggio' zone with two deliberately different resonance strategies.)

Tenor 9 is a mature singer working in pre-eminent European opera houses, whereas Tenor 10 is considerably younger and at the time of the recording of examples was in the earlier stages of an established career. His resonance strategy as a young Charaktertenor is to preserve the strong effect of tuning f_1 to H2 for as long as possible in ascending pitches on the [a] vowel (which is the same strategy as described above with Tenor 9). This suggests a high and/or rising position for f_1. In Figure 4.2.21, there is a 27 dB difference between H1 and H2 – similar to the levels seen for considerably lower pitches in the Heroic and Lyric voice categories. This presents a strong case for not attempting to define the male passaggio without reference to the specific voice type being discussed, since the acoustic/resonance events of the passaggio can be shifted in several ways and for differing reasons.

Figure 4.2.21: Tenor (10) C4 – G4 scale [a] showing f_1/H2 tuning on G4



4.3. 'Secondo Passaggio'

Miller's use of this term is somewhat vague (1986 p.115; 1993 pp.38-51), (though he asserts that it is a term in general use in Italy). In this study the term denotes the point in pitch which is the end of the passaggio zone when ascending.

In the Heroic tenors group, tenor number 5 exhibits a neat and consistent change from f_1/H2 tuning on the sustained pitch of F4, to f_2/H3 tuning on the sustained pitch of F#4. Given that there is a significant area of pitch which is 'shared' between these two notes because of the fluctuation of pitch in the vibrato cycle, it seems most probable that the distinctive change of resonance tuning here is being actively guided by the singer and not simply an accidental outcome of the position of formants in the singer's [a] vowel. Figure 4.3.1 shows in the lower half of the screen the F4, and in the upper half F#4.

Figure 4.3.1: Tenor (5) B3 – F#4 and Bb3 – F4 scales [a]

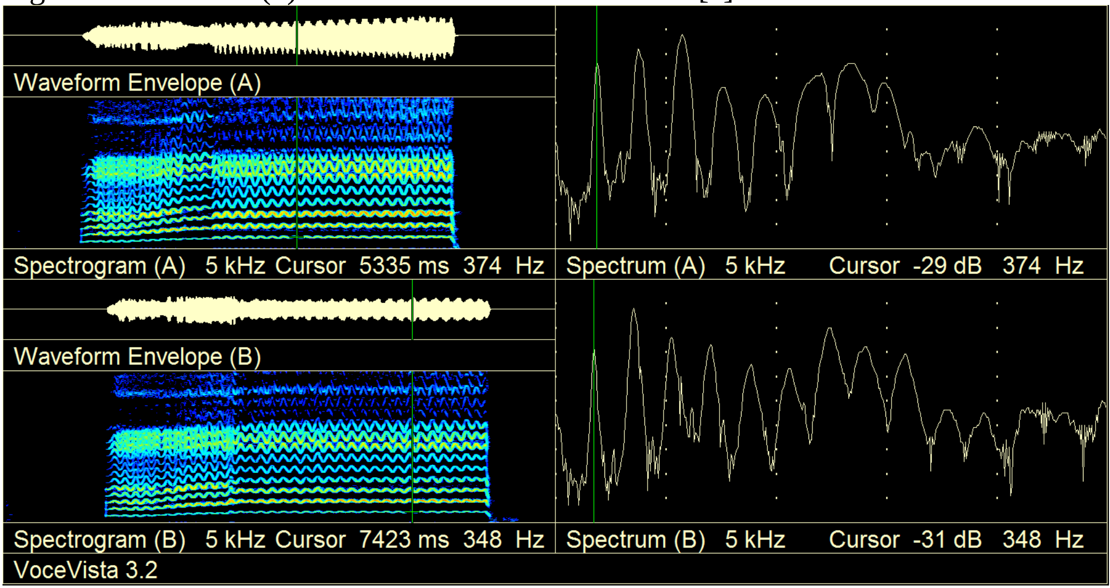
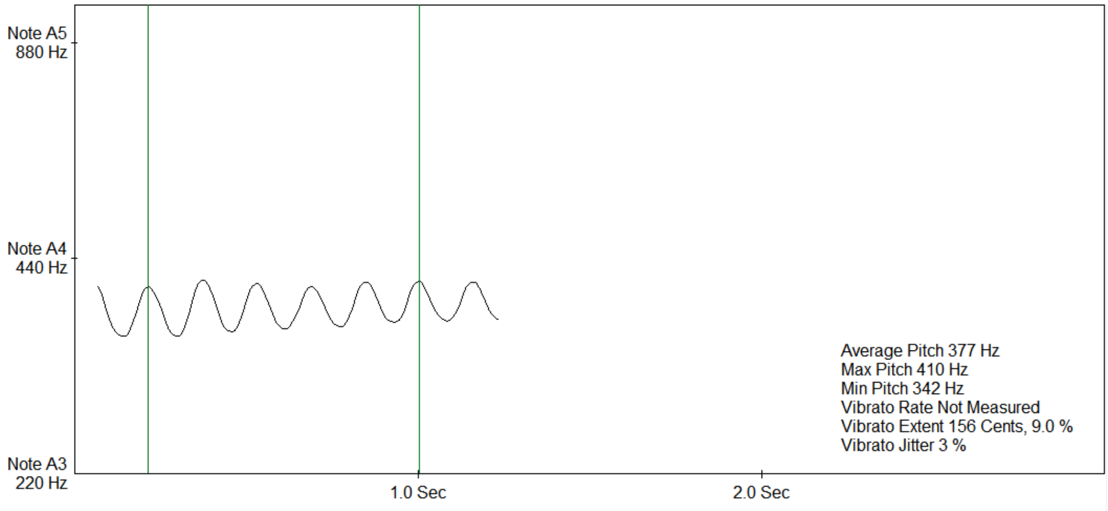


Figure 4.3.2 shows a section of the sustained F#4, using the fourth harmonic to calculate pitch deviation from the centre of the note during the vibrato cycle. It can be noted that the average pitch is slightly sharp for F#4, but that as the vibrato results in pitches slightly more than a semitone either side of this centre point, the lower pitch actually briefly moves flatter than an F4. One might expect therefore to see some fluctuation at least varying between f_1/H2 and f_2/H3, but this is not the case. This is achieved here by a subtle change which is audible in the sung [a] vowel, moving towards [ʌ] on the F#4. This lowers f_1, allowing it to disengage somewhat from being very influential on H2 and at the same time positions f_2 more favourably to strengthen H3.

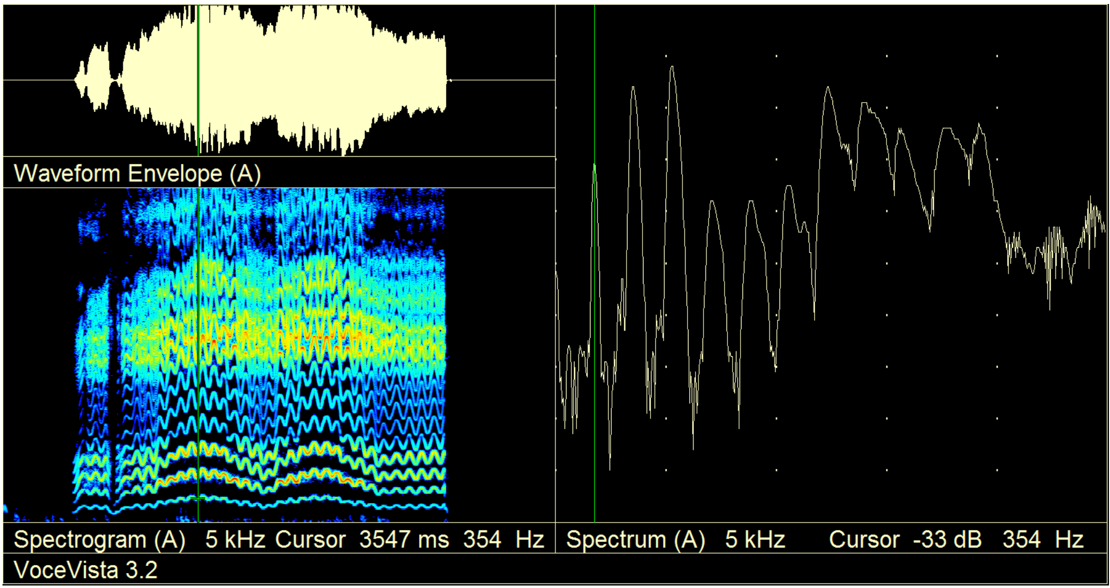
Figure 4.3.2: Tenor (5) F#4 [a], detail of vibrato



Tenor 7, the most senior in the group in terms of career profile and age, shows a similar approach to the top of the passaggio zone. As was noted above the [a] vowel is here guided towards [ɔ]. This results in the pitch of F4 displaying almost equal strength of H2 and H3 when the recorded examples of these pitches are viewed on VV with the power spectrum average set at 300 milliseconds. This gives a reasonable idea of what is perceived by the human ear and brain (Miller, 2008, pp.8-9). The result is that the F4 does not sound ‘open’, but nor does it sound heavily modified or ‘darkened’ or ‘closed’.

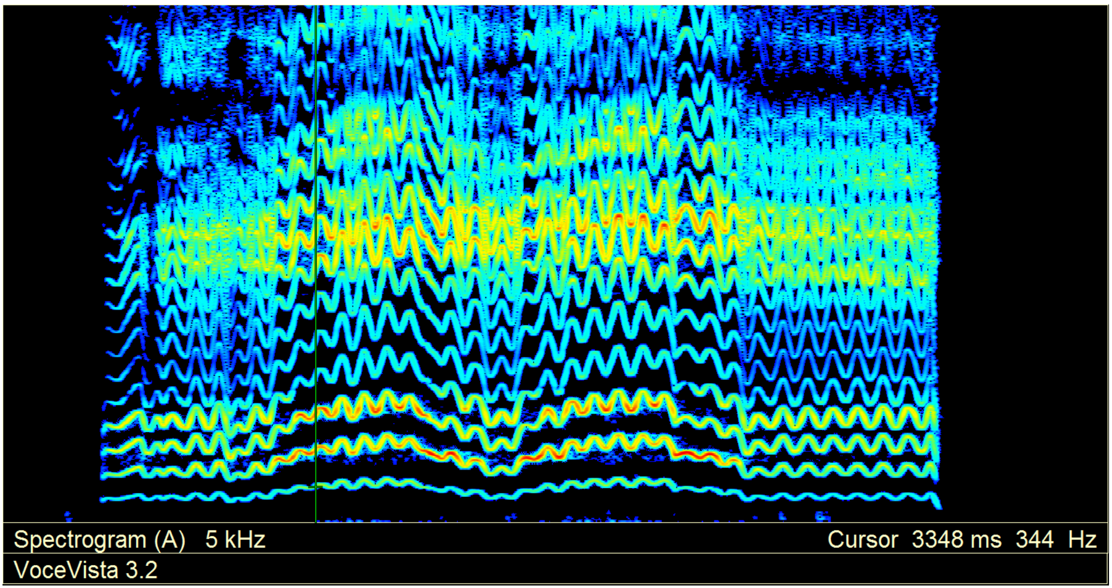
Following the same procedure (of using an averaging setting on the power spectrum of 300 milliseconds) on F#4 it can be seen that at this semi-tone higher, H3 is slightly stronger than H2. Figure 4.3.3 shows H3 as clearly stronger, though this moment is taken from the underside of vibrato pitch. It is likely that f_2 is situated nearer to 1050 Hz since when pitch is higher than this in the vibrato cycle H3 weakens as 1100 is approached. This could be valuable information for the singer, since a small adjustment in the vowel could cause f_2 to be more beneficial. (Figure 4.3.3)

Figure 4.3.3: Tenor (7) B3 – F#4 scale [a]



Though a colour spectrogram on its own can only give a somewhat generalised view of the relative strength of partials, Figure 4.3.4 is useful. This is because it shows a difference in treatment of the passaggio between Tenors 5 and 7 which can be clearly heard by a discerning listener and which is commonly encountered in public performances and in recordings. (Neither is here endorsed as one being ‘better’ than the other.) In Figure 4.3.4, showing a scale from C4 – G4, when F4 is reached in the climbing scale for that specific pitch (or very near that pitch), H2 is very similar in strength to H3. The position of the green cursor shows the location of this occurrence.

Figure 4.3.4: Tenor (7) C3 – G4 scale [a], colour spectrogram

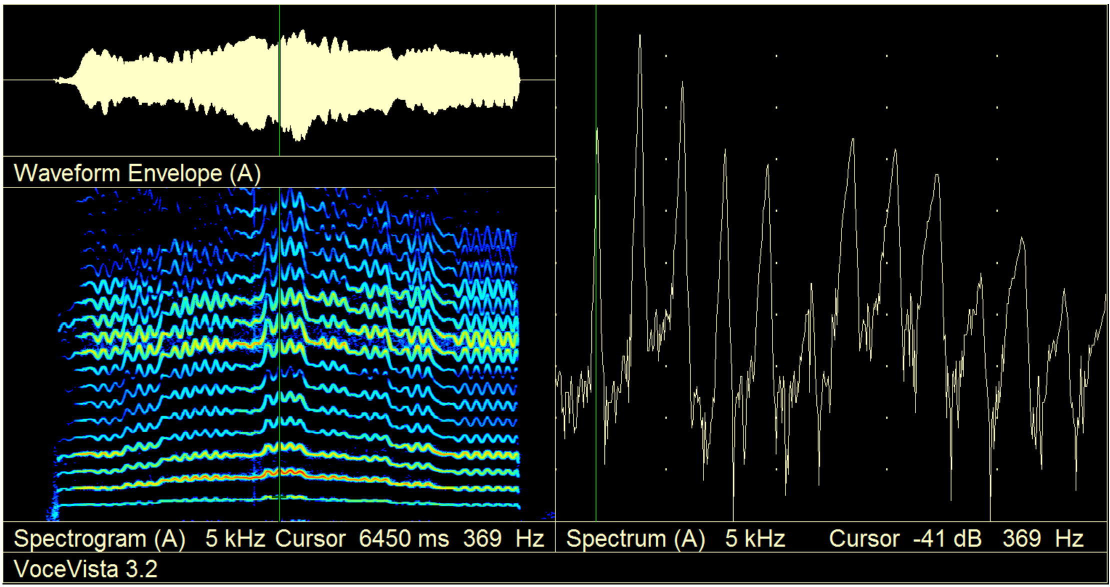


This gradual change from the influence of f_1 to f_2 where neither predominates is different from the apparently more abrupt change shown by Tenor 5. So, one choice which can be made by a tenor (or baritone singing at their comparable passaggio pitches) is whether a smoothly graduated change of timbre (caused by engaging differing relationships between formants and harmonics) is desired, or a relatively abrupt one which results in a distinct change between semitones.

Also in Figure 4.3.4 on the uppermost pitch of the scale, G4, it is clear that although it seems that f_2 is still too low to uniformly strengthen the entire range of pitch caused by vibrato, H3 is now stronger than H2. This is because with the rising fundamental pitch, H2 is now becoming too high to be influenced by f_1. In traditional vocal pedagogical language, this would be described as end of the passaggio zone and commencement of 'head voice'.

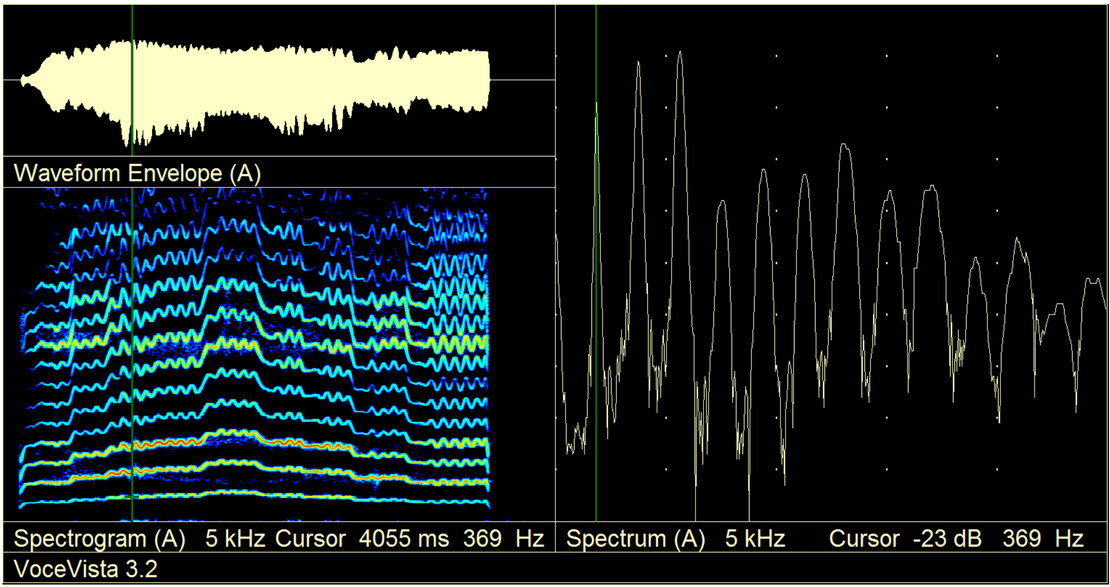
Tenor 1 (also in the Heroic group) shows some inconsistency about the moment of exit from the passaggio. In a short scale ascending from B3-F#4, (Figure 4.3.5, in which therefore F#4 was the uppermost pitch) the strength of f_1/H2 tuning remained the dominant factor in resonance on F#4. This means the entire range of the perfect fourth, C#-F#, is dominated by this coupling of f_1 and H2. The effect is actually most powerful on the upper note, F#4.

Figure 4.3.5: Tenor (1) B3 – F#4 scale [a]



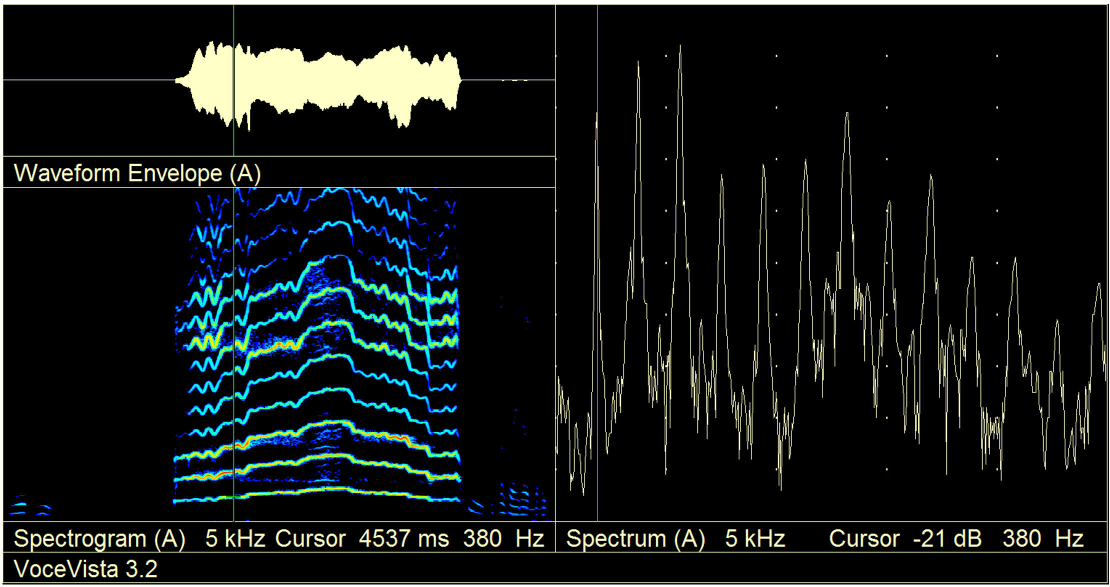
However, when ascending beyond that pitch of F#4, that particular pitch shows a nearly balanced strength of H2 and H3, though H3 is slightly stronger. The first of two examples of this is shown in Figure 4.3.6, a scale ascending from D4-A4. Perhaps the thought of the ascent is in mind for the singer, facilitating a proprioceptively memorised sensation which the singer knows will be necessary for the G4 of the scale and thereby encouraging the different transitional quality for F#4. It is also interesting to note that in both examples (Figures 4.3.6 and 4.3.7) the F#4 in the descending part of the scale has what might be termed 'cleaner' engagement with f_2/H3 tuning than in the ascending section. This will not be surprising to singers who will understand that once a resonance characteristic has been established on one pitch it becomes easier to retain on nearby ones. This also seems logical in that Echternach and Richter (2011) found that perturbation values indicative of vocal stability were lower in descending phrases than when ascending.

Figure 4.3.6: Tenor (1) D4 – A4 scale [a]



The same features occur in this scale of E4-B4 (Figure 4.3.7)

Figure 4.3.7: Tenor (1) E4 – B4 scale [a]



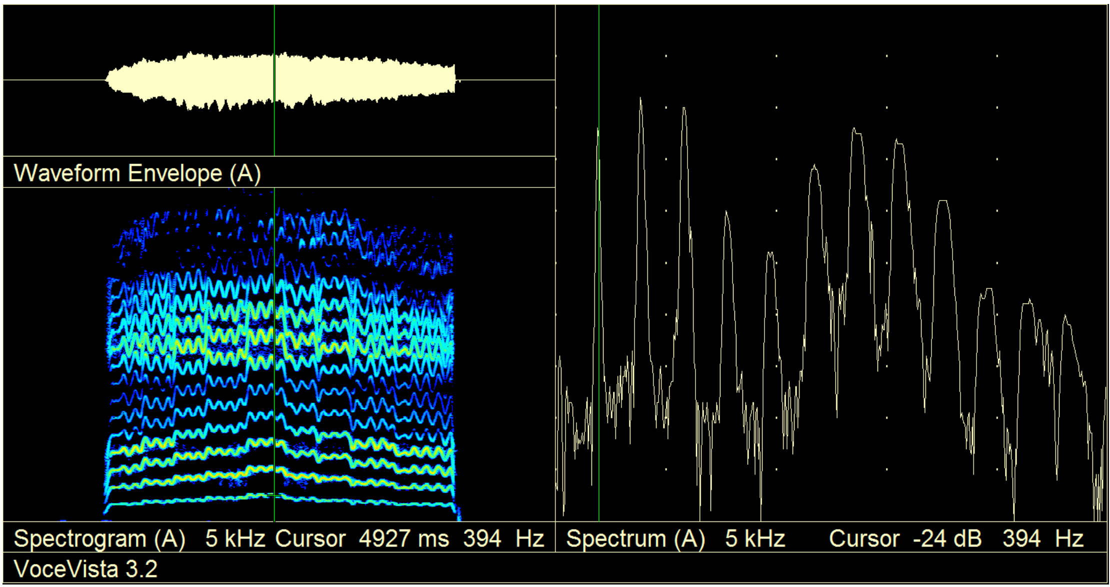
These examples are particularly interesting since they illustrate that what occurs at the secondo passaggio moment can change depending on circumstances, even when dealing with the same vowel. The f_1/H2 coupling is powerful and may help to create a strong, ringing sound. If that is considered desirable by the aesthetic guiding the singers intentions it would not be so surprising to find that on pitches which are pivotal to resonance changes f_1/H2 may remain in effect. Whereas when the singer is already aware that pitch is ascending beyond the pivotal moment, it would seem logical to forego a degree of sheer power in order to create a smoother transition to a different resonance for the upper voice.[20] Since f_2 is a less strong formant than f_1, using it relatively early may mean a sacrifice in some level of volume, or to be more precise, the radiated sound pressure level. It seems that in Tenor 1 we see a clear example of this.

With regard to Tenors 3,6,8, and also 4 (who, mentioned above, shows both Lyric and Spinto qualities) there are two main points which emerge in relation to the moment of 'secondo passaggio'. All of the group show a tendency to equally balance the strengths of H2 and H3 at some point, often on G4. Secondly though all do show a change from f_1/H2 resonance tuning to f_2/H3 tuning, this does not occur until Ab4, which is somewhat higher than many pedagogical sources advocate.

The following examples of these features show also the individuality which nevertheless exists in the group. Tenor 3 (with clear EGG signals) shows on G4 that though H2 is still marginally stronger on this pitch, H3 is almost equal (Figure 4.3.8). (Scrolling through the note with power spectrum average set to 100 ms shows this, which was also confirmed by viewing the file with the power spectrum average set to 300 ms.)

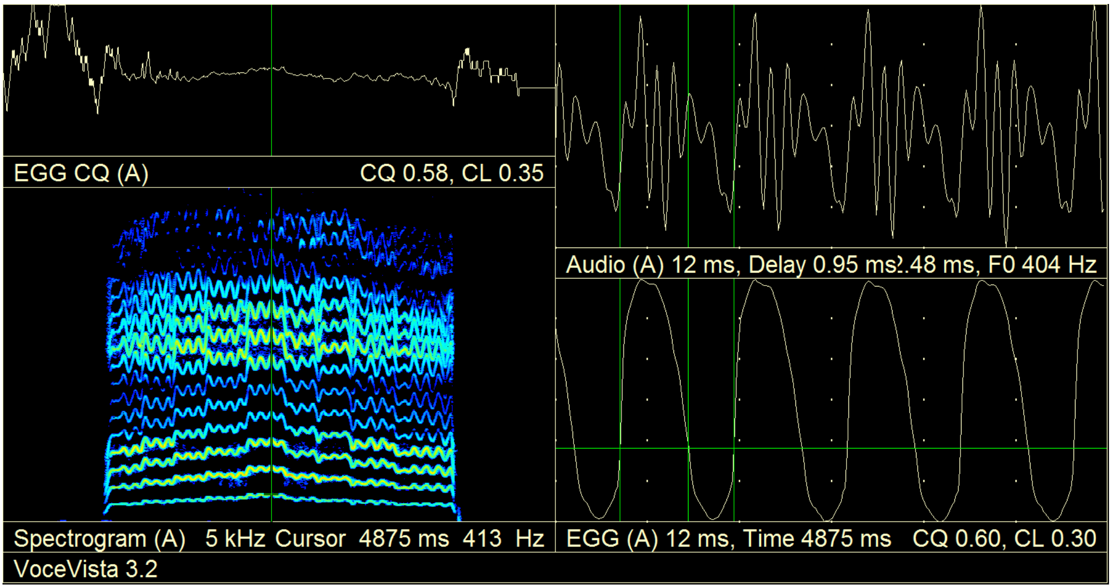
[20] Interestingly, Pavarotti had a strong view about this and discussed it and demonstrated it in his singing. In summary (not his words): retain f_1/H2 tuning on [a] as long as possible in passaggio if subsequently ascending to high climactic note. His recordings of *Una Furtiva Lagrima* consistently show this in the final unaccompanied cadenza. See this writer's short essay on this in Appendix 4, p.324.

Figure 4.3.8: Tenor (3) C4 – G4 scale [a]



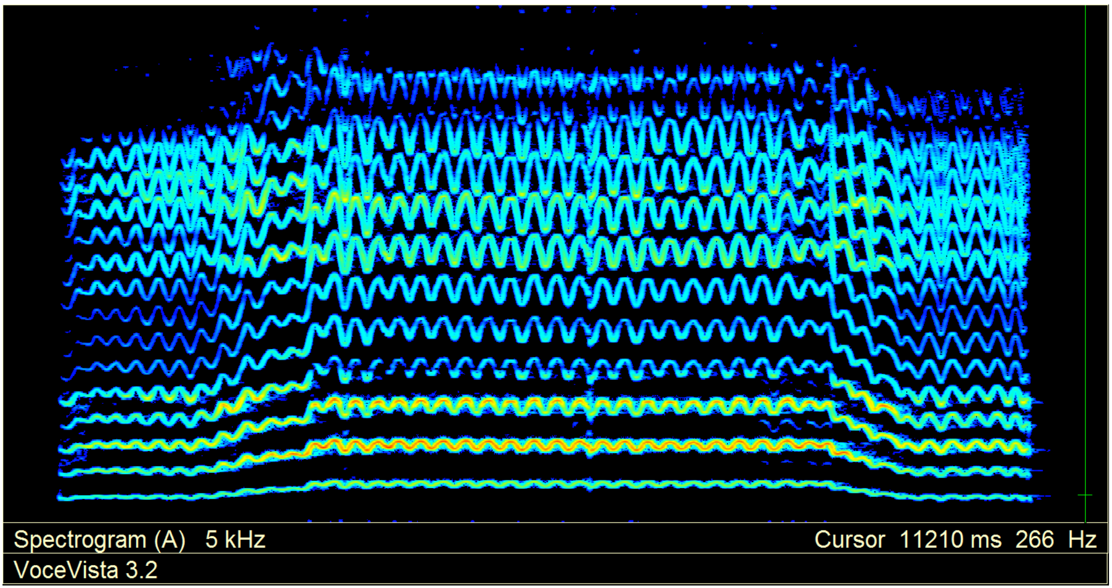
The contact quotient noted as 53% on F4 above, has now risen to 60% for G4. (Figure 4.3.9)

Figure 4.3.9: Tenor (3) C4 – G4 scale [a] with EGG



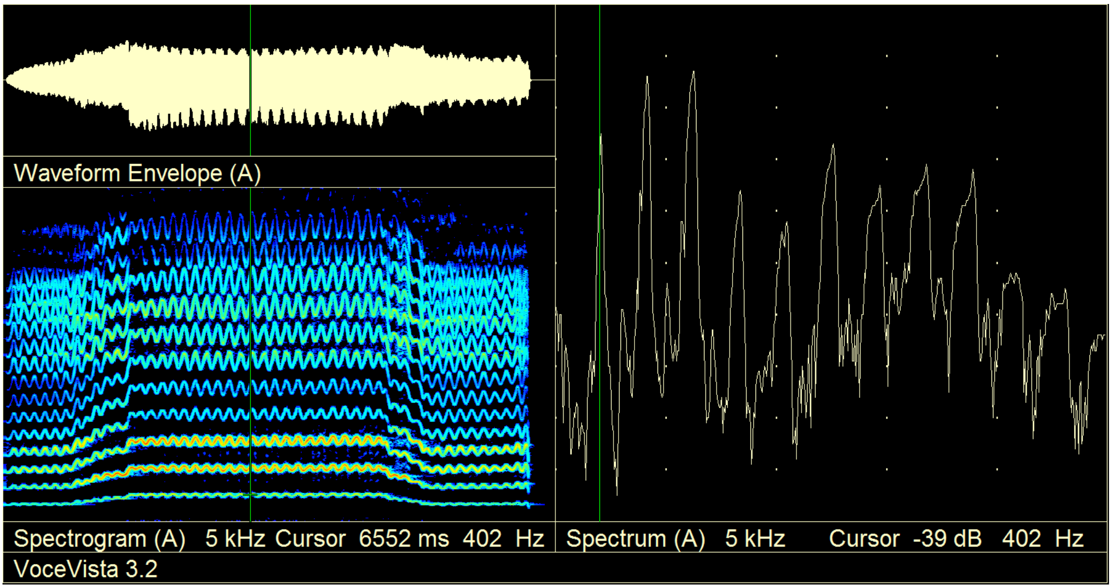
Tenor 6 showed the approach of the influence of his second formant in the sustained singing of F#4 where it was possible to see that H3 was starting to strengthen but only when the vibrato pitch cycle was at its highest point. (Clearly seen in the colour spectrogram of Figure 4.3.10.)

Figure 4.3.10: Tenor (6) B3 –F#4 scale [a] with sustained F#4



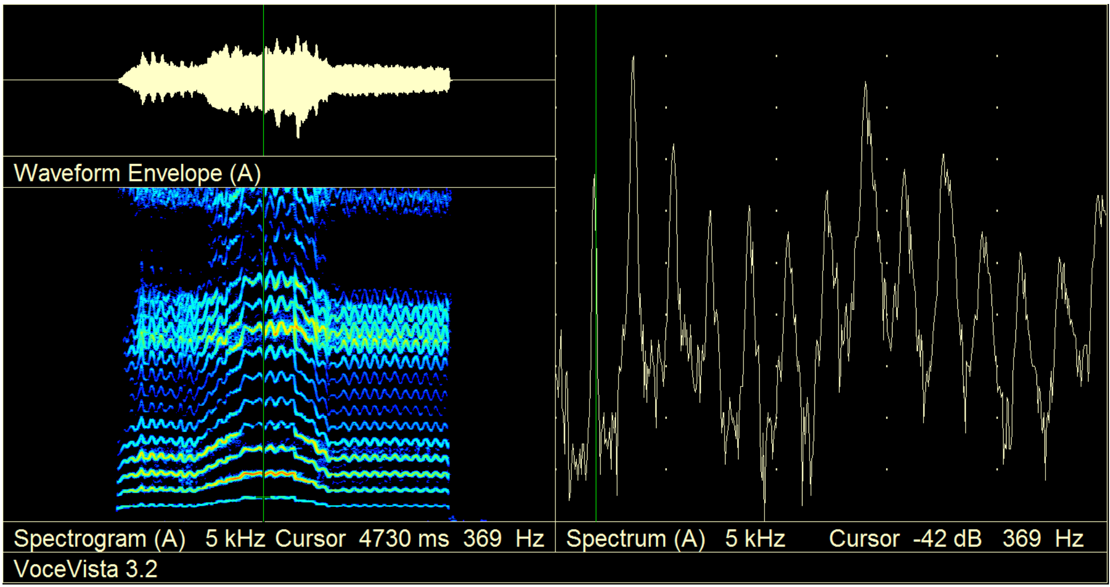
When he ascends to G4 in a scale starting on C4, similarly to Tenor 3, H2 and H3 seem almost balanced in strengths (Figure 4.3.11). The partials in the SF zone are not strong being generally below the strength of H1. This balance between H2 and H3 on the G4 is sufficient (given that there is not the possible second factor of strength in the SF zone) to prevent the G4 from sounding more 'blatantly open', which would be the case if H2 clearly predominated.

Figure 4.3.11: Tenor (6) C4 – G4 scale [a] sustained G4



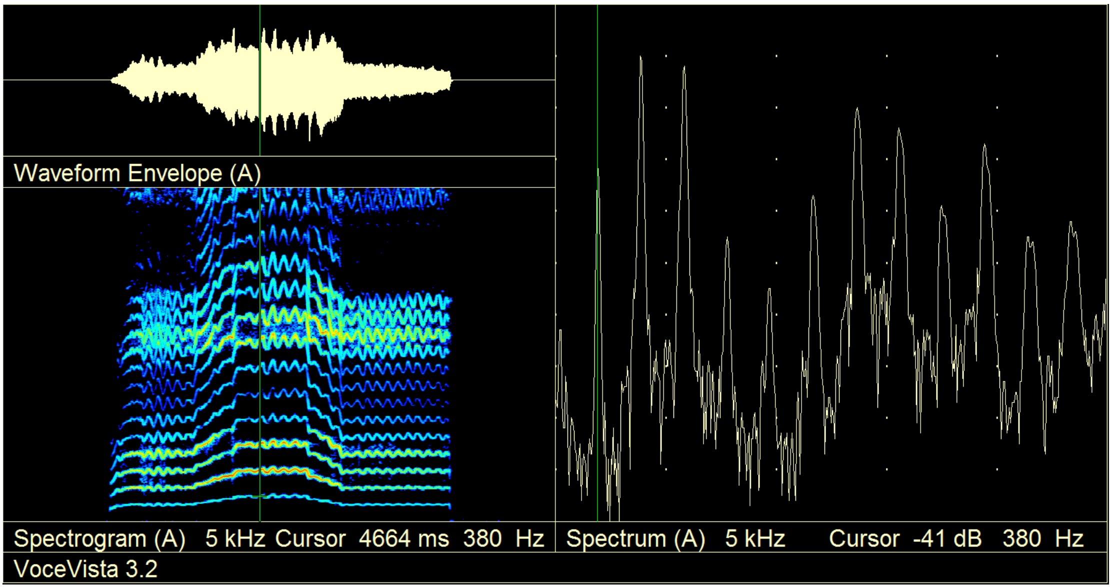
Tenor 8 shows characteristics which are similar to Tenor 6, though his G4 still has H2 predominantly strong. The F# 4 has very strong f_1/H2 resonance. There are signs at the top of the vibrato pitch cycle that f_2 is being approached as pitch rises, but H2 is very clearly the dominant resonance (Figure 4.3.12).

Figure 4.3.12: Tenor (8) C4 – G4 scale [a]



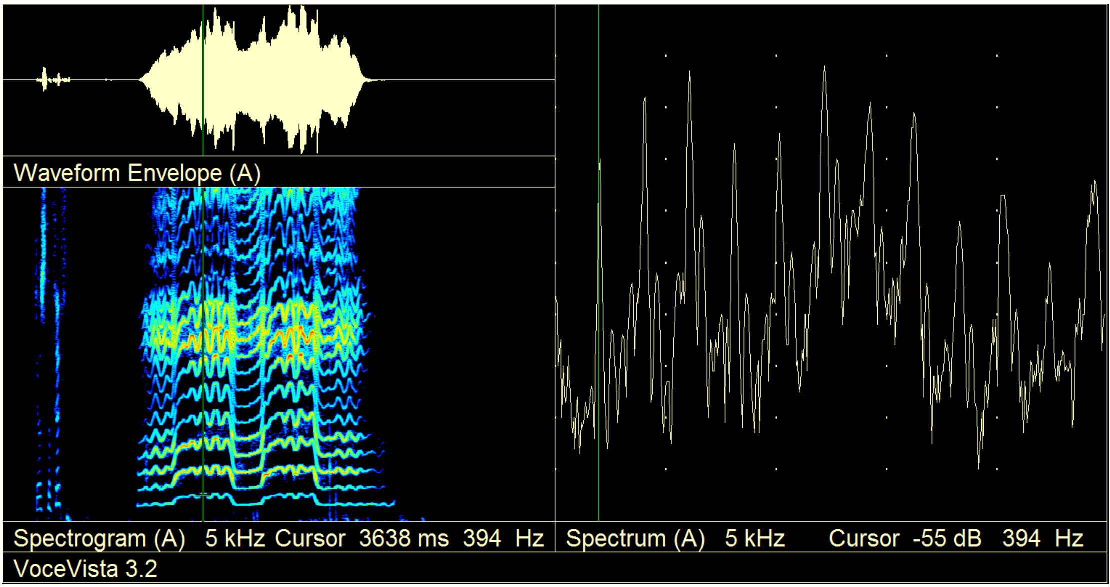
As pitch is climbing with the [a] vowel retained, providing the formants of the vowel are not altered by accidental laryngeal rising or throat constriction (or deliberately moved by vowel modification) at some point H2 will be left behind by the rising pitch of f_1. Similarly H3 will eventually reach a pitch where f_2 is situated by the [a] vowel. In Tenor 8 as he sings the scale from C4-G4 these events look as though they are taking care of themselves. Though H2 is still predominant on G4, at the top of the vibrato cycle there are now clear signs of the proximity and influence of f_2 (Figure 4.3.13). This looks very similar to the F# of Tenor 6 shown above in Figure 4.3.10.

Figure 4.3.13: Tenor (8) C4 – G4 scale [a] showing influence of f_2



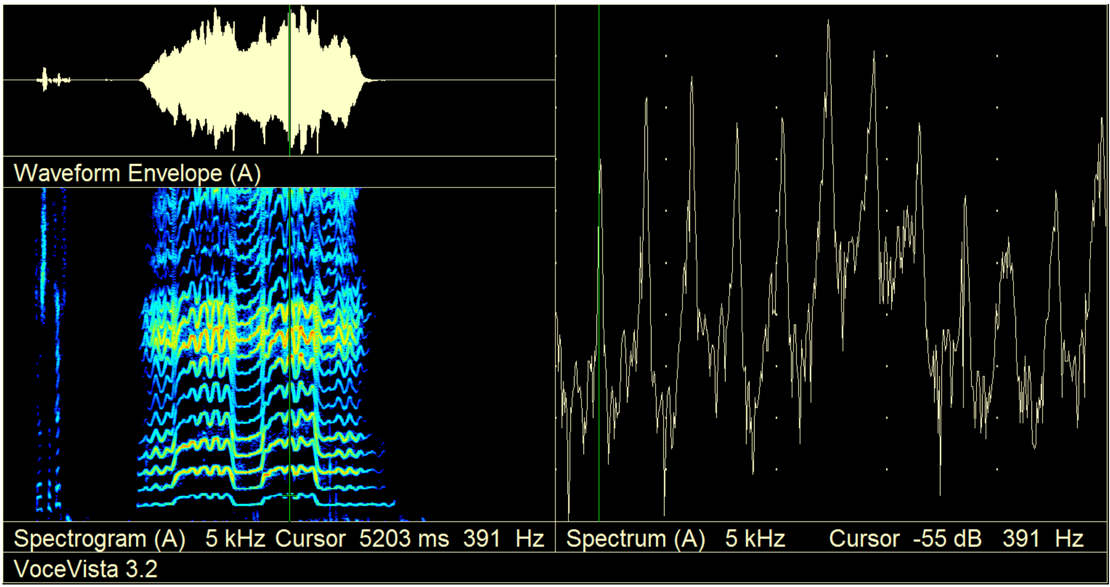
Tenor 4 has very strong partials in the SF zone which often exceed in strength the levels of H2 and H3, whereas Tenors 3 and 6 do not exhibit that element. Tenor 8 has some strong partials in the SF zone but not as strong/consistent as Tenor 4. Miller, D., (2008) points out that when there is sufficiently strong activity in the SF zone, this can be an alternative for avoiding 'blatantly open' tone (pp.79-83). However there is also some evidence that Tenor 4 seeks to avoid a f_1/H2 strong coupling beyond F#4. Singing the fifth from C4-G4 on the G4 f_1/H2 tuning is stronger at the lower pitch within vibrato cycle but f_2/H3 engagement is stronger when pitch is at its highest in the vibrato. This is sufficient, especially with the strong SF zone partials to ensure that the G4 is does not sound as open as the preceding F#4 did (Figure 4.3.14). This is therefore very similar to what was seen in Figures 4.3.10 and 4.3.13. Viewing the example with the power spectrum set to 300 ms, shows that in the first sung G, H3 is marginally stronger.

Figure 4.3.14: Tenor (4) C4 – G4 interval of perfect fifth [a]



It can be seen in Figure 4.3.14 that in the second version of the ascent to G4 (shown) the signals are slightly different and G4 looks as though it has a little less strength in H3. This singer was very aware of the quality of these notes and explained that he avoids singing a normal [a] in the upper range, preferring to always modify that vowel towards the frontal closed vowel [e]. In the above example there is an audible change between the vowel sung for the first G4, on [a], and the second vowel which was modified quite strongly towards [e]. This has the effect of raising f_2 somewhat making it possibly a little too high to be evenly beneficial throughout the sung G4. It also causes further spiking of the already strong partials in the SF zone (Figure 4.3.15). Indeed this tenor stated that he would never sing a ‘normal’ Italian [a] in the upper range, but was reliant on front vowels for upper voice resonance and ease of production.

Figure 4.3.15: Tenor (4) C4 – G4 interval of perfect fifth [a] showing strength of SF



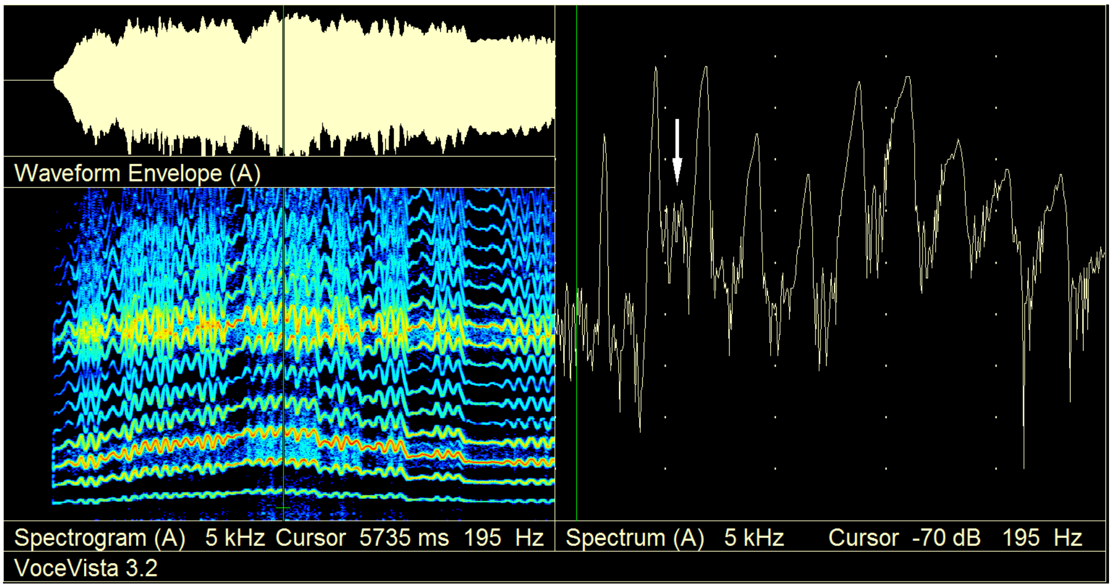
In looking at the examples taken from the group of Lyric tenors it would be reasonable to conclude that their point of 'secondo passaggio' is G4, often a point at which H2 and H3 are of equal, or near equal, strength.

The three Charakter tenors show a very different situation, which sharply contrasts with passaggio events of the other singers. Within the group there is also some inconsistency.

It was already noted above (see Figure 4.2.16) that Tenor 2 exhibits throughout the traditional zone of pitch for passaggio a strong engagement with H3, possibly facilitated by clustering formants 1 and 2. In so doing, this clustering creates what may perhaps be aptly called a 'super-formant' which has the possibility of strengthening very significantly frequencies which occur within its orbit. As pitch mounts further, the strength of H3 starts to wane slightly, and the gradually ascending H2 begins to enter the 'super-formant' area created by the clustering of f_1 and f_2. This extremely unusual resonance management is probably very effective in terms of projecting the voice efficiently above orchestral textures into opera house auditoria.

Figure 4.3.16 shows a scale ascending from D4-A4. A point was deliberately chosen when on the A4 it looks as though the strengths of H2 and H3 are similar.

Figure 4.3.16: Tenor (2) D4 – A4 scale [a]

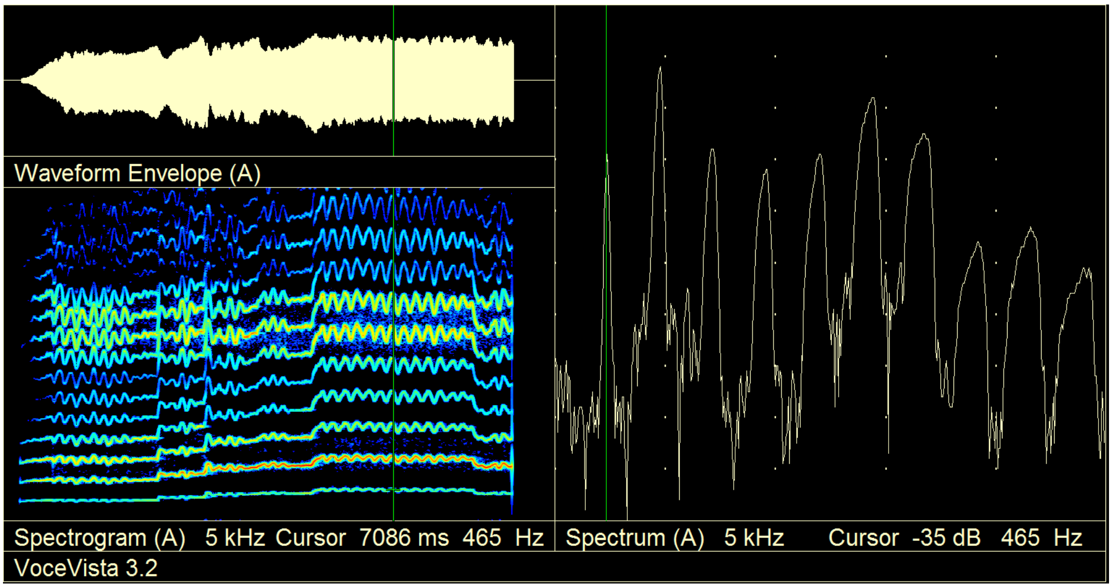


This gives some idea of the appearance of this note when viewed in real time with the power spectrum set to 300 ms to (giving a closer representation of what would be perceived by a listener). Despite the appearance in the colour spectrogram that H3 still predominates, viewing the example at the 300 ms setting shows H2 and H3 as almost equal in strengths. It can be seen in the colour spectrogram that the highest pitch within the vibrato cycle of H2 is strongest, and conversely the lower point of pitch fluctuation in H3 is strongest. This would suggest that the posited 'super-formant' is now somewhere in between these two partials. Looking more closely at the power spectrum a peak occurs where there is no harmonic but only sub-harmonic 'noise' (indicated in right-hand portion of screen with white arrow) which again points to the actual likely location of the strongest part of the 'super-formant'.

There is therefore an event comparable to a 'secondo passaggio' event in ascending pitch on an [a] vowel for Tenor 2. But this event is the reverse of what is much more often encountered. Instead of dominance of H2 yielding to H3 (or a combination of H3 and strength in SF partials) what we see here is a dominant H3 gradually yielding to H2 strength[21].

The younger Tenor 10 as pointed out above, rides the f_1/H2 coupling all the way to the top of his voice. There are therefore no ‘passaggio’ events of changes of timbre caused by differing engagement with formants. Figure 4.3.17 shows a scale ascending from Eb4 –Bb4. Once F4 is attained the strongest resonant partial is H2 and this remains the case up to and including the high pitch of Bb4.

Figure 4.3.17: Tenor (10) Eb4 – Bb4 scale [a]

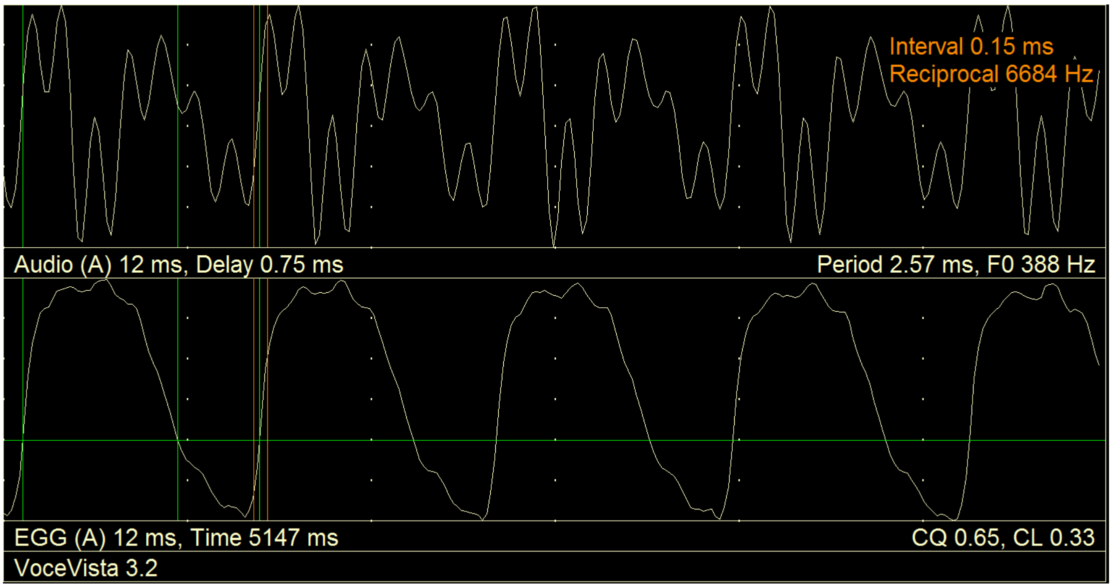


However there is an interesting different aspect. In the multiple examples collected from Tenor 10 there is a consistently audible slight change in vocal quality located between the pitches of G4 and A4. Looking at the initial closure rate (in association with contact quotient measurement using EGG), on the G4 there is an initial closure

[21] Were this to occur in a student voice one might dismiss it as ‘freakishly’ poor coordination of a unique nature. However here one needs to bear in mind that this is s singer of high international repute who has, and continues to have, a prominent and successful career.

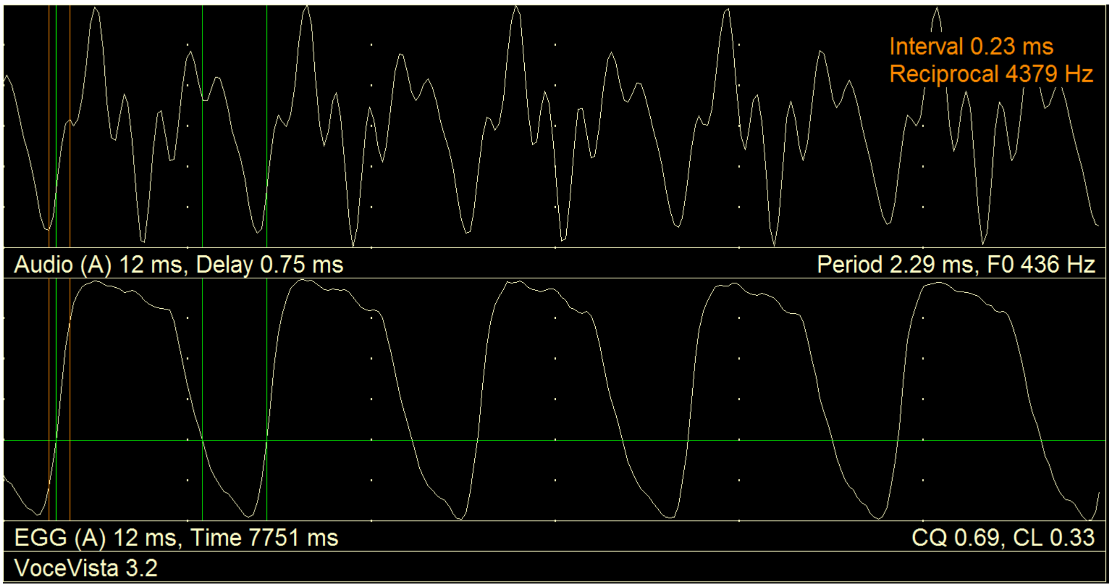
rate of 0.15 milliseconds, shown in Figure 4.3.18. (Shown here using the pair of orange cursors to make the measurement.)

Figure 4.3.18: Tenor (10) G4 [a] initial closure rate



On the A4 the initial closure time lengthens considerably to 0.23 milliseconds. (Figure 4.3.19)

Figure 4.3.19: Tenor 10 A4 [a] initial closure rate

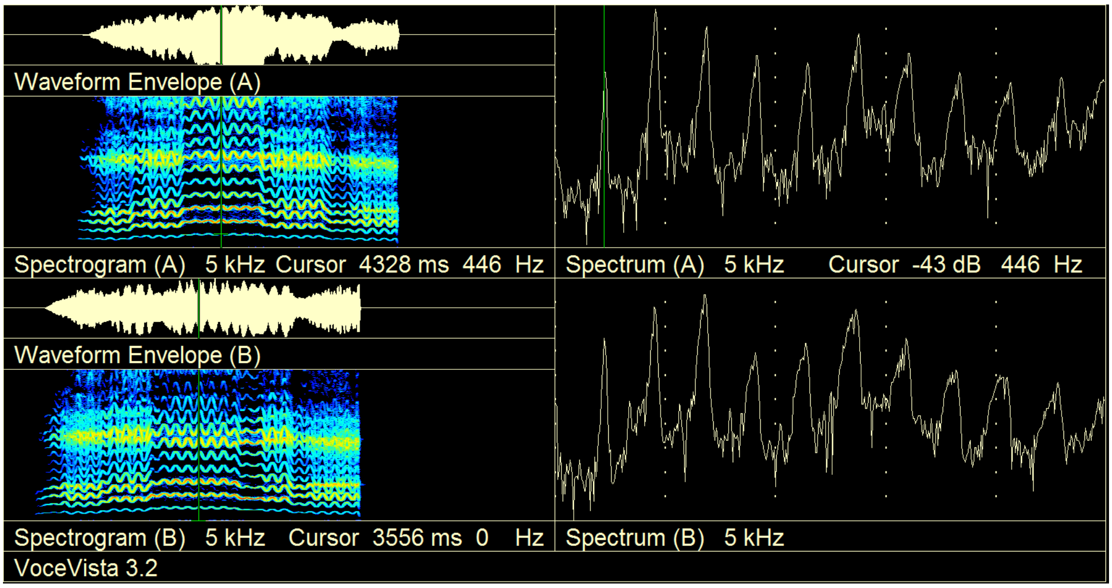


It may be that the audible change of vocal quality here is caused by/related to this change in initial closure rate. This would therefore be a 'passaggio' type event, but not of one caused by, or directly associated with, resonance issues. This raises an important question which at the current time requires further research to investigate and which is outside the scope of this study.

The mature Charakter Tenor 9 is also of special interest. It was shown above that he retains f_1/H2 coupling relatively high (as shown in Figure 4.2.19). Having sung that example Tenor 9 commented that he could also sing these pitches with what he considered to be a more conventional ‘Lyric’ tenor use of the passaggio zone. This showed a marked difference. Figure 4.3.20 shows a triad D4-A4 sung, in the upper view with his ‘Charaktertenor’ resonance where f_1/H2 is still strong on the high A4. The lower view shows the same triad sung and it can be seen that there is a marked change from the strong f_1/H2 quality on F#4 (both preceding and following the A4), creating a strong ‘heroic’ quality and then a change to f_2/H3 resonance coupling which predominates on the A4. (This was also viewed with power spectrum set at 300 ms for averaging to confirm how the note would be perceived by listeners.)

4.3 Figure 1

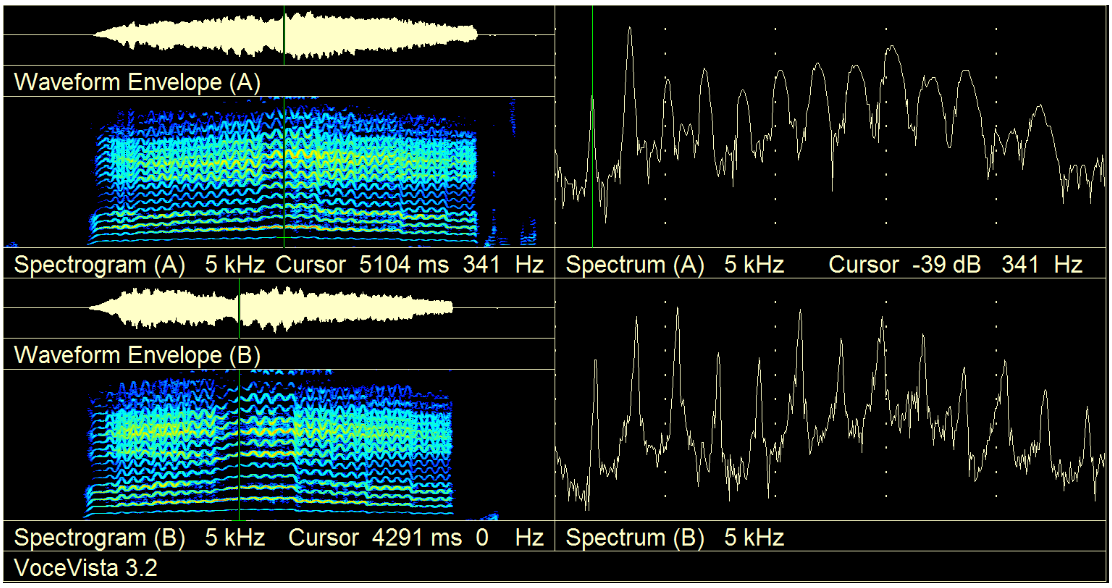
Figure 4.3.20: Tenor (9) D4 – A4 triad [a]



There is therefore a ‘secondo passaggio’ event which this tenor can demonstrate – occurring around the pitch of G4, but he mostly chooses to not use this technique, preferring to retain the strong f_1/H2 coupling as late as possible. The outcome is therefore that his approach to ascending pitch on the [a] vowel is comparable to tenor 10, once f_1/H2 becomes established. (As a point of interest, measuring the rate of initial closure of Tenor 9 showed no difference between the F#4 and A4 no matter which resonance strategy was employed, at around 0.15 milliseconds.)

Both baritones exhibit more conventional 'secondo passaggio' features. Baritone (singer number)12 shows a clear change from f_1/H2 tuning, (though this is taken somewhat surprisingly high to F4) to f_2/H3 tuning for F#4. These can be seen clearly in Figure 4.3.21, which shows a divided screen with scale from Bb3-F4 in the upper screen and a scale from B3-F#4 in the lower screen.

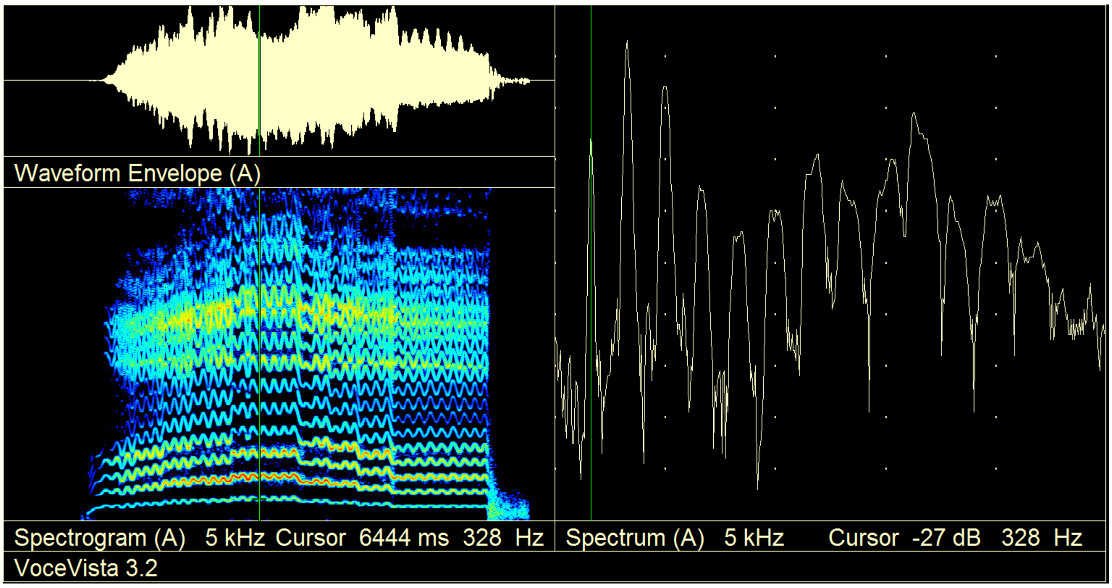
Figure 4.3.21: Baritone (12) Bb3 – F4 (upper screen), B3 – F#4 (lower screen) [a]



(The singer himself commented that he thought the F4 was 'too open'. He thought that having sung the role of Wotan in *Die Walküre* the previous evening his voice was not yet quite 'relaxed' and some stiffness in production caused him to 'yell' (his word) too high. He was much happier with the F#4.) The position of f_2 seems perhaps a little too high for full benefit in relation to H3, since H3 is distinctly stronger at the uppermost point of pitch within the vibrato. Viewing the example with power spectrum set at 300 ms shows H3 as slightly stronger than H2.

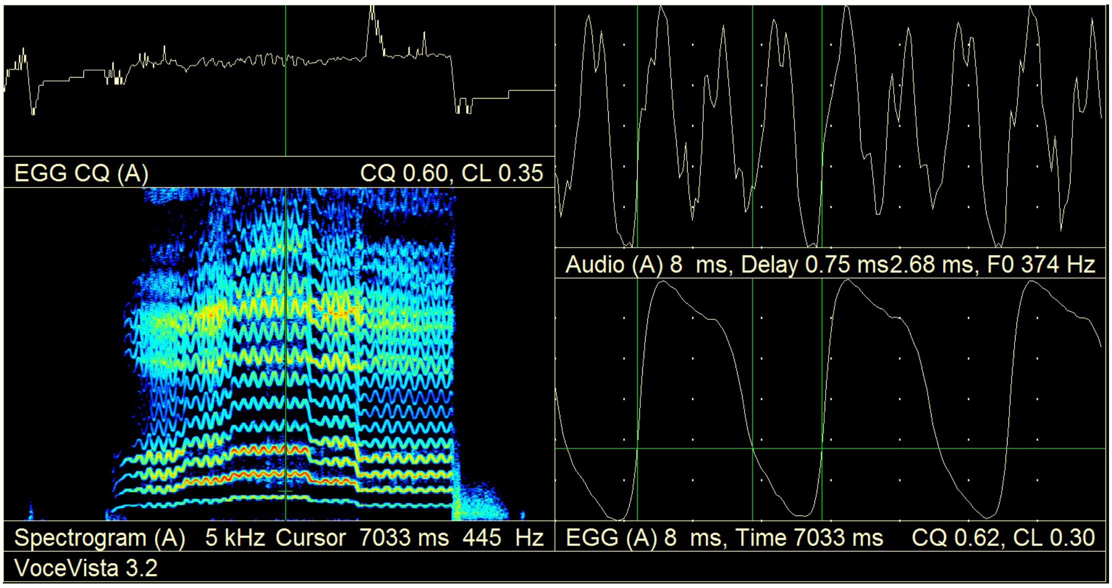
Baritone (11) shows a finely graded transition at the point of 'secondo passaggio'. Having already discussed the strength of the f_1/H2 moment on Eb4 (above), the next semitone shows the approach of f_2 influencing the uppermost part of H3 within the fluctuating pitch of vibrato (visible in the colour spectrogram). This is sufficiently strong to prevent this note from sounding 'blatantly open', even though H2 is still the dominant partial. (Figure 4.3.22)

Figure 4.3.22: Baritone (11) A3 – E4 scale [a]



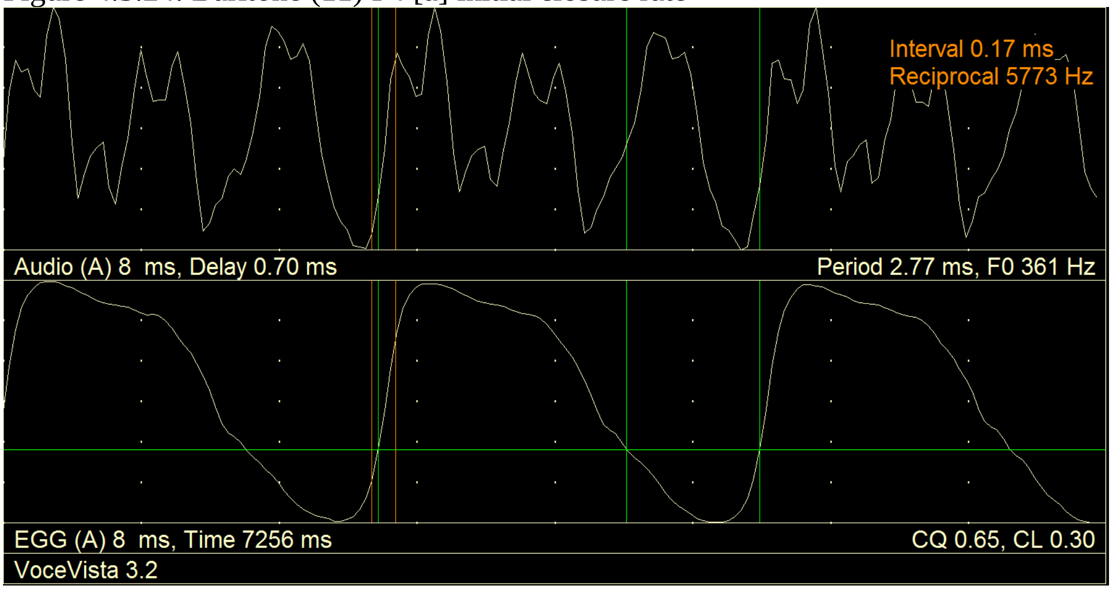
In the next example, ascending to F4, H3 is the strongest partial through the note, though H2 is not much weaker. Figure 4.3.23 shows the view with EGG, where the upper right panel showing the audio signal has three clear peaks (indicating the dominance of H3 at that point). This shows that the 'secondo passaggio' moment here is accomplished between E4 and F4, as may be expected for this type of baritone.

Figure 4.3.23: Baritone (11) Bb3 – F4 triad [a]



The contact quotient noted for this singer's Eb2 was 62% (shown above) and we note that this is consistently maintained here. The initial closure rate of 0.14 ms was noted for the Eb4 above. For the sake of completeness and comparison, this measurement on the F4 shows initial closure rate of 0.17 ms., shown by the orange cursors in Figure 4.3.24 (Several points were measured during the sustained F4 giving the same result.)

Figure 4.3.24: Baritone (11) F4 [a] initial closure rate



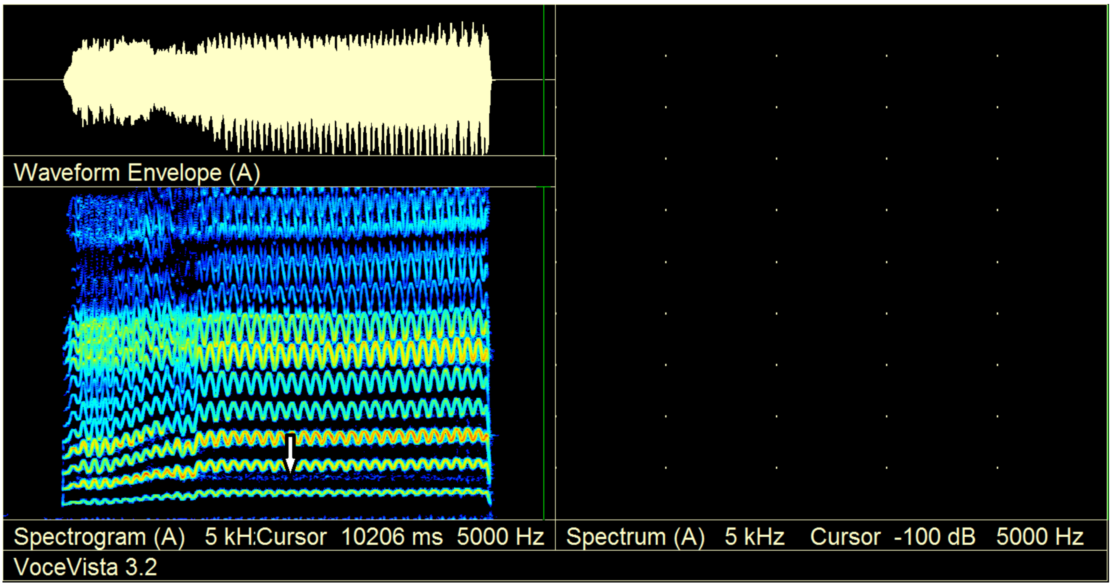
4.4. Beyond ‘Secondo passaggio’

Miller R., (1993) uses a term for this part of the male operatic voice which is once again a borrowed established Italian term, ‘voce piena in testa’ (pp.60, 77, and 79). Though this may seem a slightly clumsy term, its reference to ‘full voice in the head’ represents a concept that is in daily use by singers and pedagogues. There have been numerous attempts to establish a term which is more clearly rooted in how the voice functions but these terms have struggled to replace fully the historic use of ‘head voice’.

The challenge for the male singer who sings beyond the point of ‘secondo passaggio’ is to manage resonance and muscular effort in the most economic way for the desired aesthetic/acoustic result. For all male singers as pitch rises if the [a] vowel is kept consistent at some point H3 encounters its influence. Equally obviously, if pitch continues to rise, H3 will pass out of the sphere of influence of f_2. The only way of maintaining the beneficial resonance which can be achieved by the f_2/H3 relationship in upper voice is by permitting subtle vowel modifications which permit f_2 to rise, thereby tracking the rising H3. Miller, D., (2000) discusses this fully and also points out that an alternative strategy is to use a strong singer’s formant zone of partials, which assist to give the voice bright, clear carrying power that is well suited to the human auditory system (pp.125-147). It appears that some singers do both. This area of male singing is very challenging in terms of the skills required, as we shall see now when looking at the examples from the professional singers.

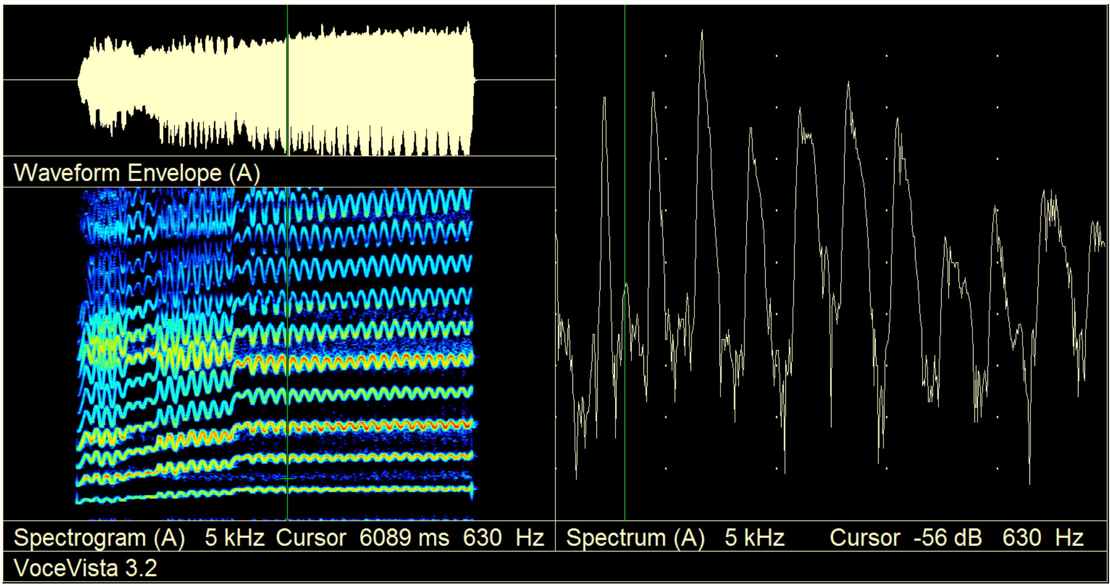
In the group of Heroic voices, Tenor 5 accomplished a change from f_1/H2 tuning on his F4, to f_2/H3 tuning on F#4 without ‘balancing’ H2 and H3 on any particular pivotal pitch. As he ascends further in pitch there is a perceptible slight change in vowel quality from the [a] towards the neutral vowel [ʌ]. In a scale from C4-G4 as might be expected the G4 shows strong f_1/H3 resonance tuning. There is a sub-harmonic shadow in blue visible in the colour spectrogram which indicates the likely position of f_1 at c.635 Hz as it is left behind by the ascending harmonics. (Figure 4.4.1, arrow.)

Figure 4.4.1: Tenor (5) C4 – G4 scale [a]



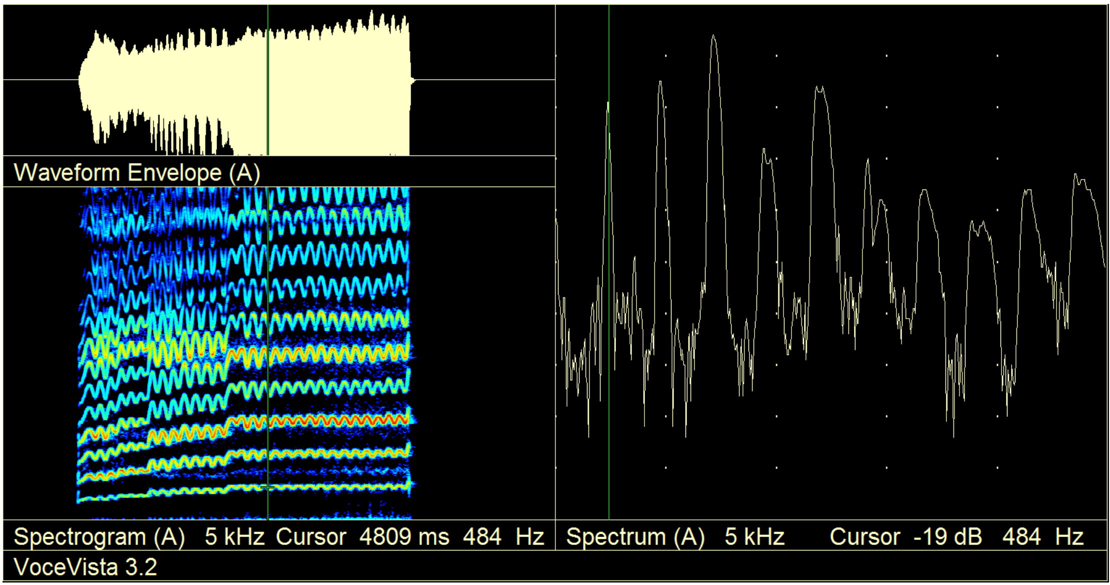
In subsequent scales of Dd4-Ab4 and D4-A4 the singer retains f_2/H3 tuning and the 'shadow' of f_1 remains visible at the same pitch (c.630 Hz). This is significant when we look at the resonance of the uppermost pitch in the next scale of Eb4-Bb4, since though H3 is the strongest harmonic it can be seen that H2 strengthens at the top of the vibrato pitch cycle. Since the 'shadow' of f_1 is still visible, H2 can only be being strengthened because pitch has risen for it to be sufficiently high to be begin to be influenced by f_2 which is more effectively enhancing H3 simultaneously. This in turn suggests that f_2 has a wide bandwidth of at least 200 Hz and that it probably is centred now somewhere below the pitch of H3. Confirming this, the strongest moments of H3 are when the vibrato cycle is at the lower point. (Figure 4.4.2, in which the green cursor of the power spectrum has been placed on the spike showing the presence of f_1.)

Figure 4.4.2: Tenor (5) Eb3 –Bb4 scale [a]



There is therefore a challenge to be met in the next scale of E4-B4, since H3 will be yet higher and therefore potentially further away from f_2. It is intriguing to see how this is solved, which we can see more clearly because of the presence of the ‘shadow’ of f_1. The singer successfully retains f_2/H3 tuning (Figure 4.4.3). In fact, it looks convincingly as though f_2 is more evenly centred on the pitch of B4 than it was on the preceding Bb4. The vowel does not seem to have been audibly changed, but the shadow formant has lifted significantly in pitch from its consistent previous location of c.630 Hz to c.715. This is likely to mean that all formants have lifted in pitch sufficiently for the high B4 to still be tracked by f_2 effectively. (Precisely how this was accomplished it is not possible to say, but reasonable speculation would include slight laryngeal lifting and/or increased mouth opening with lip-spreading.)

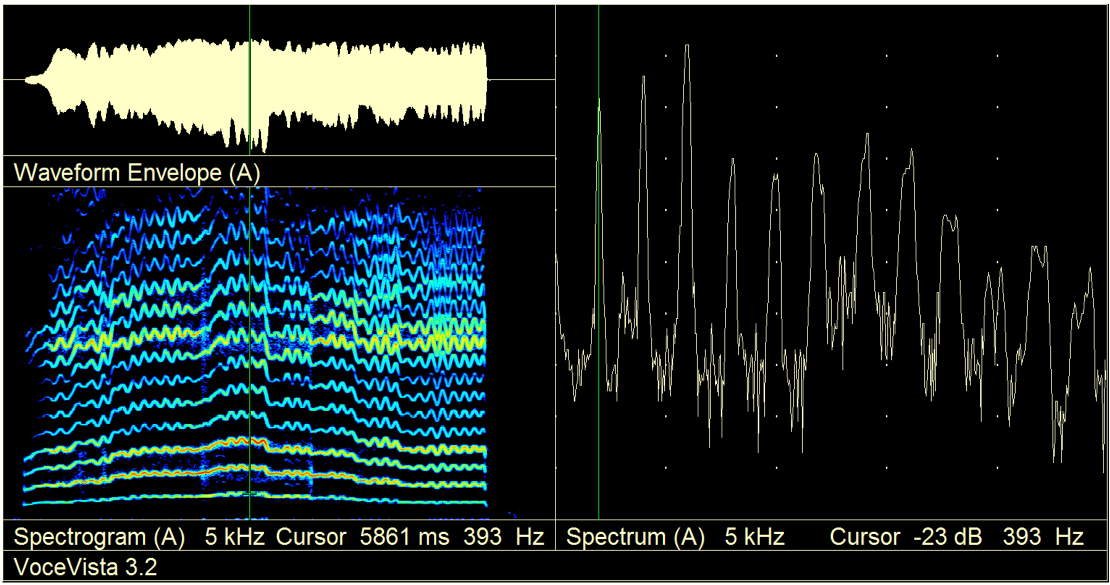
Figure 4.4.3: Tenor (5) E4 – B4 scale [a]



In sharp contrast to Tenor 5, Tenor 1 does not track either H2 or H3 ascending. Nor is his SF zone strong enough to compensate for the loss of acoustic efficiency which using f_1 or f_2 can bring.

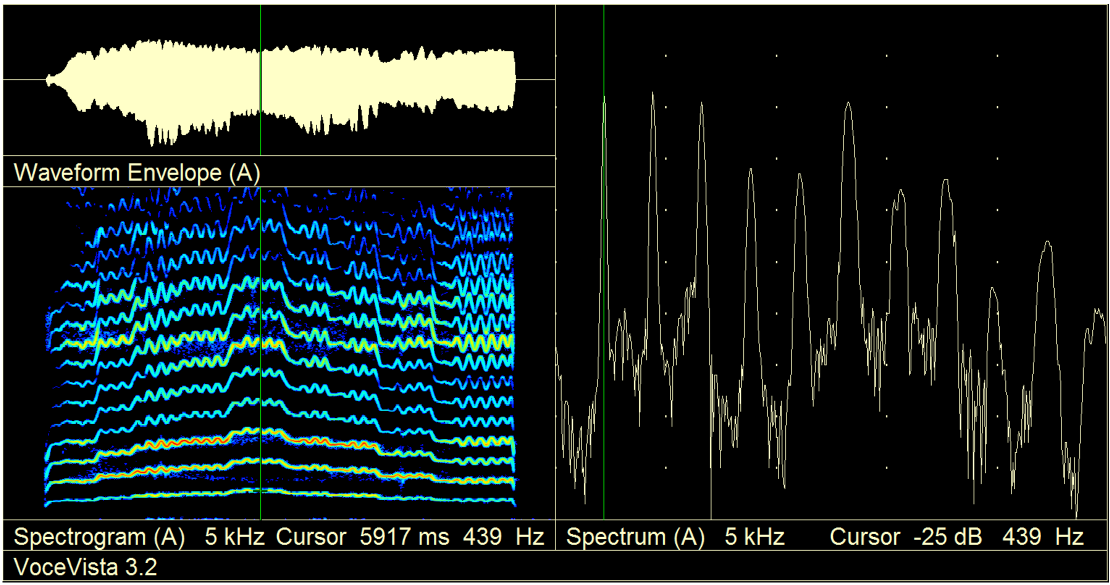
Tenor 1 did show a change from f_1/H2 tuning to f_2/H3 tuning on his scale from C4-G4. This looks like a conventional transition through the passaggio with a moment where the strengths of H2 and H3 are fairly balanced. (Figure 4.4.4, the colour spectrogram shows the gradual change of emphasis from H2 to H3.)

Figure 4.4.4: Tenor (1) C4 – G4 [a]



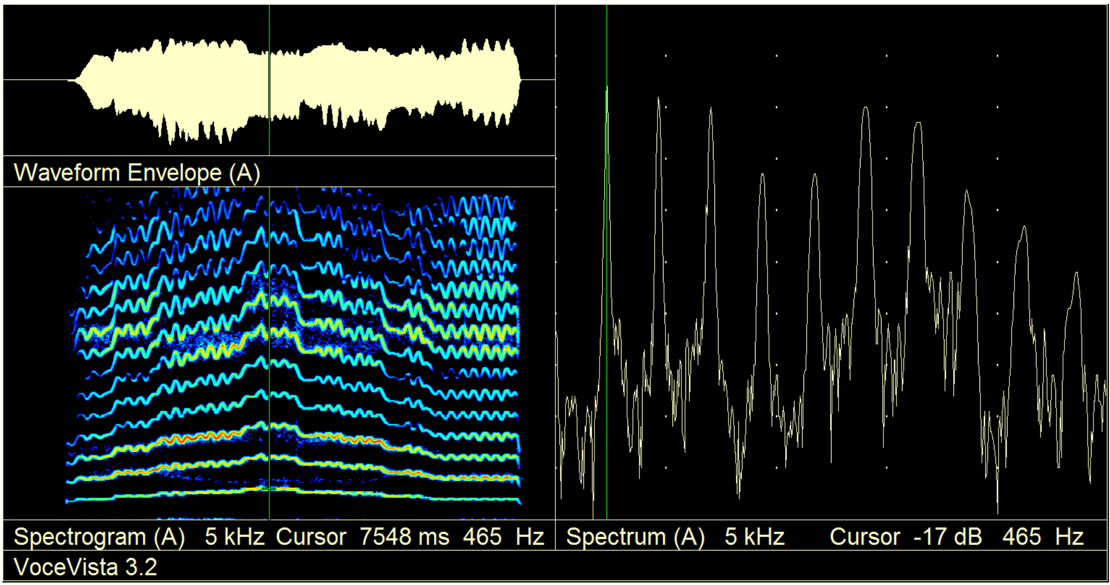
On the next rises in pitch Db4-Ab4, and D4-A4, formant tuning is lost and the upper note is consequently somewhat weaker than the preceding pitches in each of the scales. (Figure 4.4.5 shows the scale ascending to A4.)

Figure 4.4.5: Tenor (1) D4 – A4 scale [a]



This effect is more marked in the next scale of Eb4-Bb4 (Fig 6). The likely location of f_1 and f_2 can be seen in the 'shadow' blue lines below H2 and H3 in the colour spectrograms of both Figures 4.4.5 and 4.4.6.

Figure 4.4.6: Tenor (1) Eb4 – Bb4 scale [a]

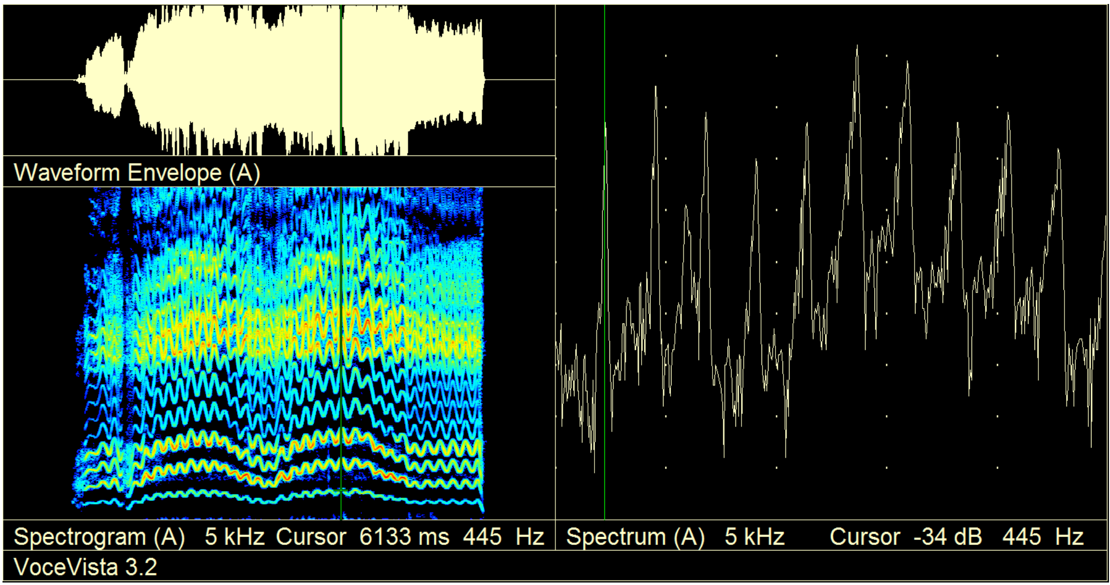


Tenor 7 is a strong example of a singer whose upper range utilises strength of the cluster of formants 3, 4 and 5 creating strong partials in the zone of pitch to which the human ear is particularly sensitive (Gelfand 2011, Zemlin 1988).

However as is often the case with elite male singers, there is also some evidence that care is taken with timbre resulting from strengths of H2 and H3. It was noted already in discussing Tenor 7 and ‘secondo passaggio’ that there was some ‘balancing’ of the strengths of H2 and H3 before H3 emerged as consistently stronger at the sung pitch of G4. The colour spectrogram of Figure 4.3.4 also provided a view (albeit generalised) of the consistent strength of the SF zone.

As pitch rises further, when examples are viewed with the power spectrum average set to 300 ms, the strength of partials in the SF zone exceed lower partials which are more susceptible to vowel changes (eg H2, H3 and H4.) Figure 4.4.7 shows a scale from Db4-Ab4. The green cursor in the power spectrum is placed at a moment when H3 is weakest. This is because at the top of the vibrato pitch cycle H3 is becoming beyond the influence of f_2. At the lowest point in the vibrato pitch, H3 is stronger than the partials in the SF zone. At no point in the detail of the Ab4 is H2 the strongest partial. (The blue 'shadow' line visible in the colour spectrogram between H1 and H2 denotes the presence of f_1, now well beneath the pitch of H2. The pitch of this moment is slightly more than a semitone above Ab4 because of the extent of vibrato.)

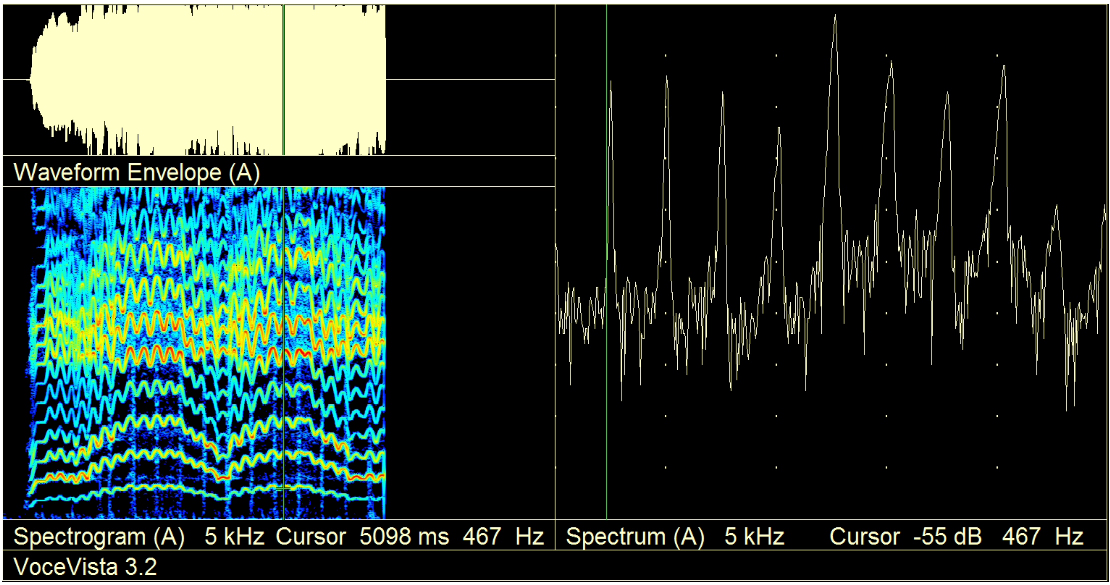
Figure 4.4.7: Tenor (7) Db4 – Ab4 scale [a]



In further examples provided by this tenor rising in pitch the same features are noted (for D4-A4, Eb4-Bb4). All of these short scale passages illustrate the consistent transition through the passaggio zone which has already been described.

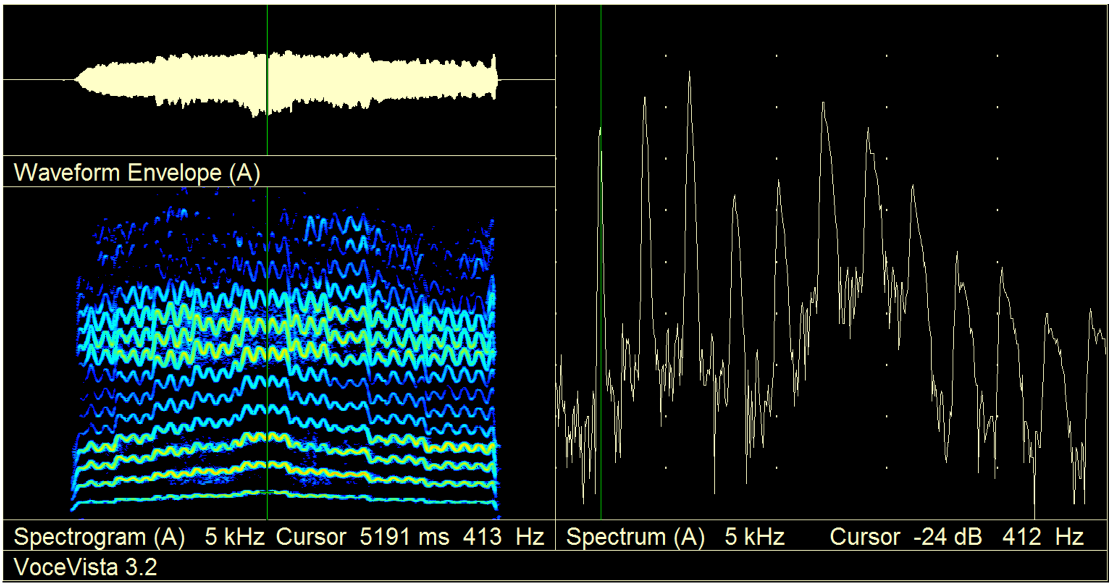
In a scale from E4-B4 (Figure 4.4.8) the high pitch of B4 causes H3 to move almost entirely out of the influence of f_2 and f_1 is much too low to be enhancing H2. This is the same situation as was described with Tenor 1 shown in Figure 4.4.6. However the SF activity is very strong in contrast to Figure 4.4.6.

Figure 4.4.8:Tenor 7 E4 – B4 scale [a]



In the group of more 'Lyric' category voices it was noted above that Tenor 3 showed the approach of the influence of f_2 whilst singing G4, but that the strongest partial at this pitch was H2. He is therefore an example of the type of singer who appears to use nearly equally balanced H2 and H3 at the top of the passaggio. In the next scale one semitone higher in pitch, from Db4 - Ab4 the small step upwards is sufficient to bring H3 into a stronger relationship with f_2 and so the transition through the passaggio is completed. The Ab4 exhibits H3 as stronger than H2 (Figure 4.4.9).

Figure 4.4.9: Tenor (3) Db4 – Ab4 scale [a]



This singer also had clear EGG signals (as noted previously). At the same point as Figure 4.4.9, Figure 4.4.10 shows the EGG which indicates a contact quotient of 61% (there is a barely perceptible 'knee' in the EGG window which helps to set the appropriate level).

Figure 4.4.10: Tenor (3) Db4 – Ab4 scale [a] showing EGG

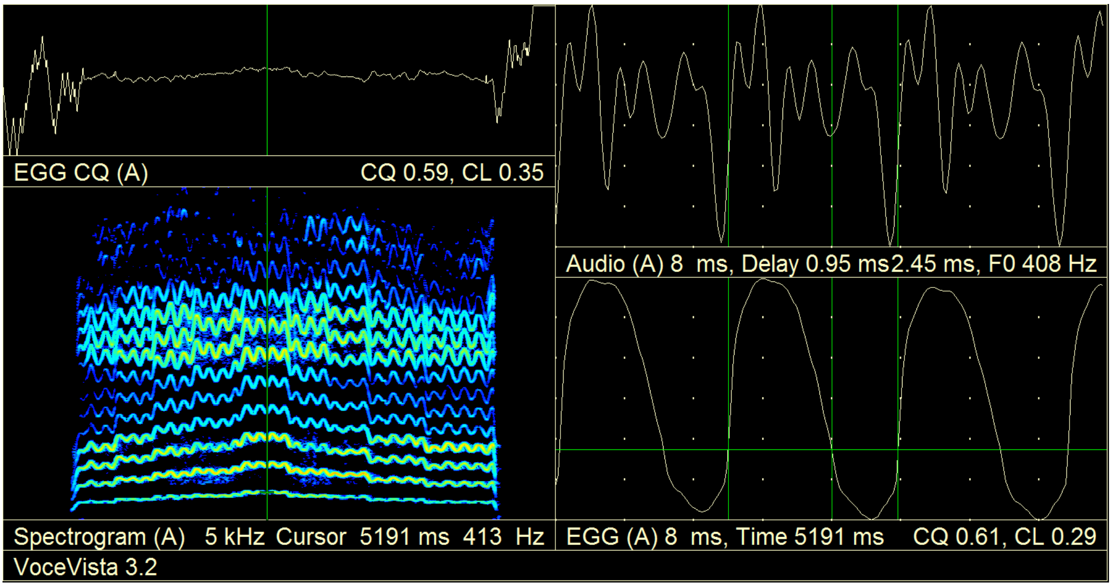
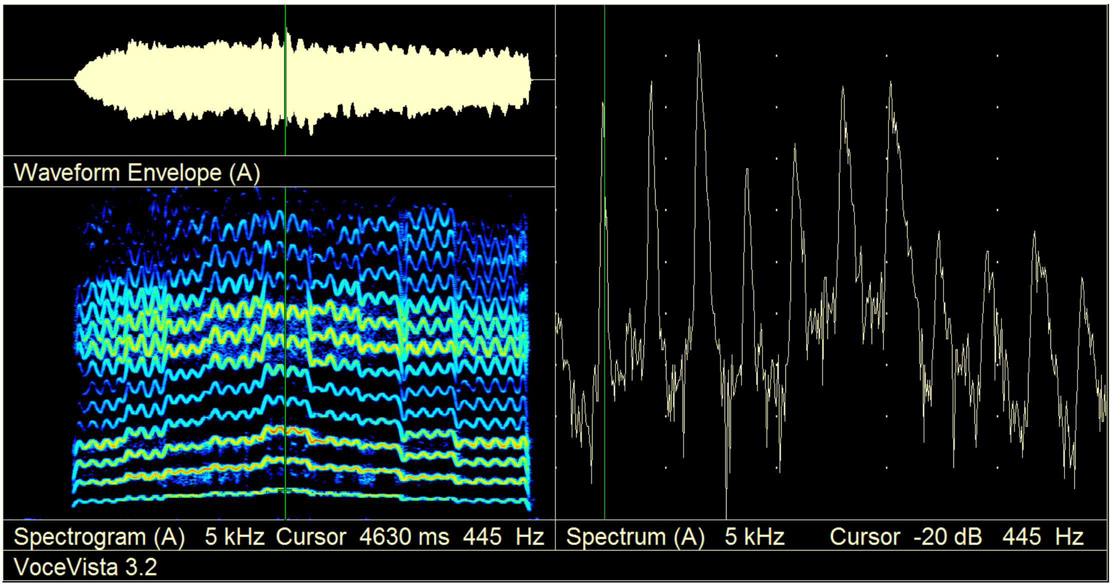


Figure 4.4.10 shows an instant taken from the lowest moment in vibrato pitch cycle, where H3 is strongest. This means than an adjustment of f_2 will be necessary if it is to

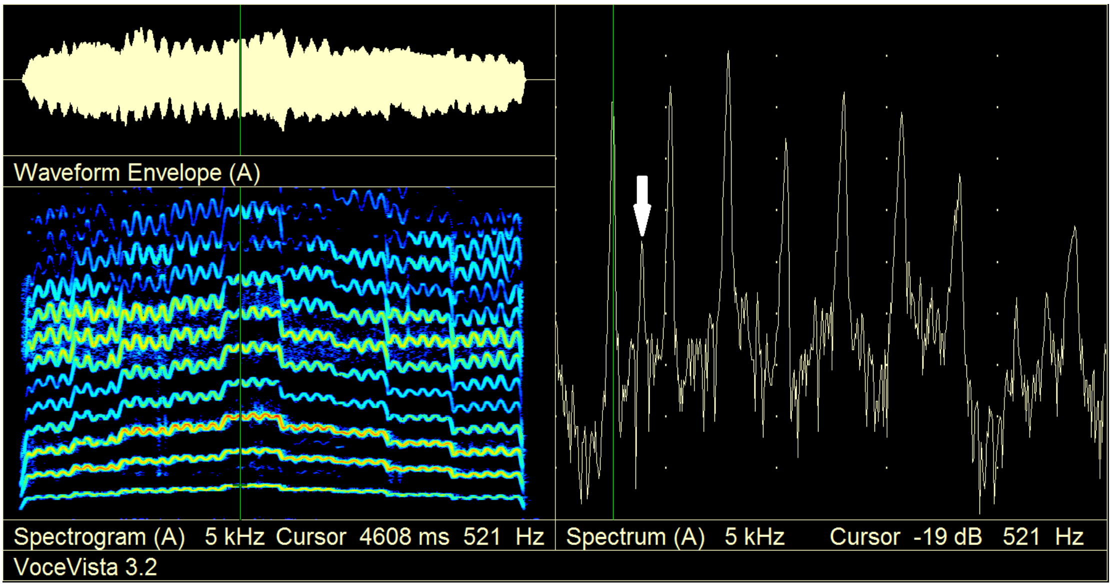
enhance H3 of the next semitone up, A4. This is decisively accomplished in the scale D4-A4 (Figure 4.4.11). The A4 here shows a strong engagement with f_2. As this voice only has modest levels in the SF zone, this accurate tracking of H3 in the upper range is important.

Figure 4.4.11: Tenor (3) D4 – A4 scale [a]



This singer manages to retain a strong H3 all the way up to his high C5. As was discussed in Tenor 5, the appearance of 'shadow' presence of f_1 lurking below H2 in differing examples suggests that the likely pitch of f_1 in the scale of D4-A4 is c.680 Hz, but this 'shadow' rises to c.780 in the scale from F4-C5. It therefore seems probable (as with Tenor 5) that formants are being permitted to rise in order to keep resonance working well. Figure 4.4.12 shows the ascent to C5 with H3 still the strongest partial. The white arrow in the power spectrum screen indicates the likely position of f_1 (now at c.780 Hz).

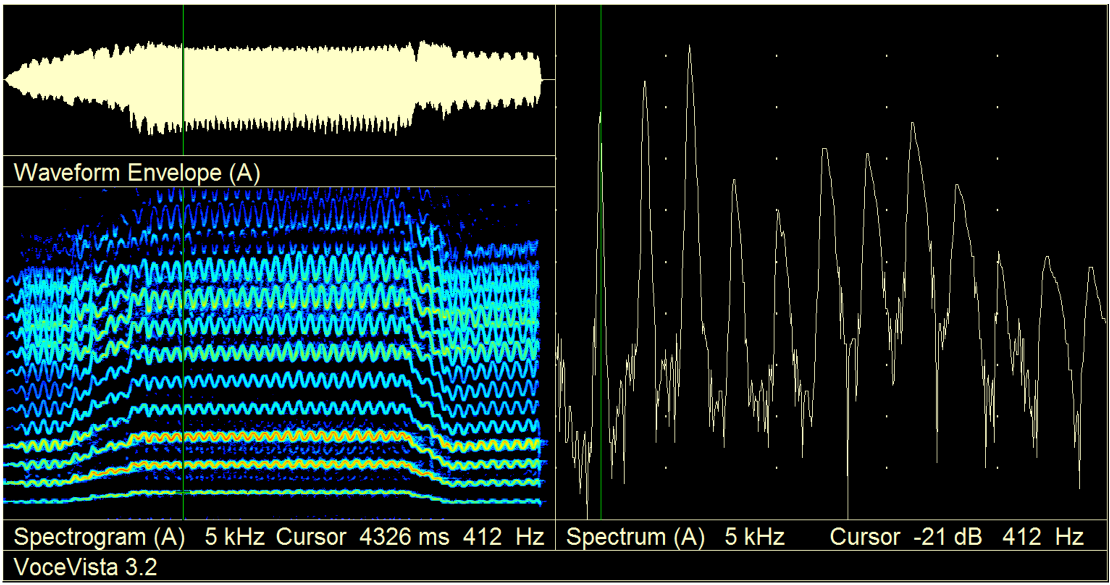
Figure 4.4.12: Tenor (3) F4 – C5 scale [a]



As with Tenor 3, Tenor 6 also has very modest activity in the SF zone, so what happens with f_2 when singing the [a] vowel in the upper range is important for achieving economically produced, effective resonance.

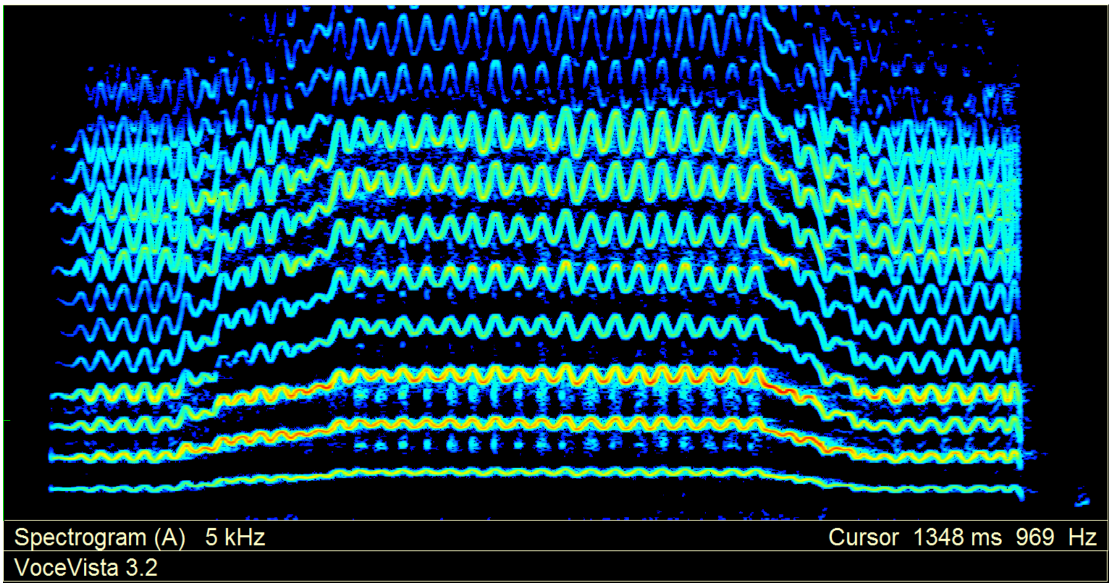
Having shown almost balanced H2 and H3 in his singing of G4, in the scale of Db4-Ab4 H3 is effectively engaged with f_2 and is the strongest partial, (Figure 4.4.13) an event denoting the end of his passaggio zone.

Figure 4.4.13: Tenor (6) Db4 – Ab4 scale [a]



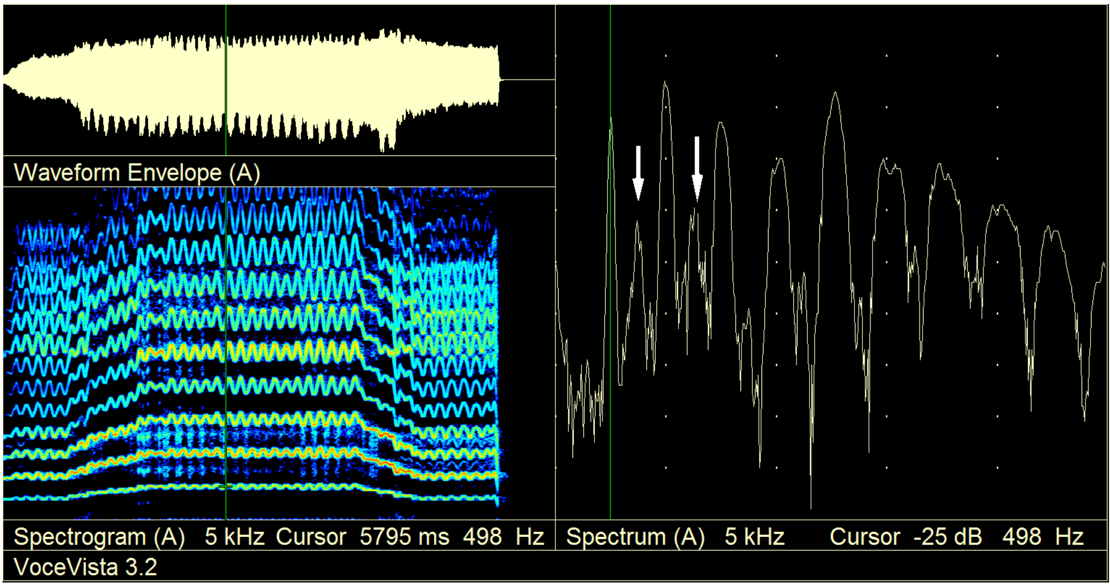
In his next example scale of D4-A4 H3 is yet stronger, but in the scale Eb4-Bb4 it seems that f_2 is now waning – being too low to evenly distribute its influence through the entire vibrato pitch change. The enlarged view of the colour spectrogram (Figure 4.4.14) shows this most clearly where it can be seen the underside of H3 is strongest. None of the partials in the SF zone are particularly strong. Viewing the example with power spectrum averaging set at 300 ms shows the SF zone as consistently c.10 dB less than H1.

Figure 4.4.14: Tenor (6) Eb4 – Bb4 scale [a]



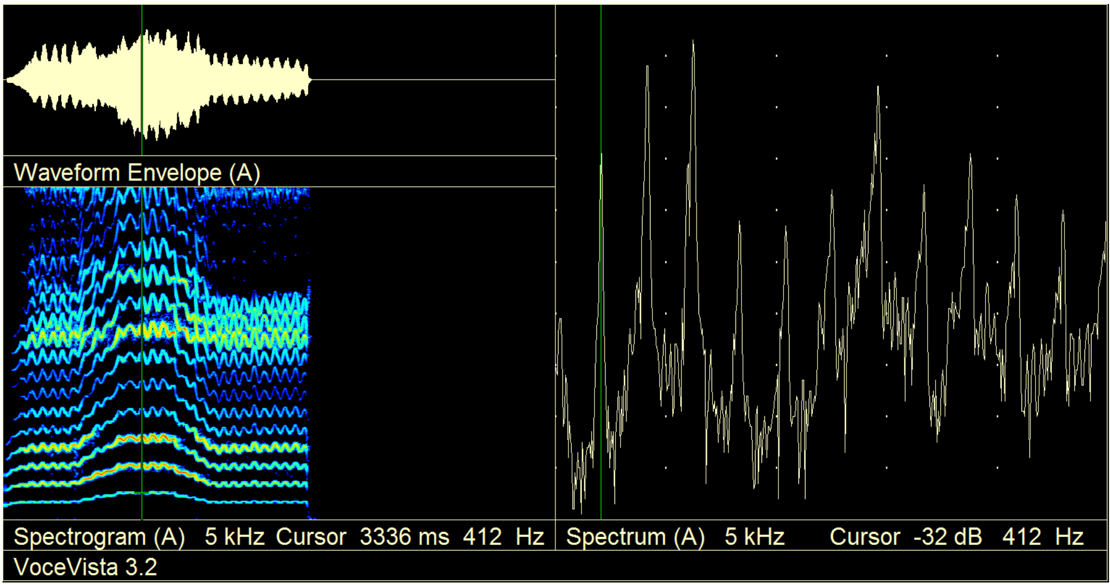
On the high B4 in the scale E4-B4 formant tuning is lost. The position of f_1 at c.740 Hz, and f_2 at 1260 Hz can be seen (white arrows showing their positions in the power spectrum view) and f_2 is not assisting H3 (Figure 4.4.15). Viewing the example with power spectrum set at 300 ms shows SF partials as weaker than H1. H2 sitting as it does almost equidistant between f_1 and f_2, receives some boost from their joint proximity. This is a poor situation as regards formant tuning helping resonance.

Figure 4.4.15: Tenor (6) E4 – B4 scale [a]



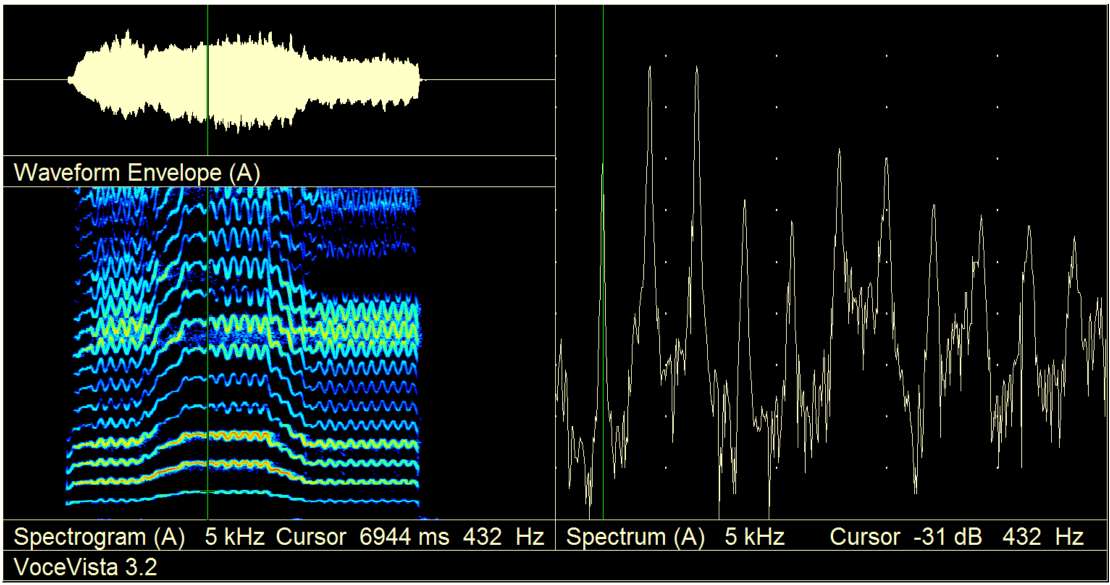
Tenor 8 has some strong activity in the SF zone and at the points where lower formants are not optimally positioned tends to still have partials in the SF zone which are strong. The ‘secondo passaggio’ moment for this tenor already shown was G4 (Figure 4.4.14), where f_2 was engaging with H3 at the highest point in the vibrato cycle. In the scale Db4-Ab4 (Figure 4.4.16) H3 becomes the strongest partial and is 22 dB stronger than H1. H2 is also strong at only 4 dB less than H3, and H7 is also strong (3 dB less than H2).

Figure 4.4.16: Tenor (8) Db4 – Ab4 scale [a]



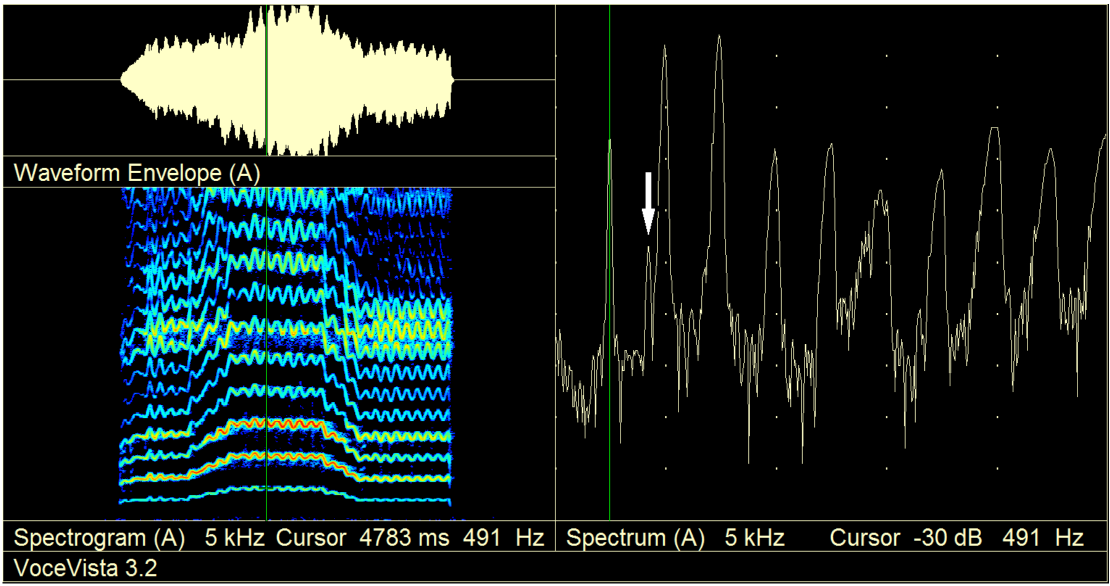
The scale of D4-A4 shows an unusual view of H2 and H3 being almost equal on A4 (this was also confirmed by viewing with averaging of power spectrum set to 300 msecs). This is because neither f_1 nor f_2 are optimally positioned. It is clear from the colour spectrum that H2 is optimally strengthened at c.720 Hz as the pitch appears to glissando upwards. Therefore H2 on A4 (centred c.880 Hz) is moving outside of the influence of f_1 (Figure 4.4.17).

Figure 4.4.17: Tenor (8) D4 – A4 scale [a]



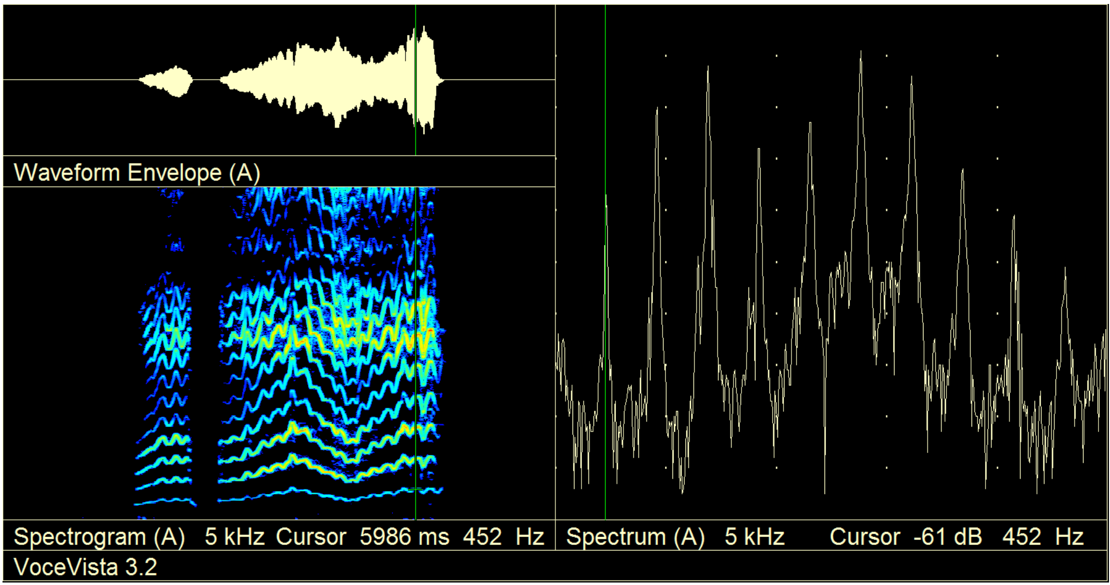
Eb4-Bb4 exhibited very similar characteristics, but the scale from E4-B4 showed H3 stronger than other partials. However somewhat surprisingly, H2 is still not far away in strength from H3. The clue as to how this is possible at this pitch is the 'shadow' blue shown below H2 in the colour spectrogram which probably represents the position of f_1 at c.840 Hz. If this is so, formants have risen significantly, enabling f_2 to react with H3. (Figure 4.4.18. The white arrow indicates the likely position of f_1.)

Figure 4.4.18: Tenor (8) E4 – B4 scale [a]



Tenor 4 shows two individual characteristics consistently in singing the [a] vowel in his upper range. He has very strong partials (especially H6 and H7) in the SF zone, and secondly tends to allow the vowel to migrate towards [e] which favourably raises f_2 to allow it to track H3 reasonably well. The example (Figure 4.4.19) shows several ascents from D4-A4. The turn towards the [e] vowel sometimes means that f_2 is slightly too high (visible in the colour spectrum where only the tip at top of H3 is strengthened significantly), but the SF remains consistently strong with H6 being 26 dB stronger than H1.

Figure 4.4.19: Tenor (4) D4 – A4 scales [a]

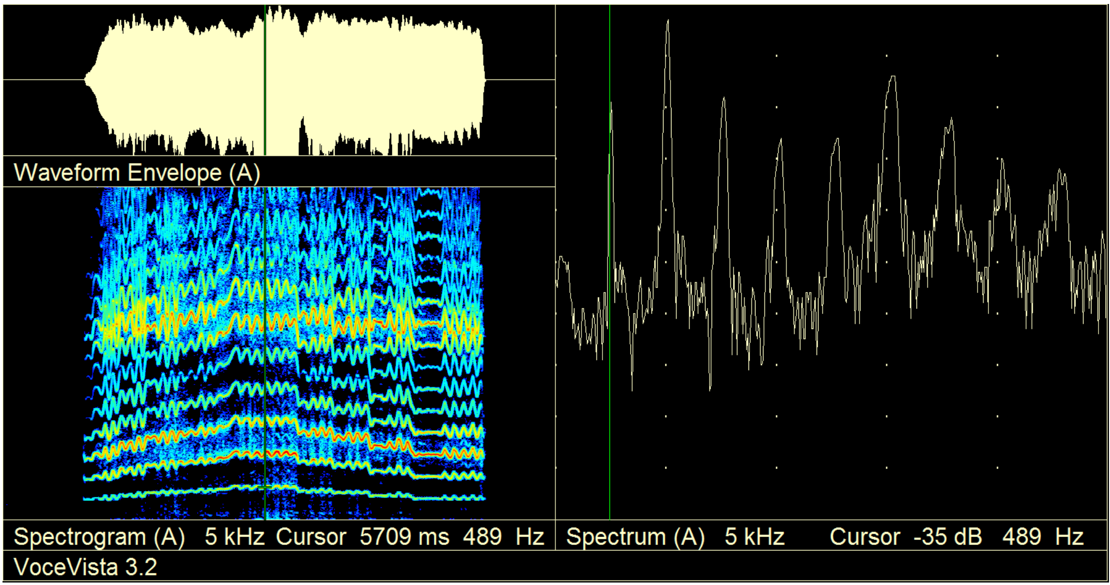


In further ascents reaching Bb4, B4 and C5 this tenor shows similar characteristics with impressive levels of SF partials.

Most of the important points as to how the character tenors ascend into the upper range of the voice were described in the 'secondo passaggio' section above. All three tenors in this group show H2 as the most prominent partial in singing to the top of their voices. This is in sharp contrast to the characteristics of the Heroic and Lyric tenor groups described above and the findings of Schutte, Miller and Duijnstee (2005).

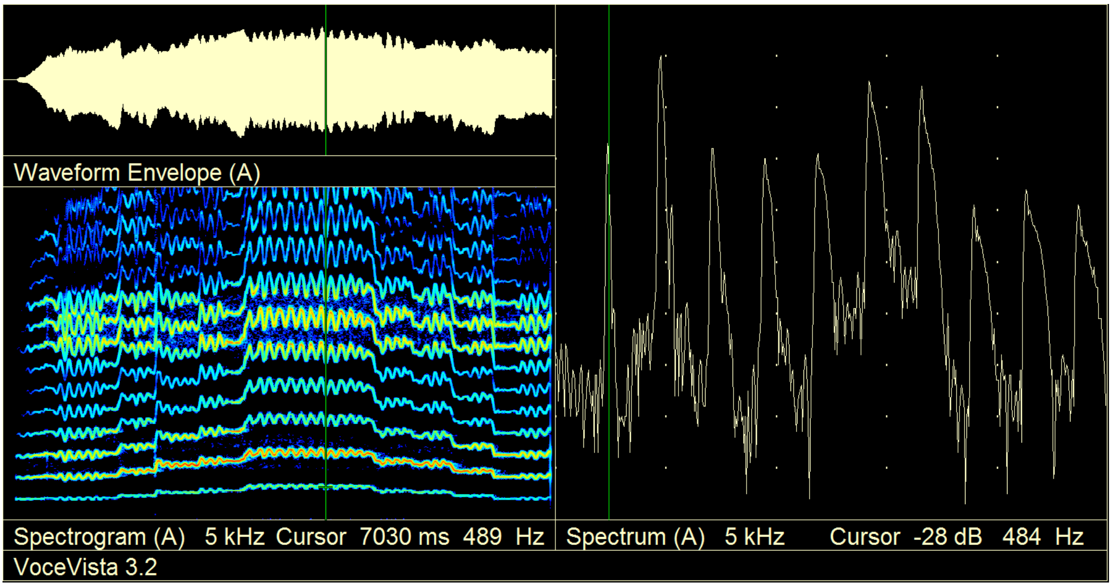
Tenor 2, having reached a pitch at which H2 begins to be strengthened by the lower side of his clustered formant f_1/f_2 continues to show a strong H2 up to the top of the voice. This example is representative of his resonance management and demonstrates the surprising engagement with H2 on a high B4 (Figure 4.4.20).

Figure 4.4.20: Tenor (2) E4 – B4 scale [a]



Tenor 10 shows a remarkably similar resonance on his B4 at the top of the scale E4-B4. (Figure 4.4.21)

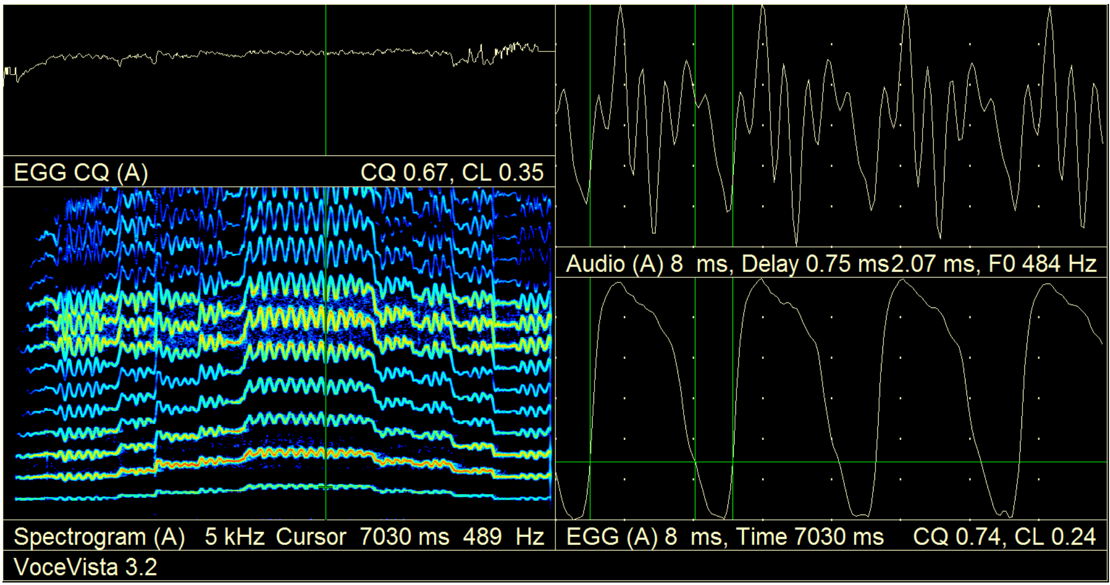
Figure 4.4.21: Tenor (10) E4 – B4 scale [a]



As this tenor also had very clear EGG signals it is also possible to see the contact quotient for the same moment as shown in Figure 4.4.21, with the differing screen view with EGG and audio signal. It appears that he has a high contact quotient of

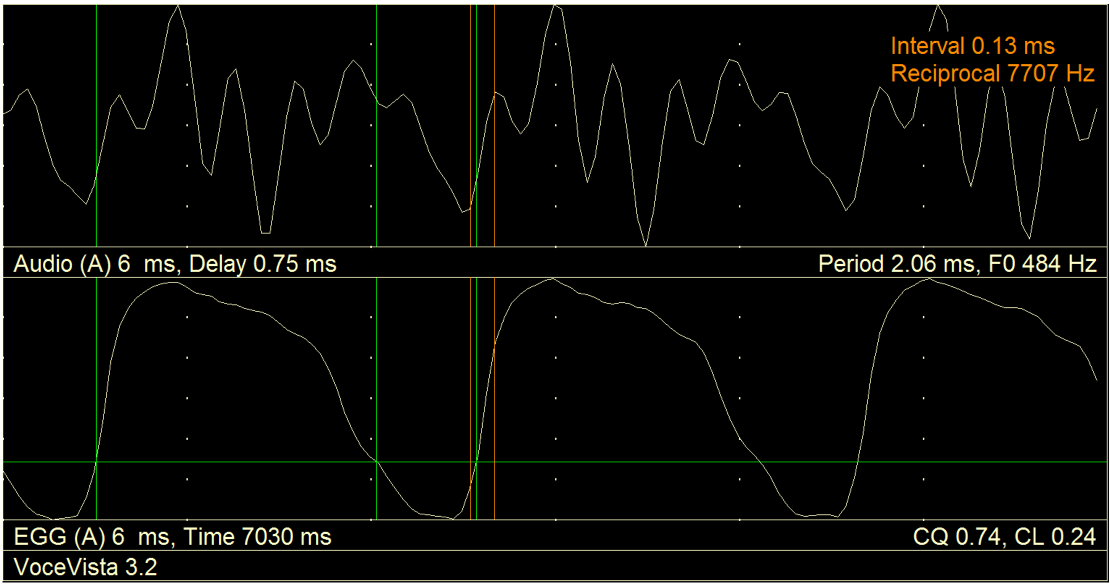
74%. (There is a slight, late knee in the EGG, discernible in the opening slope of the signal, Figure 4.4.22.)

Figure 4.4.22: Tenor (10) E4 – B4 scale [a] showing EGG on B4



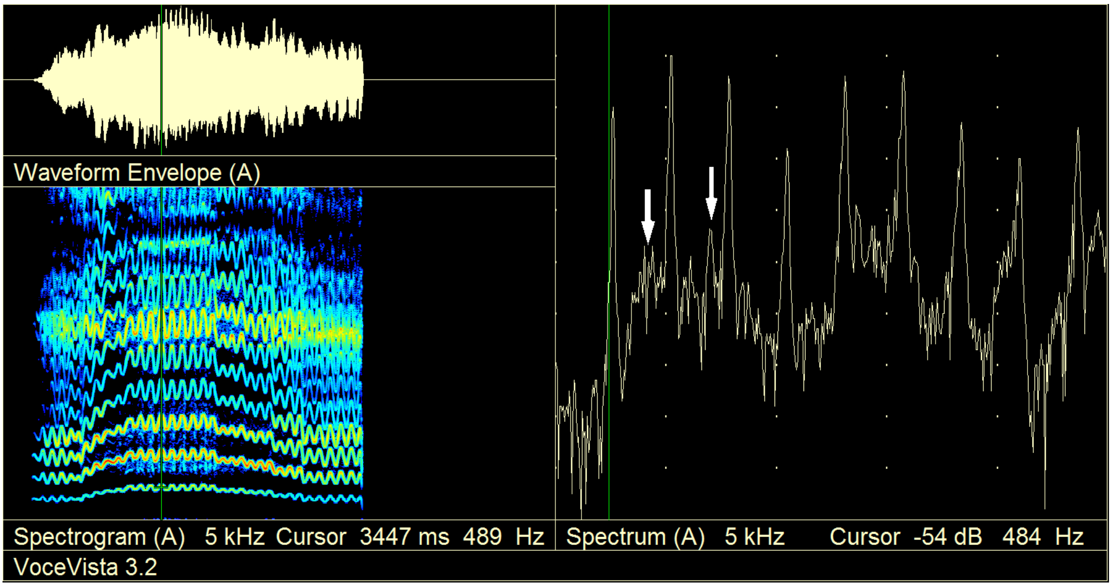
This may seem remarkably high, but measuring the initial closure rate shows an extremely fast initial closure of 0.13ms. This measurement is shown with the orange cursors for the same moment as in Figures 4.4.21/4.4.22 in Figure 4.4.23.

Figure 4.4.23: Tenor (10) B4 [a] showing initial rate of closure



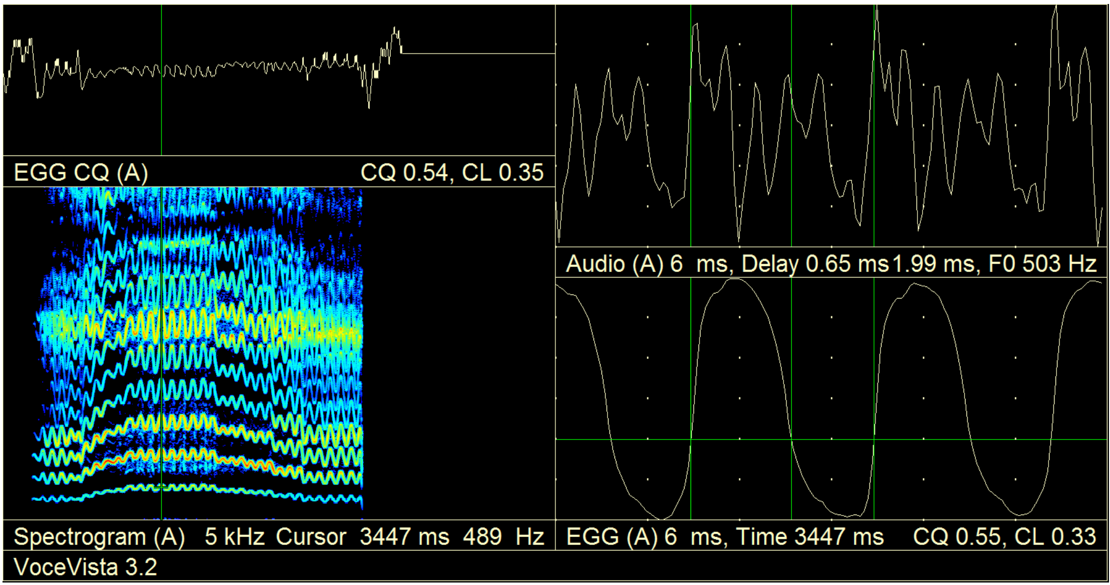
Though Tenor 9 also shows H2 as the strongest partial, the same as Tenors 2 and 10, this is not so markedly the case. The white arrows in Figure 4.4.24 show where the 'shadow' below H2 and H3 may indicate the true (somewhat elevated now) positions of f_1 and f_2.

Figure 4.4.24: Tenor (9) E4- B4 scale [a]



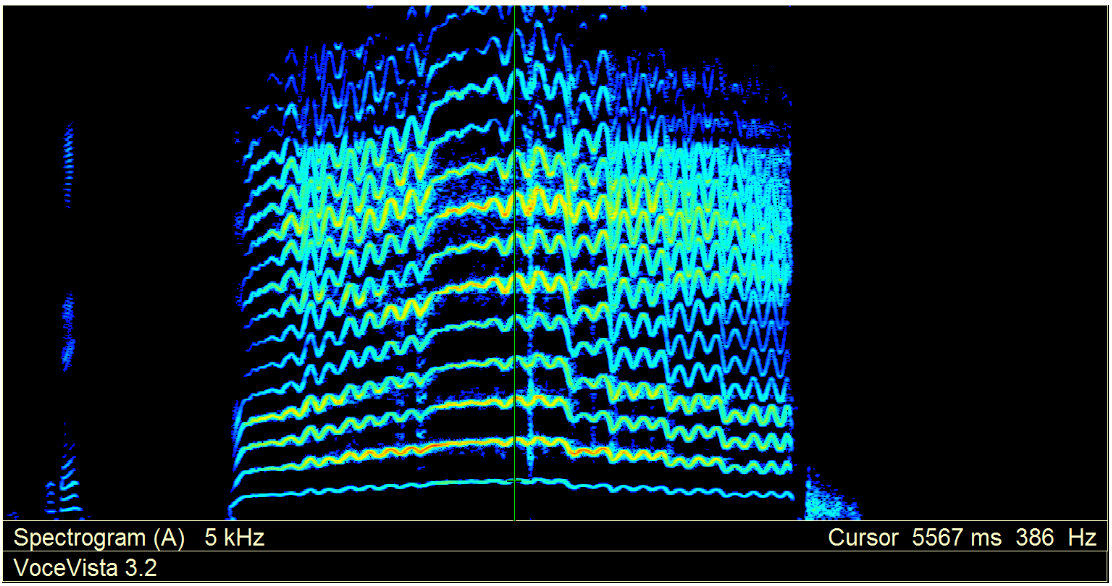
However, unlike Tenor 10 who appears to have an elevated contact quotient level, that of Tenor 9 is considerably lower at 55%. (Figure 4.4.25)

Figure 4.4.25: Tenor (9) E4 - B4 scale [a] showing EGG on B4



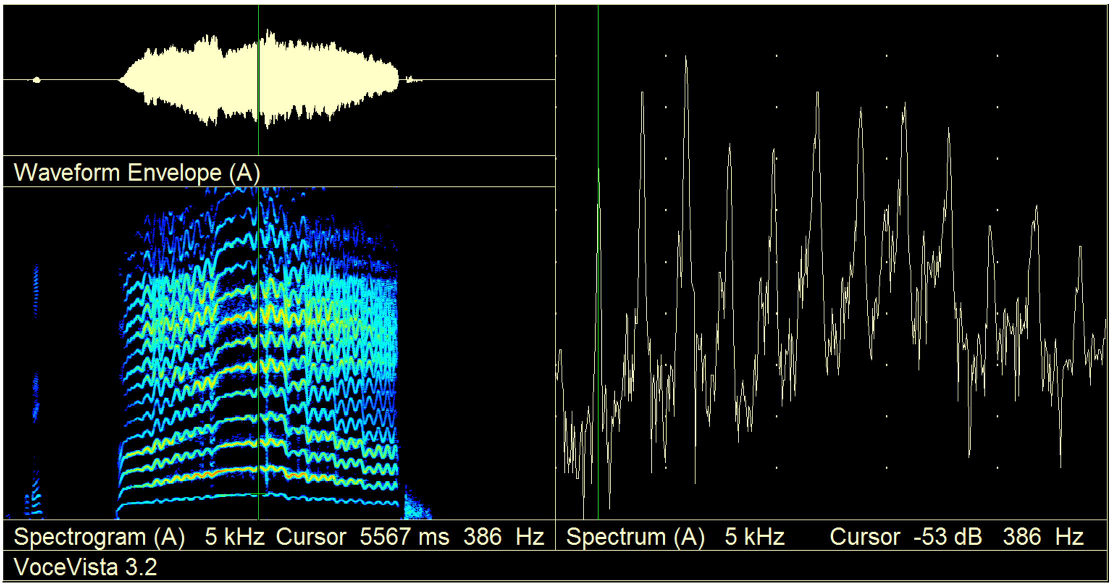
The Baritone (singer number 12) considered G4 to be the very top of his range. In the scale from C4-G4 (in the colour spectrogram Figure 4.4.26) traversing his passaggio we see how f_1 and H2 interact. Towards the top the approach of f_2 is seen in the gradual strengthening of H3. It does appear though that f_2 is slightly too high, since it is only the top part of the pitch within the vibrato cycle which is strongly influenced by f_2.

Figure 4.4.26: Baritone (12) C4 – G4 scale [a]



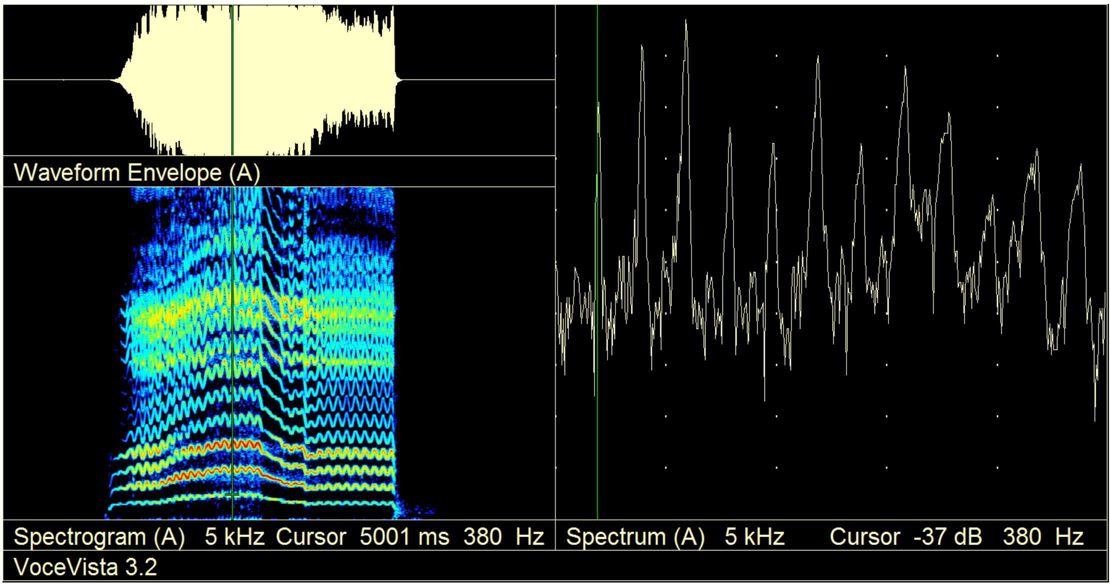
The second view of the same moment is shown with the power spectrum (Figure 4.4.27) so that the relative strengths of the partials at this instant can be seen. Viewing the example with power spectrum average at 300 ms shows that H3 is marginally ahead of H2 on the high G4.

Figure 4.4.27: Baritone (12) C4 – G4 scale [a] with power spectrum



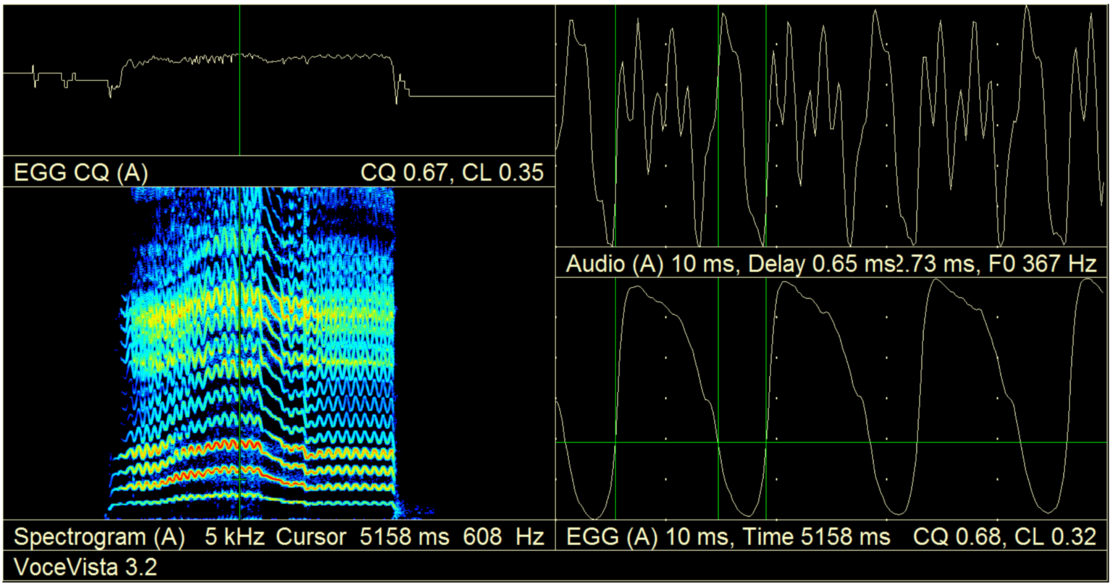
It was noted above that the 'secondo passaggio' point of Baritone (singer number) 11 was between E4 and F4. On the next semitone higher H3 is sufficiently engaged with f_2 to become the strongest partial, though H2 is also nearby in strength (Figure 4.4.28).

Figure 4.4.28: Baritone (11) B3 – F#4 scale [a]



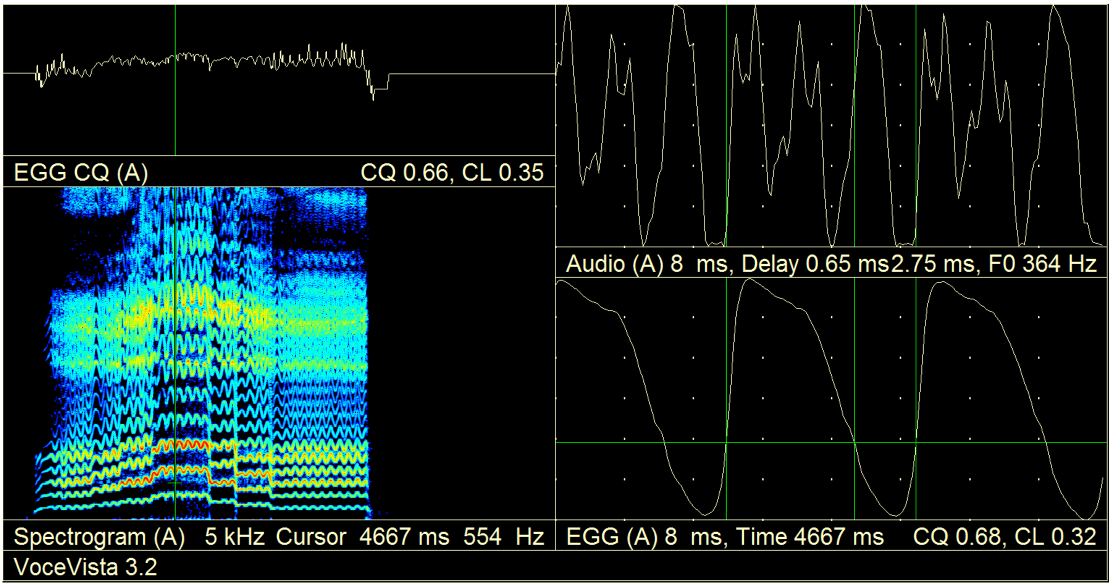
A view with EGG of the same pitch of F#4 shows likely contact quotient of 68%. The three columns in the audio signal also confirm the strength of H3 at this point (Figure 4.4.29).

Figure 4.4.29: Baritone (11) B3 – F#4 scale [a] showing EGG on F#4



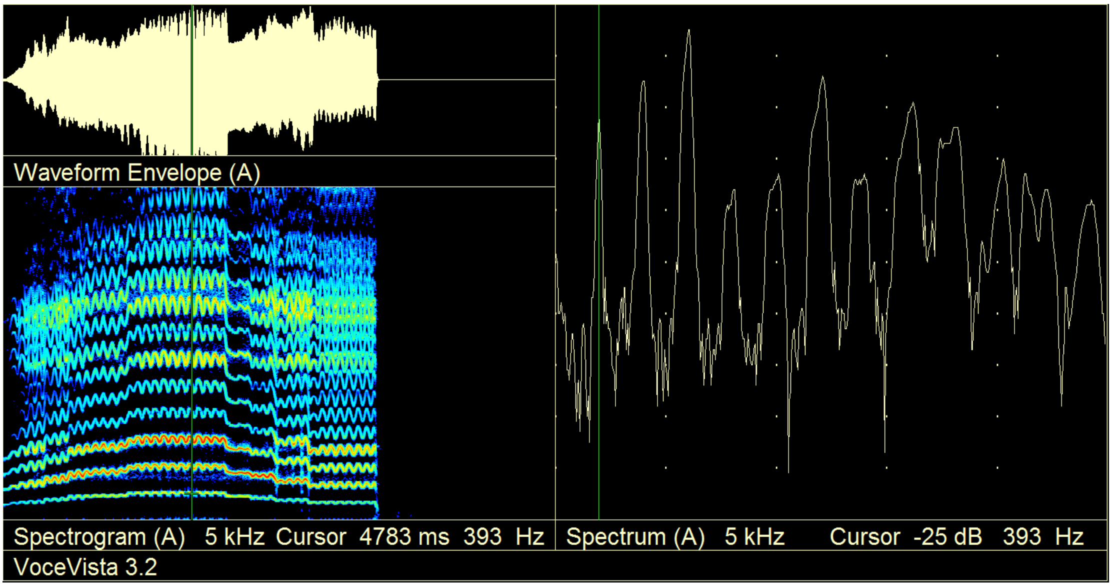
In a separate example of an arpeggio sung from F#3-F#4 this singer shows consistent resonance and contact quotient as in the previous example. (Figure 4.4.30). This seems to be a reliable coordination and not haphazard.

Figure 4.4.30: Baritone (11) F#3 – F#4 arpeggio [a] with EGG on F#4



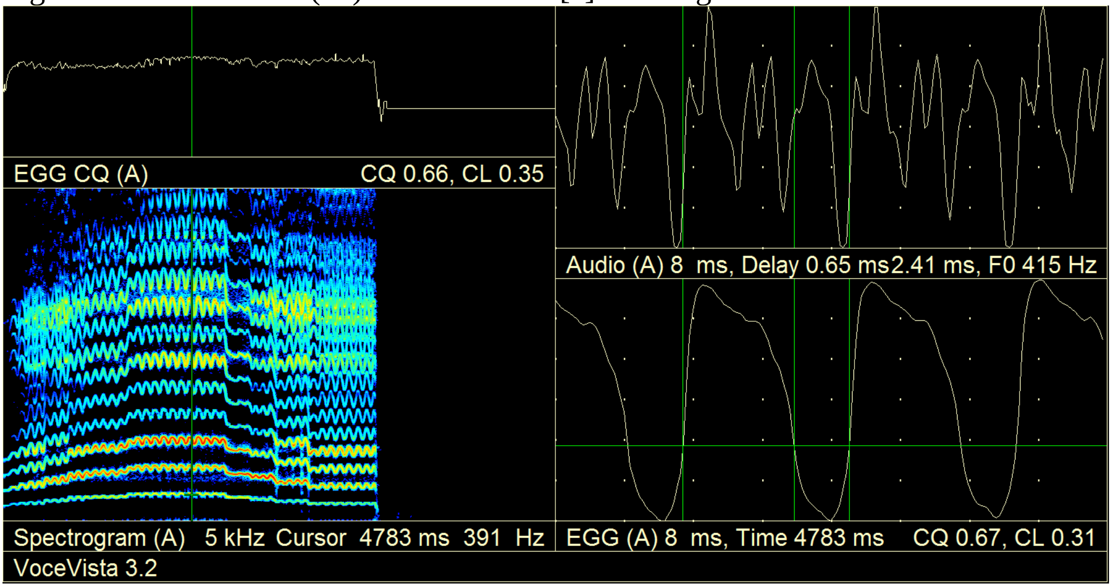
This baritone also considered his highest professional tone to be a G4. In ascent to this important note, so often exposed as climactic in both Italian and German repertoire, Figure 31 shows strong, even interaction between an accurately positioned f_2 and H3.

Figure 4.4.31: Baritone (11) C4 – G4 scale [a]



The same instant is shown in Figure 4.4.32 but with the clear EGG signals. These suggest a contact quotient of 67% which is very consistent with the previous examples from this singer. The dominance of H3 is clearly visible in the audio signals.

Figure 4.4.32: Baritone (11) C4 – G4 scale [a] showing EGG on G4



These foregoing examples offer a complex and varied set of responses to the particular challenges of the [a] vowel in the passaggio zone and beyond to higher pitches for male classical singers. The next chapter will discuss the characteristics further.

Chapter 5: Professional Singers: Discussion of Examples

5.1. Introduction

The material gathered from professional singers presented in Chapter 4 helps to provide some answers to the main research question about how the [a] vowel is managed by male classical singers in the passaggio zone and higher range. At the same time, this material also demonstrates the complexity and variety of responses to the artistic and vocal challenges presented by the open [a] vowel in the passaggio and higher range. Some aspects, such as the engagement between the first formant and second harmonic are revealed in more detail than hitherto known, and the variety of positioning of the secondo passaggio moment can also be better understood and clarified, if not exhaustively.

The modest size of the group of professional singers who contributed to this study means that some caution needs to be expressed in offering some of what follows. The group divided not only into tenors and baritones but into sub-types of tenors according to repertoire-derived Fach designations. The views expressed here are relevant to distinct groups of singers, each comprising three or four tenors (the ‘Helden’ and ‘Charaktertenor’ groups had three singers in each, and the ‘Lyric’ group had four) and would need larger groups of the same Fach types to confirm the findings of this study. It would also need more baritones, of the same vocal Fach as those here discussed, to be certain that the conclusions reached are sustainable. However, the specific aspects exhibited in the collected examples do indicate important differences which help to explain and make clearer, for the first time, some of the traditional assertions about voice categories and Fach which exist in the classical voice profession, and which are written of in traditional descriptive language in books about Fach (Legge 1998, McGinnis 2010, Shepard 2010,) and vocal pedagogy.

There are seven areas arising from the professional examples which need discussion:

- The effects of context on resonance.
- First formant and second harmonic interactions and ‘Fach’.
- The significance of differing ‘secondo passaggio’ points.
- The Charaktertenor resonance strategy.
- The concept of ‘deliberate artistic decision’ versus ‘accidental acoustic outcomes’.
- The need for vowel management in voices with less strong singers’ formant partials.
- Questions arising regarding contact quotients and initial vocal fold closure speeds.

Some of these particular facets have been the subject of interest and investigation in recent years. Though the important study of high notes in tenor voices Schutte, Miller, and Duijnstee (2005) did not immediately lead to many similar studies, Miller (2008) did provoke more widespread interest and reaction amongst voice scientists and pedagogues.

The focus of a study undertaken by Sundberg, Lã, and Gill, (2013) was the difference between classical and non-classical formant tuning strategies in professional male classical singers in the passaggio zone. That study concluded:

> A rising spectrum envelope over the three lowest partials was a common denominator of the highest tones sung on /a/ and /ae/ in classical style, even though it was produced with slightly differing combinations of formant frequencies and the spectrum varied greatly during the vibrato cycle. (Sundberg, Lã, and Gill 2013, p.288.)

This has been again demonstrated by the professional singer examples collected here, which also show a rising spectrum envelope over the three lowest partials. However, by changing the angle of focus on the subject matter and trying to relate what can be seen in spectral observations combined with what is known about voice type, repertoire-base and Fach, it is possible to understand in more depth the variety of resonance responses to singing the [a] vowel in the passaggio and higher range.

5.2. Importance of context on resonance

It is of prime importance when attempting to establish how good professional singers manage resonance issues with the [a] vowel in the passaggio and higher range to acknowledge the influence of context on resonance outcomes. The logical outcome of asserting that the 'acoustic events of the passaggio can be shifted in several ways and for differing reasons (Chapter 4.2 p.90)' is that quantitative studies of resonance in classical singers which do not discuss these factors may inadvertently offer conclusions which are either of very limited truth, or misleading.

The word ‘context’ is here intended with the widest possible meaning. The factors which might be considered as contextual include: voice type and Fach; the notional volume level intended by the singer in any offered example offered; the position of a particular note within a phrase or group of notes (in scales and arpeggios); and in the performance of repertoire, the intended imaginative/emotional quality.

This last element has not been explored here, but is mentioned because it is an obvious influence on resonance adjustment for any performer. At the most banal level, an [a] situated on the prominent passaggio pitch F4 which is associated with an emotion of triumphant exhilaration such as occurs at the end of Siegmund’s *Winterstürme* ‘aria’ will be likely to have a differing resonance quality to the same pitch on the exposed [a] of Nemorino two bars before his cadenza at the end of the reflective *Una Furtiva Lagrima*, or the prolonged [a] on F4 of Don Ottavio in *Il Mio Tesoro* (occurring twice in the aria). This latter F4 is particularly interesting as it links two different emotional states; Don Ottavio thinks of drying the eyes of his lover, then his mind moves towards deciding to seek revenge on her behalf. A skilled singer may wish to use two rather different resonance tunings over the course of this single note to convey such psychological progression. This area is not being investigated here, but mentioning its existence serves to demonstrate the pitfalls of making conclusions about the resonance tuning of passaggio notes without thinking of the context. It is not sufficient to simply speak of ‘a professional tenor’.

As previously stated (Chapter 3.5 p.57), the contributing singers were asked to sing at their personal comfortable mezzo-forte level and in a manner which they perceived as ‘normal’ were the scale or arpeggio phrase to appear within a piece of repertoire. It was hoped that this would show what one might refer to as the trained ‘default’ resonance habit of each singer.

The location of a pitch within a pattern of notes can affect the resonance for that pitch. This is clear in a number of the examples from the professional group of singers. Though some of the singers exhibited consistent resonance characteristics for secondo passaggio pivotal pitches, others did not. Tenor 5 tended to show the same resonance on pitches such as F4 and F#4, whether these notes occurred as the highest note in a scale or arpeggio or were in a medial position in the group of notes, where they were shorter in length than the pauses made on each upper note in the phrase.

It was noted previously that Tenor 1 showed differing resonance tunings for the pitch of F#4, which was pivotal in his voice, being at the top of his passaggio zone. When this note was the highest in the phrase (scale of B3-F#4) it showed strong f_1/H2 coupling, but when the same pitch occurred in the middle of a higher scale (D4-A4) the resonance swapped to f_2/H3 tuning. This was more markedly the case when descending from the A4 back to D4 in the scale. As mentioned previously this might well be because once the voice has risen to a high pitch where some f_2/H3 resonance tuning is likely (whether deliberate or not) it is then more likely that this will prevail for longer in descent than might be suggested by the ascending sequence of notes.

It is also possible that the resonance tunings which occur are influenced by the subconscious tonal model of a singer. If a note is the highest note in a phrase a singer may be tempted to make this the focus of his attention simply because of that position in the phrase. Therefore an F#4 which lies at the top of a group of pitches may be sung with a deliberately fuller sound than when it occurs as a transitory pitch leading to higher or lower notes. If a singer has a proprioceptive memory of such higher notes having a different resonance tuning (or ‘sensation’) it is possible that in seeking to find that quality it may be introduced slightly earlier than would otherwise be the case.

Another aspect of this is that where a pitch is located towards the top of a male passaggio zone it could be sung (using an [a] vowel) with four alternative resonance tunings. These are, f_1/H2, or a tuning in which the partials H2 and H3 seem almost equal, or with clear f_2/H3 tuning, finally there is the possibility of allowing strong partials in the singers’ formant cluster to dominate the resonance. Since the first formant is usually considerably stronger than the second, opting to use f_2/H3 on such a pivotal pitch (when it could be offered with the acoustically more powerful link of f_1/H2) may mean some degree of sacrifice of volume. There may be artistic/imaginative factors at work which make one tuning preferable to another.

The examples from Tenor 8 suggested that it was likely that as pitch ascended there was some laryngeal lifting (Chapter 4.4, pp.127-128), rather than maintaining a low resting position. If the position of the larynx rises this causes all formants to rise. This meant that for this tenor almost all notes which had occurred as the highest notes in phrases had different resonance tunings once they were intermediate pitches in phrases where the uppermost note was such as to cause the position of the larynx to rise. It is quite possible that such a rise in laryngeal position was accidental rather than deliberate. If this is in fact the case it strongly suggests that clearer information about the professional usefulness of formant tuning would be of assistance in achieving economic vocal outcomes.

5.3. First Formant and Second Harmonic interactions and 'Fach' type.

There are at least four parameters which our examples suggest assist in defining the differences between the 'Helden' and 'Lyric' groups. The first of these parameters is rounding of the [a] vowel. Two of the three tenors we identified as 'Helden' or the Italianate equivalent of 'Spinto' audibly rounded the [a] vowel towards [ɔ] in the passaggio zone. This was not so noticeable with Tenor 5, but that seems logical as this singer performs partly in the 'Spinto' Fach and sometimes in more lyric territory.

Secondly, and partly as a result of vowel rounding, this group as a whole showed high levels of differential in the strength of H1 and H2 in the passaggio, with H2 so strongly engaged with f_1 that H2 was often c.25 dB (or more) stronger than H1 at the strongest moments.

Thirdly, where this acoustic coupling occurred there was an increased acoustic impact of the coupling of f_1 and H2, since H3 was generally very much weaker. This has the effect of making the tone quality very strong and distinctively 'heroic'. Pedagogues describe such a quality as 'chest voice' or even as the 'yell of the voice', (without implying any pejorative meaning). The epicentre of such strength of H2 was Eb4 for Tenors 1 and 7, and a semitone higher for Tenor 5.

Finally, the fourth element noted was that there was a strong engagement of f_1 with H2 as early as Dd4 for all three tenors, whereas in other lighter tenors this engagement occurs later.

This last point concurs with established views on where passaggio points occur in 'Helden' and 'Spinto' voices, such as summarised by Miller, R., (1993) and this location for the primo passaggio moment would not surprise anyone working in the industry. The exact point at which defining acoustic events occur is not determinable, since concepts such as ‘subtlety’ are often employed in discussions about passaggio events. Indeed as classical singers strive to achieve a unified timbre throughout the available vocal range, without sudden discontinuities, they are generally aiming at subtlety. However, what is new here is that we can now start to see more clearly what are the acoustic characteristics of the choices made in resonance treatment.

By using a gently rounded [a] vowel the Helden/Spinto voices slightly lower the location of f_1 and thereby find a concomitant lower f_1/H2 coupling, creating a distinctive ‘ring’ in the voice. As the sung pitch rises (H2 rising in parallel with the fundamental pitch), the lowered position of f_1 means that it will disengage more noticeably from H2 by around F4 or F#4, which is earlier than occurs in more lyric vocal production. It is therefore important for this type of tenor to learn how to situate f_2 so as to enhance H3 as the f_1/H2 link is abandoned, or there will be inevitably a significant and audible loss of perceived loudness as well as a change of timbre. It is of course very advantageous if there is strong resonance in the singer’s formant pitch zone, since this may mitigate, or even entirely compensate, for the loss of the f_1/H2 amplification. At the primo passaggio point all three of the Helden/Spinto voices have strong SF partials but Tenor 1 lost strength in that zone when reaching the secondo passaggio moment, whereas in Tenors 5 and 7 (also Tenor 4, the voice which sings in both ‘Spinto’ and ‘Lyric’ Fachs) the SF partials remain strong. This is so even though they both show a change from predominantly f_1/H2 resonance to f_2/H3 resonance in that area of the spectrogram.

These characteristics are entirely in accord with what was suggested by Miller, D., (2000), but here we have been able to further relate the detail of formant boosting of partials to voice categorisation. Entirely new, is the material which shows that the group of Charaktertenors take a different and somewhat surprising approach. (See below, section 5.5.)

5.4. The significance of differing ‘secondo passaggio’ points

It may not actually matter what name is given to the moment when there is a change in timbre associated with resonance adjustments caused by the loss of particular formant/partial relationship at the entry into the pitch range considered to be the ‘head voice’, or more simply the upper range. However the term ‘secondo passaggio’ is at least not clumsy and can claim some international pedigree. The skilled traversing of this moment in the range is clearly not easy to achieve, otherwise all talented singers would be able to do so quickly and easily and there would be far less emphasis in pedagogy on training this element. As discussed in the Introduction, there are two factors which generate the particular challenge of the [a] vowel in the male passaggio.

First, the [a] vowel has the highest pitch for its first formant of all the Italianate vowels which form the basis for most international voice training. This is often in the range of between 620 – 750 Hz for males, depending on the exact pronunciation of the vowel, and other physiological factors such as dimensions of vocal tract, and jaw/lip position. (Peterson and Barney, 1952; Ladefoged, 1962; Sundberg, 1987; Thurman and Welch 2000.)

Secondly, the first formant is the strongest formant in most voices, with the strongest possibility of enhancing partials falling within its orbit. Titze (2003) has stated that a formant is most advantageously positioned if it is slightly above the relevant partial, and his theoretical model suggests that if a formant is positioned directly on a partial, ‘non-linear source-filter interaction’ (p.292) can occur causing undesirable and unintended register breaks or discontinuities. However, Sundberg (2013) has subsequently concluded that classical singers have found a way (as yet not fully understood) to avoid such negative consequences.

Many of the examples provided by the professional singers given in Chapter 4 suggest often that the engagement with f_1 is extremely powerful in the passaggio zone. This has already been commented on and is in alignment with the findings of Miller, D., (2000) concerning f_1/H2 in the male passaggio.

It is easily seen that if f_1 of an [a] is somewhere from 620 Hz – 750 Hz and a singer sings pitches with fundamental frequency between Eb4 – G4 (311 Hz -392 Hz) it is quite likely that H2 will be engaged with f_1. Since the bandwidth of f_1 may be in the region of 50 Hz (Schutte, 1995, p.293;) it is possible that this area of influence is somewhat wider, by a semitone lower and higher. So if a hypothetical singer has an f_1 situated with its centre at 720 Hz when singing his [a] vowel, this will engage with pitches from E4 – G4 (keeping in mind that F#4 is 370 Hz). Though this study has not used inverse filtering to explore exact formant locations, but has used the more instantly available non-periodic phonation method (Miller et al, 1997) (where possible), there are clear indications that when f_1 is located very near or even probably directly on H2, that partial receives a very strong boost of sound intensity. The practical issue therefore for the classical male singer is how to manage relinquishing the f_1/H2 coupling whilst maintaining the resting low larynx position and offering an acceptable continuity of resonance, timbre and perceived loudness - hence the importance of the ‘secondo passaggio’ moment.

The examples from the group of ‘Heroic/Spinto’ tenors showed a secondo passaggio event between F4 and F#4. Tenor 1 was not consistent in this and all three had individually distinguishing elements. Tenor 7, the singer who has had the longest highly successful career singing German Heldentenor roles, has consistently very strong partials in the SF zone. This would mean that those partials, being stronger at the top of the passaggio than either H2 or H3, carry the prominent acoustic strength of the voice. Therefore the relative strengths of H2 and H3 in merging the top of the passaggio into the upper range are less noticeable and consequently less crucial in resonance management. However it was still noted that there is a change from f_1/H2 prominence towards more equal strengths of H2 and H3 at the secondo passaggio moment.

Tenor 5 showed a decisiveness in making a change of timbre from F4 – F#4 which went beyond the possibility of these events being caused simply by rising pitch without the need for active guidance from the singer. F4 was sung with consistent clear strong f_1/H2 resonance and then subsequently F#4 with f_2/H3. It was already noted that the pitch excursion in vibrato slightly exceeded a semitone (Chapter 4.3 pp.91-92). It would be logical to expect to see the lower portion of pitch in the vibrato cycle of F#4 start to engage f_1/H2 resonance but this was not the case. Coupled with a subtle vowel modification we concluded that this singer deliberately chose a consistent resonance quality for these pitches. His control mechanism for this can only be the subject for speculation, (eg perhaps auditory or proprioceptively managed), but it was clear in discussions that he was not aware of formant tuning theory as such. It can be argued that a singer may not know, or need to know, the meaning of the word ‘formant’ and its significance in vocal technique in order to be actually acoustically adjusting his resonance in accordance with how formant tuning functions. The singer works with proprioceptive sensations, the quality of sounds perceived, and vowels employed, without a full understanding of how these elements are (at least partially) directed by formant tuning. The interesting question is whether it is pedagogically beneficial, with more economic outcomes in terms of the length of study required, to be given a more completely informed view of what is happening in vocal resonance in order to avoid wasteful ‘trial and error’ experiences.

Perhaps this latter point can be addressed (with caution and in a limited way here) whilst re-examining the secondo passaggio moment of Tenor 1. The examples from this singer suggest that (probably as is the case with many singers) the engagement with formant resonances occur simply naturally according to vowel and formant pitches, and are not being actively managed. The variety of resonance tunings for F#4 have been mentioned and these seem logical for each of the particular circumstances. (Additionally no vocal artist would want to offer performances devoid of imaginatively engaged detail for communication of mood, text and emotion which can lead to a variety of resonance qualities.) Though this singer makes a clear change from f_1/H2 tuning to f_2/H3 tuning with the latter resonance most evident on his Ab4, the very spontaneity which perhaps permitted the range of tunings for F#4 becomes problematic as pitch ascends further. The lack of effective positioning of available resonance from disciplined formant positioning on higher notes causes both a discontinuity of timbre and a loss of acoustic strength in the upper range (Chapter 4.4 pp.97-98). Attaining A4, Bb4 and B4 becomes effortful with some audible discomfort and degradation of intonation.

Tenor 4, whose career has included both ‘lyric’ and ‘spinto’ roles sung in the world’s leading opera houses, was particularly interesting in the examples he gave for the detailed way in which spectrographic information matches his career profile. The spectrographs show that the voice has very strong activity in the SF zone, often exceeding the levels of H2 and H3. Though there were identifiable moments when H2 was stronger than H1 by levels comparable to those seen in the Helden group, it could be seen that these tended to be at a slightly higher pitch and were also less sustained. Also, when H2 was particularly strong as it is on his F4, H3 is not as weak as compared with similar moments in the Helden group. The Lyric group of tenors tend to exhibit H3 as somewhat close to the strength of H2 when f_1 and H2 are maximally interacting. Therefore the levels of H2 and H3 in tenor 4 examples are a very clear indicator of his professional position in the Fach system, between the 'Lyric' and 'Spinto' categories. It should be borne in mind that H3 is likely to strengthen anyway at the slightly higher pitches which tenor 4 and the Lyric group attain before reaching the secondo passaggio moment simply because the rising pitch of H3 is starting to stray into the zone of f_2. This is not the case with the Helden group because the rounded vowel causes an earlier maximal engagement between f_1 and H2, with f_1 slightly lowered by the vowel change.

Tenor 4 also stated clearly that he avoided singing what he considered to be 'open' tone on his [a] vowel in the upper range, saying that he would 'never sing a pure Italianate [a] in the upper range'. In terms of formant behaviour we would interpret this as meaning he does not carry the distinctive quality of f_1/H2 into his upper range. The examples showed very clearly that he tended to modify the [a] towards a frontal [e] vowel whenever pitch ascended to G4 or beyond. This is readily apparent on listening to the examples. Moving the [a] towards a frontal vowel has the effect of raising f_2 sometimes slightly beyond where it is ideal in relation to H3, but also appears to have the consequence of facilitating further strengthening of partials in the SF zone. Nevertheless it can be seen that from G4 onwards H3 tends to be stronger than H2. To use a colloquial term, this is a ‘belt and braces’ approach to avoiding ‘open’ tone in the upper range, as it is here both the SF and management of strengths of H2 and H3 that achieve this. The voice is well unified in timbre across the range since the SF levels are always strong and the change from very strong levels of H2 to pitches where H3 is stronger is graduated smoothly. His secondo passaggio point at G4 is clear but receives subtle treatment in terms of the timbre of the instrument.

The group of lyric tenors showed two main characteristics in regard to their secondo passaggio point. First, there was a tendency for H2 and H3 levels to become similar before H3 emerged as leading the field of partials. Secondly, this change tended to be higher than some of the published literature suggests might be the case, occurring from G4-Ab4 in all three of the lyric voices.

It is not possible to determine with this group of voices whether the changes in engagement between formants and partials was conscious or deliberate, or tended to occur simply as the pitch of partials reached the moment of engagement with proximate formants. Some sense of the awareness of formant amplification of partials can be gleaned by examining the resonance (or lack of it) on pitches occurring beyond the secondo passaggio point. If a singer were acutely aware (by any means) of the benefit of the relation of formant to vowel, as in f_2/H3 for the [a] vowel in the upper range, one would expect to see successful continuance of that quality associated with subtle necessary vowel changes. If formant tuning is lost on notes in the upper range it would be reasonable to assume that a singer is leaving somewhat to chance that element of vocal technique. Both outcomes have been shown in the collected examples.

Tenor 3 showed equal strengths of H2 and H3 on G4 and then clear H3 dominance on Ab4. He then retains the f_2/H3 beneficial coupling on subsequent higher notes, with subtle changes to the [a] vowel. This gives this moderately light lyric tenor voice some fuller tone and carrying power in its upper range which, with only modest levels in the SF zone, it would not otherwise have.

Whilst Tenors 6 and 8 also show balanced (or nearly balanced) H2 and H3 levels at G4 and then a distinct change to f_2/H3 coupling at Ab4, it appears that as pitch continues to rise the acoustic strength available from maintaining the link between f_2 and H3 (which could be achieved by allowing f_2 to keep pace with rising H3), is lost. Some higher pitches show almost all partials of equal strength which does not assist in achieving vocal efficiency, acoustic clarity and strength in performance situations.

In attempting to consider whether formant management is being consciously used (even if by proprioceptive and vowel-led awareness rather than by comprehension of formant theory) it is appropriate to speculate on whether singers who do not appear to guide formant positions in the upper range would benefit from doing so. The evidence here suggests that they would.

The baritone singers show a secondo passaggio point of E4-F4, where Eb4 appears to be the epicentre of f_1/H2 interaction, preceding a more balanced appearance of H2 and H3. By F4 and F#4 the resonance is dominated by f_2/H3 resonance tuning. This is also slightly higher than some pedagogical literature suggests, but perhaps not so surprising as both baritones sing repertoire which has demanding higher range tessitura. It is nevertheless worth pointing out that the passaggio events of this voice type are very near those of the Helden/Spinto tenors. This is a further argument for avoiding over-simplifying classical male voice types for the purposes of investigation. It is temptingly logical to assume that a baritone will have substantially lower passaggio events in comparison with a tenor. In reality, much depends on what type of baritone or tenor is being considered. There is a further difference, which is that baritones are not expected to sing much further than a semitone or tone above their secondo passaggio point and such notes are nearly always climactic events in the melodic line and representation of emotion/drama. The tenors very often must negotiate as much as a perfect fourth above the secondo passaggio of higher range in which they are expected to sing frequently, and sometimes in a sustained manner.

5.5. The Charaktertenor resonance strategy

There is no secondo passaggio moment in the vocalism shown by the Charaktertenor group since those voices do not exhibit what may be called a conventional passaggio zone at all. Nowhere in the published literature concerning formant tuning in classical singing is there mention of the resonance tuning shown in these voices (except in this writer’s article, Robertson, 2014) . There were two surprises in the examples given by the Charaktertenors.

First, that one singer (Tenor 2) managed to apparently bring first and second formants sufficiently close together so as to create a powerful single formant. This ‘super-formant’ enhanced H3 throughout the region of pitch from B3 to A4. At A4, and beyond on higher pitches, the strength of H3 is passed to H2, as H2 reaches the pitch necessary to link with the ‘super-formant’. As may be expected, because of this concentrated ‘super-formant’ the spectrographic signals show no sign of the separate existence of f_1 and f_2 through (and beyond) the passaggio zone, nor the common boosting of H2 in the passaggio.

Secondly, and equally surprising, all three of the Charaktertenors show H2 as the dominant partial at the top of the voice in the region of Bb4 and B4. This appears to be achieved by allowing f_1 to rise in order to track H2 over a fairly wide range of pitch. In the case of Tenors 9 and 10 this is from Eb4 – C5. In all three singers it is highly likely that formants are being permitted to rise with some degree of laryngeal lifting. There is a subtle piece of evidence in connection with this which can be seen in the scale from D4 - A4 of Tenor 9 (Chapter 4.2, pp.88-90). When the pitch of G4 is reached H3 is starting to strengthen at the peak of the vibrato pitch cycle, which is c.1240 Hz. This is not strong enough to make a change of timbre in the f_1/H2 dominated sound. However when the next pitch of A4 is reached, if f_2 were to remain in the same position the lower area of pitch in the vibrato cycle would be enhanced by it since the vibrato pitch strays into the same pitch zone. This is not the case, instead once again only the peak of the vibrato pitch of H3 (now in relation to A4) is being strengthened. This, coupled with the clear dominance of f_1/H2 in the field of partials strongly suggests that all formants are rising.

Such resonance management is contrary to much of the accepted pedagogical advice about classical singing technique and the management of the passaggio zone. Yet this information suggests that there is a professionally valid, useful and desired (by those who hire singers) alternative which is used only by this voice type. This contrasts sharply with the reasonably established view that f_1/H2 strength is very noticeable on open vowels, and especially [a], in the passaggio after which in ascending pitch a different resonance tuning – usually f_2/H3 or a strong SF resonance, is used (Miller, 2000, pp.56-62; Henrich, 2006, p.11; Bozeman, 2010, p.292-295). This latter view has been used to define more clearly the singers/pedagogues labels ‘chest’ voice and ‘head’ voice. These terms seem less meaningful in the context of

Charaktertenor voices since one of the defining elements, the f_1/H2 relationship, is taken so much higher in pitch to the uppermost notes of the range. It would be a matter of subjective judgement to offer a view on whether the timbre produced by the more commonly encountered resonance adjustment in the upper voice is definitely more in alignment with traditional Italianate 'chiaroscuro' tone or not. However it can be confidently stated that the resonance qualities demonstrated by the group of Charaktertenor voices is strikingly perceptually different to the Helden or Lyric voice groups and that there are widespread commonalities in the language which is used to describe these voice types. The Helden voices are spoken of often as having a 'darker' timbre than the Lyric ones and the Charaktertenor type is identified with 'bright' sound.

One of the Charaktertenors, Tenor 9 showed convincingly that he was strongly aware of how he used resonance in his passaggio and upper range and was able to choose to offer a more 'Lyric' voice alternative. The fact that he could do so invites us to reflect on whether other singers could similarly choose how they use resonance in these ranges, were they able to develop the skills which are needed to subtly control the relation between formants and partials. This introduces the next area for consideration.

5.6. The concept of 'deliberate artistic decision' versus 'accidental acoustic outcomes'

Even within this relatively small group of successful professional singers (as compared with the very large numbers of singers sustaining careers world-wide) it is evident from the examples already given that some singers do not manage resonance with optimal acoustic efficiency the upper range.

The strongest formant with the widest bandwidth in the human voice is f_1. When partials are within its zone, allowing or finding an effective engagement with it in the male passaggio pitch area is simple to achieve and tends to occur naturally. This is caused by the specific pitches of formants of the [a] vowel, having as it does the highest f_1 value of all the vowels. When sung pitches are approximately half the pitch of f_1 they are strongly influenced and boosted by it. That is to say that f_1 will engage with H2, since that partial will be approximately twice the pitch of the fundamental pitch.

As mentioned above the location of f_1 varies with differing voices, but for any one voice f_1 can only be moved by changes affecting the vocal tract in some way, since it is the specific shape of the tract in all its complexity that causes the formant. Singers most often conceptualise and control such changes via vowels. Herein lies the central challenge for coordinating the quality of resonance during and above the passaggio zone.

Since all other vowels have a lower position for f_1, disengaging from the f_1/H2 relationship is easier on all other vowels. Once the powerful ring in the voice, caused by f_1 boosting H2 has occurred in the passaggio zone, as pitch rises further the singer will need to unlock that acoustic coupling. Otherwise he would risk the undesirable vocal consequences of persisting with it on higher pitches. Such consequences include a rising laryngeal position associated with increased muscle tension, narrowing the pharynx, retaining heavy vocalis muscle action, and in perceptual terms tone which is characterised commonly as ‘yelled’. It is highly probable in addition that subglottal pressure would become undesirably high. Ease of production, flexibility and gradation of tone, the aesthetic quality of balanced tone encapsulated by the term 'chiaroscuro', are lost in such circumstances.

Finding an acceptable replacement for the strong resonance of the [a] vowel's f_1/H2 coupling on pitches at the top of the passaggio and beyond often necessitates locating f_2 so as to enhance H3, especially in voices which do not have particularly strong singers' formant partials. This accomplishes reasonable vowel recognition, in which an audience will continue to perceive an [a] vowel as well as acceptable continuity in perceived loudness. Yet this may not be simple to achieve since partials become ever wider separated in ascending pitch. Singing an A4 at 440 Hz means that the next partial is 440 Hz distant. This gap is certainly wide enough for the possibility of a formant being accidentally positioned between two adjacent partials, thereby having negligible, or no, effect on resonance.

The examples from the professional singers here show that all, except the Charaktertenors, find f_1/H2 resonance in the passaggio and then subsequently f_2/H3 resonance on ascending pitches. Some showed moments where H2 and H3 were of almost equal strength on what might be termed pivotal pitches, at the point where H2 is weakening because of ascending pitch and at the same time H3 is strengthening as its pitch reaches the location of f_2. This pivotal pitch we have called the secondo passaggio. Tenors 1, 3, 6, 7, and 8 all showed moments where H2 and H3 appeared to be almost equal. However, tenor 7 had very strong SF zone partials and therefore was less reliant on the changing strengths of H2 and H3. Tenor 3 subsequently retained a clearly boosted H3 on higher notes whereas the others did not. This suggests that he had a strong awareness (by whatever means) of the f_2/H3 acoustic coupling. Conversely, though it is impossible to be certain, the examples suggest that the change from f_1/H2 to f_2/H3 which the remaining three tenors showed is the accidental result of f_1 and f_2 reacting with partials as they attained the relevant pitch. All three lost this acoustic coupling as pitch ascended further and it was not replaced by any alternative.

In differing ways, tenors 4, 5, and 9 and both baritones all showed active management of f_2 for resonance quality in the upper range (as did tenor 3). Tenor 4 both described and demonstrated a deliberate strategy to deal with this issue, using the front vowel [e]. Tenor 5, made a deliberately managed decisive change between F4 and F#4. Tenor 9 showed that he could choose to change the way he tuned resonance in his passaggio and upper voice depending on the vocal Fach quality desired. Both baritones showed in their examples clear strong engagement with f_2 in the higher range that was unlikely to be accidental and which required some subtle vowel adjustment. These singers show sophistication in the skilled manipulation of the relationship between formants and partials.

There are important implications for vocal pedagogy in this. The argument that vowel modification is unnecessary cannot be supported by the information here offered. If a singer simply concentrates on establishing other known basics of vocal technique and omits the craft/art of vowel modification he risks missing a very important component. This can make or break a career since without reliable, good quality singing in the upper range career potential is clearly compromised. The ability to make artistic choices is also limited. There are many examples of recordings from the most celebrated singers who show that they are able to sing 'pivotal' pitches at the secondo passaggio point in several different ways, responding to the particular emotion/vocal colour required by text/mood/drama. Not all of these different resonances can be deliberately chosen by a singer. Current research[22] is investigating whether strong SF partials are caused by genetic factors relating to speed of glottal

[22] Being conducted by Miller and Ritzerfeld, not yet unpublished.

closure which may be beyond a singer’s ability to control or develop. It is clear however that a singer may choose to situate a formant beneficially or not, and that training this skill, (by whatever method is most effective), gives a singer valuable craftsmanship in the coordination of whatever resources he has.

5.7. The need for vowel management in voices with less strong singer’s formant partials

It is still not clear whether strong partials in the SF zone are something which can be achieved through training or whether they are present in some voices as a natural gift, possibly associated with the inherent speed of glottal closure which an individual voice may possess.

It has been suggested that if the epilaryngeal tube is less than approximately one third of the diameter of the pharyngeal space immediately above, strong resonance is created in the zone which is referred to generally as the ‘singer’s formant’ zone (Titze, 2003). This is where formants 3, 4, and 5 tend to cluster. The positioning of these formants is not as strongly affected by vowel choice as are formants 1 and 2, though some limited changes occur when using the back vowel series moving from [a] to [ʊ]. However there is as yet no published evidence that shows that changing the clustering of formants 3,4 and 5 yields acoustically more beneficial results in the general strength of partials in the ‘singer’s formant’ zone.

The [æ] vowel, referred to by phoneticians as the near-open front unrounded vowel, appears to be associated with strong partials in the singer’s formant zone. It may be posited that perhaps this vowel causes a slight tightening of the aryepiglottic sphincter helping to create the 1:3 ratio conditions needed for strengthened SF partials. This is however speculative since it has thus far proved difficult to gain the clear views which would be necessary to test such a hypothesis. The examples from the professional singers raise two points in relation to the strength of SF partials.

First, though it may simply be a matter of coincidence, the two singers who have by far the strongest partials in the SF zone, tenors 4 and 7 are also the two singers who have had the longest most distinguished international careers at the highest levels. In both cases their SF partials are consistently 20 dB more than H1, and c.6-10 dB louder than the strongest partials influenced by formants 1 and 2. The presence of such strength and clarity in the high partials of a tenor voice will greatly assist audibility and what may be called ‘projection’ in large auditoria and contexts where there are competing acoustic forces such as an orchestra or other voices. Conversely, examination of recordings by world-class premier artists such as Luciano Pavarotti show clear strength on partials in the H2, H3, and H4 area, rather than very strong SF partials. Either appears to be possible as discussed by Miller D., (2000, 2008.)

Secondly, and of more importance, the professional examples show what occurs when there is neither strength in the partials which can be boosted by the vowel formants 1 and 2, nor strength in the SF zone. As may be expected this tends to occur when singing the highest pitches as it is then that there are the largest gaps between partials, making it more possible for a formant to be disadvantageously placed. Tenors 1 and 6 both showed a point where f_2 engages with H3, which is strongest for both on Ab4. As pitch ascended further in both this resonance coupling of f_2 and H3 is lost, and the SF zone partials are also weaker than H1. There is no strength in any of the partials higher than H1 (the fundamental), and in consequence the radiated sound cannot project in the efficient way which is caused by boosting a particular partial in the vowel formant zone, or a small group of partials in the SF zone.

For singers who do not possess an acoustically efficient SF zone, ‘vowel tracking’ which uses subtle modifications of vowels to ensure that formants continue to engage with partials is an important technical accomplishment. For Tenors 1 and 6 it would have been possible to raise f_2 so that it continued to engage with H3 as it rose in tandem with the sung note (H1). This would have been accomplished using a vowel which modified gently towards [ʌ] or [ɛ]. This is what occurs in the resonance tuning of the other professional singers who gave examples, excluding the Charaktertenors who it has already been noted used f_1/H2 on high pitches in their range, allowing f_1 to rise well beyond its more normal position as encountered in speech and classical singing.

Finding a way to track H3 using f_2 in the higher range when singing the [a] vowel is important but it can also be seen that some singers manage to simultaneously avoid a situation in which f_1 also rises and therefore continues to track H2. If f_1 continues to enhance H2 in some way the benefit of f_2/H3 tuning is disguised to some extent. Miller D., (2008) has suggested that f_1/H2 tuning is associated with thicker/stiffer vocalis muscle engagement which is often described by both vocal pedagogues and singers alike as ‘chest voice’. This is not problematic in the middle passaggio zone, but on higher notes it is desirable for reasons of comfort, vocal health, and economy of effort to avoid excessive vocalis muscle engagement, as the vocal folds should become slimmer with less depth of vocal fold mass involved in vibration/mucosal wave (Sundberg, 1987, pp.51-57). Not only must an effective replacement be found for the strong resonance coupling of f_1/H2, which may be f_2/H3 for an [a] vowel, or other back vowel (or f_2/H4 for a front vowel) but in addition the f_1/H2 coupling must be disengaged. This may be quite sudden as in the examples from Tenor 5, or graduated as shown by Tenor 3.

Tenor 8 did manage to keep f_2 effectively working with H3 on pitches above Ab4, but H2 remained almost as strong as the levels of H3. This may mean that the muscular effort expended was greater than necessary to sustain professionally acceptable consistent loudness across the passaggio and into the upper range. Studies done by Miller and Schutte (1990, p.233) suggest that, when one of the 'vowel formant' harmonics stand strongly and clearly isolated, this can be an indicator of a highly efficient standing wave in the vocal tract.

It is interesting to reflect that the traditional pedagogical language using terms such as 'slimness', 'clarity', and 'focus' of tone, to describe admired/desirable characteristics of the classical aesthetic, as opposed to the pejorative term of 'spread' tone, may well have a surprising basis in the way that skilfully resonated partials can efficiently enable a voice to project. This is clearly visible in spectrographic signals.

5.8. Questions arising regarding contact quotients and initial vocal fold closure speeds.

Of the group of professional singers, only four singers had clear EGG signals that were stable and of consistent quality. These were tenors 3, 9, and 10 and singer number 11 (baritone). In addition some signals were clear from tenors 5, 6, and 8 and singer 12 (baritone), though as pitch ascended, the signals from these became decreasingly clear with unstable laryngeal position indicated in the contact quotient history window view of VV, and consequently poor signals in the EGG window. It was not possible to make any useful measurements from this group. Of the remaining four, tenors 1, 2, 4 and 7, there were either physical impediments to the successful placing of the EGG electrodes, or the neck band required to hold the electrodes in place was found to be not well tolerated.

The following remarks concerning the EGG contact quotient figure (CQ), and the initial closure rate (ICR) of the vocal folds, are offered here since they raise important questions; more examples would be needed, however, to confirm or contradict these views. As discussed in the Literature Review it is acknowledged that the interpretation of EGG signals is still a matter of debate, though since all the singers here were singing with full classical operatic quality it is likely that the CQ figures are accurate enough to be useful. They can only be estimates, since some skill and experience is required to coordinate the audio and EGG signals in order to adjust the settings for EGG readings within VV. It is possible that another slightly different setting of the relationship between audio and EGG signals would result in slightly differing results for the CQ percentage figures.

Similarly the placing of the orange cursors which are used within VV to establish the likely ICR are a matter of judgement on the part of the operator. Viewing the audio and EGG signals alone with only a small number of glottal cycles shown gives the maximum clarity for seeing the most rapid rise in the initial part of the EGG signal and viewing the coordination of this aspect with the audio signal. This is needed to place the orange cursors as accurately as possible though again different operators may arrive at slightly different placements.

The CQ figures for all the four singers whose signals were consistently stable and clear showed that when ascending beyond the passaggio into the upper range the CQ percentage either stays approximately stable (with only 2-3% differences), or rises slightly. This should not be a surprise, implying as it does that the vocal fold closure mechanism remains somewhat similar between middle passaggio and upper range. This is important because the change in timbral quality which has at least partly given rise to the idea that ‘chest’ voice has a different vocal fold quality to ‘head voice’ can be misleading. Though there is no direct or completely reliable relation between CQ percentage and the degree of vocalis muscle stiffening in phonation, it is likely that a rather abrupt change of vocalis stiffening would have an effect on the CQ percentage. As pitch ascends into the upper range we already know that the vocal folds are stretched by the action of the cricoid muscles as vocalis involvement is gradually decreased (Thurman and Welch, 2000, pp.421-447 offer a clear description of the mechanics involved, also Sundberg, 1987, pp.49-92) . For the professional male classical singer this balancing of elements is the essence of being able to sing with full sound, 'voce piena in testa', in the upper range. To do so requires that the singer give up a degree of the muscularity of vocalis muscle which characterises full singing in the lower and middle range, and yet retain enough of that quality to offer virile strength in the upper range.

Singer 11 (baritone) showed a CQ figure of 62% on his Eb4 which remained the same for F4, even though the Eb4 had f_1/H2 tuning and F4 showed f_2/H3 resonance predominating. So though there was a perceptible and acceptable change of timbre between these notes the CQ was constant. It does not seem plausible or logical to think that there may have been a substantial change of vocal fold vibratory characteristics between the two. On ascending to F#4 the CQ figure rose to 68% which was noted to be the same in two differing examples (one as the top of a scale, the other the top note of an arpeggio covering the range of an octave). The highest pitch in this singer's range, G4, showed a very similar figure of 67%.

Tenor 3 when singing F4 had a CQ of 53% which rose to 60% for G4 and then a similar figure of 61% for his Ab4. Interestingly subsequently his CQ figure fell to 55% for Bb4 and then 52% for B4 and C5. This does make sense. It is physically possible to extend the muscular strength of the voice for a short period after the top of the passaggio, but beyond that unless the individual is of a particularly strong physical type it becomes preferable to allow some of the muscularity to reduce in order to avoid excessive effort and possible vocal harm. It is quite possible therefore that this drop in the CQ figure for the highest notes in this tenor's voice reflect less vocalis muscle involvement, as the vocal folds slim at the top of the voice. Tracking the ascending H3 with f_2 resonance very economically, this voice achieves a professional viability and facilitates sustained singing in the upper range without undue vocal stress.

The relatively young Charaktertenor tenor 10 appears to be a voice which has a naturally high CQ level. Even on pitches below C3 his CQ is generally in the region of 65%. This rises to 68% on G4, and 70% on his high C5. These figures are not indisputable, since it is a question of judgement based on experience to adjust the horizontal cursor in *VoceVista* which establishes the likely CQ percentage. However even if they are only approximately correct it remains true that this voice appears to have a high CQ closure percentage. This may well be related to the very rapid ICR of this singer (see below for further discussion of this aspect).

Tenor 9 shows a remarkably consistent CQ of c.56% in his passaggio and the upper range. It is interesting that when he sings the two different versions of the triad from D4-A4, (one version using Charaktertenor quality and the other more Lyric) the CQ remains unaffected by the changed resonance strategy. This CQ rate also remains consistent (actually measured as 55%) at/near the top of his range on B4. These CQ figures are thought-provoking since they are quite modest in comparison to the somewhat higher figures that are claimed for voices which sing demanding operatic repertoire. This tenor shows that he uses his resonance resources very skilfully and with a high degree of awareness about the resulting timbre.

It is not yet known whether the CQ level of a voice (and the ICR) is particularly susceptible to long term training or whether these aspects are mostly an inborn element which could be regarded as part of whatever the term ‘natural talent’ covers. Amidst the profusion of confusing terms which singers and vocal pedagogues use are words and expressions such as ‘soft-grained’, ‘metallic’ and ‘hard-edged’. Tenors 3 and 9, both with modest CQ levels and both demonstrating deliberate skilled resonance management have voices which may well be described as ‘soft-grained’ but have had (and continue to have) highly successful careers sustained over a long period exceeding thirty years with repertoire which is regarded as requiring exceptional projection of tone and text.

The human vocal tract is spoken of by acousticians as a tube in which one end is effectively closed, but because of the way the vocal folds chop up the air stream in order to make the phonation signal, the open phase of the glottal cycle means that the vocal tract is only partially closed at one end (Kent and Read, 1992, pp.13-40). For those voices which have relatively high CQ figures it is theoretically easier to produce loud tones since less of the acoustic signal in the vocal tract is dissipated by being damped in the subglottal area, having passed through the glottis during the open phase of the glottal cycle, rather than being reflected upwards. Whilst there is currently interesting research in progress (reported by Herbst, 2016) on the information that EGG can yield as regards CQ, and other methods which can show CQ detail, the figures here discussed suggest some specific research questions which are important for the future. Is there a CQ level which could be thought of as ideal for efficiency in the production of tones in the passaggio and above in male classical singing? Can the CQ levels of a singer be influenced towards attaining such a level? What would be methods for this?

If issues concerned with CQ levels are of further research interest this is even more true as regards the ICR of the vocal folds. Again it must be acknowledged that establishing this accurately is a matter which involves judgement and experience in placing the orange cursors appropriately on the rising slope of the EGG glottal closure signal within VV.

Tenor 10 who showed high CQ levels also exhibits remarkably fast ICR measurements. On D4 this was c.0.13ms as it is also on B4, and 0.14 ms on C5. The question arising is, are these fast closure rates causative in achieving the high CQ levels? Logic would suggest that they would be. Singer 11 also showed quite high CQ levels and his ICR measurements are fast, with 0.14 ms noted for Eb4 and 0.17 ms for F4 and F#4. However the ICR levels shown by tenors 3 and 9 do not contrast significantly with those of tenor 10 and singer 11, who both show rates in the range of 0.14 – 0.17 ms regardless of which pitches are examined in the passaggio and upper range.

We do not claim that these particular figures can be regarded as highly significant since it would require far more example material before any conclusions could be treated as reliable. However, the measurements do raise important questions for further research. What is the relationship between CQ and ICR in professional quality male singing voices? Do these measurements change because of intended dynamic levels? Do these levels change with differing pitches and vowels? Do ICR measurements relate in any way to focal Fach? To what extent can the ICR be influenced by training?

Chapter 6: Student Singers: Examples

6.1. Introduction

216 examples were accumulated from a total of 8 undergraduate student singers. As in Chapter 4 (Professional Singers: Examples), these recordings were taken using the software programme VoceVista (VV). All recordings have clear spectrographic information and most had simultaneous electroglottograms (EGG), which this programme can coordinate with the spectrographic material. The following table shows the singers, who were all undergraduates (UG), with voice type and approximate age.

TABLE 2: UNDERGRADUATE SINGERS

Singer 1	Tenor	c.21 years old	Year 2 of UG
Singer 2	Tenor	c.20 years old	Year 1 of UG
Singer 3	Tenor	c.23 years old	Year 2 of UG
Singer 4	Tenor	c.22 years old	Year 3-4 of UG
Singer 5	Tenor	c.22 years old	Year 4 of UG
Singer 6	Baritone	c.21 years old	Year 3 of UG
Singer 7	Baritone	c.22. years old	Year 4 of UG
Singer 8	Bass	c.25 years old	Year 4 of UG

As with the professional singers' examples, there emerged a large amount of information in relation to the main research area (of how male singers manage the passaggio and higher range with special reference to the [a] vowel). In Chapter 4 on the professional singers, the information was presented in three sections:

1) The area of pitch in the passaggio zone in which f_1 engages strongly with H2. ('Primo passaggio'.)
2) The area of pitch towards or at the top of the passaggio zone, where the influence of f_1 on H2 begins to weaken. ('Secondo passaggio'.)

3) The area of pitch in the upper voice which is likely to move beyond the easy coupling of f_1 and H2. (Beyond 'Secondo passaggio'.)

This is both less simple and less relevant with regard to the student examples. Student voices have less established techniques, and often the sections of pitch referred to above in 1, 2, and 3 are less clear and consistent. One of the objectives of this study is to show the characteristics that are encountered in the less-established, partly- trained voices. It would therefore to a certain extent be pre-judging and categorising the characteristics of these voices-in-training to force their examples to fit into the three areas of pitch outlined above. Some of the student examples were taken over an extended period, (as long as four years): during this time there have been developments and changes. When this is the case it is referenced below.

The clearest manner of presenting the examples is to offer a case-history for each. This allows the individuality and variety of important facets to emerge more clearly. In Chapter 7 these examples will be discussed and compared, both within the student group and also in comparison to the professional singers.

6.2. Student 1

There are two sets of files from this singer. The first set (of 14 example files) was made at the start of his training in a major UK Conservatoire, when 18 years of age, and the second set (of 29 example files) three years later. He is 1.7 metres tall and mesomorphic body type[23]. The two sets of examples, which cover similar vocal material, are particularly interesting as it is possible to see how this singer progressed.

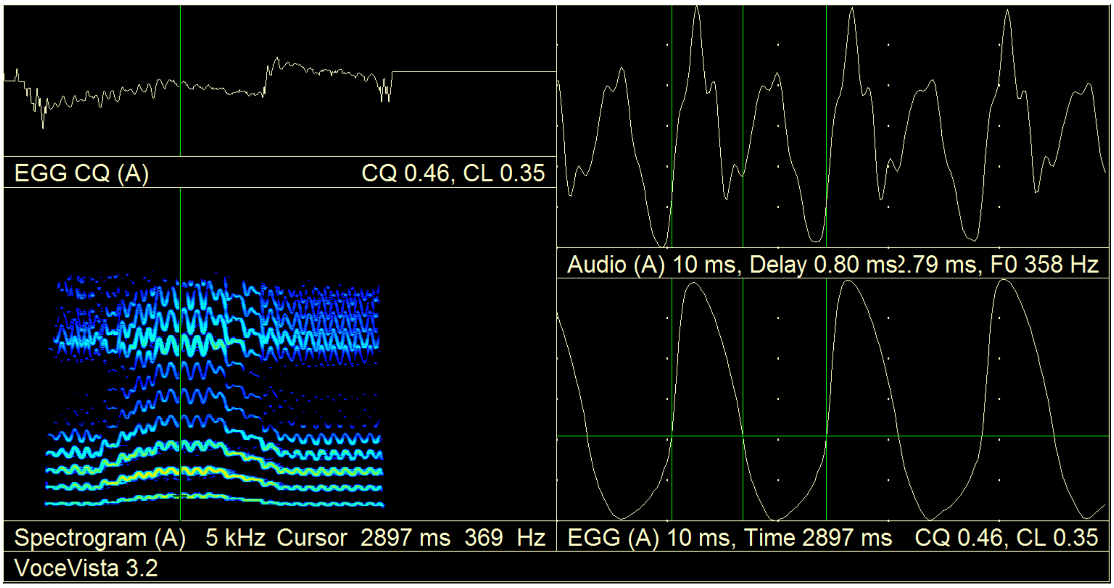
The earlier set of examples shows that H2 responds to f_1 from D4 and higher, as far as Ab4. On the pitches Eb4, E4, F4 and F#4, the maximum strength of H2 is c.9 dB stronger than H1. Viewing those examples with the power spectrum average set to 300 ms shows H2 as only c.3 dB stronger than H1. As the pitch at the top of scales climbs higher to reach G4 and Ab4, the maximum strength of H2 is c.3 dB stronger than H1. The power spectrum averaging set at 300 ms shows H1 and H2 as almost equal. There is very little indication that f_2 engages with H3 in the upper range, and its strength never exceeds that of H2. On A4 and Bb4 the strongest partial becomes H1. All contact quotient estimates from the EGG are below 50% in a range from 45% - 49%. Partials in the SF zone never exceed the strength of lower partials H1, H2, H3 or H4. These features taken together indicate very limited resonance and strength in the voice, although it is vibrant.

Figure 6.2.1 shows a scale from B3-F#4 and the EGG shows a moment during F#4. The contact quotient indicated (lower right-hand part of the screen) is 46%. The audio signal reflects the fact that H2 was the strongest partial at this moment, but H2 was only c.3 dB stronger than H1. The strongest partial in the SF zone was

[23] Age, height and body type may have a bearing on how a voice functions so this information is offered in order to provide a basic background framework which may inform what follows. See 'Body types' in Appendix 1, Glossary of Terms p. 312.

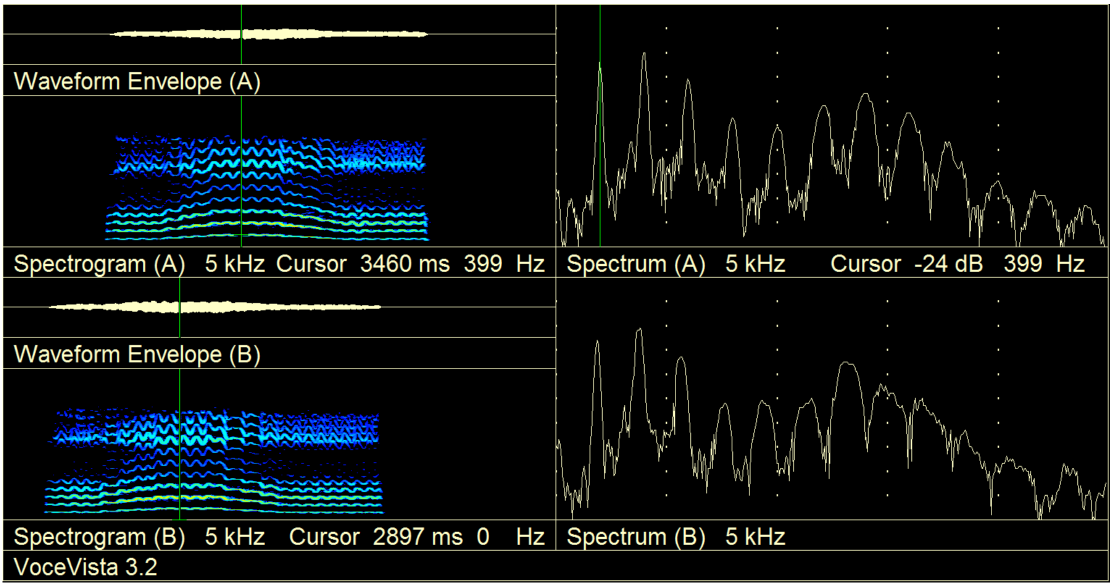
7 dB weaker than H1. There is therefore no strong resonance in any partials above the fundamental (H1). The timbre therefore lacks colour, and the ability for the sound to project, let alone the desirable ‘chiaroscuro’ quality which is distinctive in classical male voices.

Figure 6.2.1: Student Tenor (1) B3 – F#4 scale [a]



The next scale in ascending pitch, C4-G4, was extremely similar. Figure 6.2.2 shows the spectrographic views for the previous scale (B3-F#4) in the lower screen and for C4-G4 in the upper screen. The EGG showed that the contact quotient on the G4 was c.47%. (Not illustrated.)

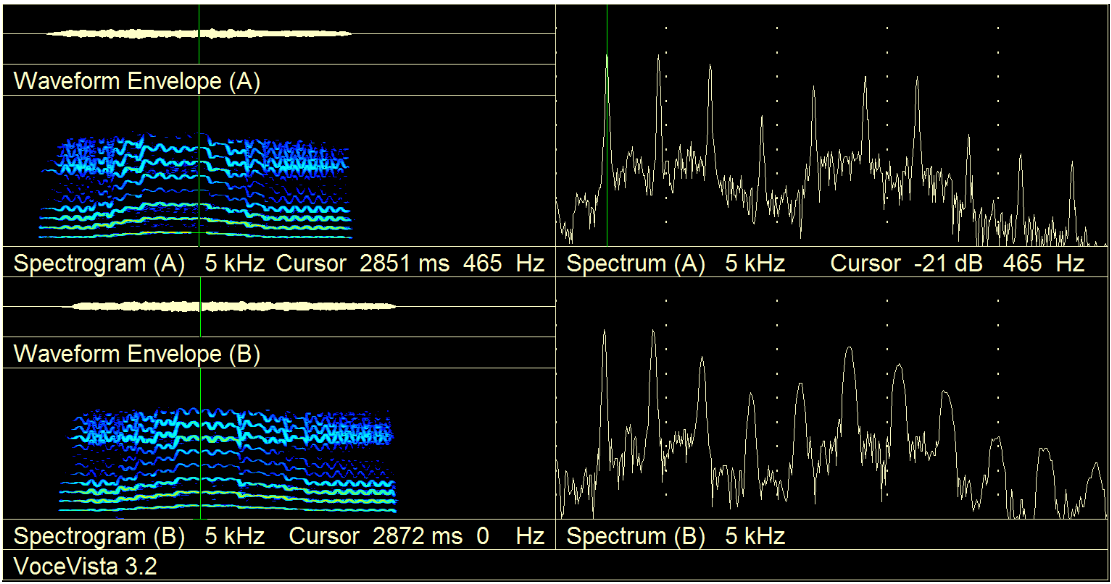
Figure 6.2.2: Student tenor (1) C4 – G4 and B3 – F#4 scales [a]



It can be seen that H2 is slightly higher than H1 and that all other partials are weaker than H1.

In the next two scales of D4-A4 and Eb4-Bb4, H1 and H2 are almost equal (this can be confirmed by viewing the files with the power spectrum average set to 300 ms.) Activity in the SF remains weak. In Figure 6.2.3 the scale from D4-A4 is shown in the lower part of the screen and the scale from Eb4-Bb4 above.

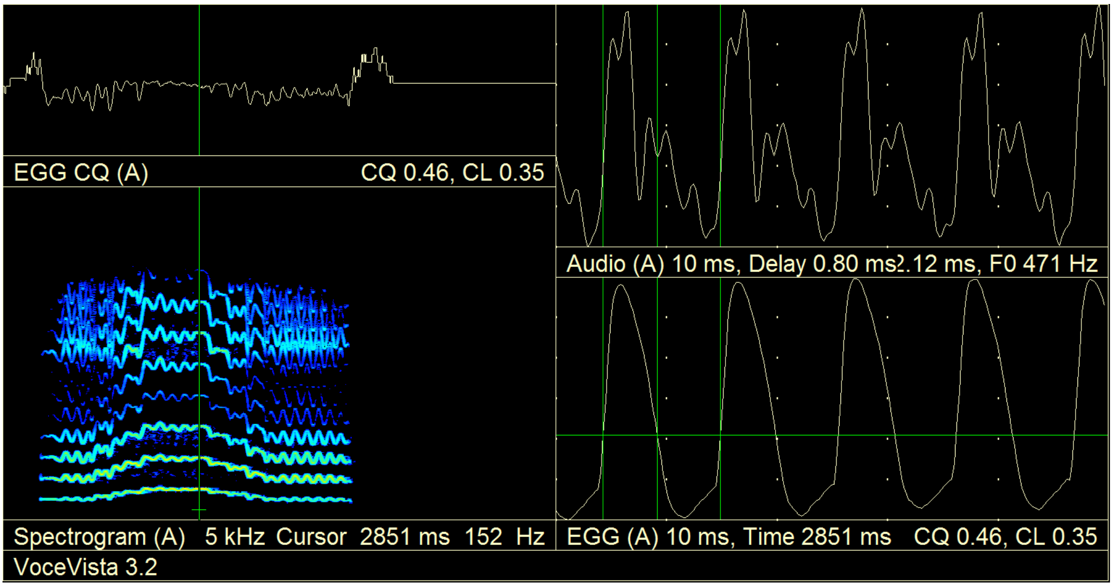
Figure 6.2.3: Student tenor (1) Eb4 – Bb4 and D4 – A4 scales [a]



Again it is clear that the partials in SF zone are weaker than H1, and this cannot compensate for the fact that f_2 and H3 are not effectively engaged to assist in resonance.

Figure 6.2.4 is the EGG viewed at the same moment as shown in the upper part of the screen of Figure 6.2.3 (above) indicating a contact quotient of 46%. This could reasonably be regarded as too low for any voice seeking to offer a professional operatic quality on a tenor's high Bb4. However, such a judgement here is perhaps immaterial as this is an example from a young 18 year old singer commencing training, with the far-off aim of becoming an operatic singer. What these observations show is a voice of very modest resources being used in an undeveloped or unsophisticated manner.

Figure 6.2.4: Student tenor (1) Eb4 – Bb4 scale [a] with EGG at Bb4

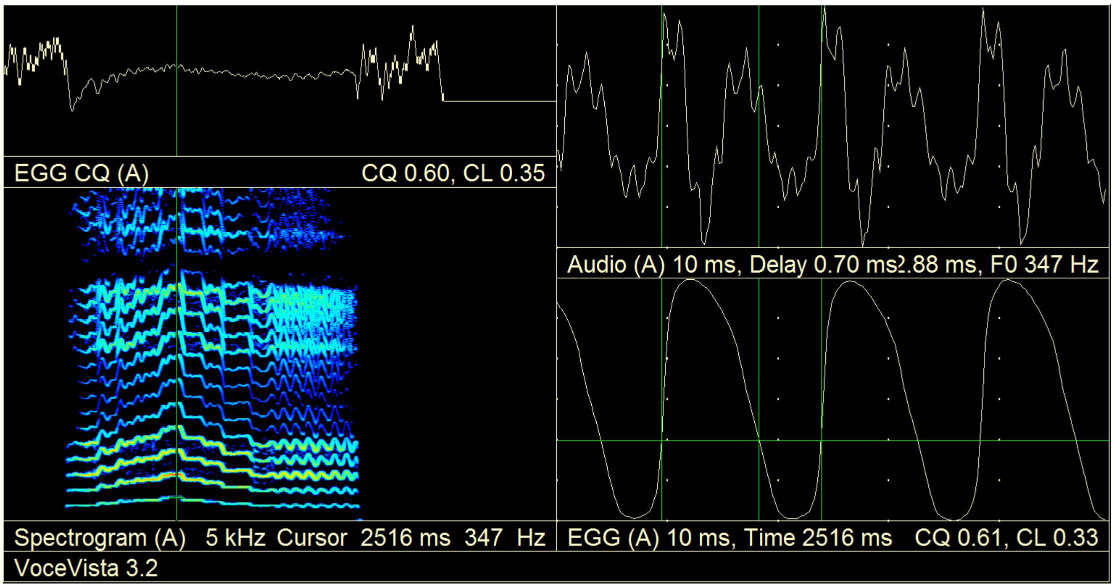


Three years later there is a very substantial change in the characteristics of resonance in this voice. All contact quotient figures are in the range from 56%-69%. Partials in the SF zone are much stronger than before, often exceeding H1 by c.8 dB. In the upper voice as H2 becomes less strong after the secondo passaggio moment (around G4), H3 becomes a strong partial engaging with f_2.

These factors present a voice which is far more resonant, and which appears to have a classically trained passaggio.

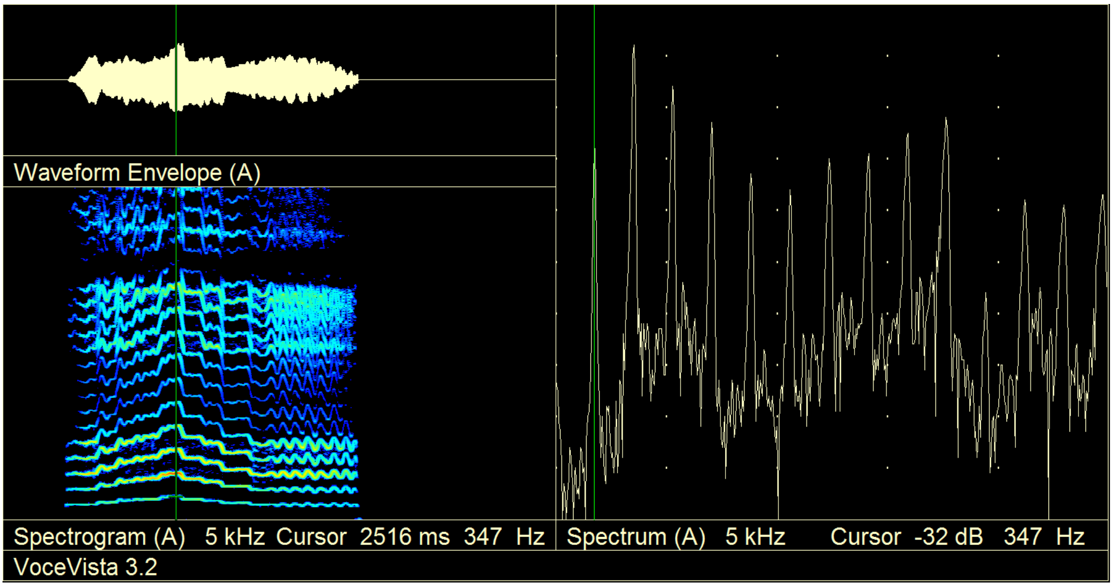
The scale of Bb3-F4 is shown in Figure 6.2.5 with the EGG indicating a contact quotient of 61%.

Figure 6.2.5: Student tenor (1) Bb3 – F4 scale [a] with EGG at F4



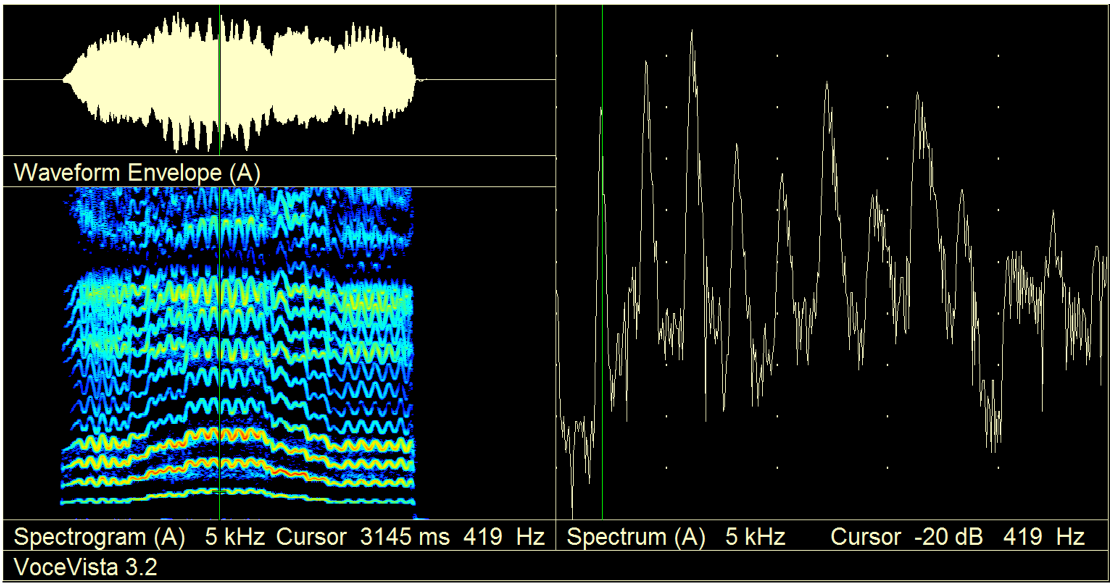
In a view of the same moment showing the power spectrum H2 is seen to be substantially stronger than H1 (at this moment 24 dB) and two partials in the SF zone, H9 and H10, exceed H1. (Figure 6.2.6)

Figure 6.2.6: Student tenor (1) Bb3 – F4 scale [a] with power spectrum



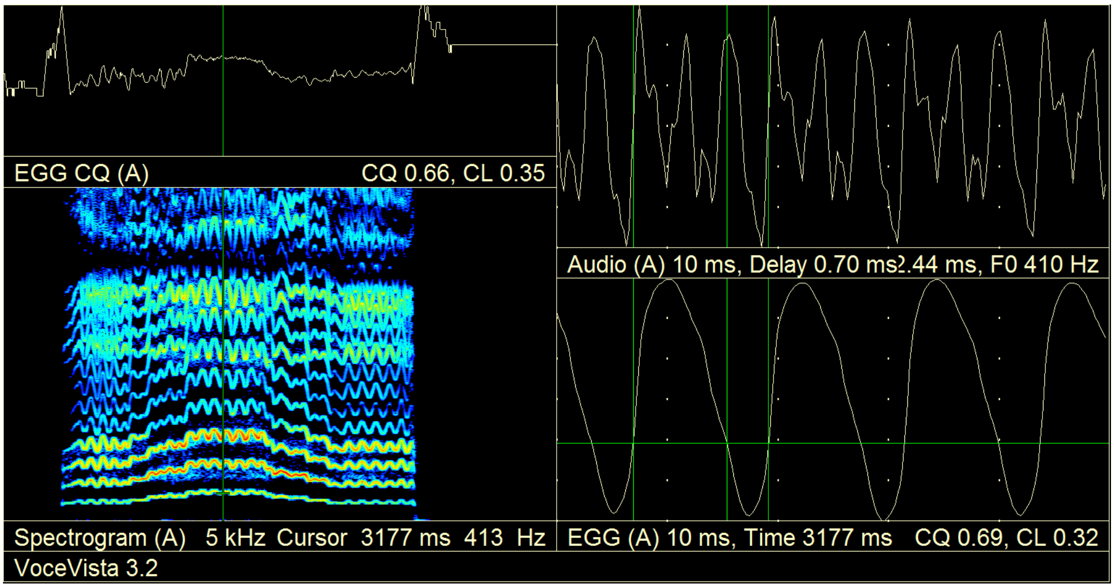
Singing the scale of Db4-Ab4 as shown in Figure 6.2.7, the journey through the passaggio zone can be clearly seen (in the colour spectrogram). It commences as H2 becomes strong, reaching maximum strength on the pitch of Gb4 and then waning, whilst H3 becomes the strongest partial on the uppermost note, Ab4.

Figure 6.2.7: Student tenor (1) Db4 – Ab4 scale [a]



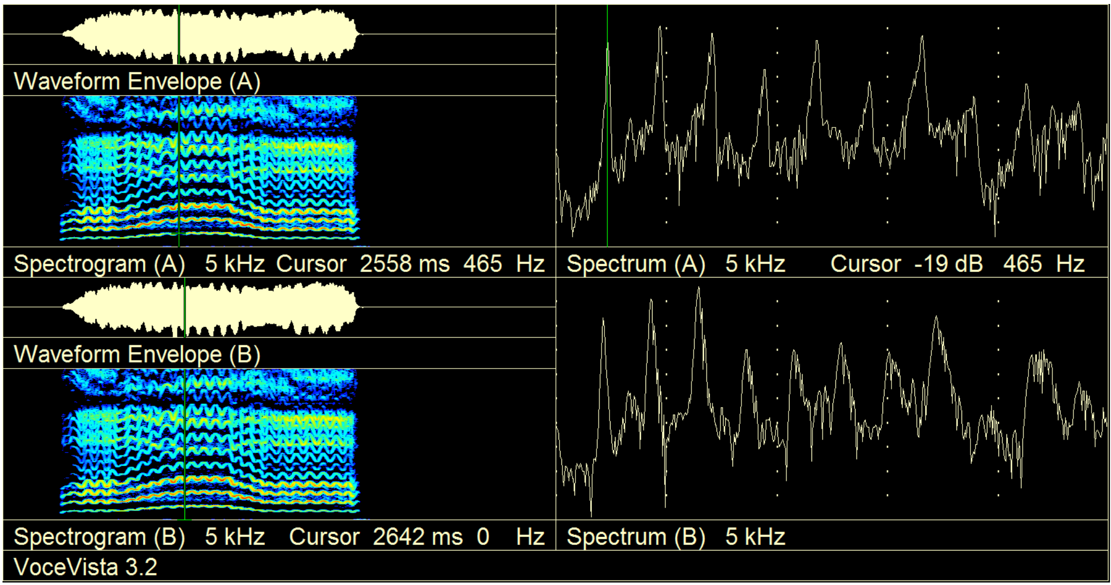
The contact quotient varies slightly during the sustained Ab4 from 65%-69%. Figure 6.2.8 shows this as 69%. The comparable moment on Ab4 from three years earlier had a contact quotient of 49% (not illustrated). It is clear from both Figures 6.2.7 and 6.2.8 that H3 is strongly engaged with f_2 and is clearly the strongest partial. (See, in addition to the power spectrum in Fig 7 the three columns showing in the audio signal in Fig 8.)

Figure 6.2.8: Student tenor (1) Db4 – Ab4 scale [a] with EGG at Ab4



In singing the next scale of D4-A4 it seems that f_2 may be fractionally too low for maximum effect on the A4. When the vibrato pitch cycle is at its lowest moment, H3 is maximal and reaches 17 dB stronger than H1 momentarily. (Shown in the lower portion of the screen in Figure 6.2.9.) However when the pitch within the vibrato cycle ascends some of this strength is lost. (Upper portion of screen.) Viewing the example with the power spectrum averaging set to 300 ms shows H3 as leading fractionally in strength.

Figure 6.2.9: Student tenor (1) D4 – A4 scale [a]



The contact quotient (not illustrated) is c.66-69%.

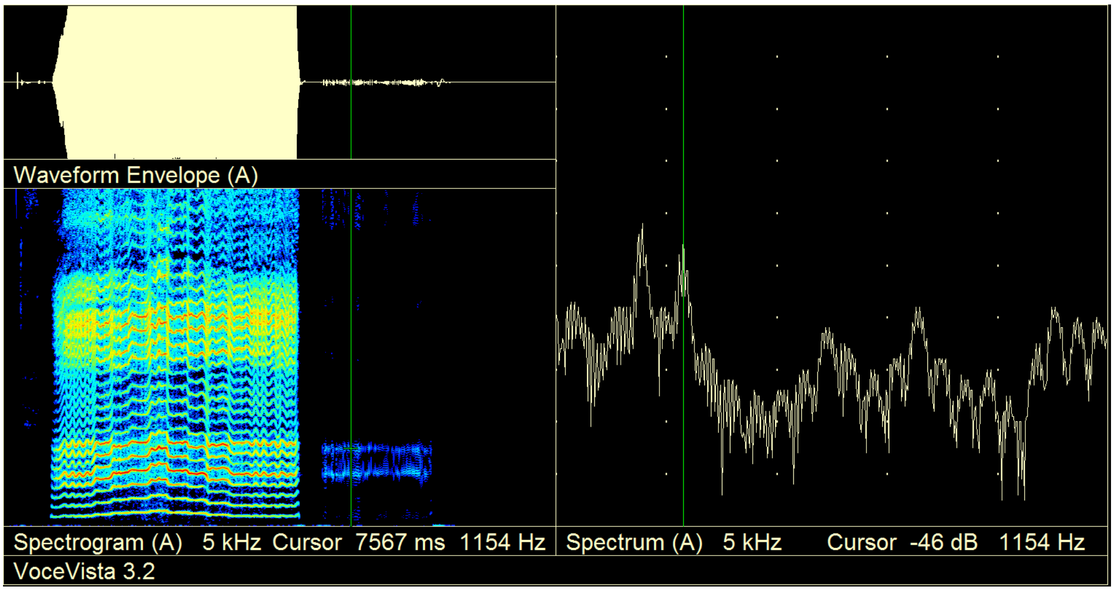
This student is clearly still developing, but is showing characteristics in his singing as illustrated here which can be regarded as professional in quality.

6.3. Student 2

This singer had had nine months of study in a major UK Conservatoire. Of slimly athletic ectomorphic body-type, 1.78 metres tall, the student was 19 years of age. There is a total of 23 recorded examples. These were all made at one session.

The singer was reasonably comfortable with vocal fry, though he did not manage to de-voice the fry completely. He was asked to sing a scale of a fifth in the most comfortable part of his range and then maintain the same vowel, [a], whilst using vocal fry. It can be seen in Figure 6.3.1 that the phonated section was over-recorded. However this meant that the recording level was appropriate for the much quieter vocal fry. As the phonated section is only for the singer to establish his accustomed [a] vowel the over-recording of the vowel section is of no consequence, and is not used here for any kind of analysis or comment.

Figure 6.3.1: Student tenor 2 vocal fry showing formants in power spectrum



Vocal fry gives a good approximation of the true position of formants 1 and 2 during this student's 'normal' [a] vowel. f_1 is c.760 Hz and f_2 1150 Hz. Since the events in the passaggio are so often concerned with H2 and H3, the figures for these formants are particularly interesting. If H2 has F#4 (at 370 Hz) as its fundamental (H1) it would be in the region of 740 Hz. At the same time, H3 for the same pitch of F#4 would be 1110 Hz. There is therefore the possibility that this singer's formant values could quite 'naturally' enhance simultaneously both of the partials which are known to be decisive in the passaggio. This would also be true of his G4, with H2 for that pitch at 784 Hz and H3 at 1176 Hz, both of which would still be within range of the relevant formants f_1 and f_2. However, once the pitch moves up to Ab4 both H2 and H3 would be likely to be beyond the influence of those formants, potentially creating something of a resonance deficit. The examples (given below) demonstrate what actually occurs.

In a scale from G3-D4 there is no sign of significant strengthening of H2 on the upper note. The white arrow in Figure 6.3.2 shows the likely location of f_1 (at c.748 Hz). Predictably, (if the formant values given above are retained in this example) F4 at around 1180 Hz is being strengthened by f_2. This suggests the voice has not yet entered the passaggio zone.

Figure 6.3.2: Student tenor (2) G3 – D4 scale [a]

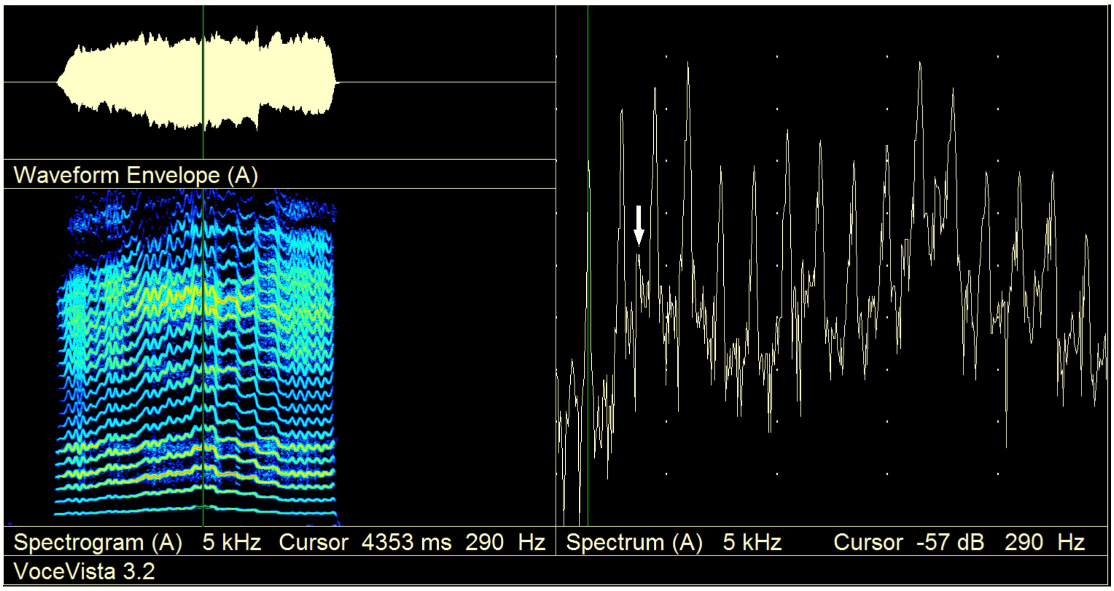
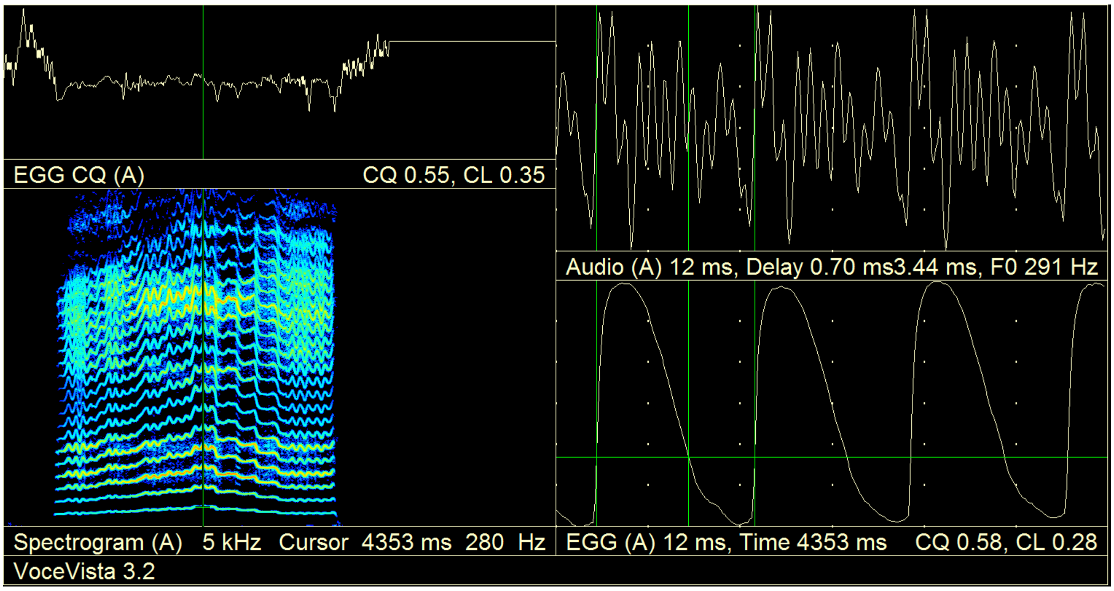


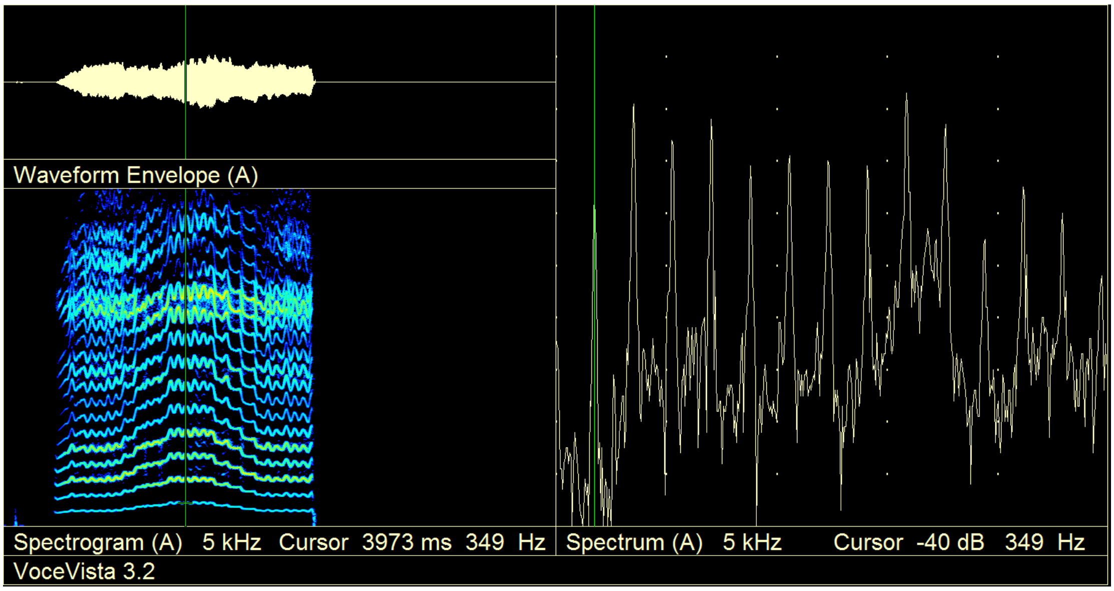
Figure 6.3.3 shows the contact quotient (CQ) at D4 as c.58%.

Figure 6.3.3: Student tenor (2) G3 – D4 scale [a] with EGG at D4



In scales from Ab3-Eb4, and the next semitone rise of A3-E4, the resonance and CQ remain very similar (not illustrated). However on reaching Bb3-F4, H2 is now some 18 dB stronger than H1. (Figure 6.3.4)

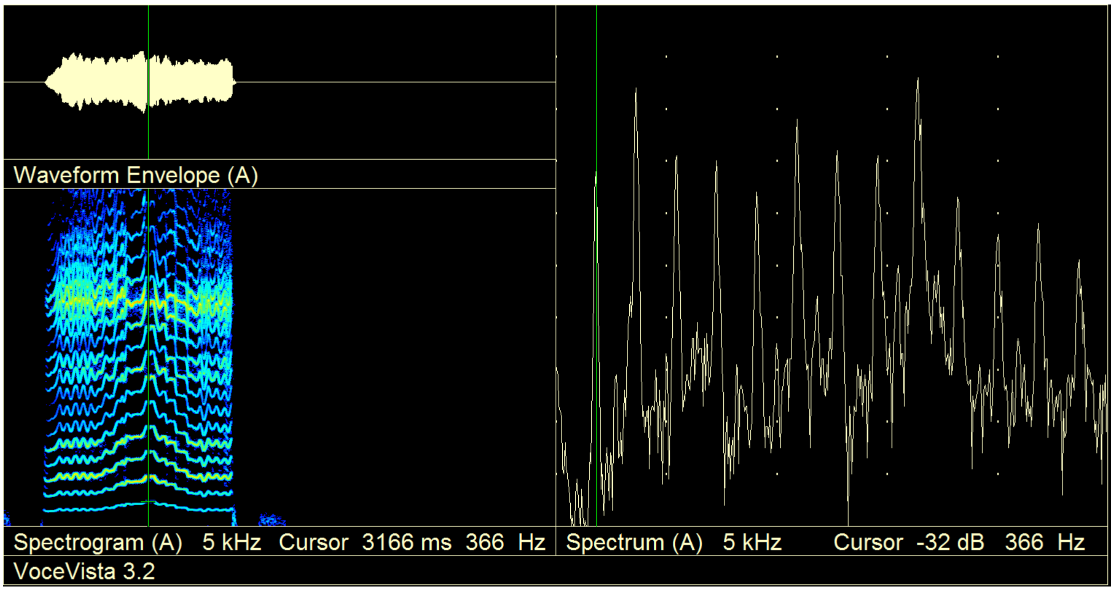
Figure 6.3.4: Student tenor (2) Bb3 – F4 scale [a]



This would seem logical, if the position of f_1 has remained consistent and there has been no ascent of the laryngeal position or ‘drift’ in the vowel. H2 is now within c.50 Hz of the estimate of f_1 given above using vocal fry. The EGG readings indicate that the CQ is marginally higher at c.60%.

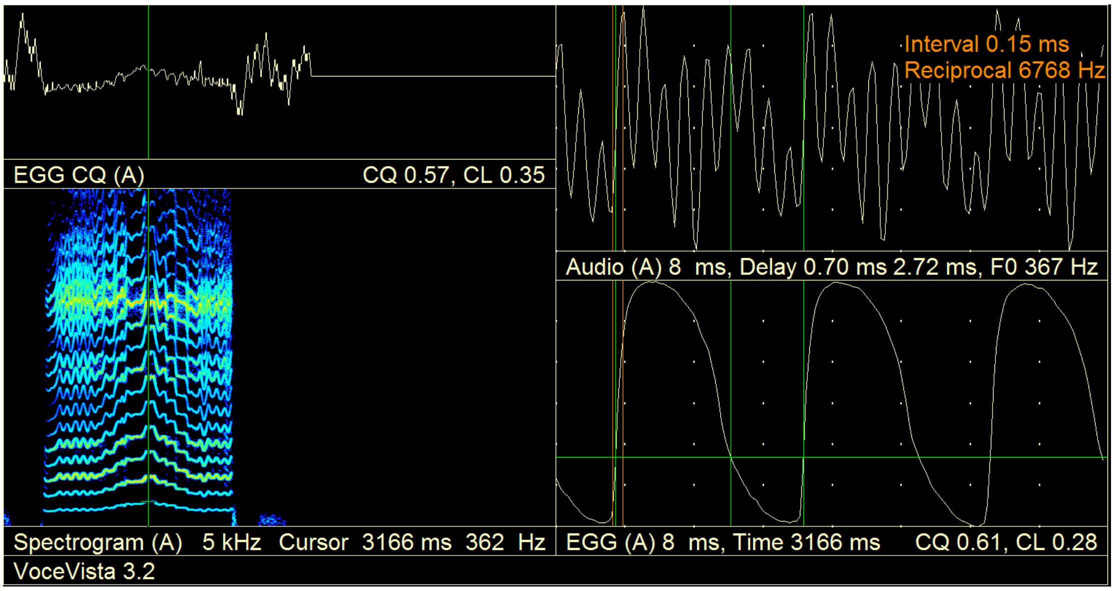
On ascending to F#4 in a scale from B3, H2 is again strong, exceeded slightly (around 2 dB) by H9 in the SF zone. (Figure 6.3.5)

Figure 6.3.5: Student tenor (2) B3 – F#4 scale [a]



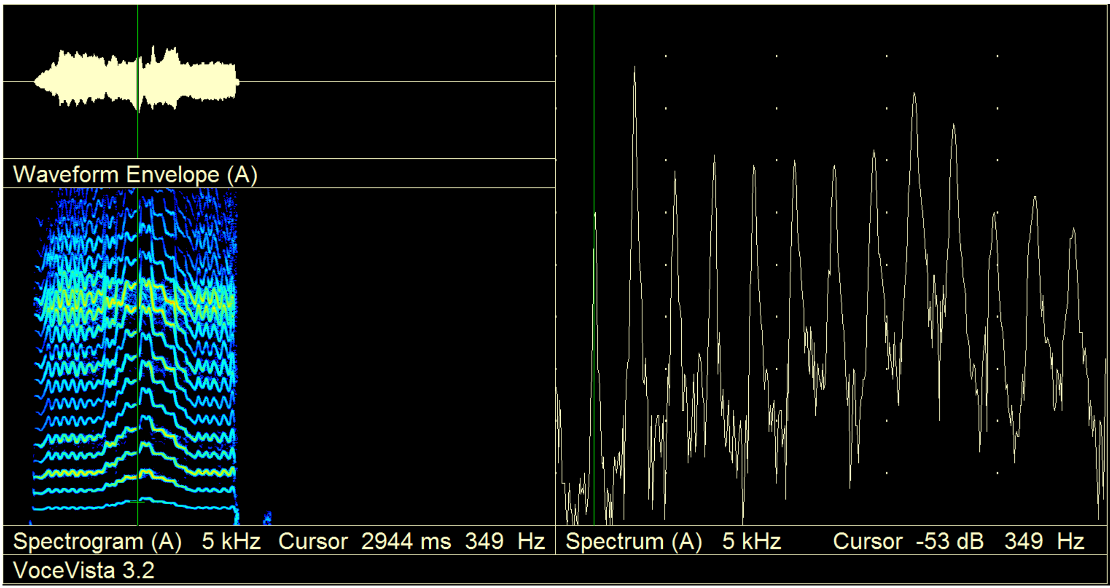
The view with EGG shows the contact quotient as remaining fairly constant at 61%. The measurement for the initial closure rate is c.0.15 ms which is rapid. (Figure 6.3.6.)

Figure 6.3.6: Student tenor (2) B3 – F#4 scale [a] with EGG at F#4



A common challenge for all student singers is to not allow vowels simply to accidentally drift away from the target vowel. This 'vowel drift' occurs in the next scale sung, C4-G4. The vowel has audibly moved from [a] towards [ʌ], perhaps because the student thinks this is the right thing to do, or he has been instructed to do so at this pitch. However this has the effect of taking f_2 higher. Consequently it is too high to influence H3 of the uppermost note in the scale. Instead it enhances H4 at 1320 Hz of the transitory E4 of the scale. Conversely this change in vowel causes f_1 to drop slightly so that H2 is more strongly influenced on the pitch of F4, when H2 is at c.700 Hz. (Figure 6.3.7.) H2 then weakens slightly as pitch ascends to G4 starting to move out of the strongest effect of f_1 at its now lowered pitch.

Figure 6.3.7: Student tenor (2) C4 – G4 scale [a]

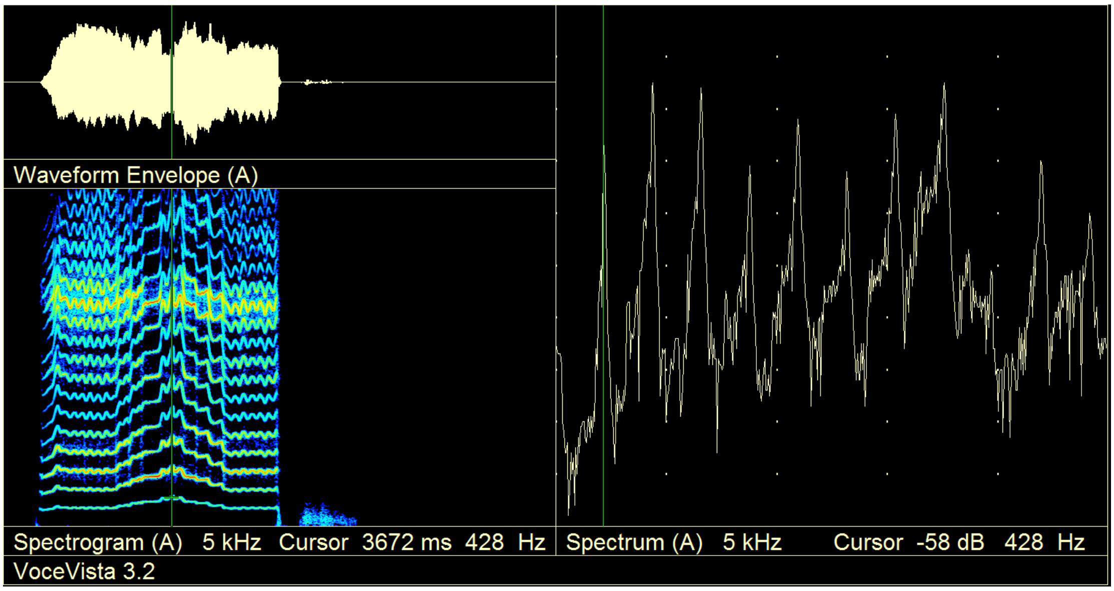


Albeit brief, in the ascending scale there is momentarily a very strong spike in H2 at this moment where it is 29 dB stronger than H1[24].

The scale from Db4-Ab4 shows a loss of quality in formant-enhanced resonance on the uppermost note. The very strong H2 of the Gb4 either side of Ab4 indicates the top of the passaggio zone for this scale. However there is some evidence that f_2, which could enhance H3 on Ab4, is slightly too high. (Figure 6.3.8)

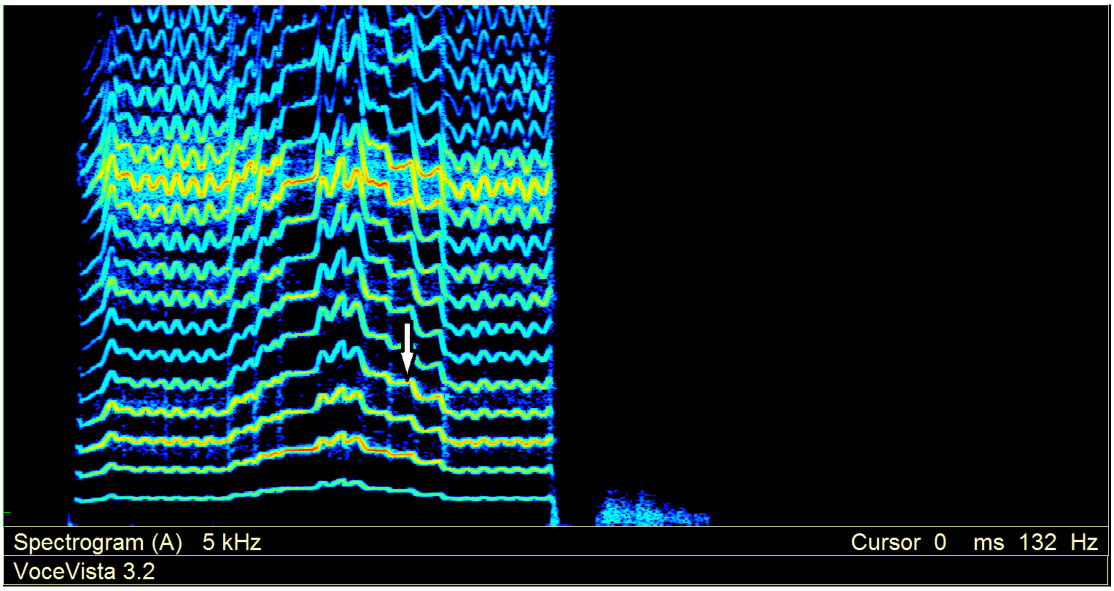
[24] The singer could learn from this: a more decisive f_1 H2 such as this on his F4 would be beneficial and he could then make a subtle vowel change to enhance G4 with f_2 more effectively.

Figure 6.3.8: Student tenor (2) Db4 – Ab4 scale [a]



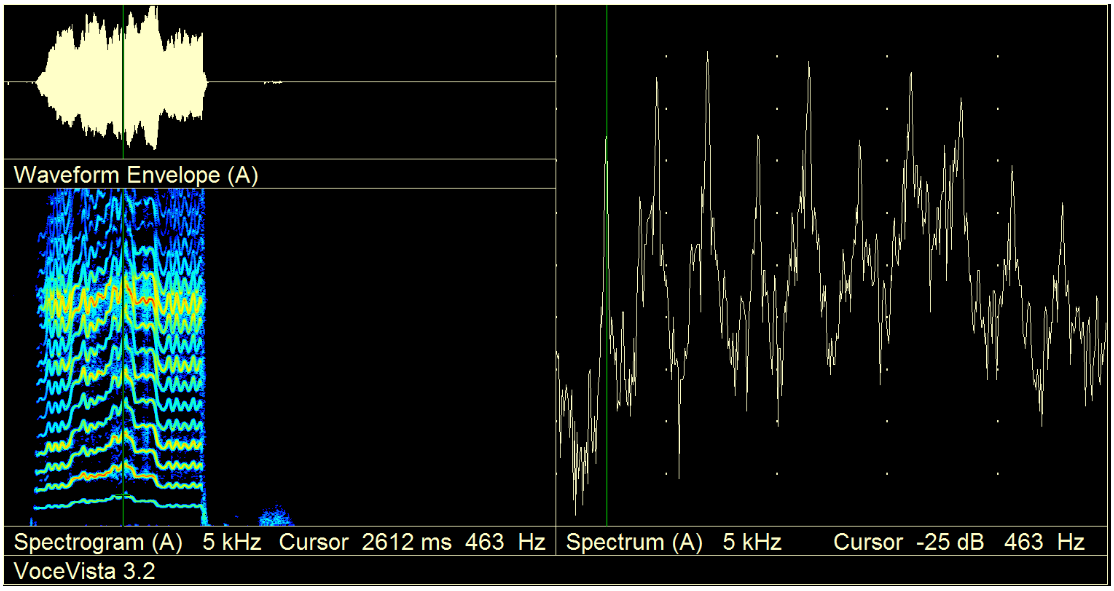
It can be seen that even on the upper side of vibrato pitch cycle H2 and H3 are almost equal. It is only on the upper part of the vibrato pitch cycle that H3 significantly strengthens. Looking at the colour spectrogram alone (Figure 6.3.9) the white arrow indicates where a harmonic at c.1390 Hz is influenced by f_2. This is too high to be ideal positioning for helping H3 on the Ab4 of this scale. The loss of formant tuning for the Ab4 is offset by reasonably strong activity in the SF zone, though there is a decrease in the level of H8 and H9 at the exact moment of the uppermost note in the scale. Immediately prior to that H8 is as strong as the spiked H2 on Gb4, 22 dB stronger than H1.

Figure 6.3.9: Student tenor (2) Db4 – Ab4 scale [a] colour spectrogram alone



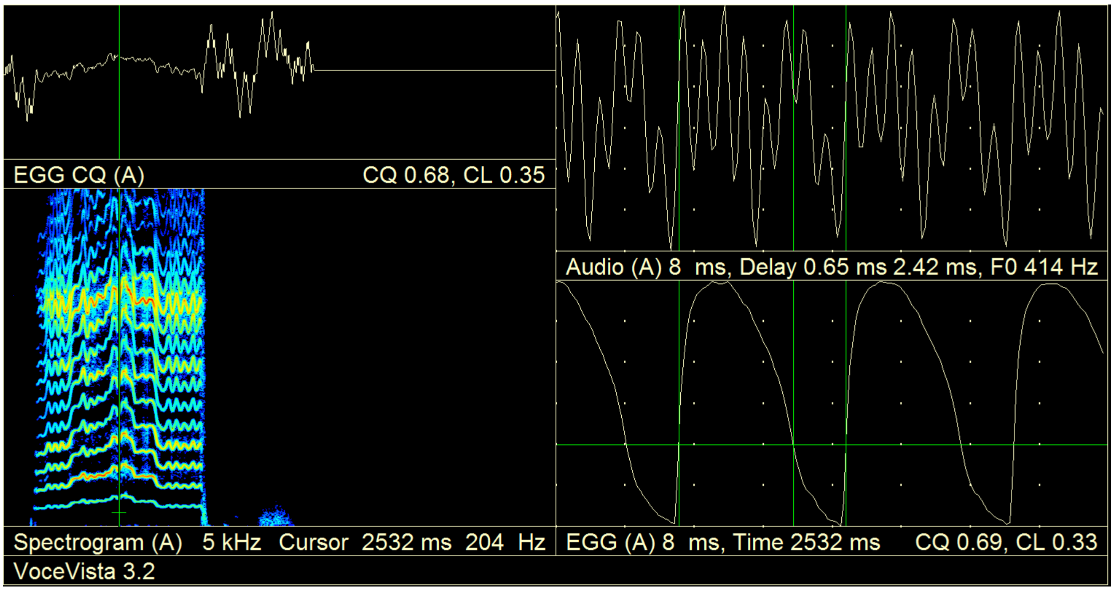
In the final scale attempted of D4-A4 the resonance situation is very similar to the Db4-Ab4 scale. However, when the student offered a triad covering the same pitches, D4-A4, on the uppermost note H3 emerged more strongly than any other partial. (Figure 6.3.10) This is strongest on the upper side of the vibrato pitch cycle. Observing the power spectrum whilst the averaging is set to 300 ms also shows H3 as clearly strongest throughout the A4 pitch.

Figure 6.3.10: Student tenor (2) D4 – A4 triad [a]



The EGG indicates that contact quotient has risen to c.69%. (Figure 6.3.11.)

Figure 6.3.11: Student tenor (2) D4 – A4 triad [a] with EGG at A4



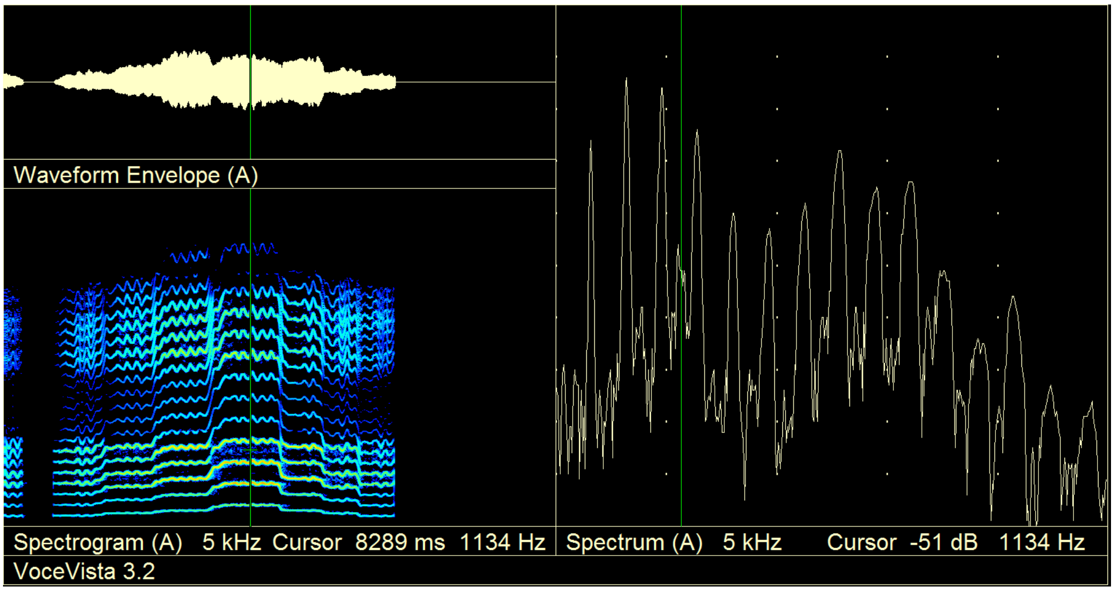
The indications here are that this student has a fairly high secondo passaggio point, but that at this stage of development there is more efficiency to be achieved in the formant tuning at that point and beyond.

6.4. Student 3

Student 3 had been studying at a major UK Conservatoire for a year and a half; he is of mesomorphic body type and 1.75 metres tall. At the time of the first group of recorded examples, he was 22 years of age. Out of the total of 21 recorded examples, four were taken one year after the others (as indicated below). Most of the examples were of arpeggios.

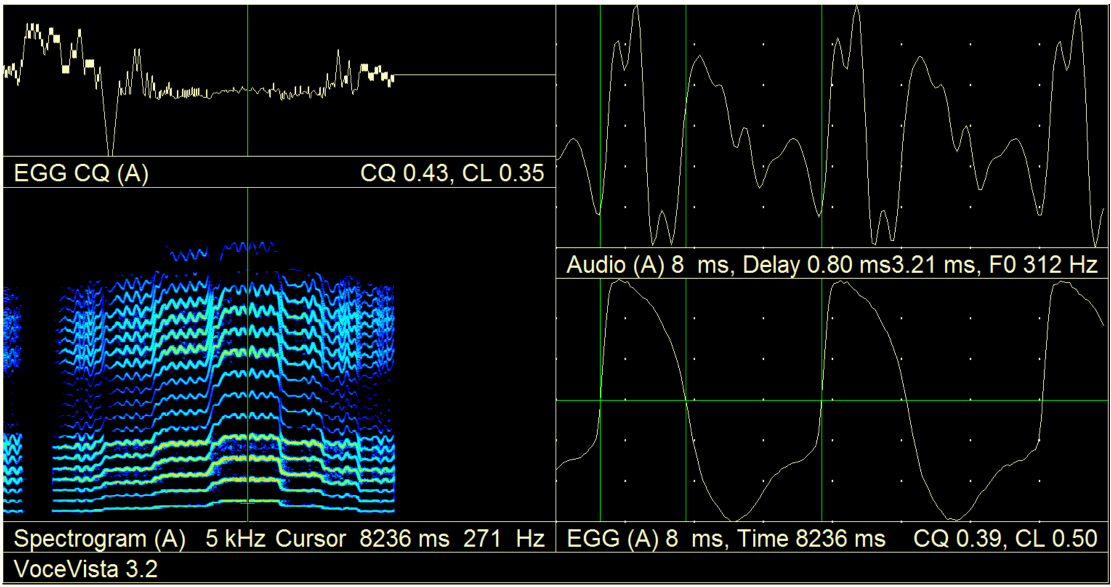
The first arpeggio offered was E3-E4. The vowel does not sound quite conventionally like a long Italian [a] vowel but has a slight aspect of [æ]. At the top of the arpeggio H2 is starting to strengthen as does H3 also, but close inspection of the colour spectrogram in coordination with the power spectrum shows that both are strongest in the uppermost part of the vibrato pitch cycle. In addition it can be seen in the power spectrum that there are columns between H2-3, and between H3-4. These probably indicate the true location of f_1 at c.775 Hz and f_2 at c.1134 Hz. (Figure 6.4.1)

Figure 6.4.1: Student tenor (3) E3 – E4 arpeggio [a]



This student has an unusual loop with a knee[25] visible in the open phase of the EGG signal approaching the rapid closing rise. This is visible in all the examples from this student until the pitch of F#4 is attained in arpeggios, after which the EGG looks more conventional. Figure 6.4.2 shows the EGG on the uppermost pitch of the E3-E4 arpeggio. The contact quotient is low at 39%.

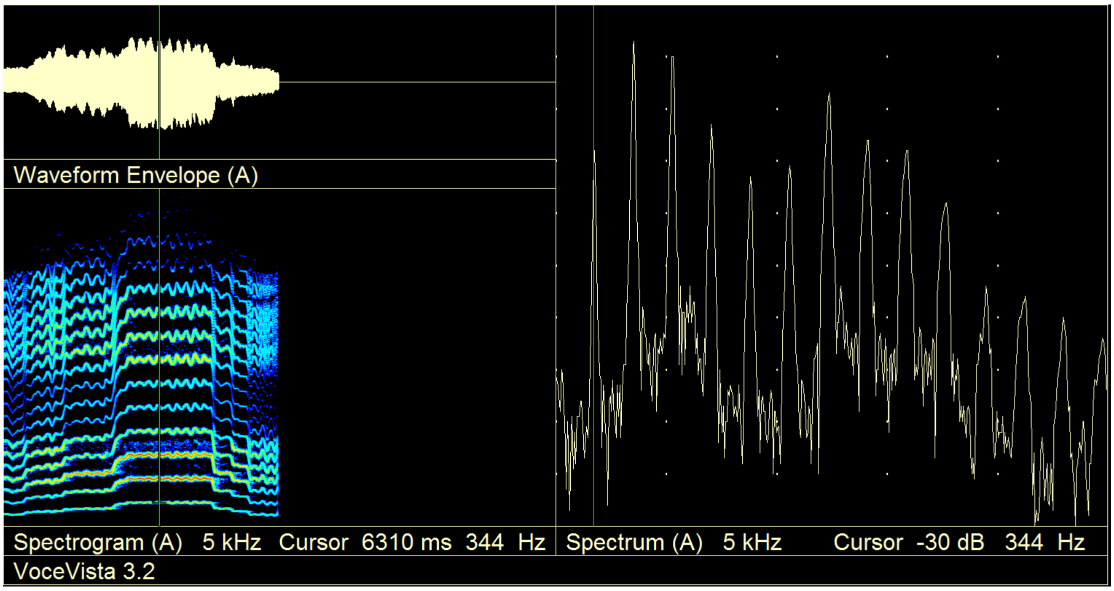
Figure 6.4.2: Student tenor (3) E3- E4 arpeggio [a] with EGG at E4



The signals for the arpeggio from F3-F4 show both H2 and H3 as strengthened on the top note. At first sight this may look like the aesthetic balancing of H2 and H3 at the top of passaggio, prior to entry into the upper range. (Figure 6.4.3)

[25] This is the conventional way of describing the visible distinctive shape shown in the EGG signal (Titze, 1990). This can often be seen in the righthand slope of each EGG cycle denoting the gradual opening of the glottis in the EGG signal. In the above example the knee is (unusually) visible during the open phase of the glottis, prior to the rapid rise of the signal.

Figure 6.4.3: Student tenor (3) F3 – F4 arpeggio [a]

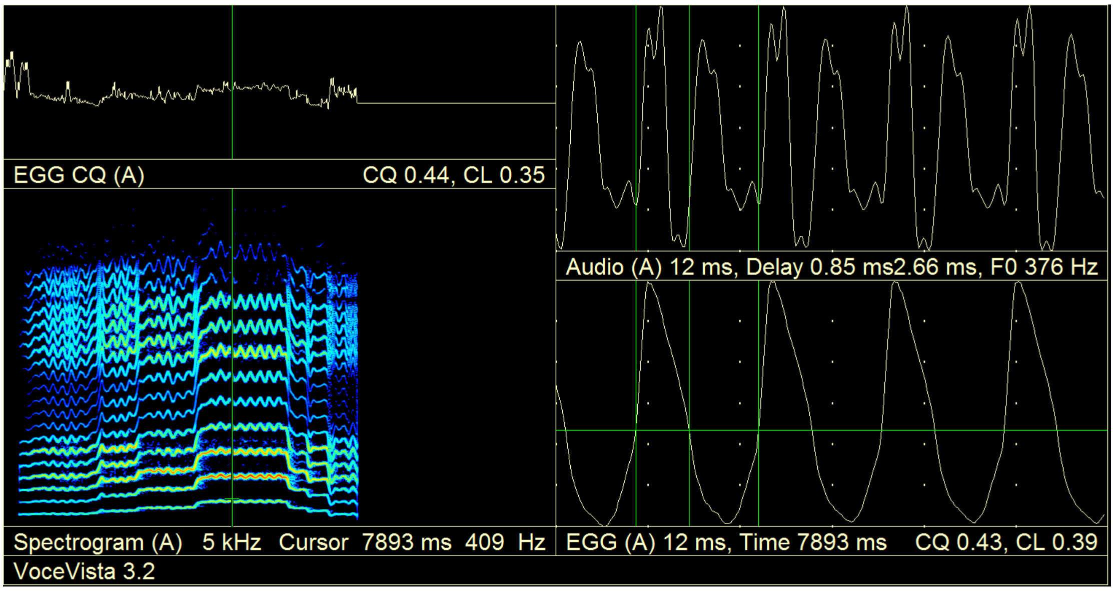


(As was discussed in Chapter 5.6, p.158, as a possible deliberate choice in the professional tenor examples). This turns out to be not the case here (explained below). The peaking of H5 (at c.1134 Hz) on the sung pitch of C4, coupled with the visible 'shadow' (at c.1128 Hz) between H3-4 on F4, indicate a somewhat high level for f_2, even though it is clear there is some influence on H3 of the F4. The strong f_1/H2 effect is seen clearly with consistent strength throughout the sung F4.

The clear EGG signals indicate a contact quotient of a modest 49%. (Not illustrated.)

The next rise in semitone in the arpeggio F#3-F#4 shows a similar effect. f_2 (at c.1260 Hz as seen in the 'shadow' presence between H3-4 and also influencing H5 on the upper part of vibrato pitch cycle of sung A3) is above H3. f_1 and H2 are strongly linked on the uppermost note of F#4. Viewing the example with the power spectrum average set to 300 ms shows H2 consistently powerful throughout the F#4. The EGG shows again a very modest contact quotient of 43% (Figure 6.4.4).

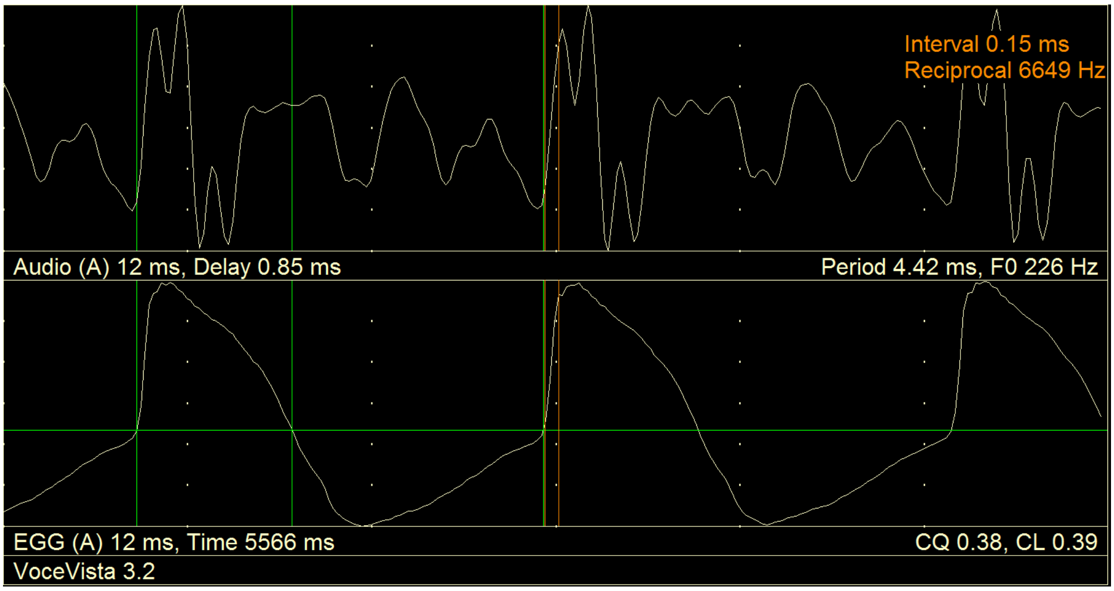
Figure 6.4.4: Student tenor (3) F#3 – F#4 arpeggio [a]



The unusual appearance of the open portion of the EGG signal has now gone.

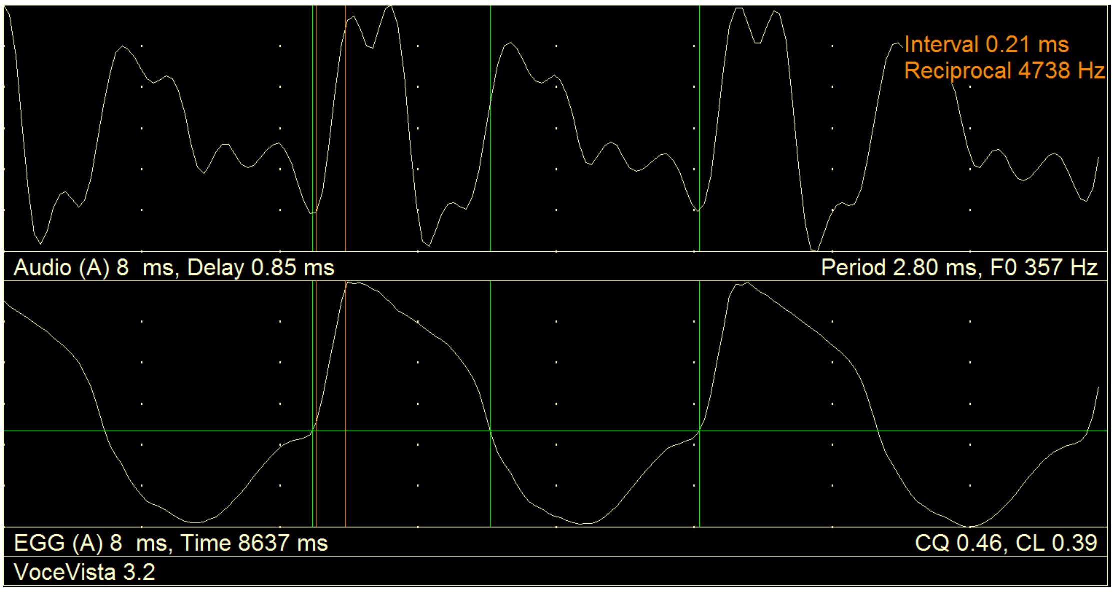
A further subtle issue is reported here for interest, and because it is in an area currently being researched elsewhere (currently, by Miller and Ritzerfeld). It was mentioned in relation to Tenor 10 of the professionals (Chapter 4.3 p.107-108) that there was a discernible change in vocal quality which seemed to be related to a change in the rate of initial closure. Student 3 has something of the same characteristic. When his initial closing rate is measured in any pitch below F#4 the signals indicate a rapid initial closure. On A3 during the arpeggio F#3-F#4 this is c.15 ms. (Figure 6.4.5).

Figure 6.4.5: Student tenor (3) EGG at A3 showing initial closure rate



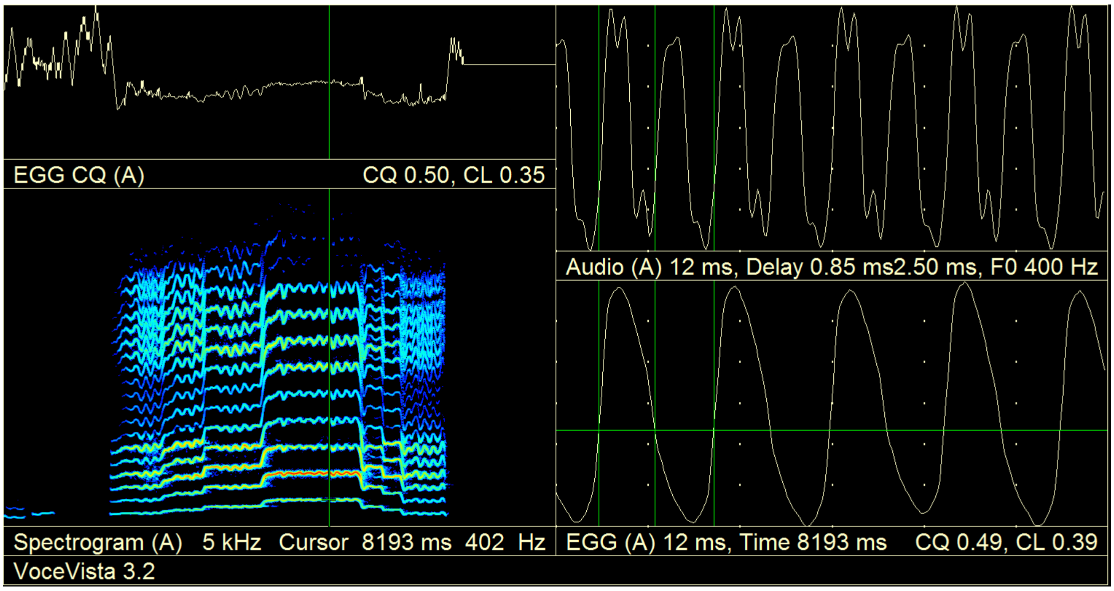
However once F#4 is reached, and subsequently higher notes, the initial closure rate is slower. Figure 6.4.6 shows that on F#4 this is now c.0.21ms. This coincides with a slight but audible change in vocal quality which can be heard in the recording.

Figure 6.4.6: Student tenor (3) EGG at F#4 showing initial closure rate



In the arpeggio of G3-G4 it can clearly be seen how dominant H2 is on the G4 (enhanced powerfully by f_1) from both the colour spectrogram and the acoustic signal, where the presence of two clear columns indicate this. (Figure 6.4.7)

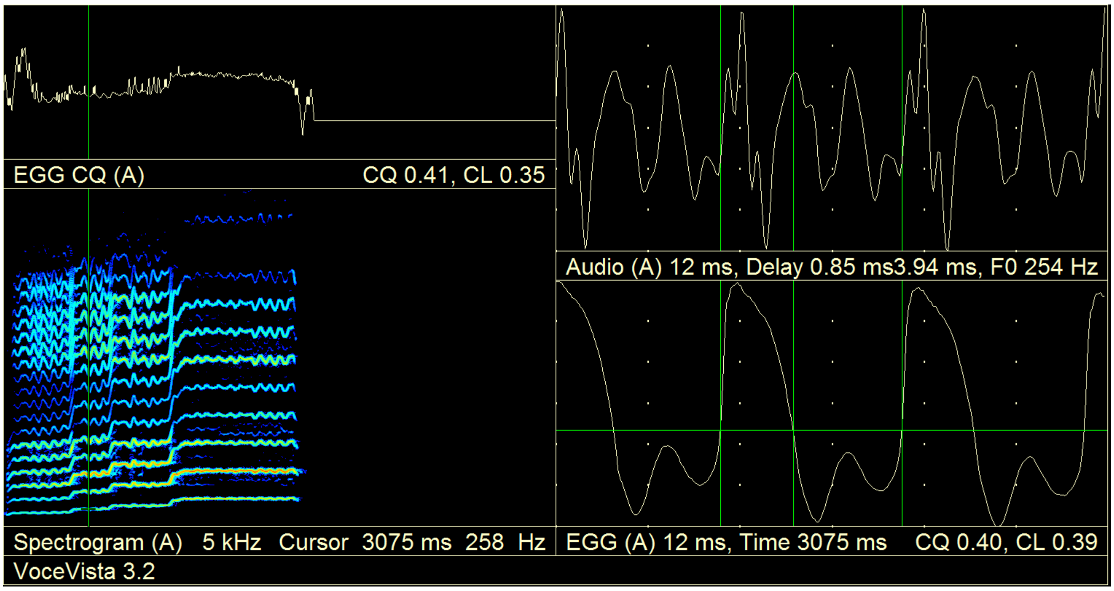
Figure 6.4.7: Student tenor (3) G3 – G4 arpeggio [a]



Measuring the strength of H2 at this same point in the power spectrum indicates that H2 is c.18 dB consistently stronger than H1. Activity in the SF zone is mostly at the same strength as H1. The contact quotient is very modest at c.49%.

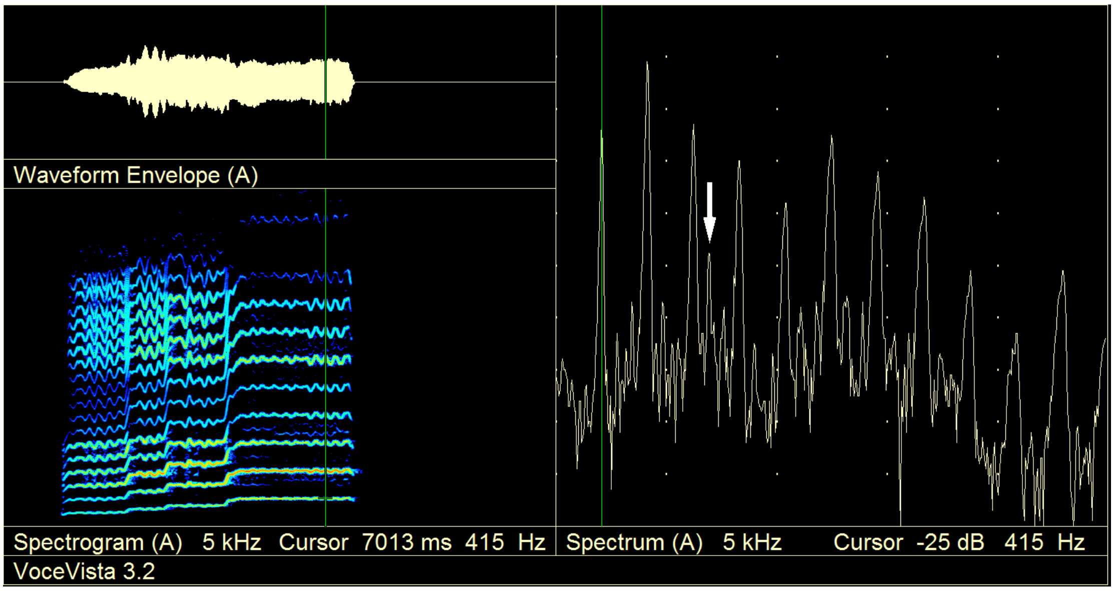
The next arpeggio of Ab3-Ab4 shows in the EGG signal again the unusual loop in the open phase prior to the closure slope commencing. This is consistent on all the lower pitches and ceases on the uppermost pitch. Figure 6.4.8 shows a moment on C4 where this can be seen.

Figure 6.4.8: Student tenor (3) Ab3 – Ab4 arpeggio [a] with EGG at C4



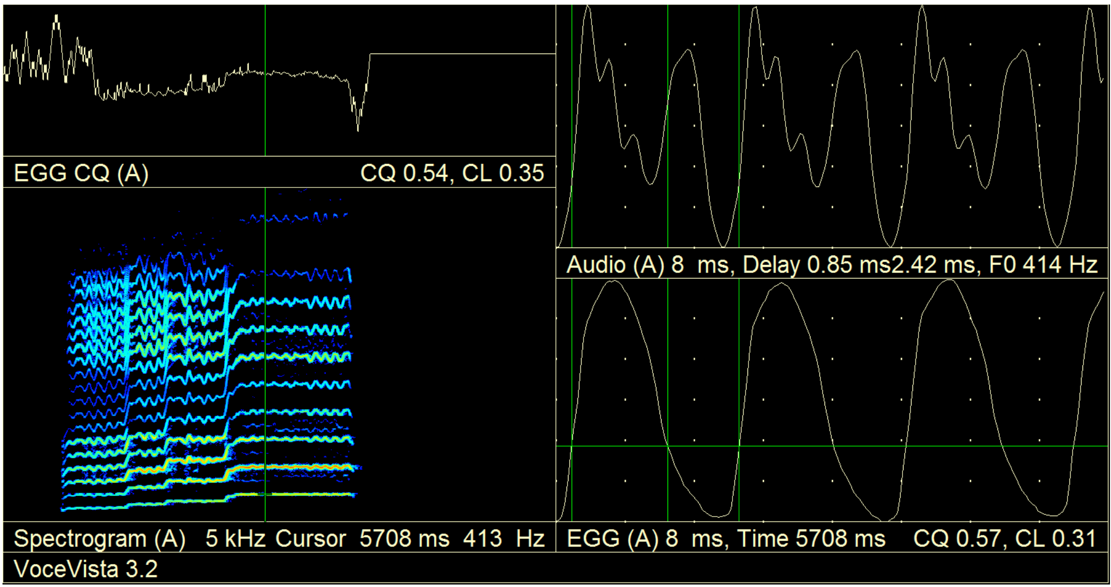
On the uppermost note, Ab4, it is clear that f_1 interacts with H2 causing it to be the strongest partial. Activity in the SF zone is below the strength of H1. It is probable that f_2 is too high to influence H3 significantly. This can be seen in the ‘shadow’ blue line above H3, which also aligns with the strengthened H5 on C4, the second sung note in the arpeggio (on the upper side of the vibrato pitch cycle). Since this is comparable to the situation reported in the F#3-F#4 arpeggio, except that now f_2 may well be as high as c.1380 Hz, there is a likelihood that formant levels are rising with ascending pitch (possibly caused by rising larynx). The white arrow in Figure 6.4.9 indicates the possible position of f_2.

Figure 6.4.9: Student tenor (3) Ab3 – Ab4 arpeggio [a] possible position of f_2 indicated with arrow



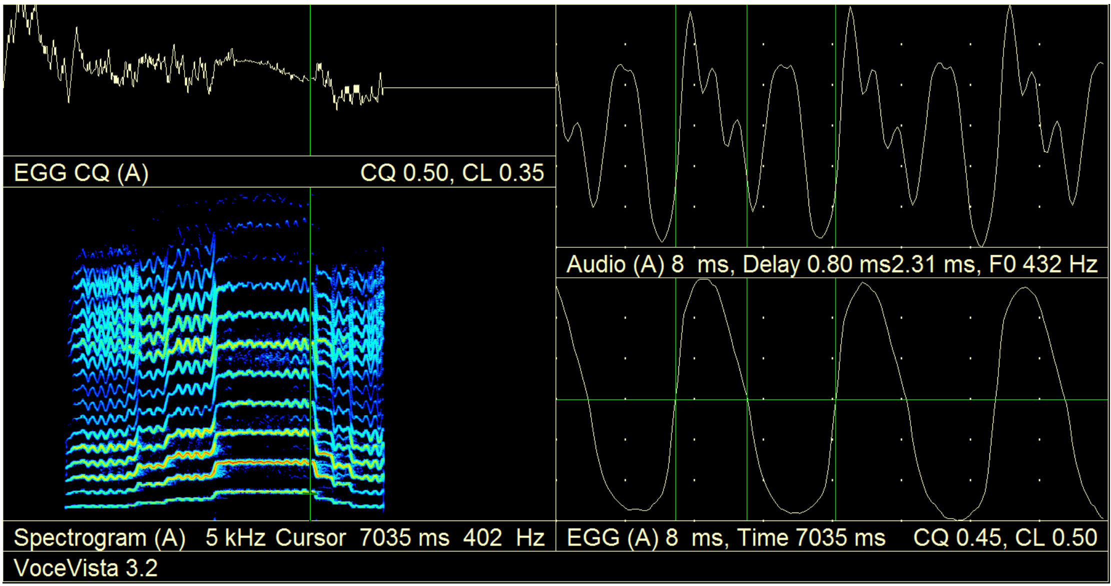
The contact quotient during the Ab4 has risen to 57% as shown in Figure 6.4.10.

Figure 6.4.10: Student tenor (3) Ab3 – Ab4 arpeggio [a] with EGG at Ab4



The final example taken from this student at the first session was the arpeggio from A3-A4. The uppermost note is sung lightly and the EGG signal resembles a sine wave, perhaps indicating a move towards falsetto lightness in the registration. It is difficult to be certain about this, since there is no knee in the EGG (one would not expect this if the source were to be falsetto) and it is has been established that in less full singing in the higher range EGG signals can be misleading/inaccurate Herbst, 2016). Where the signals are clearest, at the end of the phonated A4, the EGG contact quotient appears to be very modest at 45%. (Figure 6.4.11)

Figure 6.4.11: Student tenor (3) A3 – A4 arpeggio [a] with EGG at A4



However the singing of the note is perceptibly very light and not consistent with the three other notes of the arpeggio[26]. H2 is clearly the strongest partial, visible in the colour spectrogram but also indicated by the two clear columns in the audio signal. The previous suspicion that f_2 is rising with rising fundamental pitch is further supported here by the fact that H3 of A4 shows some strengthening at the tip of the upper pitch in vibrato cycle (at c.1350 Hz) as does H4 of the sung E4 (again at c.1350 Hz). If this is the case and is being caused by a rising larynx, f_1 is allowed to continue to track H2 and f_2 is too high to enhance H3. In instances such as this, possible controversy and confusion can arise, since some may think this an acceptable situation with a viable aesthetic outcome, and others that this

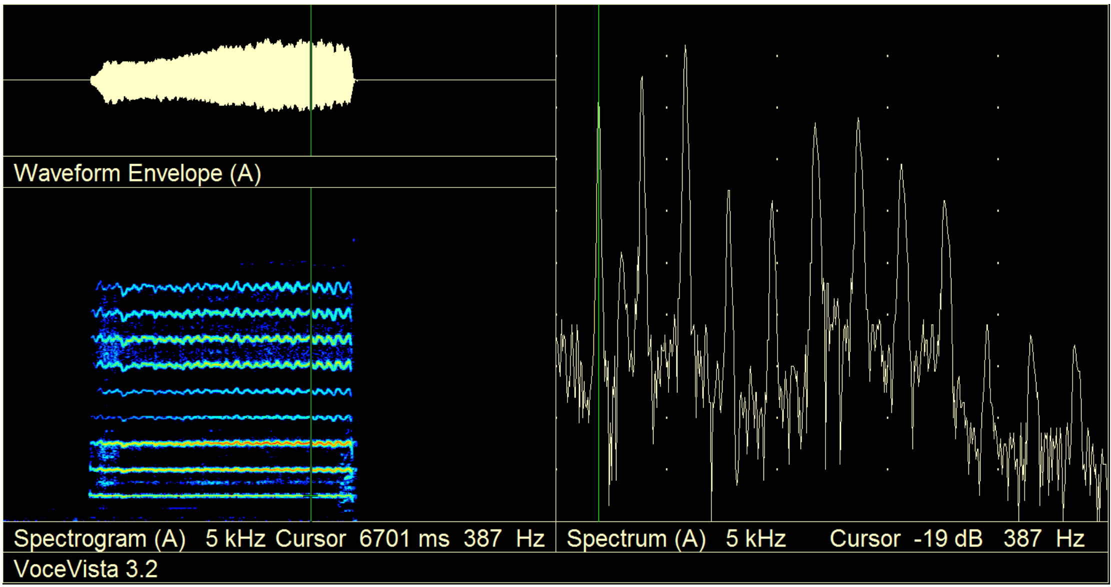
[26] This does not mean that such a manner of singing would not be professionally viable; this very light vocalism could be appropriate to some Baroque or Renaissance repertoire.

indicates a less developed vocal technique where preferable outcomes could be achieved in terms of both function and aesthetics.

In the light of such possible controversy it is therefore particularly relevant and interesting to examine the few examples given eleven months later. The student explained that he had been working on avoiding what he termed ‘shallow’ singing in the upper range. Part of this had been seeking improved f_2/H3 tuning. He was familiar with spectrographic signals.

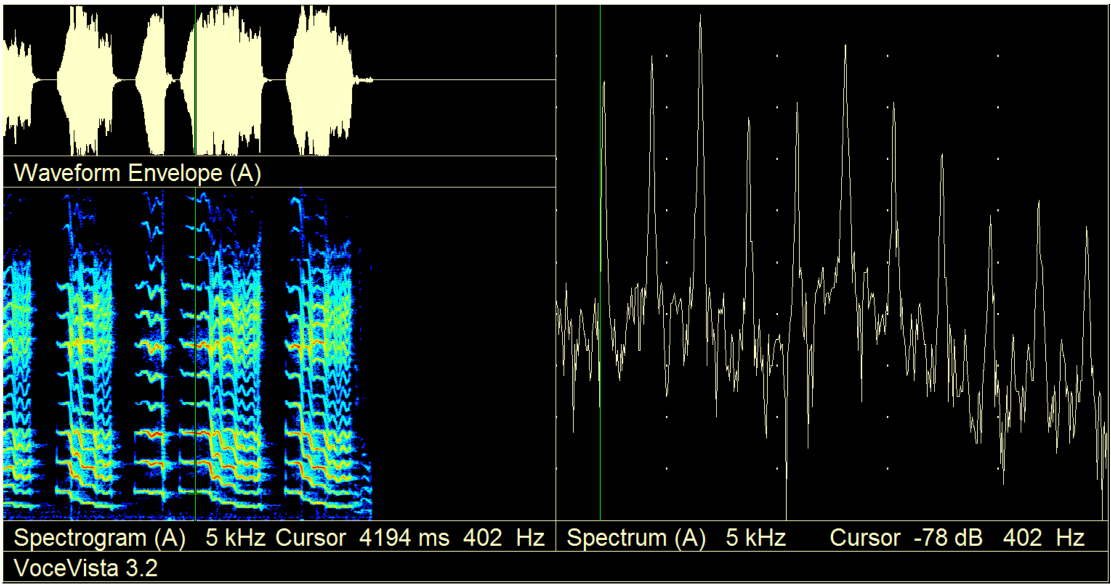
Figure 6.4.12 shows the student singing a sustained G4 (whilst looking at a screen showing a power spectrum). He is ‘seeking’ an enhanced H3. As H3 increases in strength it becomes 11 dB stronger than H1.

Figure 6.4.12: Student tenor (3) sustained G4 showing f_2/H3 tuning



The student was then keen to find this sensation on the pitch of A4. Three example files all show the same characteristics, though the vowel and associated result is not yet quite consistent. Figure 6.4.13 shows a moment where there is a much stronger engagement with f_2/H3 tuning which the student was seeking. It can also be seen that there is stronger activity in the SF zone where H6 is strengthened[27].

Figure 6.4.13: Student tenor [3] A4 showing f_2/H3 tuning



The preceding examples from student tenor (3) show a voice very much in transition in passaggio management and establishing a professional sound in the upper range.

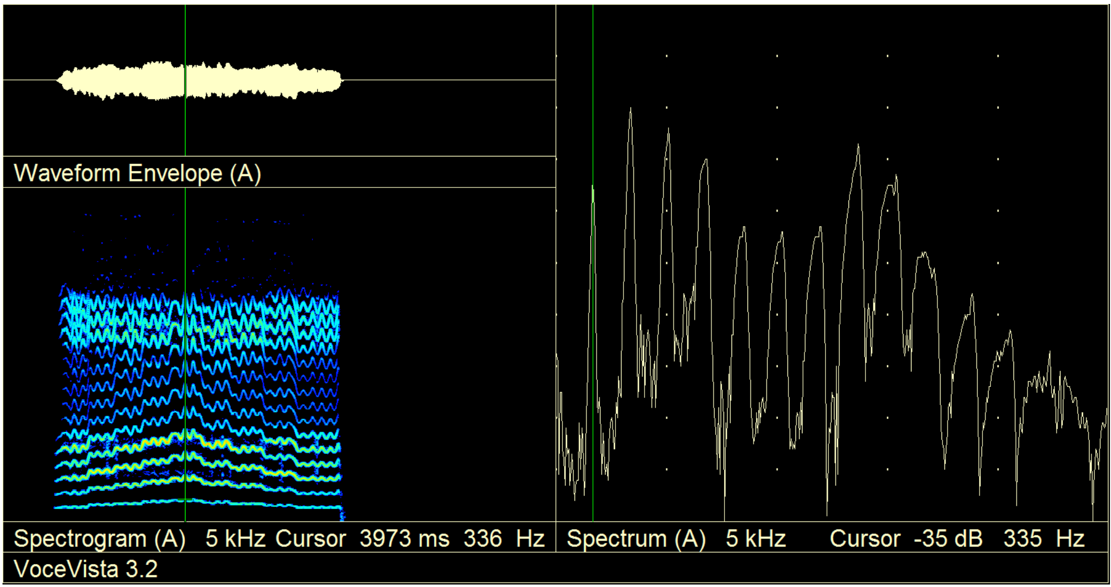
6.5. Student 4

This singer had three years of tuition at a major UK Conservatoire. He was 20 years old at the time of the first set of recordings. His body type is mesomorphic with a height of 1.91 metres. Seventeen examples were recorded at one session and a further ten examples were recorded 21 months later. During this 21 month period the student received tuition for 13 months (owing to how term dates work in the calendar year). The examples all have clear EGG signals.

[27] Without EGG it is not possible to state that the change in resonance was solely due to formant tuning issues. It may have been that air-flow and basic quality of phonation was changing. However, were this student to be able to choose to offer f_2/H3 tuning in the upper range [a] it could make an important difference to the repertoire which the singer could undertake.

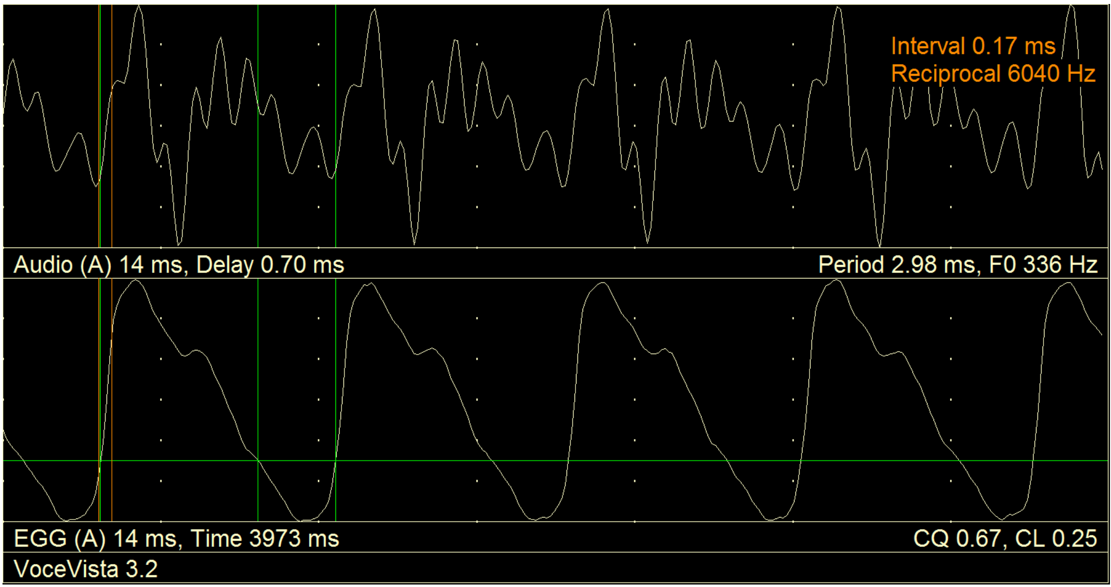
In the scale A3-E4, on the uppermost part of the vibrato pitch cycle H2 is starting to be influenced by f_1 and at those moments is the strongest partial. (Figure 6.5.1) Close examination of the light blue 'shadows' which are visible in various places in the colour spectrogram between partials suggest that f_1 may be c.735 Hz and f_2 c.1200. There is strong activity in the SF zone (see H8 and H9 in Figure 6.5.1).

Figure 6.5.1: Student tenor (4) A3 – E4 scale [a]



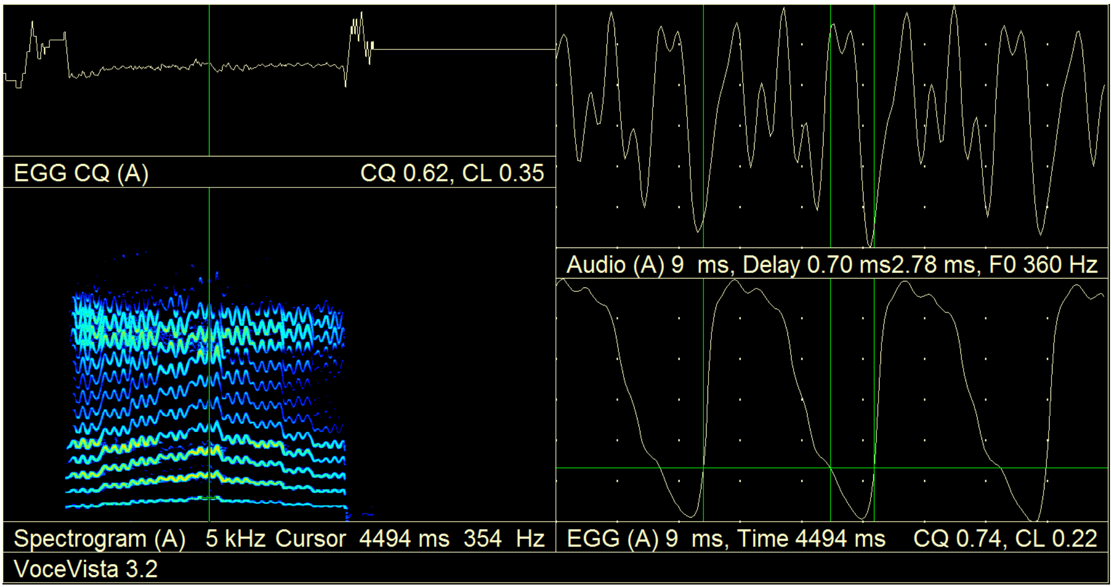
The EGG shows a fairly robust contact quotient of c.67%, and the initial closure rate is quite fast at 0.17 ms. (Figure 6.5.2)

Figure 6.5.2: Student tenor (4) E4 [a] with EGG showing initial closure rate



On ascending to F4 in the next scale (starting on Bb3) the student sings a markedly modified vowel for the F4 which does enable him to engage f_2 with H3 at the top of the vibrato pitch cycle. Viewing the scale with power spectrum average set to 300 ms, also shows that H3 is the strongest harmonic on F4. However it is probable that most listeners would find such a degree of vowel change unacceptable if the target vowel for an audience (as required by a text) was supposedly [a]. The audio signal shows the three columns denoting the strength of H3 and the EGG indicates a high contact quotient of c.72%. (Figure 6.5.3)

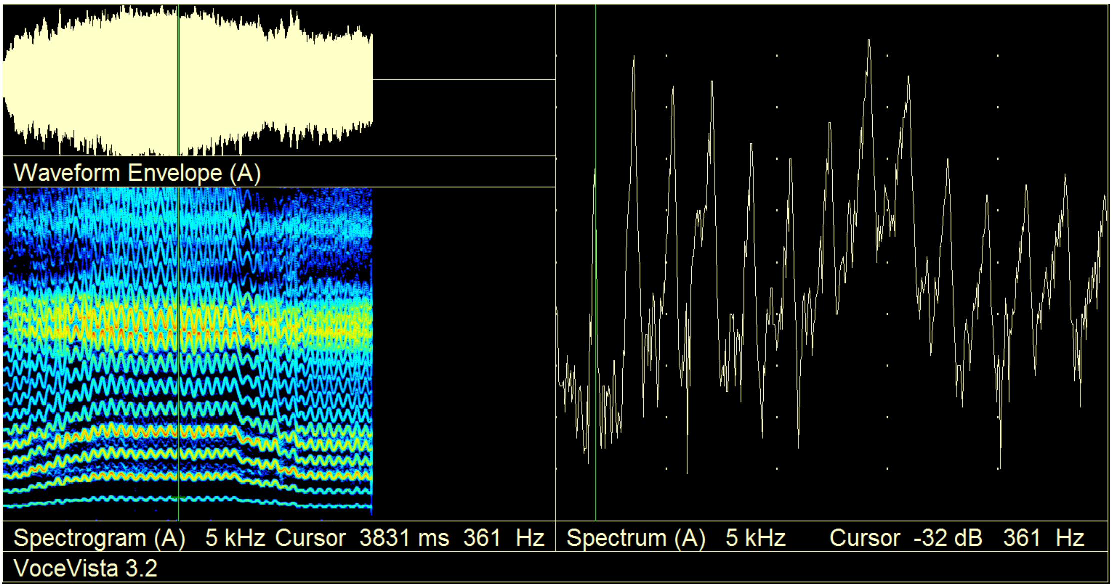
Figure 6.5.3:Student tenor (4) Bb3 – F4 scale [a] with EGG at F4



Immediately prior to the uppermost note, Eb4 has a strong F/H2 relationship when H2 is c.16 dB stronger than H1. Perhaps this student is seeking to achieve a clear, change from f_1/H2 to f_2/H3. If so, the attempt is either too early in pitch needing an unacceptably distorted vowel (since f_2 is too far away otherwise) or just vocally clumsy.

The same scale 21 months later shows significant change in resonance management. At this more developed stage, there is no attempt to modify the vowel on the F4 (which is confidently sustained). The EGG (not shown) indicates that the contact quotient has stayed at 72%. Now f_1 strengthens H2 effectively (and throughout the vibrato pitch cycle) and H2 is the strongest partial, even though f_1 is probably rather higher, the two are clearly close enough for engagement. (Figure 6.5.4.) H4 strengthens at the lowest moments in vibrato pitch change as it nears 1200 Hz, because of the presence of f_2. It can also be seen that H8 and H9 are vying for attention from a formant which must be lurking c.2800 Hz since H8 strengthens as it rises (in vibrato pitch cycle) towards that pitch and H9 conversely as it drops towards that pitch. At the strongest moment H8 is 25 dB stronger than H1. Viewed with the power spectrum set to 300 ms for averaging, H2 and H4 look almost equal and activity in the SF zone is slightly stronger than both.

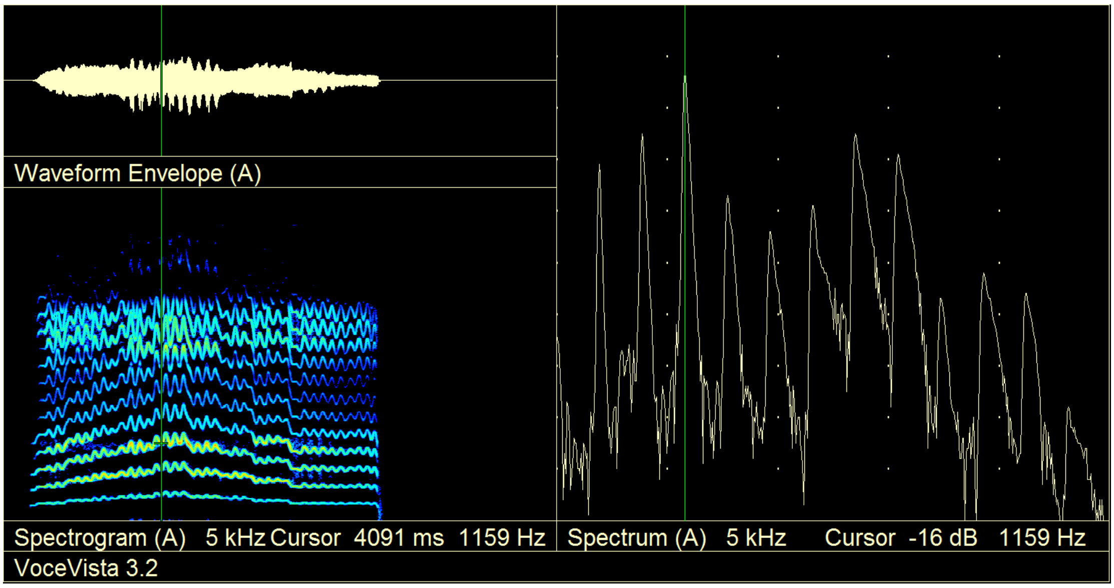
Figure 6.5.4: Student tenor (4) Bb3 – F4 scale [a] later version



This is a big change from the perhaps overly-managed, distorted vowel of 21 months earlier and yields a note with balanced and richly resonant partials, (coupled to a stable and regular vibrato).

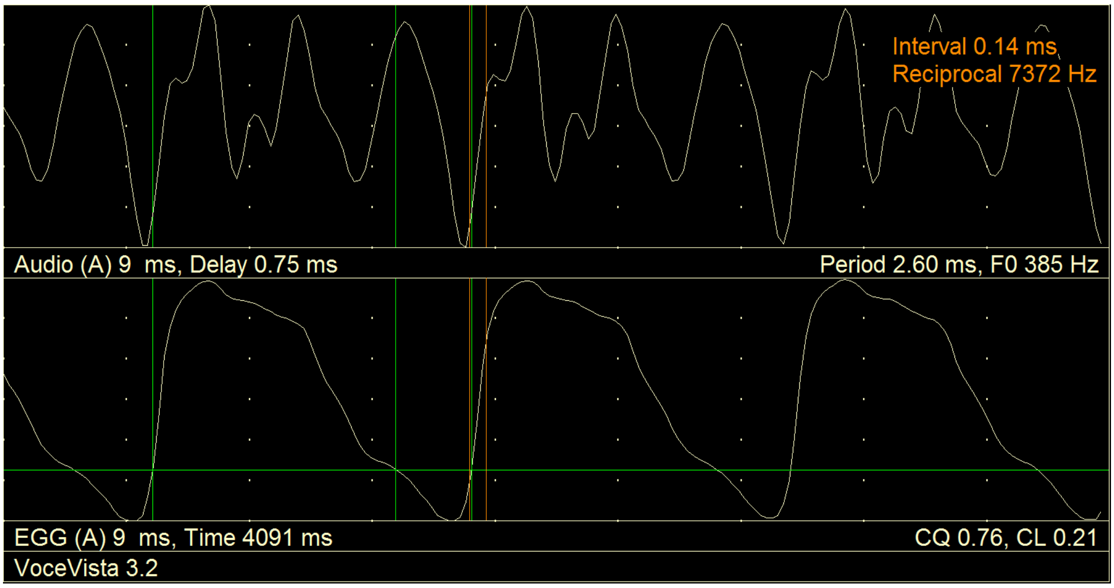
The examples of scales subsequently, B3-F#4, C4-G4 and Dd4-Ab4, exhibit the same characteristics as the Bb3-F4 scale discussed above in association with Figure 6.5.3 (i.e. the earlier version). At the top of each scale there is a vowel change which facilitates some strength in H3 reacting to f_2, but the vowel changes are very obvious and also do not position f_2 very advantageously. The scale of C4-G4 uses a [ʌ] vowel at the top and this is less obvious than in the previously discussed example. However this places f_2 slightly too low for maximum effect on the G4 as can be seen in Figure 6.5.5, where H3 is strongest at the lowest point in the vibrato pitch cycle. This means that the vowel did not need such a degree of modification and could have been nearer the target vowel and at the same time facilitated better engagement with f_2. If as surmised previously, f_2 is around 1200 Hz in this singers' normal [a] vowel, then a G4 (at 392 Hz) would cause H3 to be well placed for interaction.

Figure 6.5.5: Student tenor (4) C4 – G4 scale [a]



It has been mentioned that with some singers there is some evidence to show that the initial closure rate slows at, or after, the top of the passaggio. In this case the rapid closure rate is maintained, indeed appears to be even more rapid, at the secondo passaggio moment where it is 0.14 ms. (Shown with the orange cursors showing the measurement in Figure 6.5.6.)

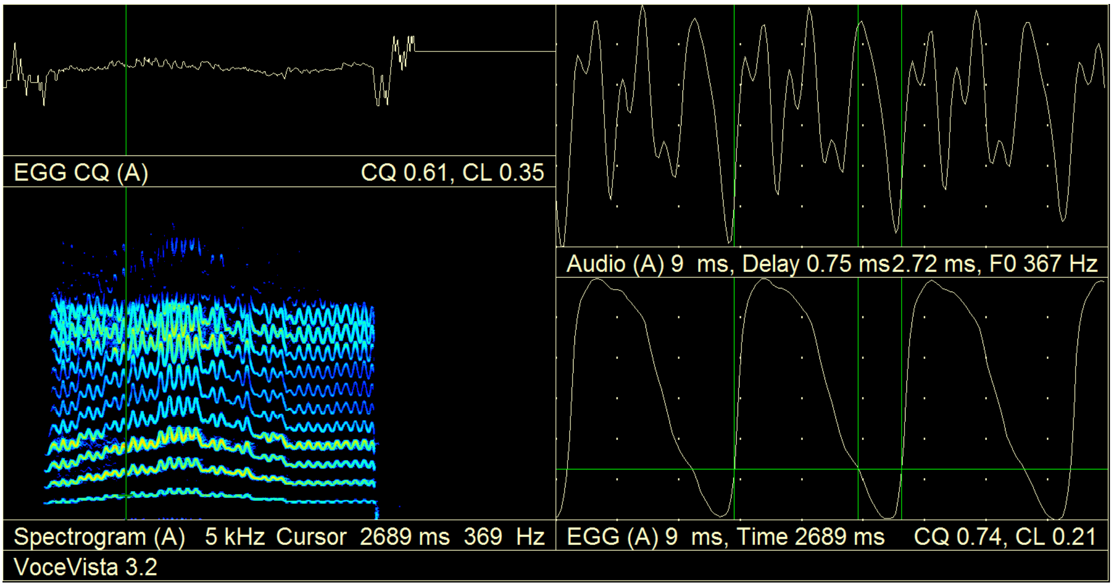
Figure 6.5.6: Student tenor (4) EGG at G4 showing closure rate



The contact quotient also remains very high at c.76%.

In the following Dd4-Ab4 scale the vowel is changed towards [ʌ] at the point of reaching Gb4 and again this does cause f_2 to react with H3 as it does also on the uppermost note, though there f_2 is a little too low for strongest interaction with H3. This can be seen in the colour spectrogram though the clarity of engagement between f_2 and H3 is seen in the rather neat three clear columns in the audio signal when looking at the lower frequencies of the vibrato pitch cycles (also confirmed in power spectrum views, which are not shown here). (Figure 6.5.7.)

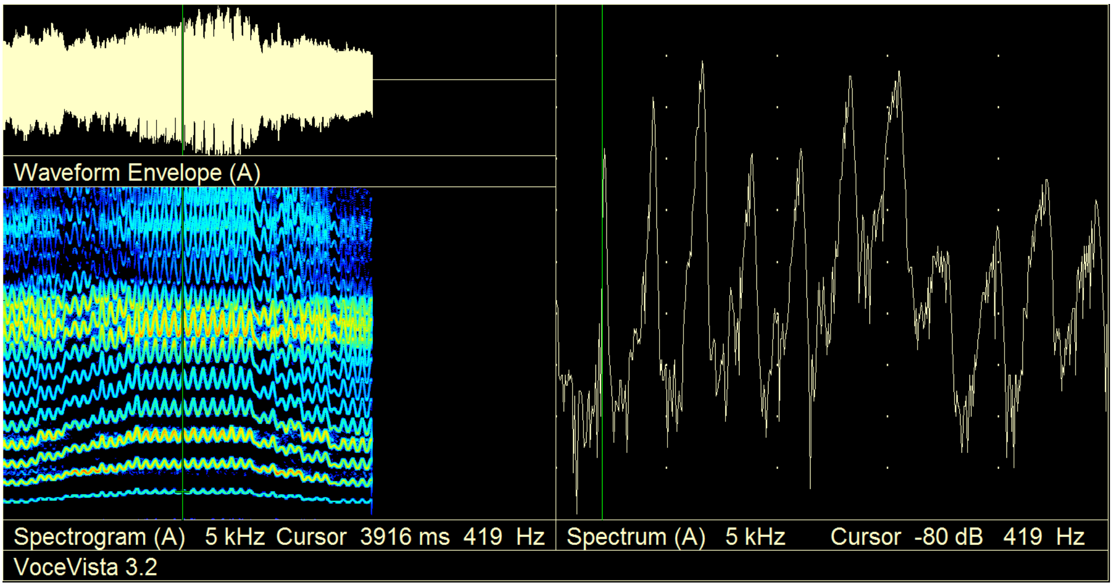
Figure 6.5.7: Student tenor (4) Db4 – Ab4 scale [a] EGG at Gb4



In the example of the same scale recorded 21 months later there is less obvious vowel change, and the result is a more consistent engagement with f_2 throughout H3 as the pitch moves up and down in the vibrato cycle. SF activity is also strong, and the pitch is confidently and evenly sustained[28]. (Figure 6.5.8.)

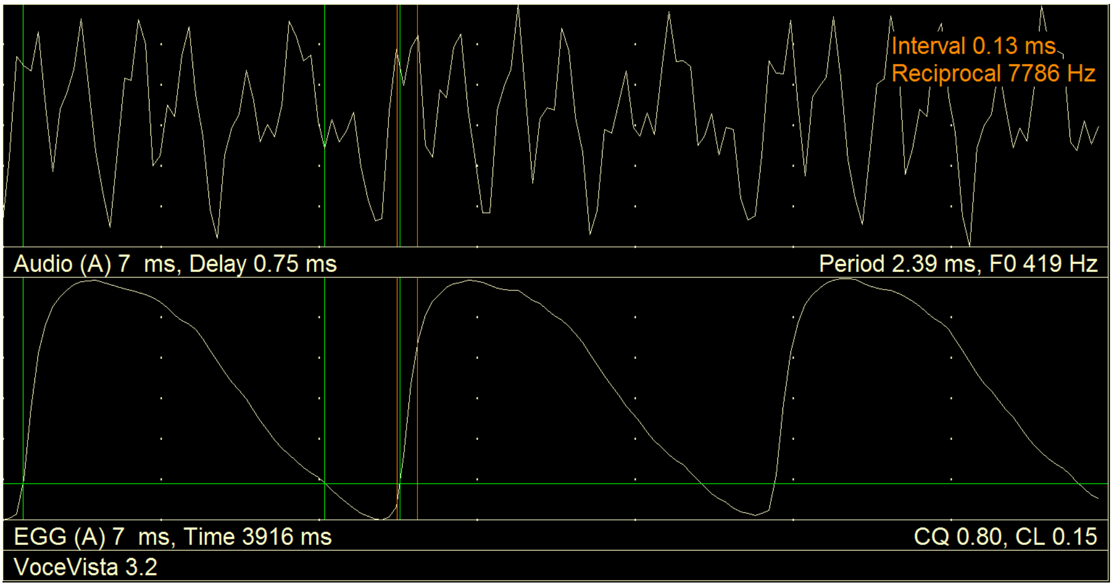
[28] There is high interest in establishing whether formants are most effective when slightly above partials, but this has tended to remain a theoretical model (Titze, 2003) rather than one based on live data. Here one can see in the early part of the colour spectrum the blue shadow between H2 and H3 which is caused by f_1 at 760 Hz. Yet the partials in the sung example react to f_1 maximally when around 720-730 Hz. This would suggest that f_1 is most influential when c.30 - 40 Hz higher than a partial.

Figure 6.5.8: Student tenor (4) Db3 – Ab4 [a] later example



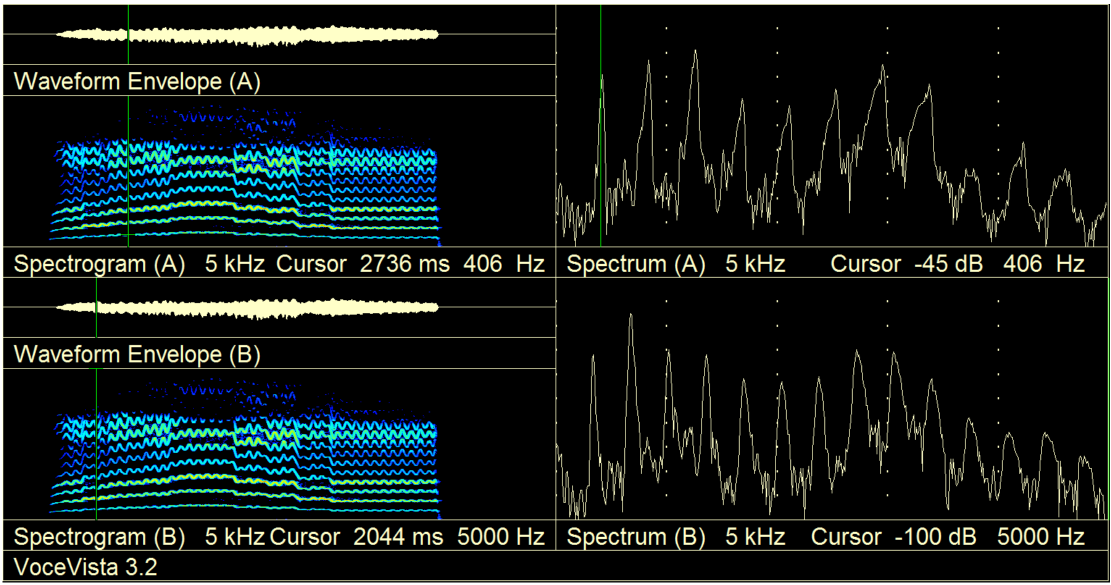
The EGG for this pitch is shown as high at 80%, with a remarkably high rate of initial closure at 0.13 ms (shown with the orange cursors). (Figure 6.5.9)

Figure 6.5.9: Student tenor (4) Ab4 with EGG showing closure rate



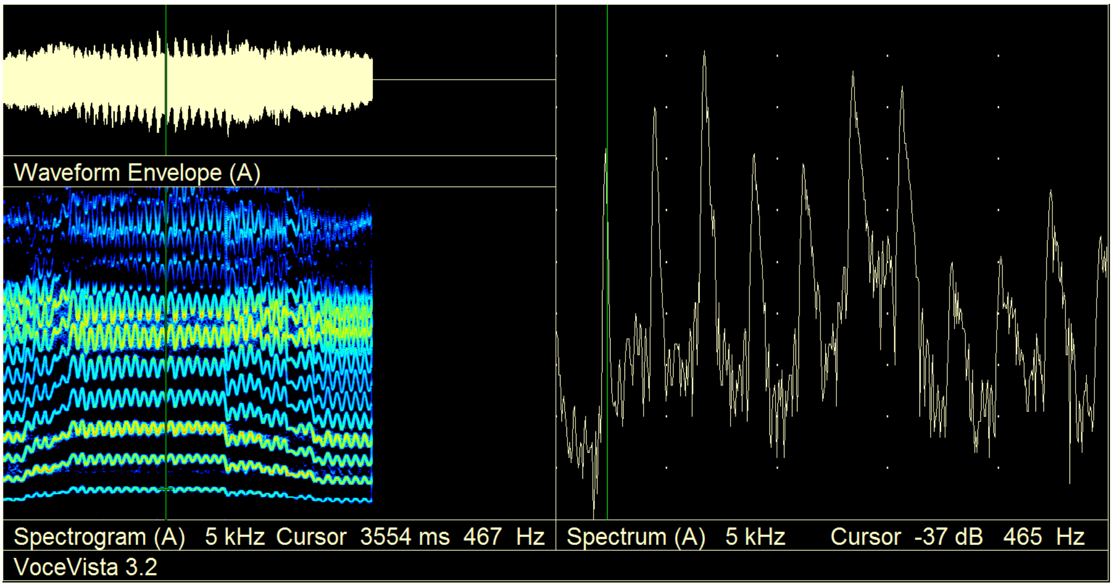
As the range extends further upwards in scales of D4-A4 and Eb4-Bb4 there are less obvious vowel changes and the location of formants enhances partials with greater strength. In both scales there is a change from f_1/H2 tuning to f_2/H3 tuning which occurs on G4. Despite the relatively young age of this tenor it would seem reasonable to conclude that his secondo passaggio moment is F#4 and that thereafter he enters what Miller, R., (1993) calls 'voce piena in testa' (full voice in the head), using f_2 and H3. This is shown in Figure 6.5.10 where the lower screen shows f_1/H2 on F4 and the upper screen shows the next pitch of G4 where f_2/H3 is established. (These were also checked with repeated viewings of the example with the power spectrum set to 300 ms.)

Figure 6.5.10: Student tenor (4) scale [a] showing change from f_1/H2 to f_2 H3 tuning



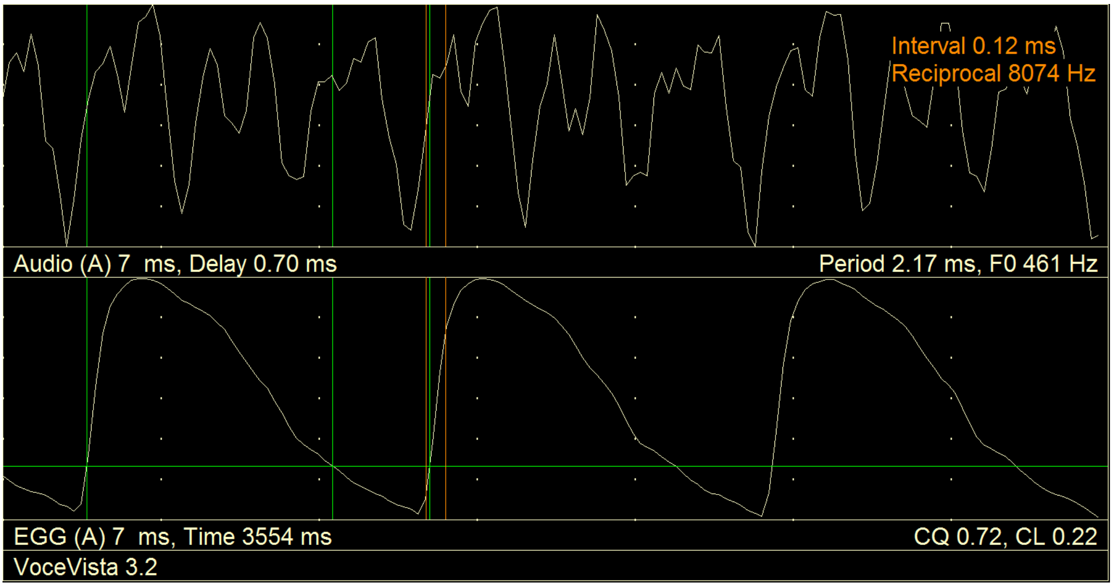
The same scale 21 months later shows strong engagement between f_2 and H3 on the high Bb4 and the sustained full singing of the note, with its also strong SF partials suggest confident resonance. (Figure 6.5.11.)

Figure 6.5.11: Student tenor (4) Eb4 – Bb4 scale showing sustained Bb4



The initial closing slope rate is remarkably fast at 0.12 ms and contact quotient is c.72%. (Shown in Figure 6.5.12.)

Figure 6.5.12: Student tenor (4) EGG at Bb4 showing closure rate



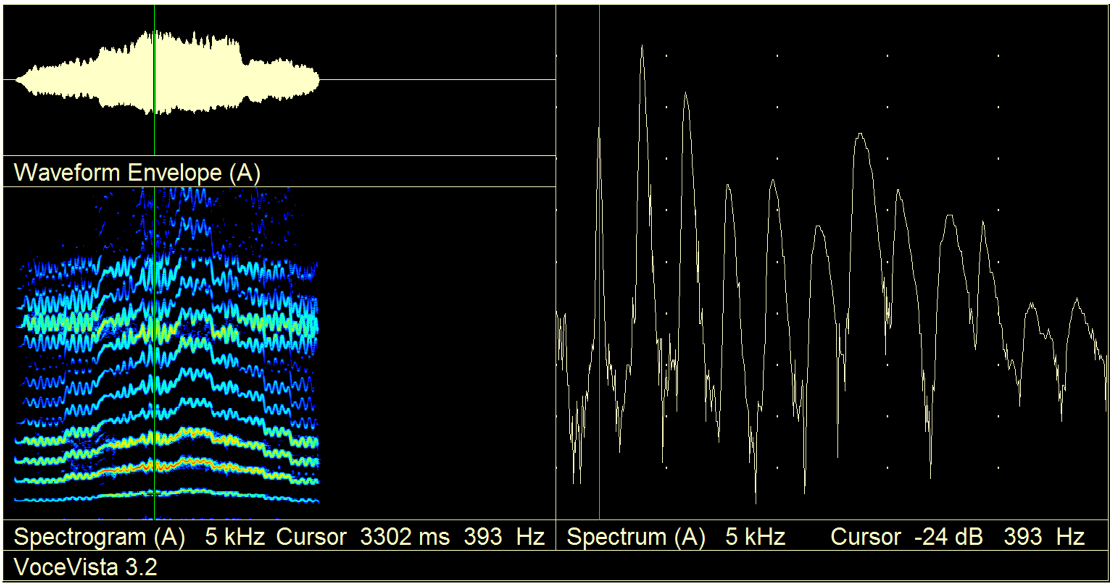
In summary student 4 exhibits in his later examples characteristics in the negotiation of his passaggio and upper voice which are strongly professional in quality.

6.6. Student 5

Student 5 provided a total of 31 examples over a three year period. At the commencement of this period the student was in his second year of undergraduate study. Five examples date from that year of study. Eleven examples are from his final year 4 of study, and all the others from year 3. He was 20 years old in year 2. Physical type is ectomorphic (of very slim build) and height of 1.7 metres. The earlier examples from 2009 do not have EGG, but signals from 2010 and 2011 have clear EGG.

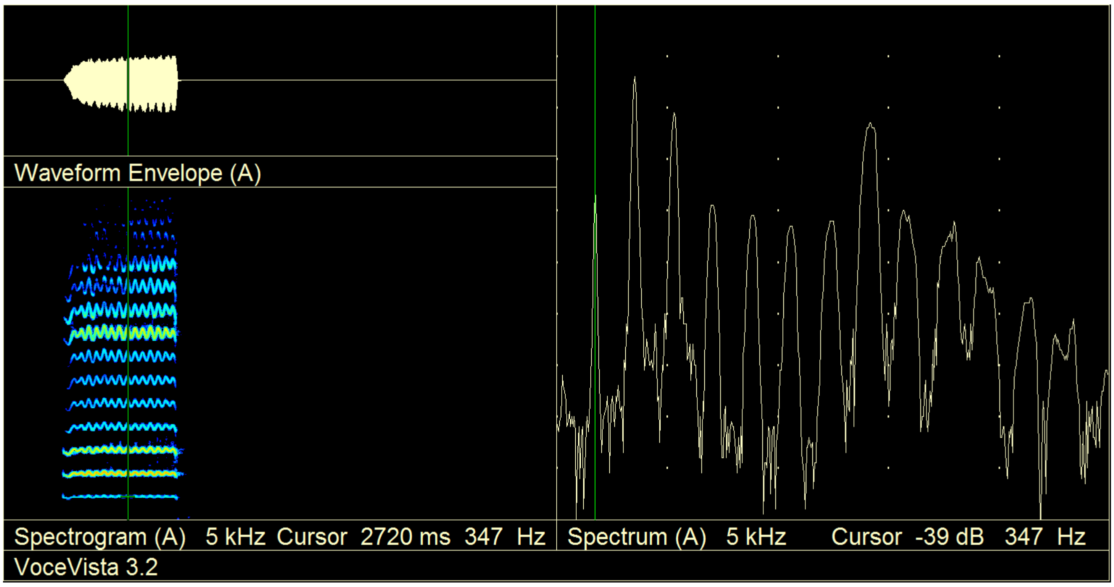
Of the small number of examples from 2009, the scale from D4-A4 illustrates the salient characteristics. Figure 6.6.1 shows how H2 starts to strengthen from E4 onwards reaching maximum strength during G4. It remains the strongest partial during the uppermost note of A4. Though H3 is strengthened at that pitch also, it is at no point as strong as H2.

Figure 6.6.1: Student tenor (5) D4 – A4 scale [a]



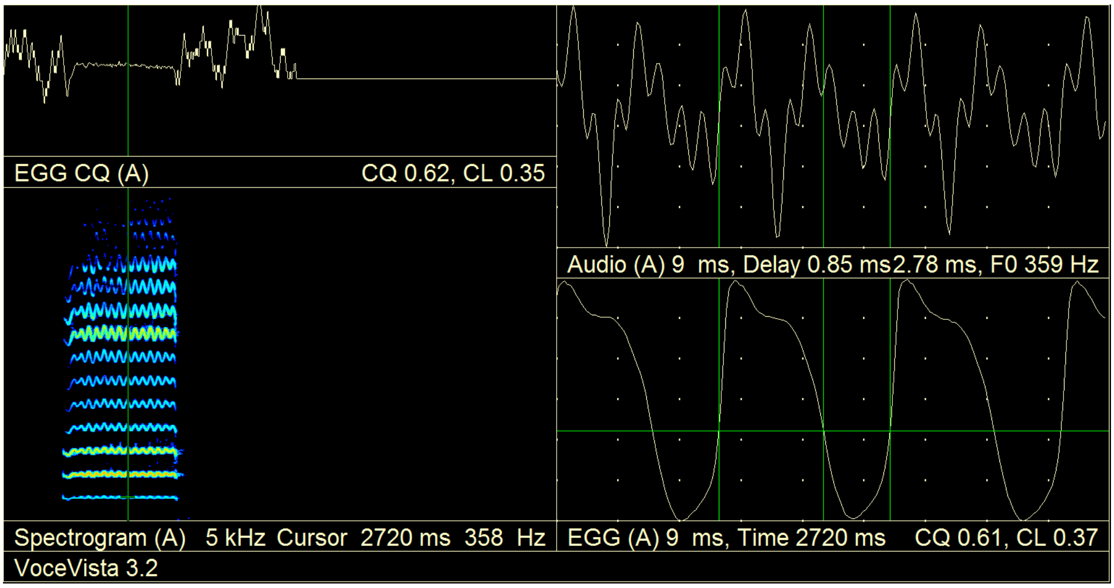
A year later an example of a sustained F4 shows strong f_1/H2 interaction and also stronger activity in the SF zone where H8 is 20 dB stronger than H1 (when at its maximum) and only 6 dB less than H2. (Figure 6.6.2.) The vowel, though clearly an [a], sounds influenced by [ɔ] but this is relatively slight.

Figure 6.6.2: Student tenor (5) sustained F4 [a]



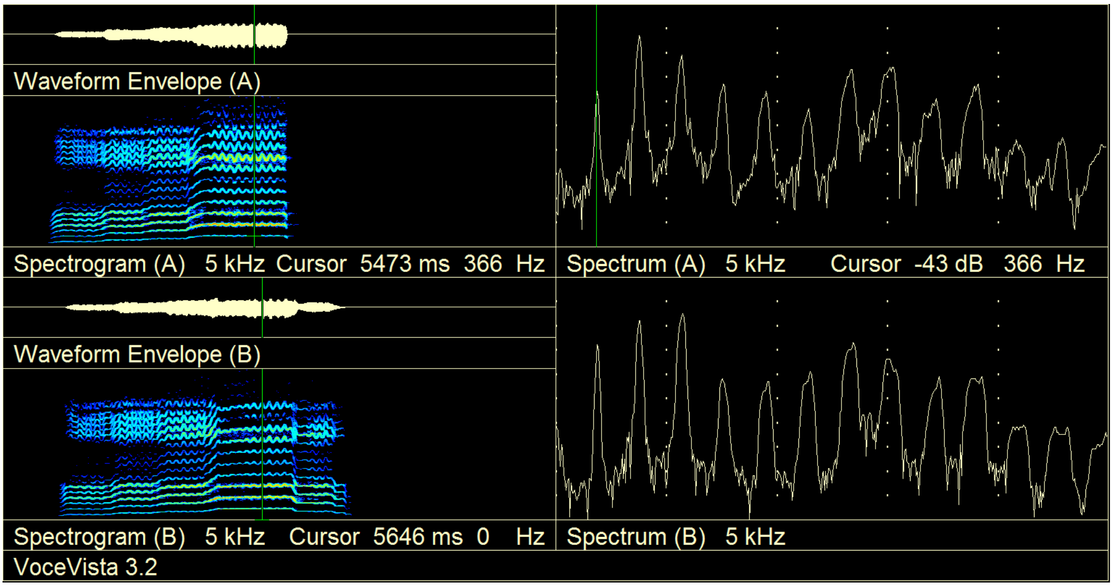
The view of this with EGG (Figure 6.6.3) displays a contact quotient of c.61%.

Figure 6.6.3: Student tenor (5) sustained F4 with EGG



There are two examples of arpeggios sung from F#3-F#4 from 2010. These are quite striking since they show an ability to sing the F#4 with f_1/H2 tuning as seen in the upper part of the screen in Figure 6.6.4, and in the lower part of the screen the same arpeggio is sung with the vowel very slightly adjusted towards [ʌ] which enables the alternative f_2/H3 resonance tuning. This would suggest that this note is pivotal in the student's voice and may be regarded as his secondo passaggio. There are many examples in the professional repertoire where such a skill has artistic applications[29].

Figure 6.6.4: Student tenor (5) F#3 – F#4 arpeggio [a]



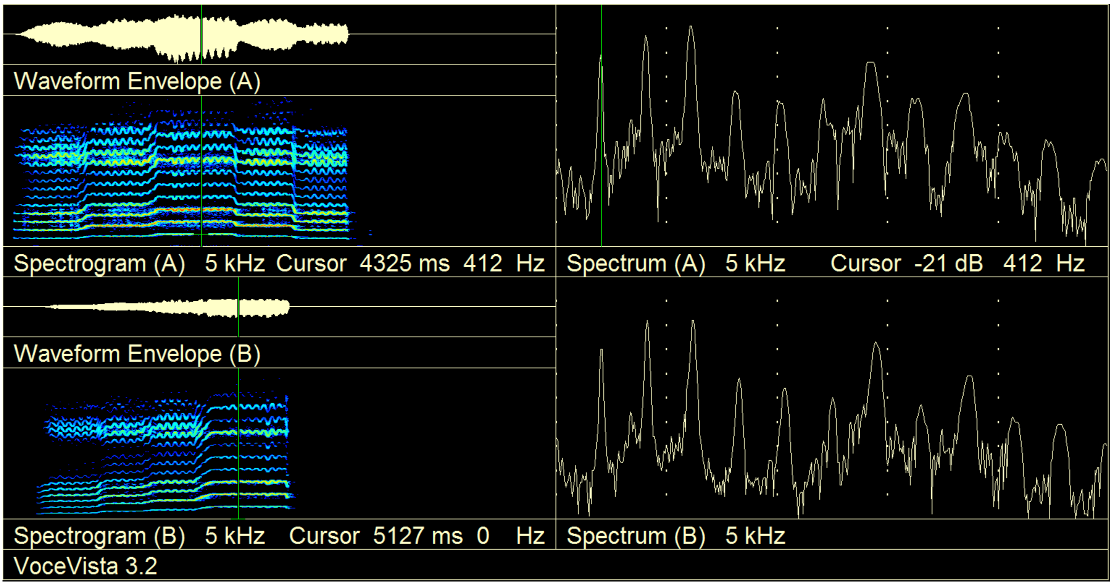
When the contact quotient was measured for each of these the f_1/H2 version was c.62% and the f_2/H3 version a little lower at 58%. The initial closure rate appeared to be the same at c.0.15 ms. (Not shown.)

In January of 2010 this student shows (in an arpeggio of Ab3-Ab4) almost equal strengths of H2 and H3 at the top of the arpeggio. (Seen in the lower part of the screen in Figure 6.6.5.) However a year later in February 2011 the same pitch is sung with secure and even resonance distribution showing f_2/H3 tuning. The vowel remains convincingly an [a] though very marginally influenced by [ʌ]. (Upper part of screen, Figure 6.6.5.) The change from f_1/H2 resonance on the F4

[29] Don Ottavio's aria 'Il mio tesoro' (Don Giovanni) and Nemorino's 'Una furtiva lagrima' (L'elisir d'amore) are two obvious examples.

in the (upper screen) to f_2/H3 resonance for the uppermost note seems decisive and the pitches are evenly sustained.

Figure 6.6.5: Student tenor (5) Ab3 – Ab4 triad [a]



Multiple recorded examples from these two periods covering this same area of pitch demonstrate that this is a consistent element. Both versions of the Ab4 have fast initial closure rates. The version which has f_2/H3 tuning is remarkably rapid at c.0.12 ms (Figure 6.6.6), but the earlier example with f_1/H2 tuning is also rapid at c.0.13 ms (Figure 6.6.7).

Figure 6.6.6: Student tenor (5) Ab4 [a] f_2/H3 tuning

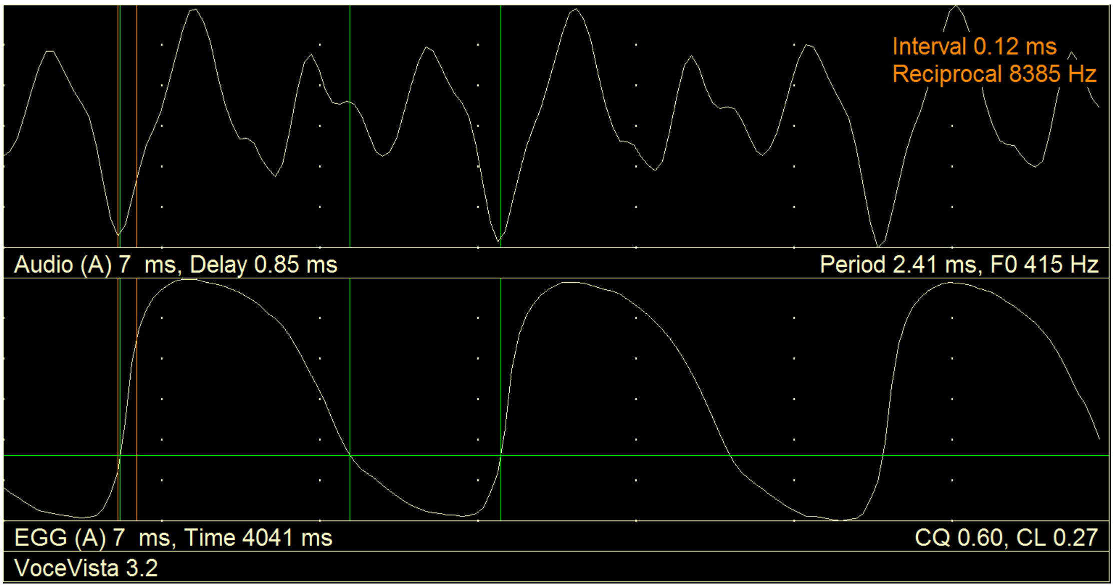
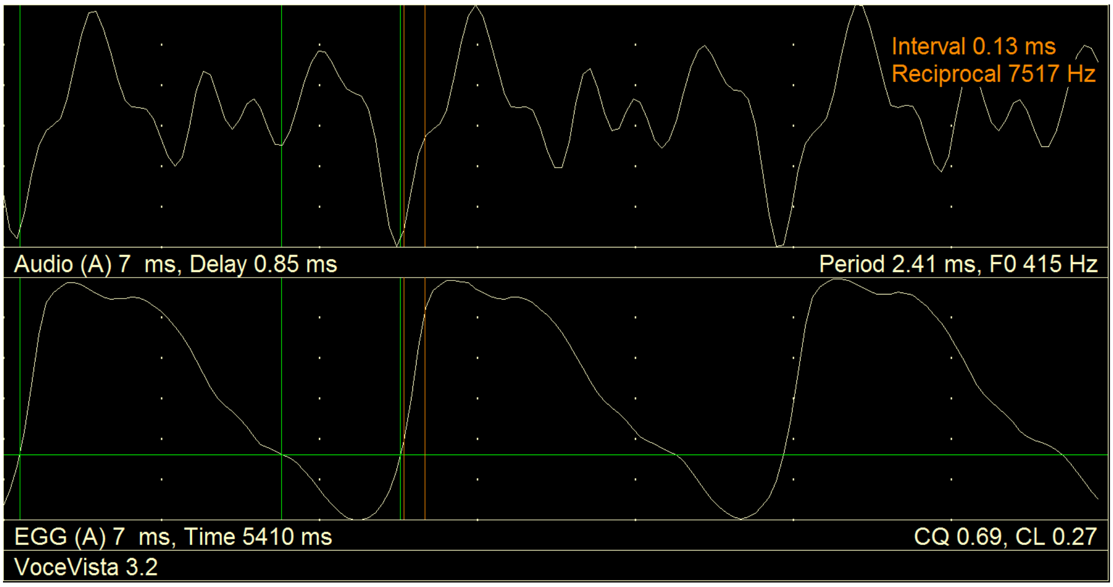
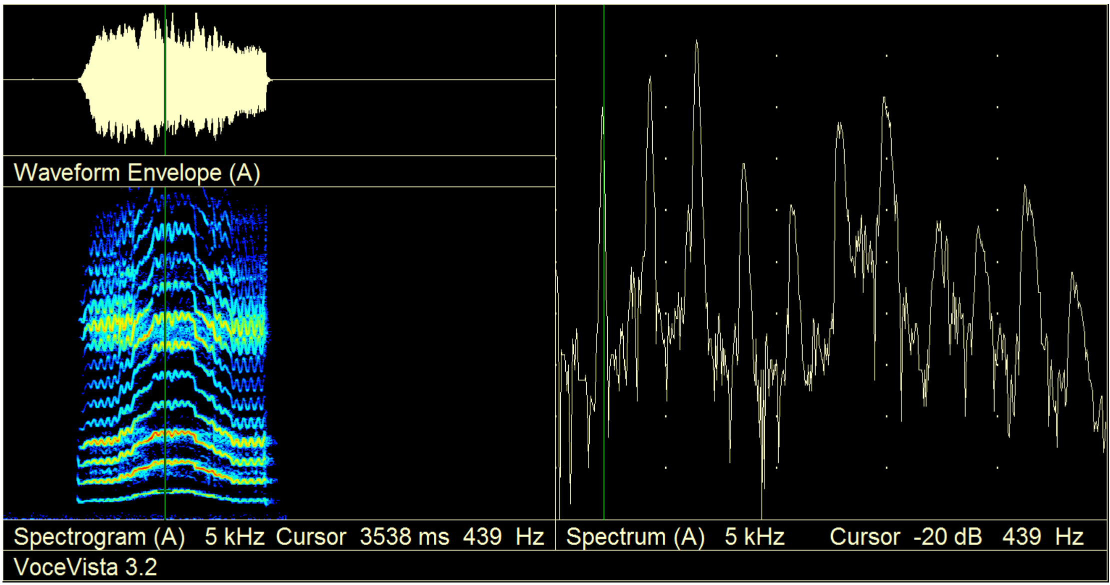


Figure 6.6.7: Student tenor (5) Ab4 [a] f_1/H2 tuning



In a scale from D4-A4 recorded in May 2010 (ie four months after the example in which Ab4 had almost equal H2 and H3) the student shows a clear change from f_1/H2 resonance to f_2/H3 for the uppermost note A4, making the change at G4 (the G4 apparently has f_1/H2 tuning but the note is very rapidly sung and uses a glissando to approach A4 during which the resonance tuning changes). (Figure 6.6.8.)

Figure 6.6.8: Student tenor (5) D4 – A4 scale [a]

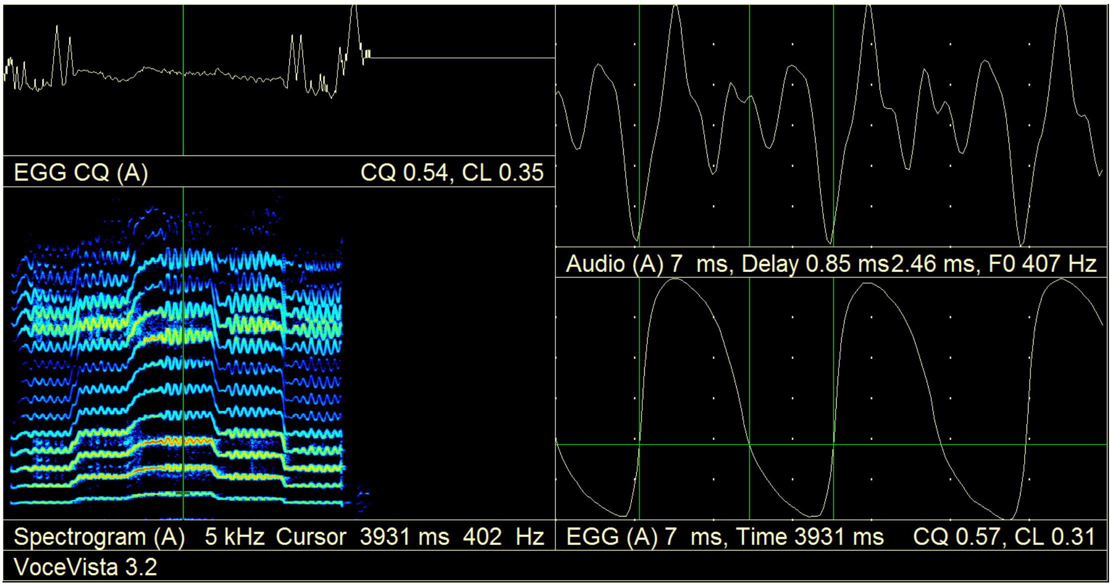


There is a second example recorded one day later which shows the same characteristics (that is to say, this was not an isolated example).

Examining further examples from 2011, it seems that this student had acquired the ability to always use f_2/H3 tuning in singing in his upper range with the pitches of F#4 and G4 marking his secondo passaggio.

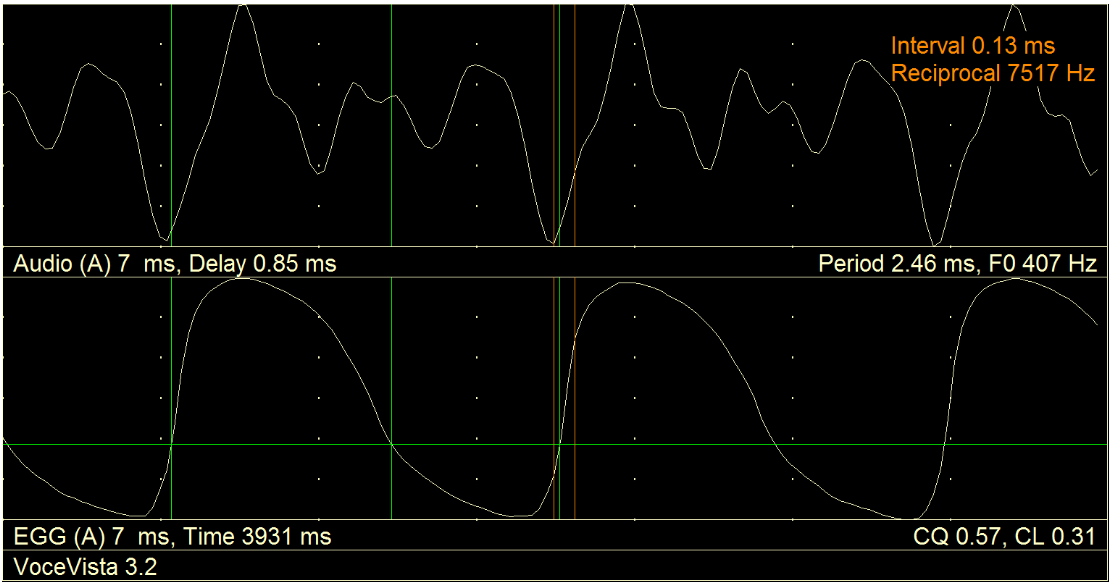
The triad on C4 recorded in 2011 shows again a clear switch from f_1/H2 tuning to f_2/H3 tuning on the G4 of the triad. This can be seen clearly in the colour spectrogram, and the emphasis on H3 is clear in the three columns in the audio signal. (Figure 6.6.9.)

Figure 6.6.9: Student tenor (5) C4 – G4 triad [a]



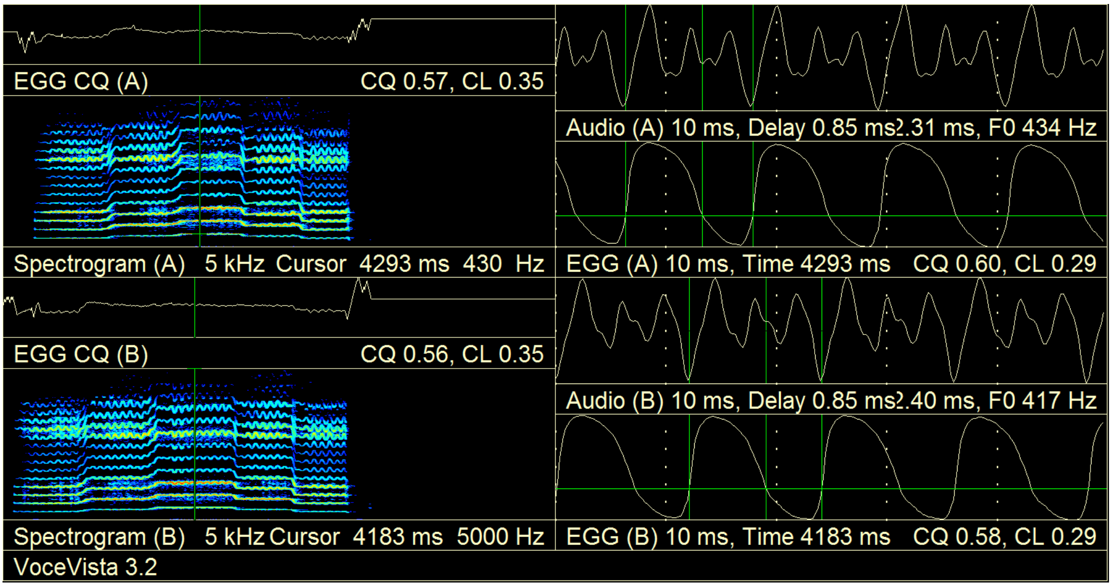
The EGG indicates a contact quotient of c.57% (shown above) and as in other examples from this singer the initial closure rate appears to be fast at 0.13 ms as seen in Figure 6.6.10.

Figure 6.6.10: Student tenor (5) G4 with EGG showing initial closure rate



In the next triads of Db4-Ab4 and D4-A4 (recorded in 201l) both show the change from f_1/H2 in the passaggio to f_2/H3 for the uppermost notes. In Figure 6.6.11 the lower screen shows Ab4 and the upper screen A4. In these examples the [a] vowel is only very subtly modified, if at all, towards [ʌ]. The respective EGG signals show the contact quotients as 58% for Ab4 and 60% for A4. When the initial contact rise slope was measured in each example the rate was fast at c.0.12ms (not shown).

Figure 6.6.11: Student tenor (5) Db4 – Ab4 triad [a] lower screen, D4 – A4 triad [a] upper screen



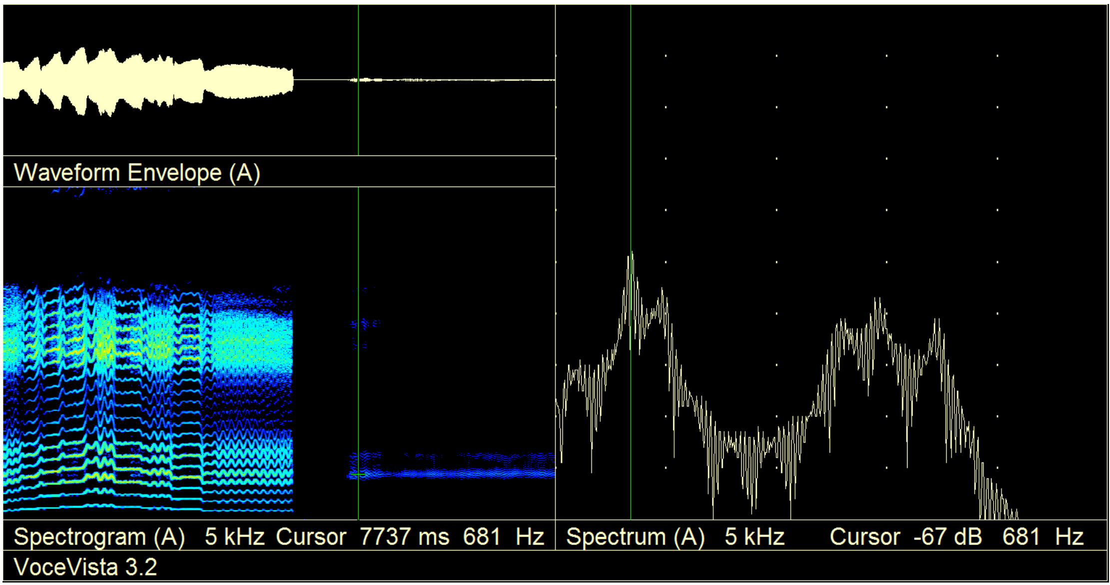
Reviewing the files from this student it appears that he learned to evade maintaining f_1/H2 tuning when ascending beyond the top of his passaggio. The fact that he was able to offer two different resonance tunings of F#4 indicate that it is unlikely that the resonance he uses in upper voice simply occurs by accident. The audible manipulation of vowels, at times a little crude, also point to an awareness of the importance of vowels in resonance tuning.

6.7. Student 6

This singer had three years training at the time of recording examples. There are 24 recordings, all of which were made at the same session thereby providing a ‘snapshot’ picture of some characteristics of his singing in the passaggio at that stage. He was 21 years of age, 1.8 metres tall and of ectomorphic body type.

This student was comfortable using vocal fry, and his first example was a scale from D3-A3 on [a] which was followed without a break in the recording with fry of the same vowel as used in the sung scale. The vowel used when using fry phonation seems reasonably close to the sung vowel. This tessitura was chosen in discussion with the student as he identified it as the most comfortable part of his vocal range. (Figure 6.7.1)

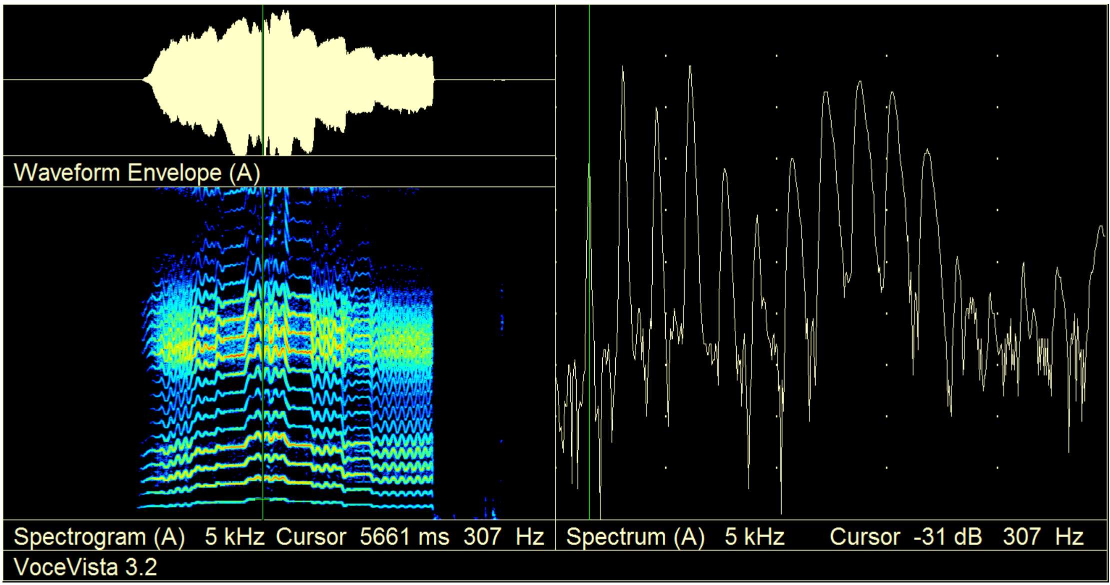
Figure 6.7.1: Student baritone (6) D3 – A3 scale [a], with vocal fry of vowel



This shows f_1 at c.680 Hz and f_2 at c.970 Hz. The value for f_2 was surprisingly low. In order to ensure that this was not an unrepresentative result, a second recording was made of the same material and this confirmed the same formant values. It is worth considering the implications for this singer's passaggio of these formant values (if the vowel is consistently maintained) as they create a challenge in terms of resonance management. The low value of f_2 will be too low to assist with H3 on the pitches of E4 (H3 = 990 Hz) and F4 (H3 = 1047 Hz) which is where many baritones make a change in timbre denoting secondo passaggio. On an Eb4 it is likely that the much stronger f_1 would influence H2 (at 622 Hz) and that the weaker f_2 would be too high to engage strongly with H3 for Eb4 (H3 = 935 Hz). This is a good example of why the [a] vowel with its high value for f_1 is a challenge for male singers in the passaggio zone. As it happens, this singer has very strong activity in the SF zone which often is considerably more than 10 dB stronger than H1[30].

Figure 6.7.2 shows a scale from Ab3-Eb4. The vowel has modified a little towards [ʌ], though subtly so. This has the effect of raising f_2 and dropping f_1. The voice is richly resonant with both H2 and H4 strong, but almost equally strong are H8, H9 and H10 in the SF zone. All of these partials are in the region of 18-20 dB stronger than H1.

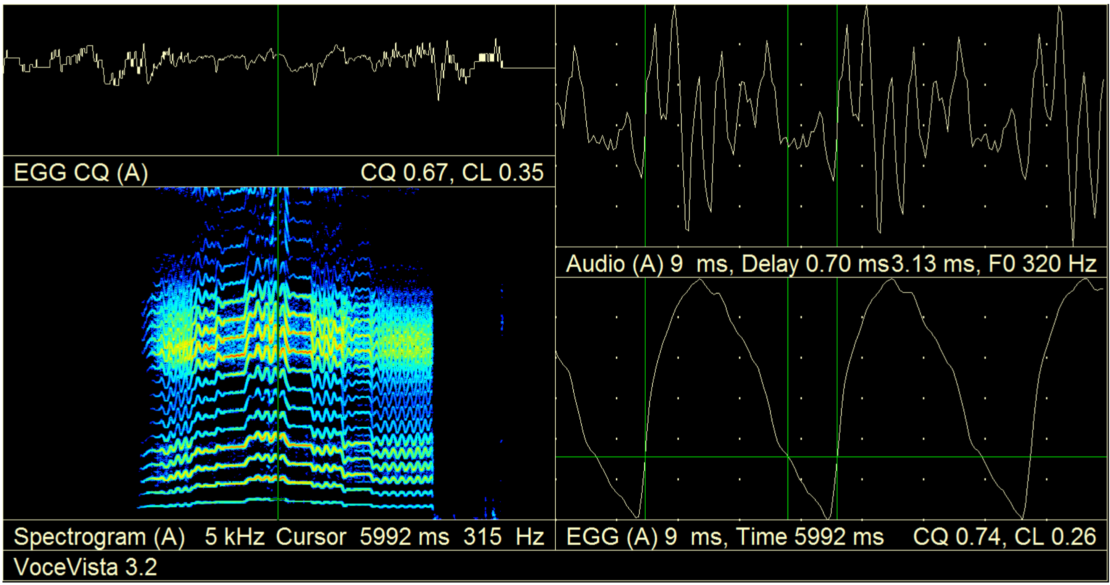
Figure 6.7.2: Student baritone (6) Ab3 – Eb4 scale [a]



The EGG signal suggests that this is a voice which uses a high contact quotient, here shown as 74%. (Figure 6.7.3.)

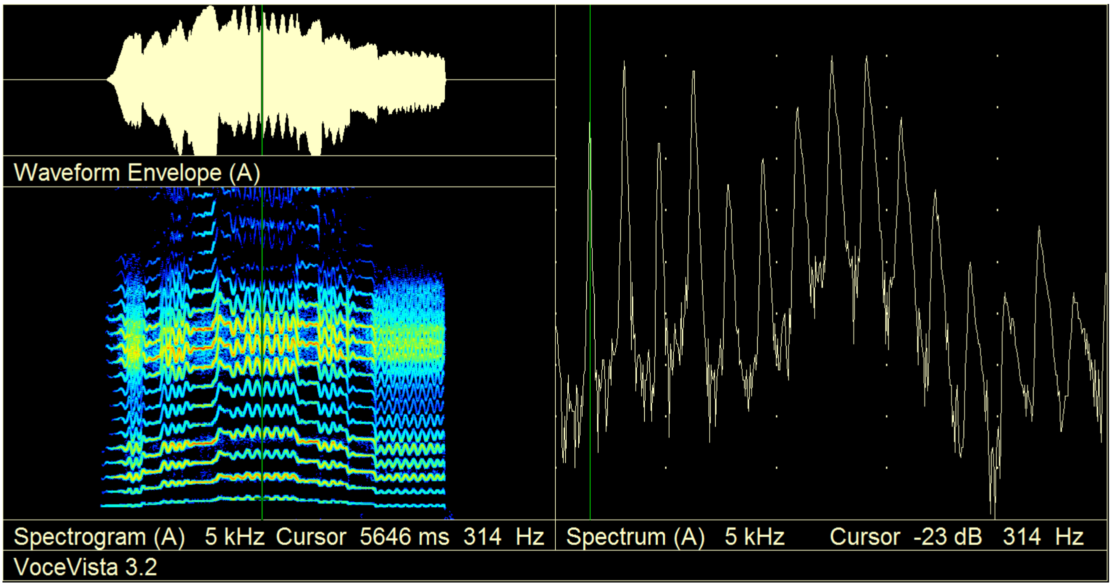
[30] This is one of the already known strategies for avoiding H2 dominated 'yell' quality in the upper voice.

Figure 6.7.3: Student baritone (6) Ab3 – Eb4 scale [a] with EGG at Eb4



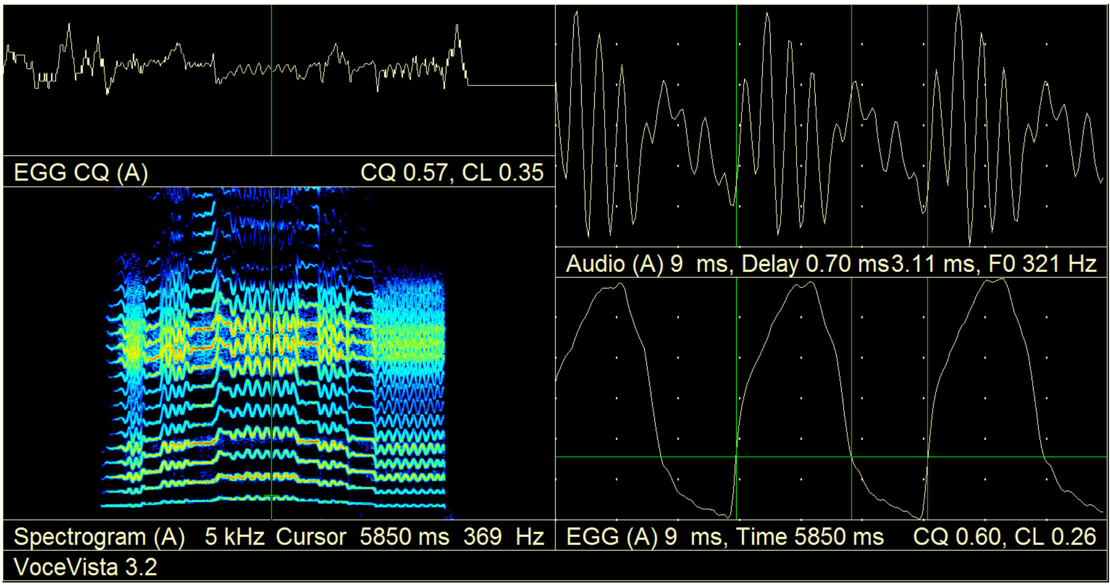
In the next scale of A3-E4 wherever the spectrograms are examined (both colour and power spectrum) the strength of partials in the SF zone either exceeds the strength of partials in the lower area where formant positions are more influenced by vowels (ie partials from H2-H4) or equals those lower partials. On attaining the E4 the student makes a change in the vowel, towards [ʌ] and [ʊ] combined, which is a quite obvious change from the preceding [a] (presumably thinking that this is necessary to assist in avoiding an overly 'blatant' or 'open' E4). This is partly successful in that neither the strong H2 or H4 exceed the strength of H8 and H9 in the SF zone, but it may not have been necessary to make the adjustment, since his voice has these strong high partials. Looking at the strength of H4 during the sung scale it appears that f_2 must be hovering around/above 1200 Hz since up to that pitch H4 is very much strengthened but when H4 moves higher anywhere it rapidly loses strength. It is likely that the vowel modification employed drops f_2 somewhat and it can be seen that whilst singing the E4, the partial H4 strengthens only on the lowest moment of the vibrato pitch cycle when entering the pitch c.1250 Hz. (Figure 6.7.4 shows a moment of the sustained E4 on the underside of vibrato pitch.) The effect of the sudden loss of strength of H4 (as seen on the preceding pitch of D4) makes a very noticeable change of timbre on E4.

Figure 6.7.4: Student baritone (6) A3 – E4 scale [a]



The EGG signal shows a contact quotient level of considerably lower than on the previous Eb4, now at 60%. (Figure 6.7.5.)

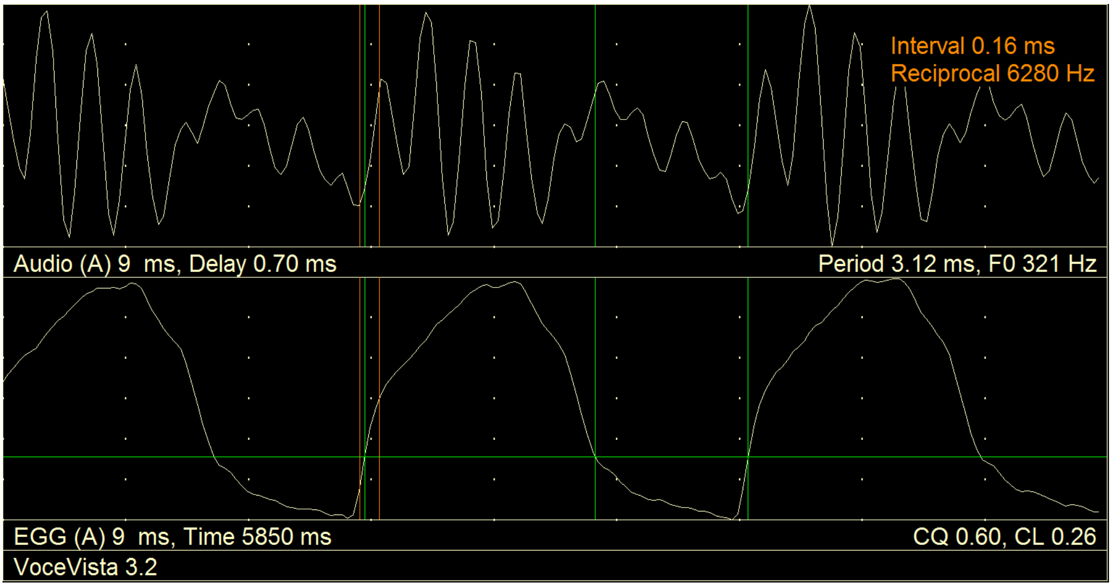
Figure 6.7.5: Student baritone (6) A3 – E4 scale [a] with EGG at E4



It can be seen that there is a rapid initial closure, followed by a gentler slope.

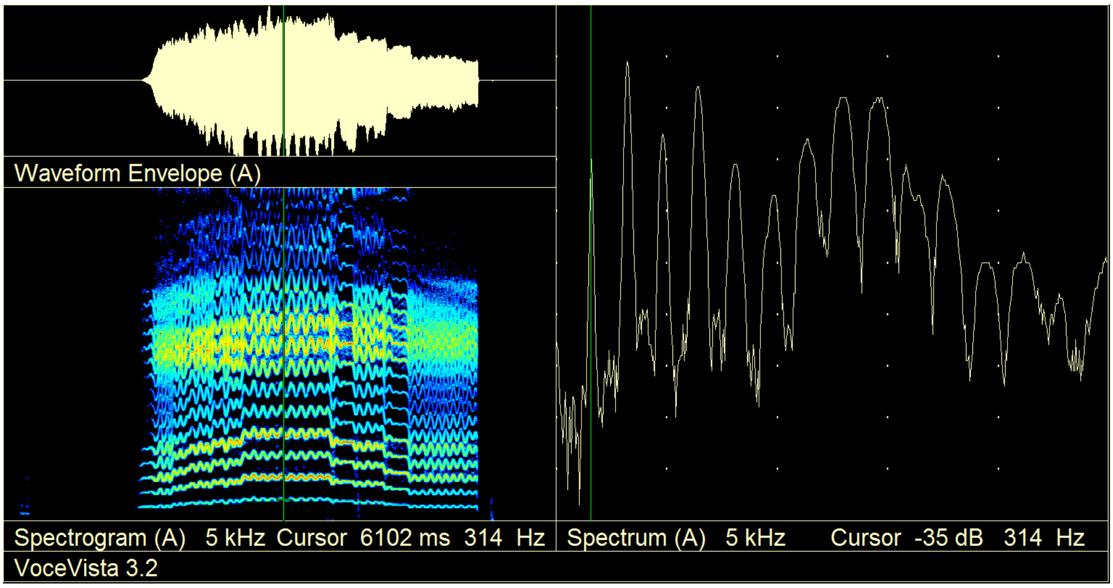
Measurement of the initial slope rise shows a rate of 0.16 ms as shown (orange cursors) in Figure 6.7.6.

Figure 6.7.6: Student baritone (6) A3 – E4 scale [a] with EGG at E4 showing initial closure rate



The student offered the same scale in what he considered to be a more 'open' quality at the top, without the noticeable vowel change previously used. When observed with power spectrum averaging set to 300 ms this showed H2 (c.24 dB stronger than H1) as the strongest partial but also with H4 as only a few dB less than H2. H8 and H9 remain strong but are now exceeded by the lower partials identified. Figure 6.7.7 gives a reasonably accurate view of what is presented when the averaging is set as described. (This requires some judgement since it is not possible in *VoceVista* to retain a power spectrum view with averaging set to anything more than 200 ms.)

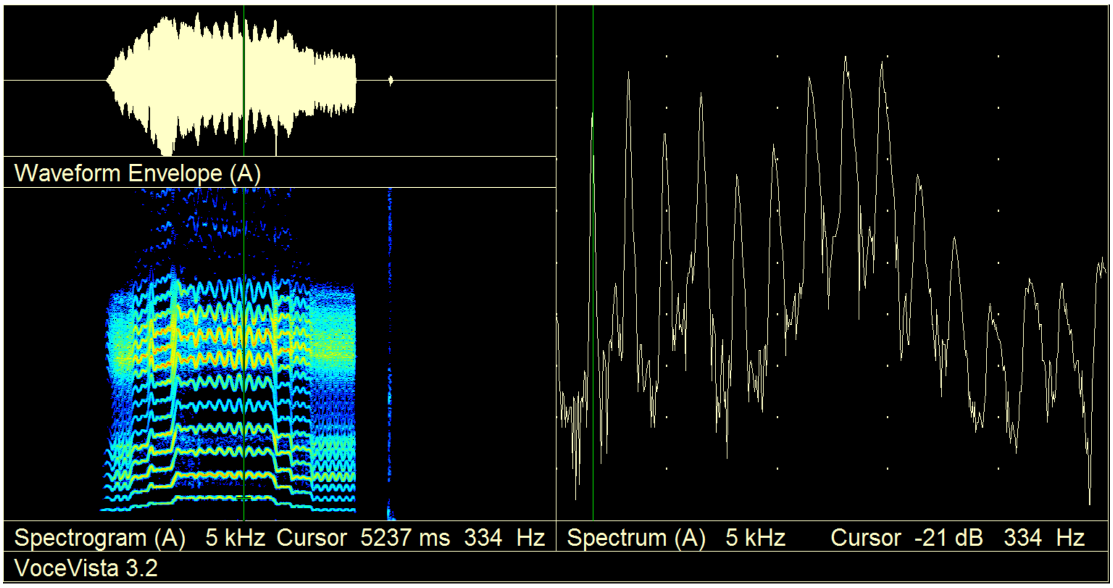
Figure 6.7.7: Student baritone (6) A3 – E4 scale [a] second version



The EGG signal showed that contact quotient was higher in this example at 68%. (Not shown.)

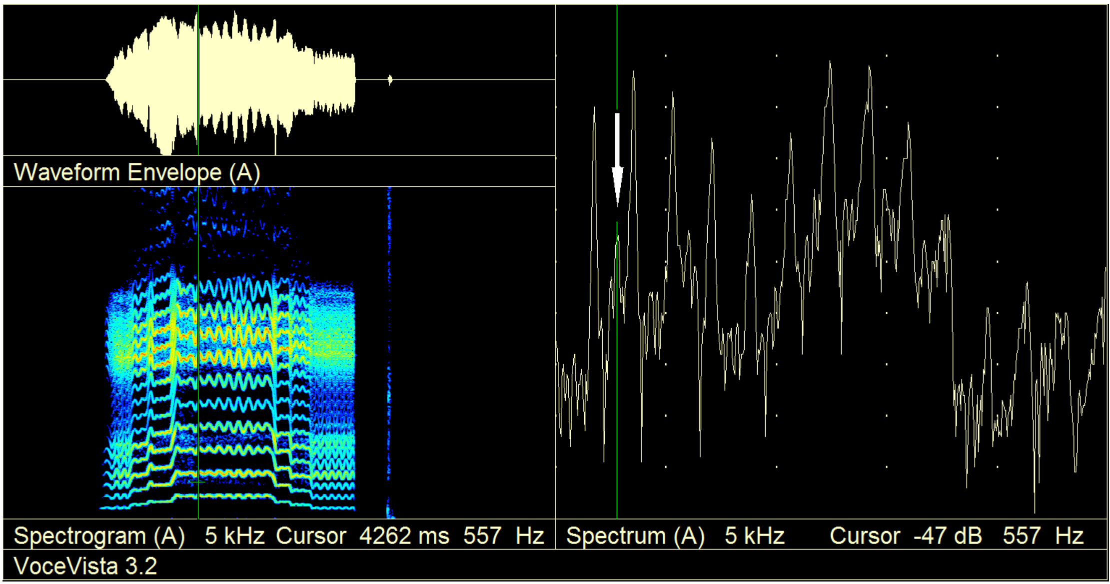
The student made three attempts at singing F4, though he preferred to do so in arpeggios rather than scales. He declared himself dissatisfied with each of these. Figure 6.7.8 shows the balance of partials on the F4.

Figure 6.7.8: Student baritone (6) F3 – F4 arpeggio [a]



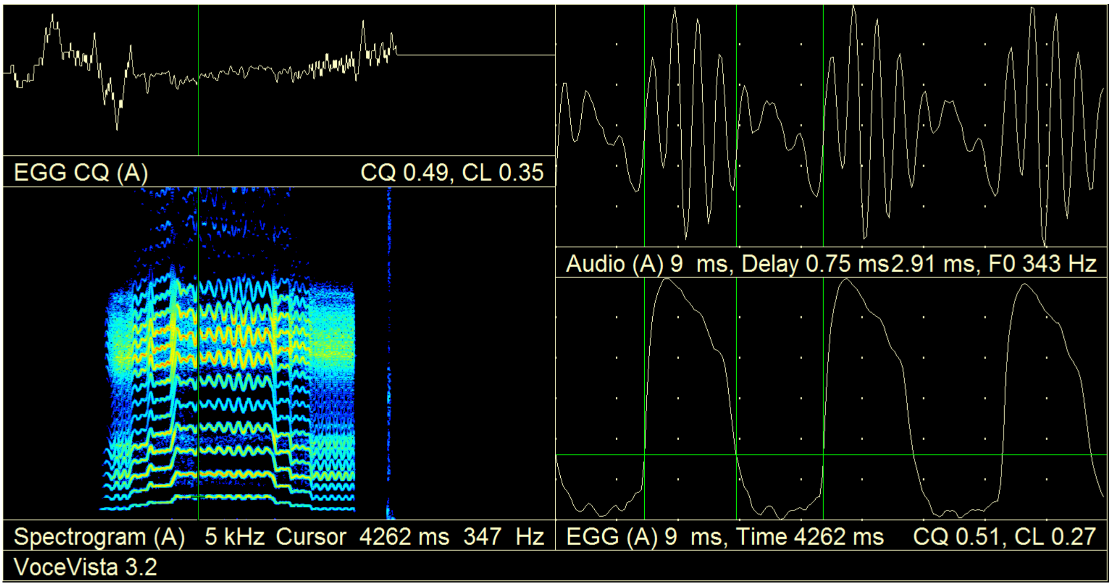
There is a marked change in vowel quality from [a] to [ʌ] at the F4 which is likely to cause f_1 to drop and f_2 to rise. The blue shadow visible in the colour spectrogram between H3 and H4 may be due to the presence of f_2 indicating that it is around 1245 Hz. Also there are similar signs (below H2) that f_1 is now c.560 Hz, indicated here in Figure 6.7.9 with the white arrow.

Figure 6.7.9: Student baritone (6) F3 – F4 arpeggio [a] showing possible position of f_1 (white arrow)



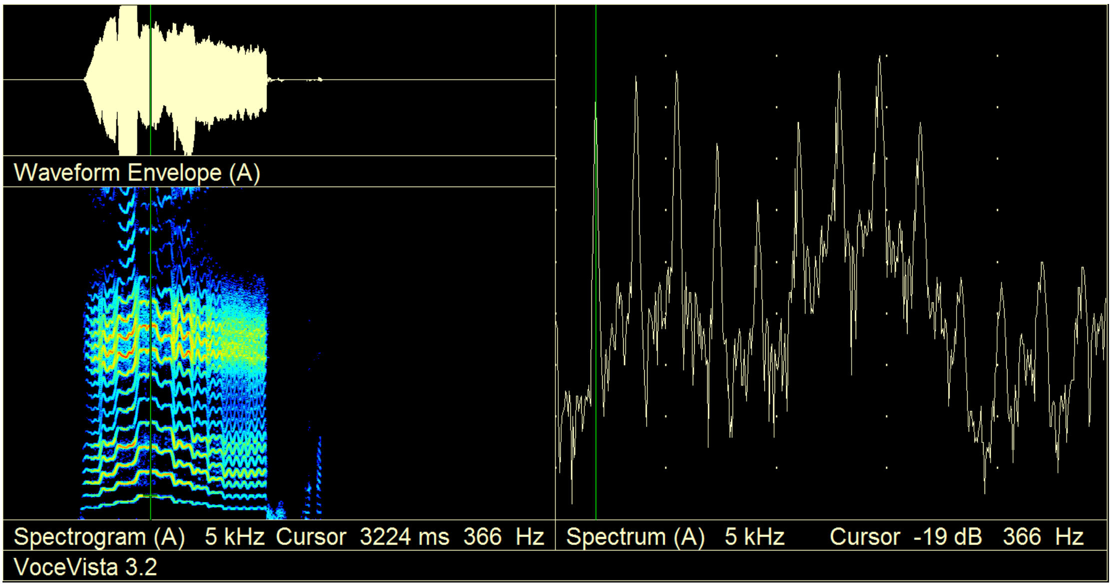
H3 strengthens visibly at the tip of the upper part of the vibrato pitch cycle, also indicating that f_2 is somewhere above, but seemingly too far away to be very influential. The conclusion would be that the vowel is over-modified and needed a more subtle change to allow f_2 to be better engaged with H3. Nevertheless, as both H7 and H8 exceed all other partials the timbre of the pitch is not ‘open’ nor lacking in upper, ‘bright’ resonance. The EGG signal shows a more modest contact quotient for this F4 of 51%. (Figure 6.7.10.)

Figure 6.7.10: Student baritone (6) F3 – F4 arpeggio [a] EGG at F4



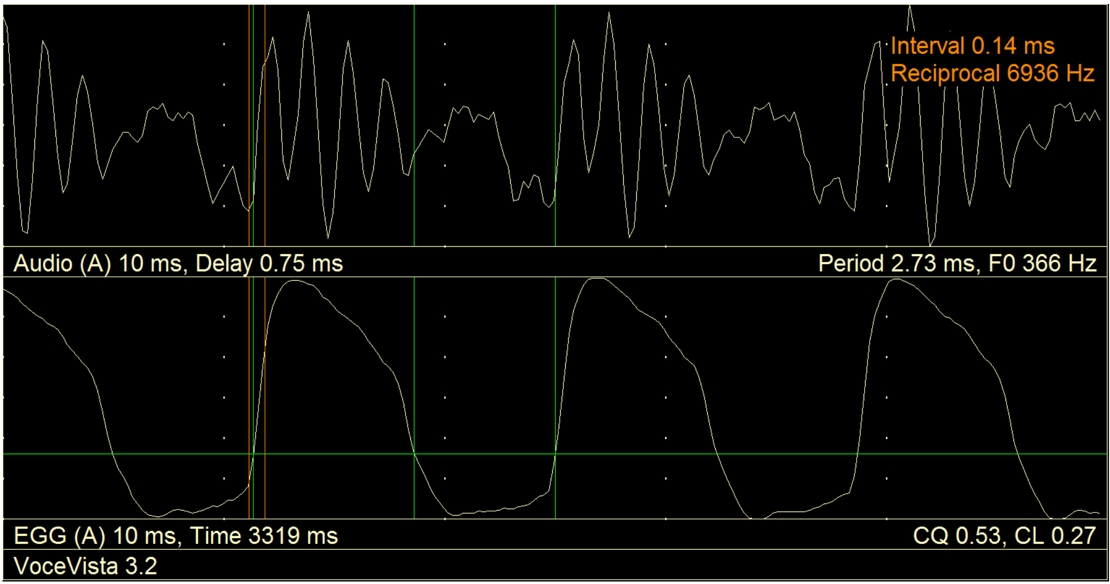
A semitone higher, singing an arpeggio from F#3-F#4 with less obvious (but noticeable) vowel modification allows H3 to engage a little more with f_2 and shows as fractionally ahead of H2 on the uppermost note (both when viewed with the detail of power spectrum averaging set to 100 ms and when set to 300 ms). (Figure 6.7.11)

Figure 6.7.11: Student baritone (6) F#3 – F#4 arpeggio [a]



As in the last example the contact quotient was modest at 52%. H7 and H8 in the SF zone both exceed the partials which are more susceptible to vowel changes moving formants around. The initial contact closure is very fast at 0.14 ms. (Figure 6.7.12 with orange cursors showing measurement.)

Figure 6.7.12: Student baritone (6) F#4 [a] EGG and showing initial closure rate



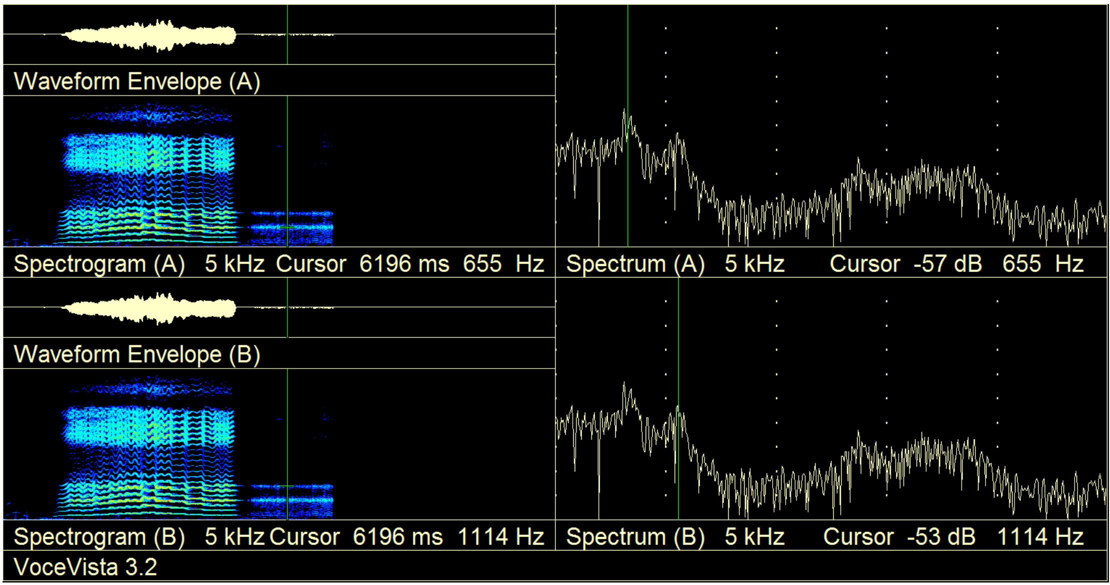
This student appears to be using some vowel modifications in seeking to achieve his upper passaggio and beyond. Some of these vowel modifications are too exaggerated for the task which they are intended to achieve, but his strong activity in the SF zone means that the upper voice is nevertheless resonating successfully, achieving a sense of 'brightness' and helping to avoid sounding as though 'yelling' (Bozeman, 2013, p.36).

6.8. Student 7

This baritone student was in his final year of undergraduate study at a major UK Conservatoire having had three years and four months of tuition prior to the recording of the first examples. There are 26 files of recorded examples which were made in two sessions, four months apart. At 22 years of age he was 1.7 metres tall with slim ectomorphic build. Most of the recordings have clear EGG signals.

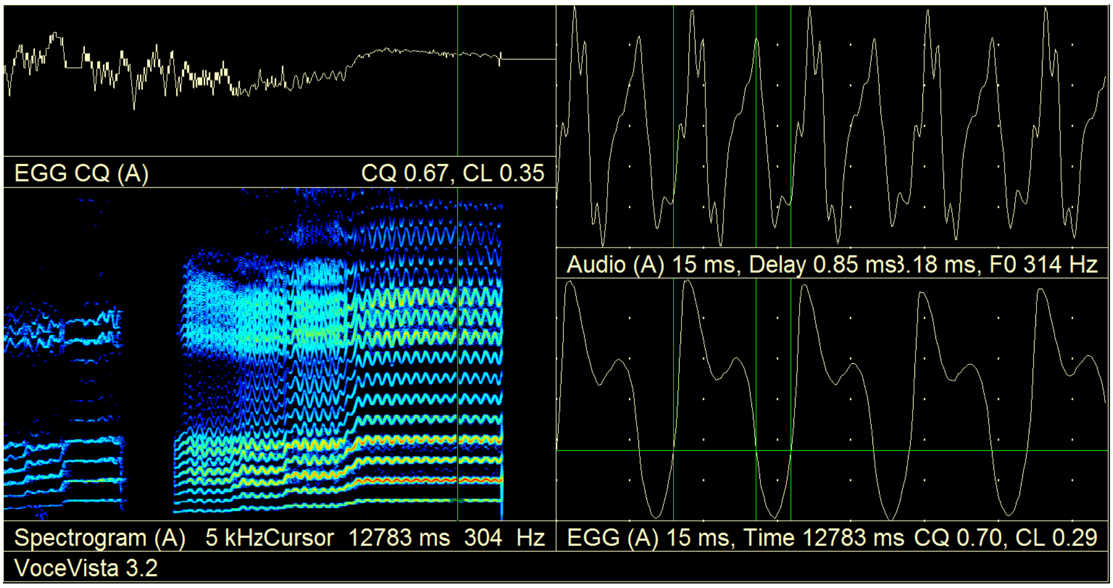
This student was completely comfortable producing vocal fry and therefore was able to give a clear example using a brief middle voice scale on [a] from Db3-Ab3, followed by fry phonation maintaining the same vowel. Figure 6.8.1 shows f_1 as c.655 Hz in the upper screen (green cursor) and f_2 as c.1114 Hz as shown in the lower part of the screen (green cursor).

Figure 6.8.1: Student baritone (7) Db3 – Ab3 scale [a] with vocal fry



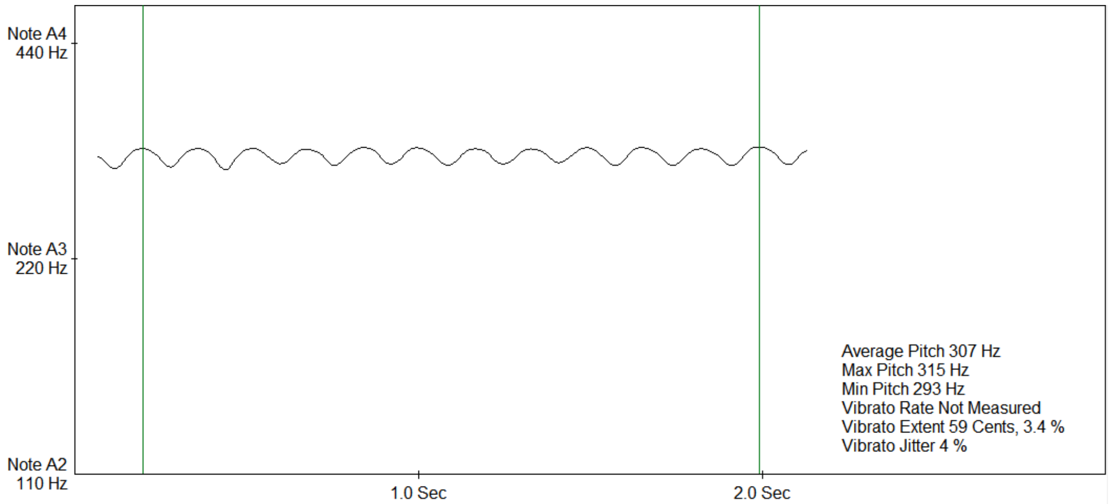
In an arpeggio from D3-D4 it is immediately obvious that H2 of D4 is very much strengthened by f_1. As the vibrato pitch cycle reaches its lowest point H4 is strengthened by f_2. These can be seen, together with the EGG indication of contact quotient of c.70% in Figure 6.8.2. The acoustic signal shows very strongly the clarity with which H2 dominates the partials in displaying two clear columns.

Figure 6.8.2: Student baritone (7) D3 –D4 arpeggio [a] with EGG at D4



Analysis of the vibrato shows that the average mean pitch of the fundamental is slightly sharp at 307 Hz instead of the target of 294 Hz for a concert pitch (A4 = 440 Hz) of D4. This is shown in Figure 6.8.3 (calculated using the same sustained D4 as shown in Figure 6.8.2).

Figure 6.8.3: Student baritone (7) detail of vibrato on D4

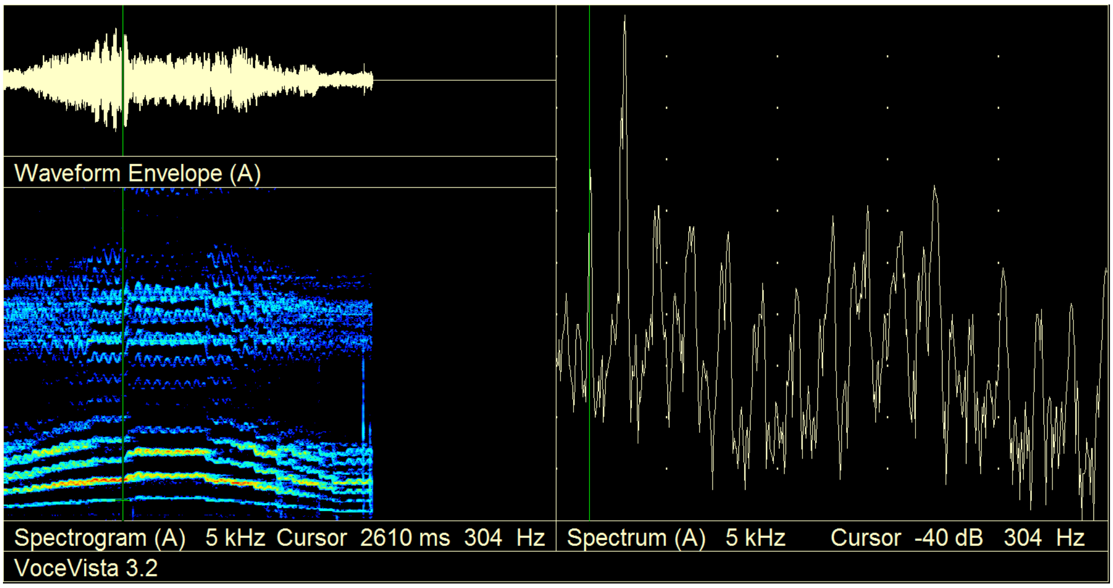


This means that H2 is centred at 614 Hz bringing it to a close relationship with f_1 as established in the example with vocal fry. H4 (with H1 as 307 Hz) would be 1228 Hz which explains why it strengthens when the vibrato cycle drops to its lowest point, if f_2 is as established in fry.

The question may arise that if f_1 and H2 are already firmly linked on D4, where does this engagement commence and therefore where is the point of primo passaggio? Since an arpeggio has a leap of a perfect fourth in approaching the top note, this is less easily identified than in scale passages which offer conjunct pitch changes rather than leaps. However other arpeggios offer the pivotal notes of C4 and C#4 as the fifth in arpeggios of F major and F# major respectively. These show that when H1 reaches c.280 Hz causing H2 therefore to be c.560 Hz, H2 starts to strengthen significantly. Therefore though there is some spiking of the upper part of vibrato pitch cycle of C4, really the pivotal note is C#4 at 277 Hz.

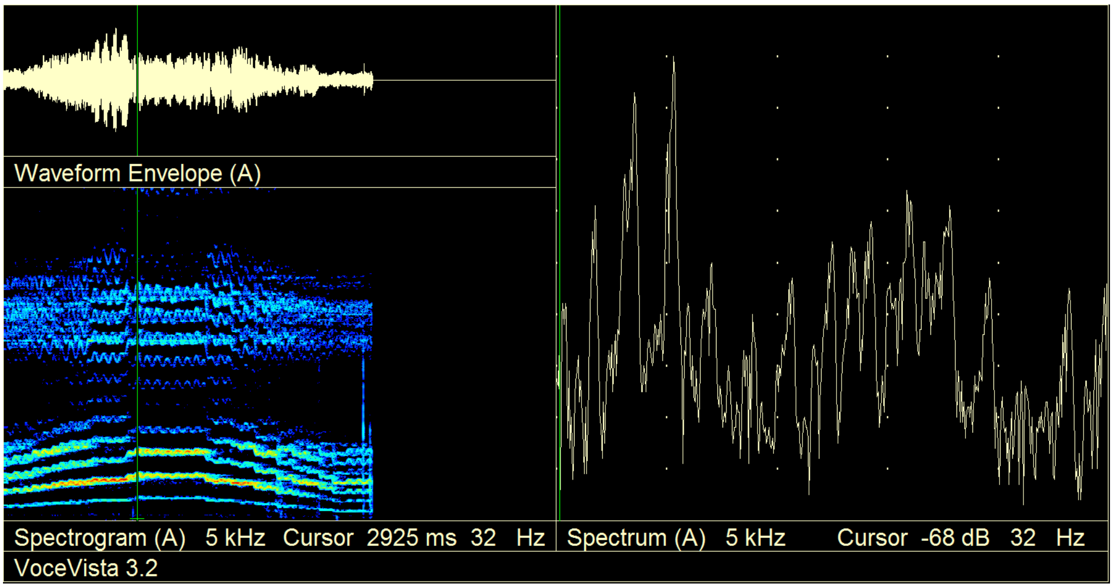
There is one example recorded from the student made two years earlier than the others, (without EGG) singing a complete major scale to a ninth, from D3-E4. Though the target vowel was [a] the sung vowel is audibly nearer to [o] or [ɔ]. However the registrational result is interesting. By B3 H2 shows a marked spike in strength, presumably at least partly because of the proximity of f_1 which has been lowered somewhat by the rounded vowel. Ascending in the scale there is a very high level reached in the strength of H2 compared to H1. Figure 6.8.4 shows H2 on the upper side of the vibrato pitch of D4 at 622 Hz. H2 is 30 dB stronger than H1, even if only momentarily so. This strength recurs on the same pitch when the scale is descending.

Figure 6.8.4: Student baritone (7) D3 – E4 scale [a]



Only 300 milliseconds after the last moment at which H2 is clearly the dominant harmonic, H3 becomes the strongest. Though H2 remains quite strong in relation to H1, H3 is stronger than H2 by 21 dB at the maximal differential between the two. (Figure 6.8.5.)

Figure 6.8.5: Student baritone (7) D3 – E4 scale [a] showing strength of H3 on E4

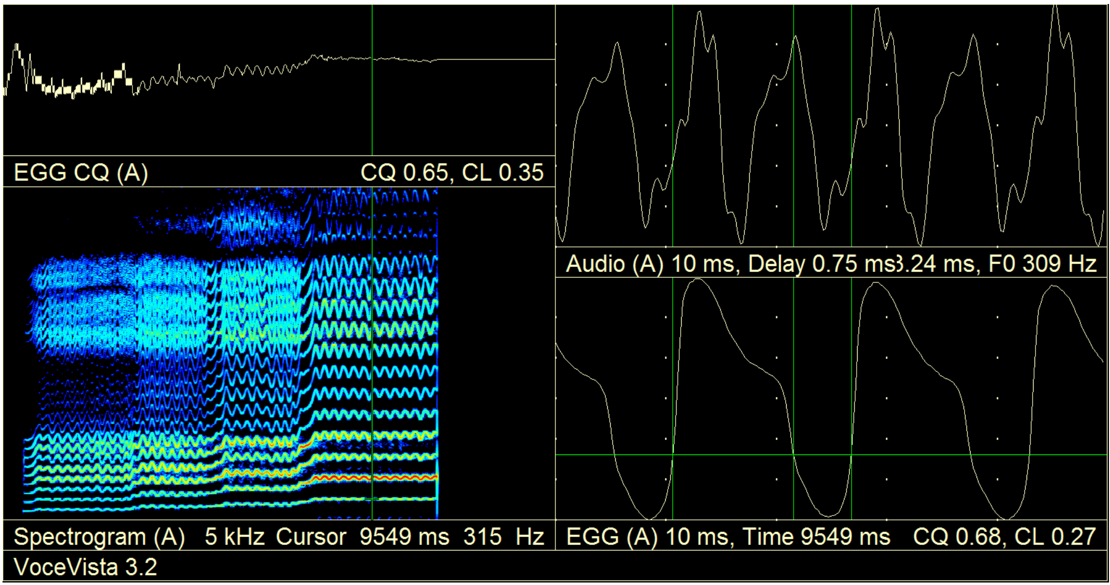


This is on the upper side of the vibrato pitch fluctuation on the sustained E4. (The upper pitch within the vibrato cycle reaches F4 at 346 Hz.) Setting the Power

Spectrum average to 300 ms shows H3 clearly stronger than H2 throughout the duration of the E4. This is sufficient for the human ear to perceive this note as ‘turned’ or ‘not open’, or ‘in head’ or any other of the terms which are used to denote the change in timbre when males ascend into the upper range.

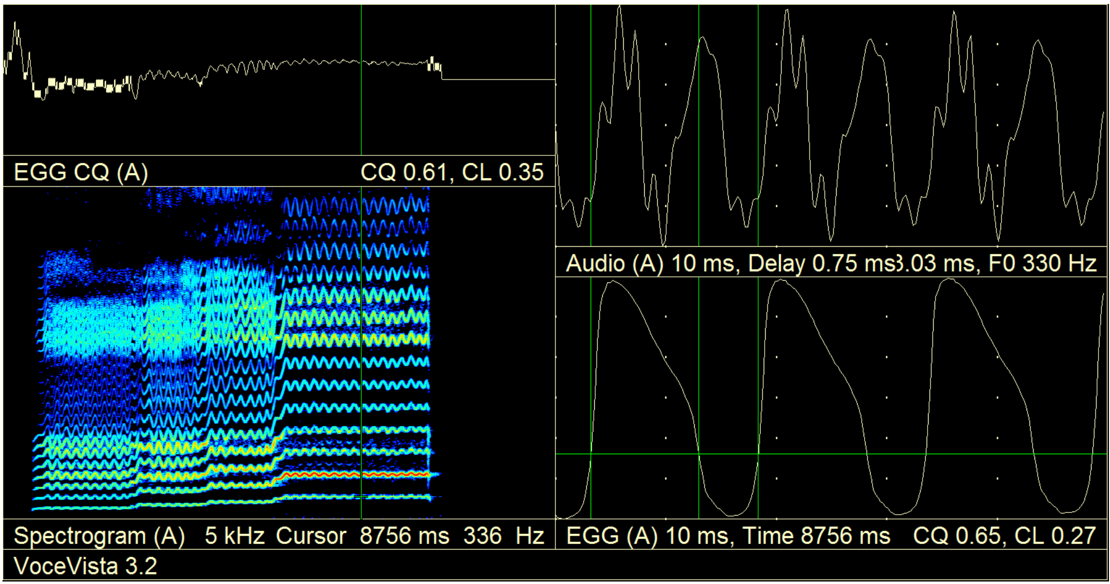
The next example arpeggio recorded at the time of the bulk of the examples is Eb3-Eb4. At the top of the arpeggio H2 is clearly very dominant as can be seen in the audio signal as well as in the colour spectrogram of Figure 6.8.6. (The power spectrum is not shown in this view, but H2 is 22 dB stronger than H1 at this moment with very little variation from that strength within the vibrato pitch cycle). The contact quotient is shown as 68%.

Figure 6.8.6: Student baritone (7) Eb3 – Eb4 arpeggio [a]



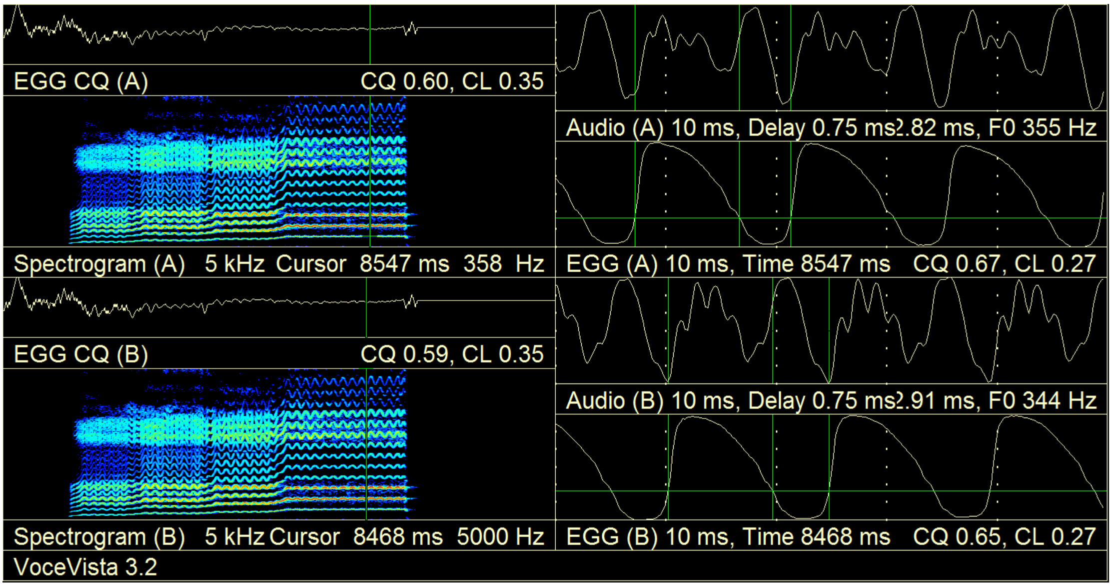
The next arpeggio a semitone higher from E3-E4 looks very similar with H2 strongly and evenly spiked by the engagement with f_1 (Figure 6.8.7). In both of these examples it can be surmised that f_2 is lurking around 1110 Hz from the behaviour of a variety of other harmonics and from the blue ‘shadow’ traces visible in the colour spectrogram. H4 and H5 during the sung Bb4 in Figure 6.8.6 show the effect of f_2, as does H4 during the sung B3 in Figure 6.8.7. The contact quotient remains quite consistent with the previous arpeggio at 65%.

Figure 6.8.7: Student baritone (7) E3 – E4 arpeggio [a]



The ascent to F4 in the next arpeggio (F3-F4) shows f_2 as influencing H4 on the C4 and subsequently engaging with the uppermost pitch in the vibrato cycle of H3 on F4. Viewing the example with the power spectrum set to 300 ms for averaging makes it clear that H2 is still the strongest partial during the uppermost note, but H3 is sufficiently strengthened to stop this being comparable to the timbre of the very 'open' D4, Eb4 and E4 of the preceding examples. The upper extent of vibrato reaches 363Hz on H1 therefore resulting in the tip of H3 attaining 1089 Hz. This makes sense in relation to the identified location of f_2 using vocal fry as shown in Figure 6.8.1 above. The two views shown in Figure 6.8.8 show the moments when vibrato pitch is lowest in the lower window and when vibrato pitch reaches its peak 79 ms seconds later, in the upper window.

Figure 6.8.8: Student baritone (7) F3 – F4 arpeggio [a]



When singing the uppermost note in the arpeggio F#3-F#4 it is clear that with H1 now at c.370 Hz (the pitch centre of the sung note is slightly sharp at 378 Hz) there is a strong influence from f_2 on H3. The vowel on the F#4 leans towards [ʌ] slightly lowering f_1 and simultaneously raising f_2. Vibrato on this pitch causes H3 to sweep from a lowest pitch of 1083 Hz to highest point of 1152 Hz[31]. Figure 6.8.9 shows H3 as the strongest partial (confirmed by viewing the example with power spectrum averaging setting set to 300 ms). This indicates a change of timbre in the voice which would be regarded as the quality of 'head voice'.

[31] The pitch of H3 is sweeping directly through the area earlier identified as f_2. f_2 is now probably a little higher as a result of subtle vowel alteration.

Figure 6.8.9: Student baritone (7) F#3 – F#4 arpeggio [a]

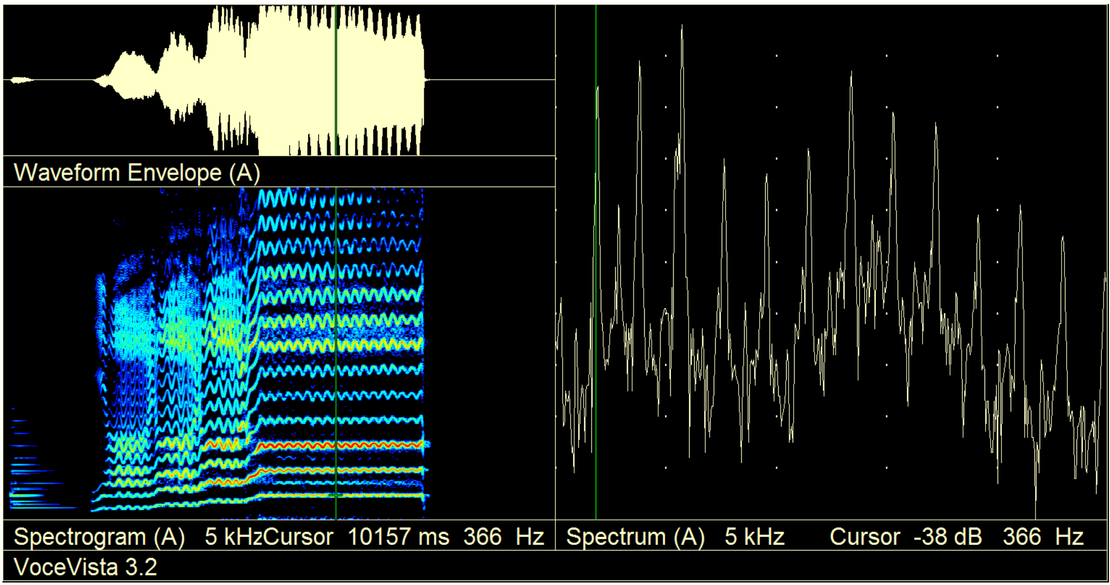
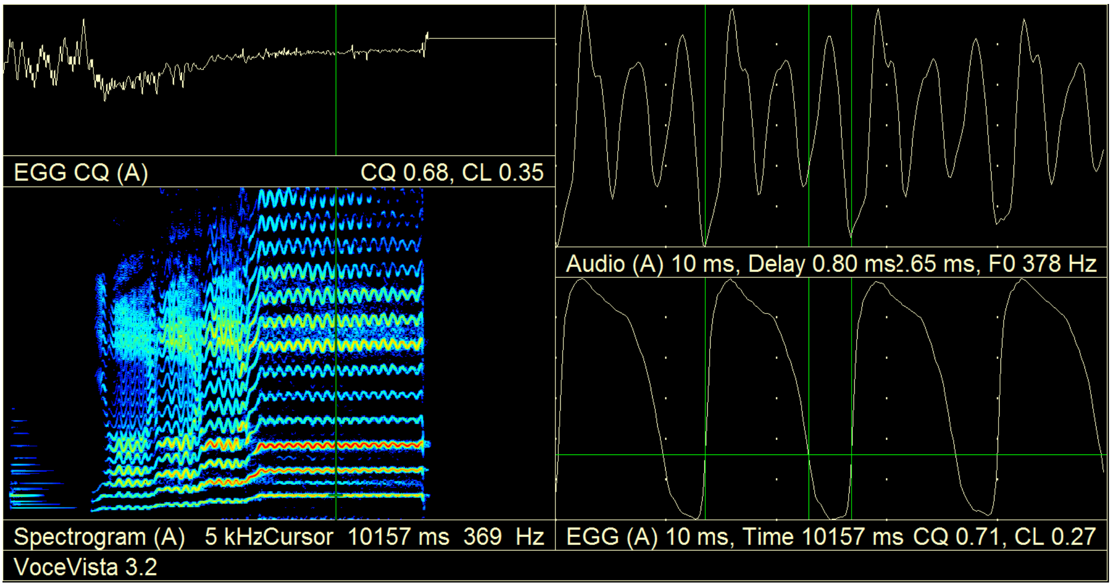


Figure 6.8.10 shows the same moment but now with the EGG view, which indicates the clarity of the H3 in the three columns shown in the audio signal. The EGG indicates a slight rise in contact quotient to 71%.

Figure 6.8.10: Student baritone (7) F#3 – F#4 arpeggio [a] with EGG at F#4



This student also offered an arpeggio from G3-G4 which shows very similar qualities to those seen in the arpeggio of F#3-F#4. On the high G4 the strongest partial is clearly H3. H2 has weakened further compared with the same moment in the arpeggio of F#3-F#4. (Not illustrated.)

In summary this student shows a migration through his passaggio which seems to be achieved with only minimal vowel modification. The strong engagement between f_1 and H2 turns on higher pitches to f_2 influencing H3. This is a clear demonstration of passaggio events.

6.9. Student 8

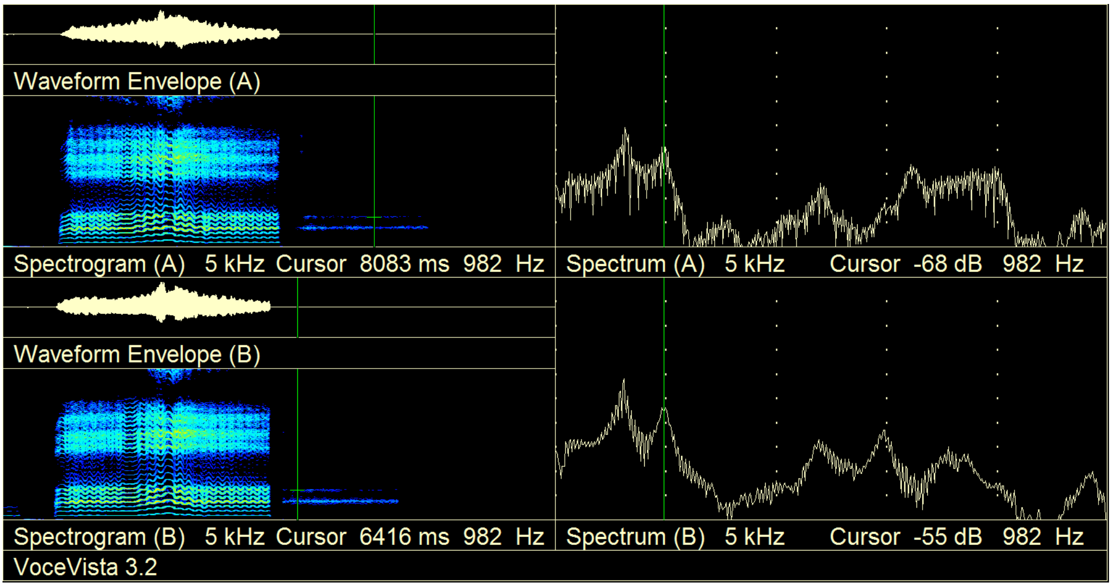
This student was 24 years old at the time of making the recordings of examples, having had three and a half years of tuition in a major UK Conservatoire. He is 1.8 metres tall and his body type is mesomorphic. There are 21 examples, all of which were recorded at one session.

There are two examples of the student singing a scale from D3-A3 on [a] followed immediately by vocal fry aiming to sustain the same vowel as used during the scale. The student was asked to do this twice to try and lessen the possibility that one lone example would be unrepresentative[32].

f_1 is located c.635 Hz and f_2 c.985. The green cursor shows the close alignment of the position of f_2 in the two different recordings. (Figure 6.9.1.)

[32] It is acknowledged that simply performing the same scale and fry twice does not guarantee accuracy but it can be seen in Fig 1 that the results are extremely consistent.

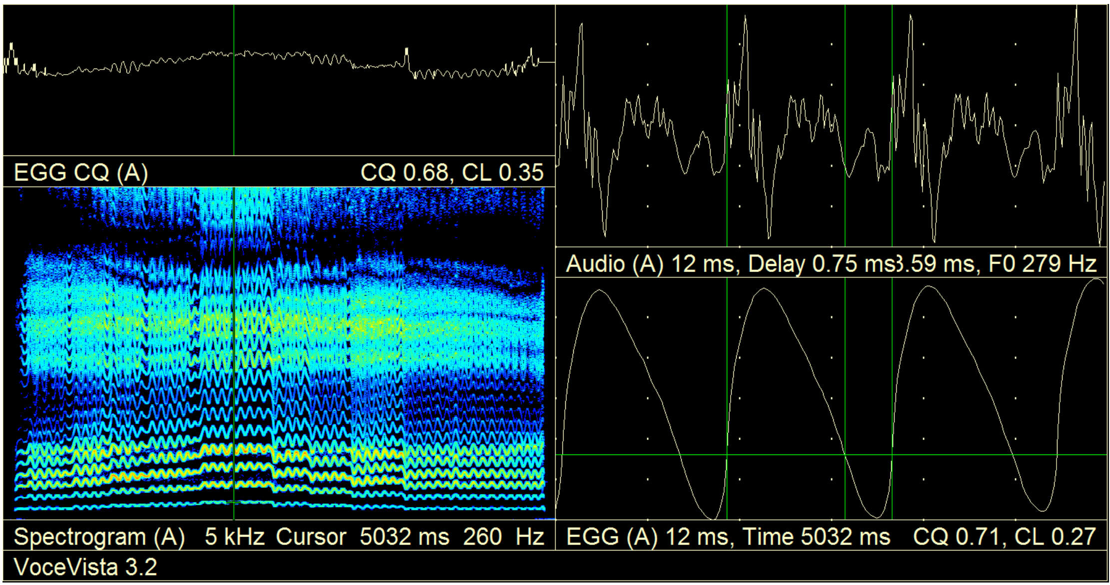
Figure 6.9.1: Student bass (8) D3 – A3 scale [a] with vocal fry



These are quite low formant values, but this student has the timbre and range of a genuine bass, (which has become a somewhat rare voice type). The perceived 'dark' quality of timbre may well be at least partly attributable to the formant values exhibited.

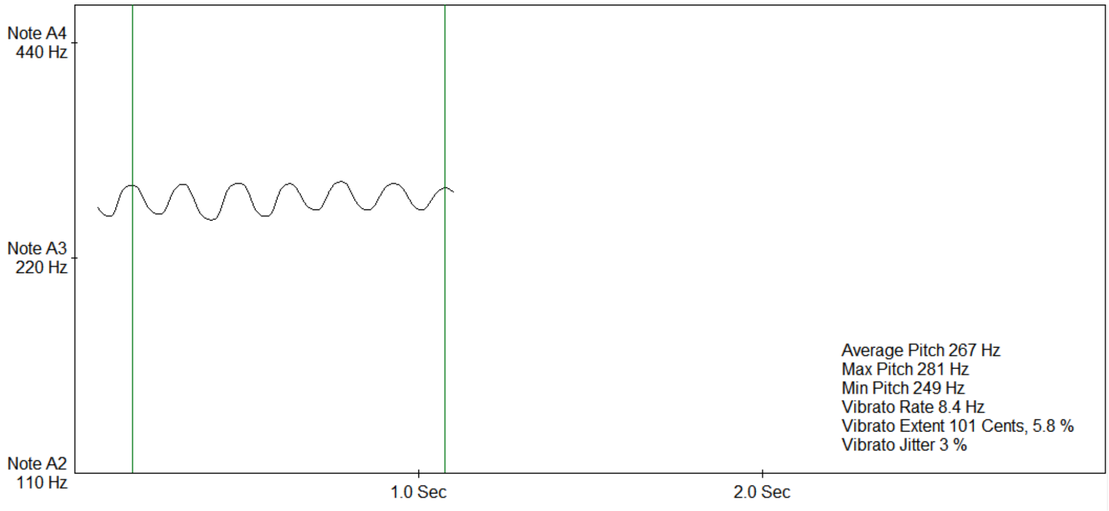
Ascending in a scale from F3-C4, H2 only begins to show signs of being influenced by f_1 on the upper side of vibrato pitch cycle on the C4 denoting the entry into the passaggio. H4 is actually more prominent and it is noticeable that at this pitch the EGG shows a high contact quotient of 71%. (Figure 6.9.2.)

Figure 6.9.2: Student bass (8) F3 – C4 scale [a] with EGG at C4



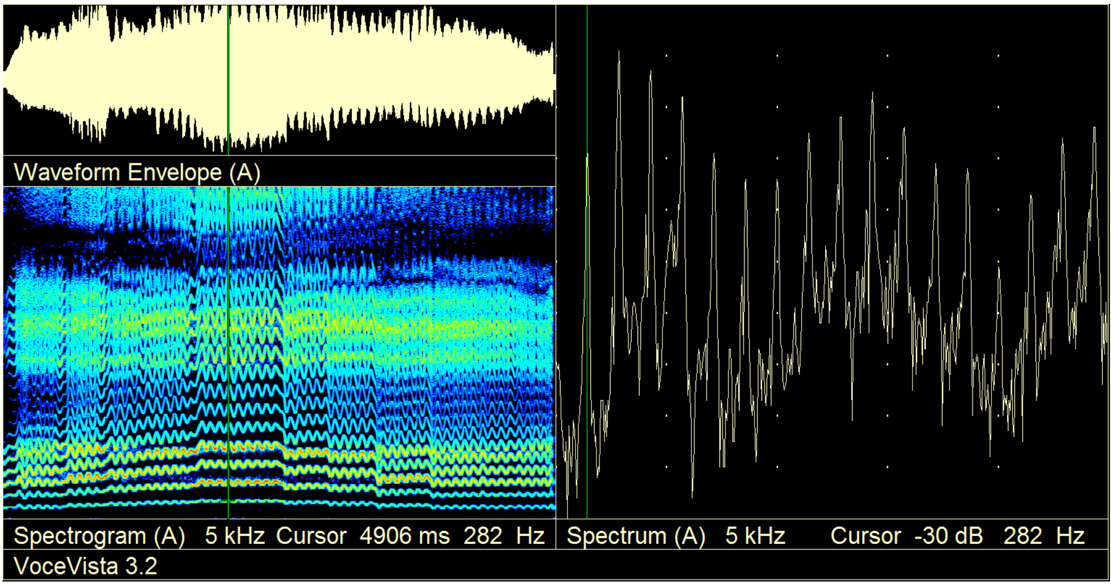
Closer examination of the vibrato shows that the highest pitch reached within the vibrato cycle is 281 Hz. (Minimum is 249 Hz with the average centre of pitch being 264 Hz as shown in Figure 6.9.3.) Therefore when H2 reaches 582 Hz it is beginning to be near enough to the formant already identified as being probably c.635 Hz, that is to say only c.70 Hz away. Similarly H4 would sweep to within the sphere of f_2. It would therefore be expected that on the next semitone higher at C#4 H2 would be significantly more fully reacting to f_1. This denotes the primo passaggio point.

Figure 6.9.3: Student bass detail of vibrato on C4



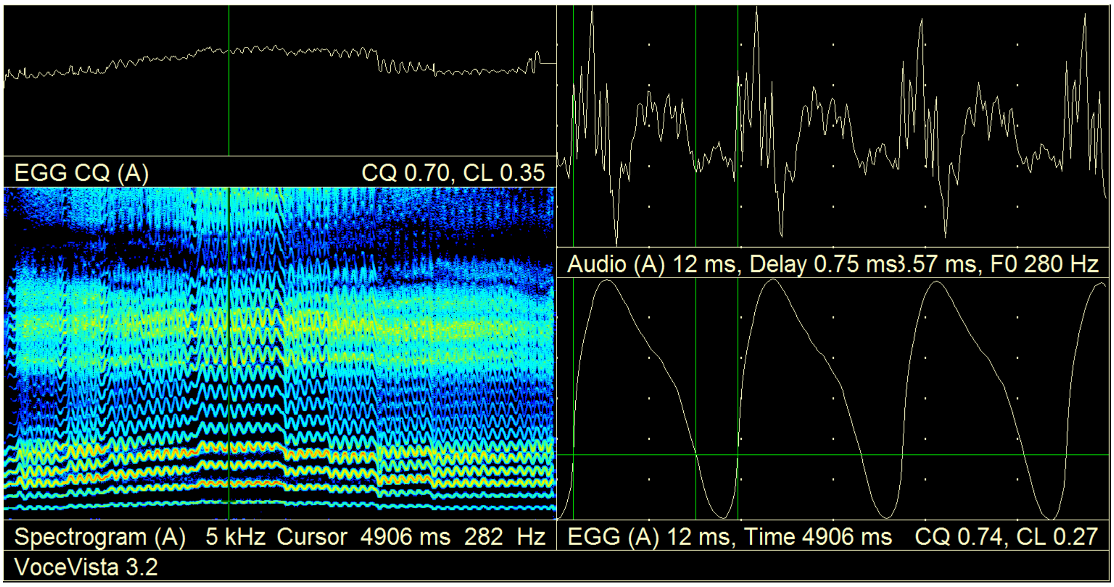
As predicted in the next scale, (F#3-C#4) H2 is strongly reacting with f_1 and H4 is still reacting in the lower moments of the vibrato cycle to f_2, though H4 is beginning to move beyond the influence of f_2 as can be seen clearly in the colour spectrogram. Viewing the file with the power spectrum set to 300 ms for averaging shows that H2 is clearly the strongest partial. Figure 6.9.4 shows a moment when H2 is strongest, and H4 weakest (top of vibrato pitch cycle).

Figure 6.9.4: Student bass (8) F#3 – C#4 scale [a]



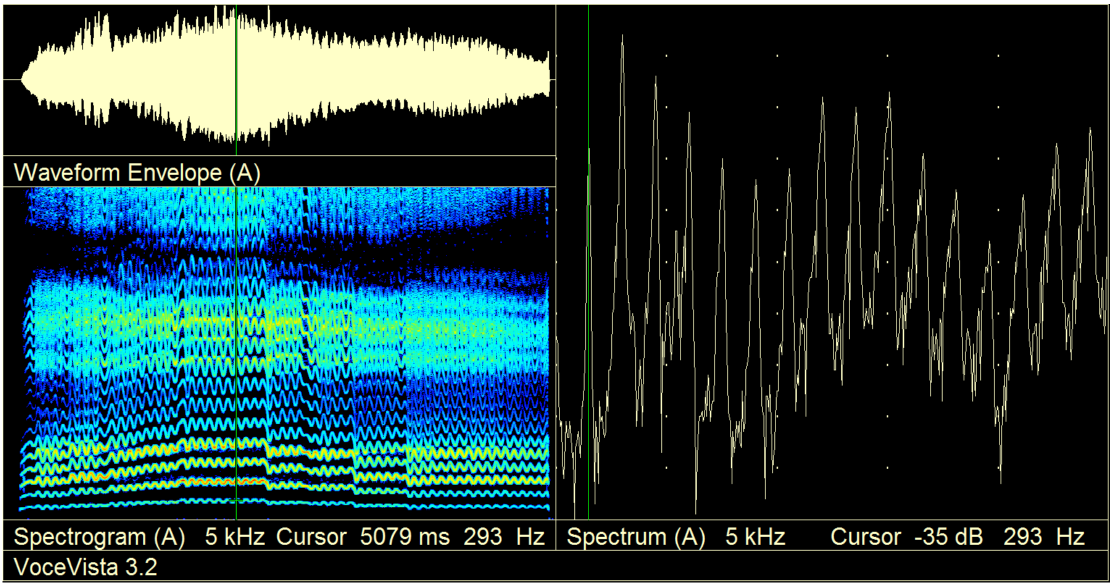
The EGG for the same moment suggests again a high contact quotient of 74%, shown in Figure 6.9.5.

Figure 6.9.5: Student bass (8) F#3 - C#4 scale [a] with EGG at C#4



Once D4 is reached in the next scale (G3-D4) H2 is much stronger because of the influence of f_1, reaching c.22 dB stronger than H1. Some partials in the SF are also strong at the moment of the peak of pitch within the vibrato cycle with H8, H9 and H10 all showing as nearly 10 dB above H1 when they are at their strongest moment. (Figure 6.9.6.)

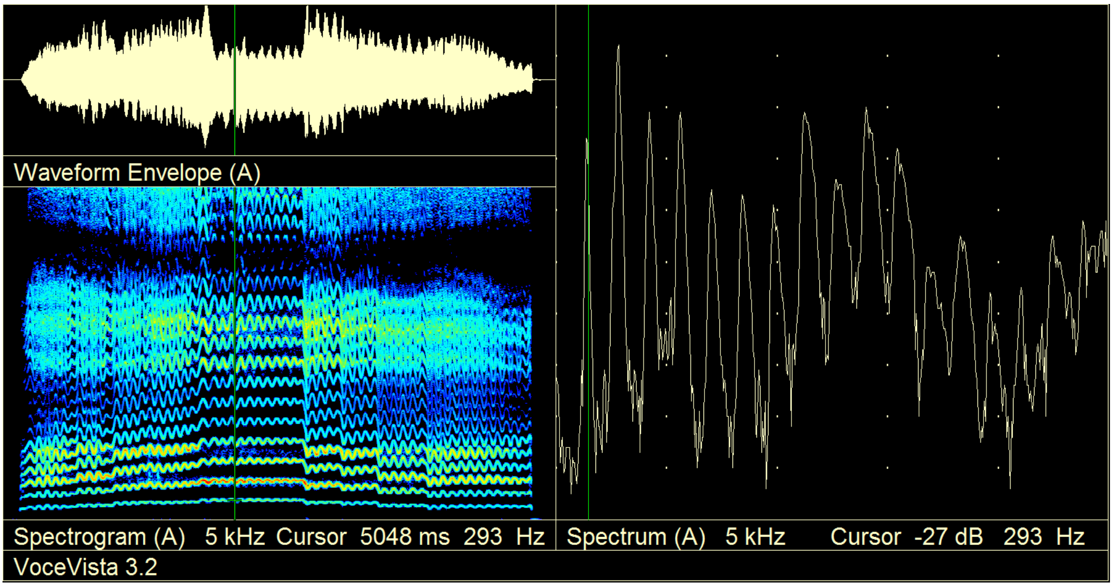
Figure 6.9.6: Student bass (8) G3 – D4 scale [a]



The extent of vibrato pitch excursion whilst sustaining the D4 is 4.9% taking the pitch down as far as 273 Hz and as high as 302 Hz. Therefore H2 will be moving between 546-604 Hz bringing it within the sphere of influence of f_1. The EGG shows the contact quotient as remaining c.72%.

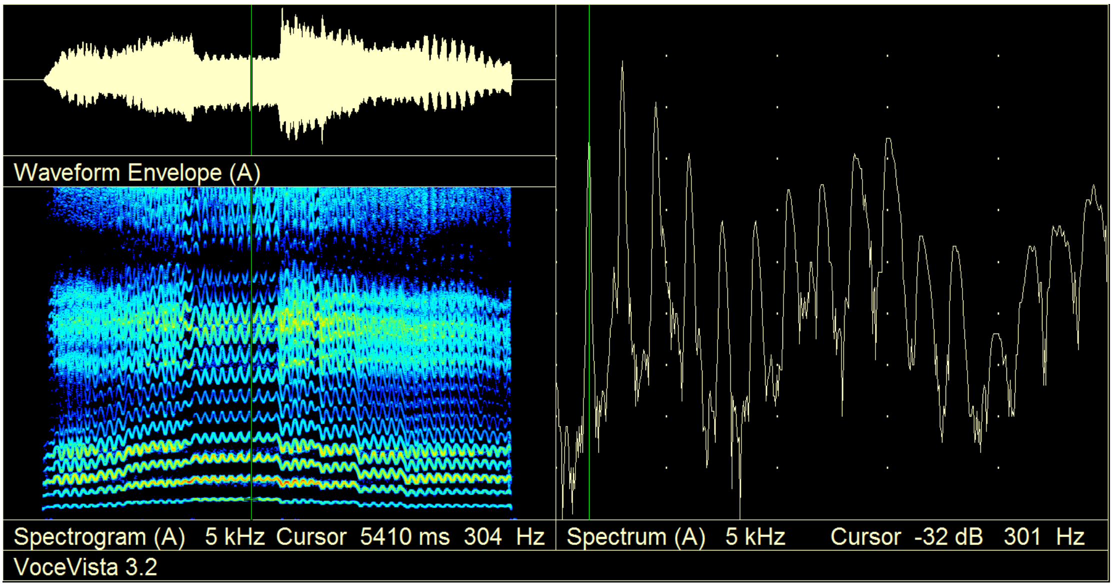
The student himself wondered if this D4 (above) was too ‘open’ and thought perhaps he should modify the vowel. He was invited to demonstrate what he meant and sang the scale again (G3-D4) mostly on [a] as before but using an obvious change of vowel to [ʊ] on the uppermost note. This is shown in Figure 6.9.7, where it can be seen that despite the vowel change H2 clearly remains the strongest partial and there is evidence in looking at the varying strength of H4 on the approach note to D4 and D4 itself, that f_2 must have lifted somewhat. In any case, it is clear that f_2 is not boosting H3 to the extent that H3 becomes the strongest partial. f_2 is not low enough to efficiently find H3 at this point and so this vowel modification could reasonably be described as not successful. The audio envelope suggests that there is a reduction of overall richness in partials (and therefore the sound that would be perceived) on the D4. Though it is normal to sacrifice some sheer volume when H2 is given up, this example is somewhat excessive as there is nothing really to help the partials higher than H2 here. The EGG at this moment (not shown) shows a drop in contact quotient to 66%. A second version of the same manoeuvre has very similar results in all respects. (Not shown.)

Figure 6.9.7: Student bass (8) G3 – D4 scale [a] second version



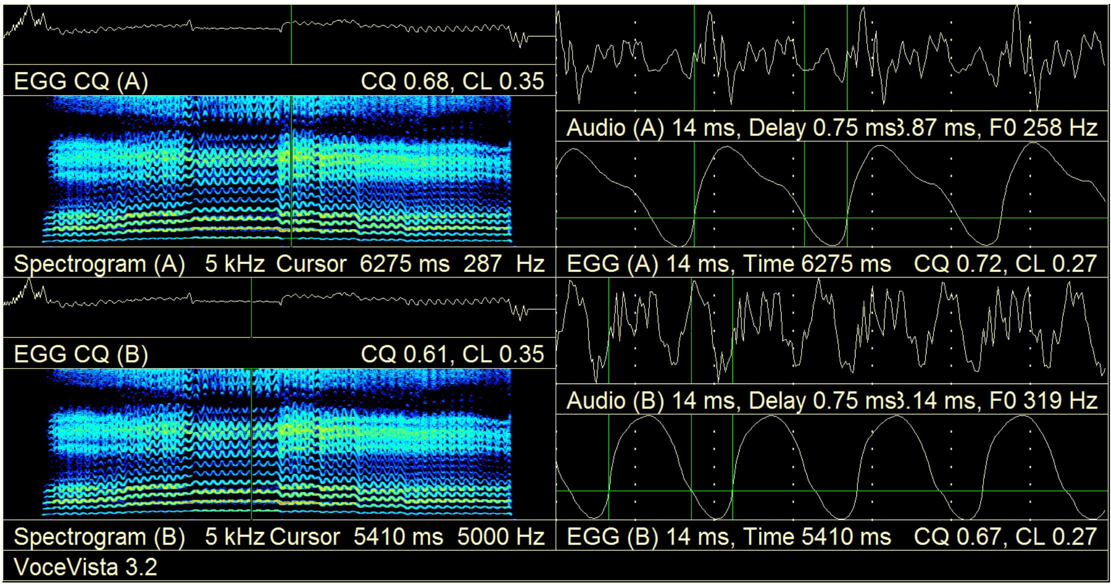
In the next scale from Ab3-Eb4 the student used a similar vowel change as described above, and the result is very similar. H2 is the strongest partial on the uppermost note, though the vowel is substantially altered from [a] to [ʊ]. The detail of the spectrograph suggests that f_2 is still too high to assist in strengthening H3. The very substantial change of timbre is clearly seen in the audio envelope when the pitch returns to Db4 following the uppermost note. (Figure 6.9.8.)

Figure 6.9.8: Student bass (8) Ab3 – Eb4 scale [a]



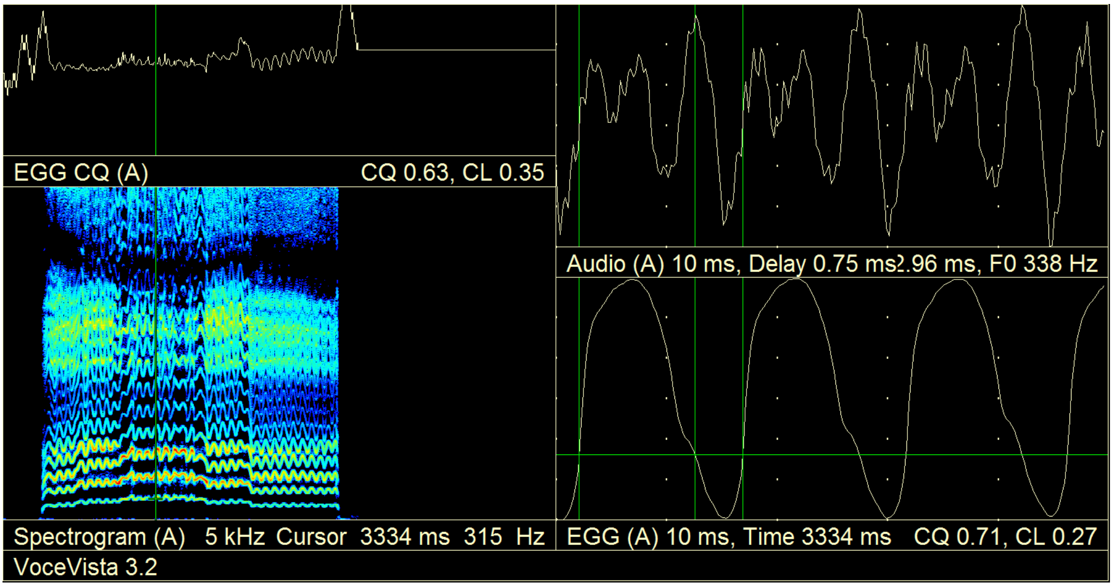
As noted already there is a drop in contact quotient on the uppermost note compared with the Db4 either side. This is shown in Figure 6.9.9 where the lower screen shows Eb4 and the upper screen the immediately following moment after pitch descends to Dd4.

Figure 6.9.9: Student bass (8) Ab3 – Eb4 scale [a] with EGG



Though the E4 in a subsequent triad of A3-C#4-E4 is not quite stable, with some moments where the full sounds 'cracks' momentarily, the signals in the recorded example suggest that the student may be at least on a helpful path. H3 is engaging with f_2 though f_2 appears to be a little too high to assist optimally. The colour spectrogram shows H2 weakening a little on the uppermost pitch. Figure 6.9.10 shows three clear columns in the audio signal and the EGG a contact quotient of 71%. The power spectrum at the same point (not shown) displays H3 as 18 dB stronger than H1, and 8 dB stronger than H2[33]. It would be of some benefit here if both f_1 and f_2 were to be slightly lower, so that H2 is deliberately weakened and H3 strengthened by a more advantageously situated f_2. This would be possible with more refined vowel choice.

Figure 6.9.10: Student bass (8) A3 – E4 triad [a] with EGG at E4

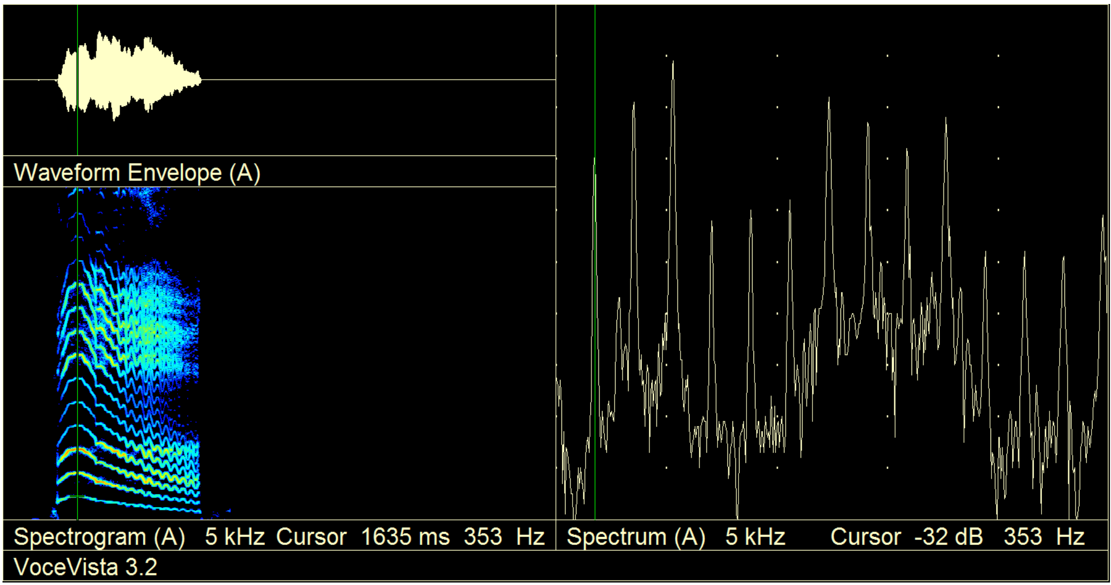


This student explained that he was aware that he became somewhat tense with a degree of constriction when tackling his upper range. He wanted to show that with care he could onset successfully with a modified vowel (instead of [a]) in the upper range and with good resonance if he could avoid such tension. Figure 6.9.11 shows an attempt to do so using a semi glissando onset but which targets F4. The

[33] If this note were stable without cracks in this manner it would be a good professional sound.

vowel used was close to [ʌ]. H3 is clearly strengthened here and not challenged by a strong H2[34]. The contact quotient as indicated in the EGG signal is c.69% (not shown).

Figure 6.9.11: Student bass (8) glissando onset for F4 using modified [a]



The pitch of F4 is at the top of the expected professional range for a bass; this may be an indication that this young singer is on a reasonable path to learning professional coordination in his passaggio and upper voice, even though it is clearly not yet sophisticated. This singer delivers his singing with vigour and strong physicality which may relate to the relatively high levels seen in the contact quotient figures.

[34] This singer may be on a reasonable path of development: it should be borne in mind that for a basso F4 is the extreme top of the range.

Chapter 7: Student Singers: Discussion of Examples

7.1. Introduction

The examples gathered from professional singers resulted in seven main areas for discussion. The same areas appear here but in different form. There are several reasons for this. The most obvious difference between the two sets of sung examples is that some of the student ones have an important longitudinal aspect which was not available for any of the professional ones. Some individual student examples were accumulated over a period which is sometimes as long as three years, making it possible to track some linear progress in the development of resonance skills. This is hitherto unknown in published classical singing voice research.

The origin of this project was to attempt to clarify what could be called 'best practice' in an area that is traditionally acknowledged to be a challenging and complex zone of aesthetics, skills and physical coordination. The writer is not aware of any hitherto published material that seeks to show something of the detail of student endeavours as regards the resonance management of the [a] vowel in the passaggio and higher range. There are assumptions and assertions made, but these tend not to be linked to anything which could be regarded reasonably reliably as illustrative proof. It therefore seemed desirable to spend time over an extended period to collect and examine evidence concerning student singing in these areas. It is hoped that by a closer examination of what actually occurs in the students' singing it will be possible to understand something of the detail of the student 'starting point'. This could assist in ensuring that singing instruction is better founded and more economic in terms of the time and effort which has to be expended in training for the profession.

It cannot be argued that the material here is definitive. It is rather exploratory and investigative. It if turns out subsequently that this relatively modest study (in terms of student numbers) does illustrate some areas which have general application and truthfulness, it will have been worthwhile. However we acknowledge that this is only a beginning in terms of the quantity and variety of source material.

This project has been designed to explore the complex ecology of the ‘real world’ of living classical singers, both professionals and students. This is clearly very different from the closed, designed experiment, deliberately conducted in what might be called ‘laboratory conditions’. It is argued that in order to uncover something of the truth about how male classical singers resonate the [a] vowel in the passaggio and in the higher range it must be acknowledged that there are a variety of factors which can affect resonance. It is misleading to think that even one singer will be consistent in the resonance strategy employed for any one pitch, producing consistent spectrographic characteristics for that particular pitch, because there are factors which may cause differences in the way resonance is created. We have already mentioned some of these such as dynamic level, position of a note within a phrase, length of a note, and prevailing emotional mood. The factors affecting how a particular note is resonated multiply when considering not just one note from one singer, but the same pitch from varied singers, in view of voice type or Fach. To that can be added the effects of training and the consequences of the singer’s internalised ‘model’ of what is considered to be acceptable or good. In the case of students who are undergoing professional training it is logical that as skills develop, resonance characteristics change.

It is simply fortuitous that some examples had been gathered from students (using *VoceVista*) even before the design of the project was clear, since these examples dating from early in various students’ development play an important role in enabling us to see how any particular student’s coordination of resonance develops and changes over the period of time. This illustrates something of the student journey towards professionalism, which can be related to the examples given by the group of professional singers. This aspect is also new in voice research. As some of the examples were recorded in the flow of a normal singing lesson there is not always EGG, (since setting up the EGG equipment takes rather more time and is therefore a little more disruptive of the tuition process). Nevertheless the spectrographic signals are usefully informative.

Of the eight students from whom examples were taken, three students recorded their examples at one session only. Two students recorded examples over three years and one student over two years. The remaining two student recordings were taken over a period of one year.

Table 3: Student singers, duration of example recordings period.

Singer 1	Tenor	3 years
Singer 2	Tenor	single session
Singer 3	Tenor	1 year
Singer 4	Tenor	2 years
Singer 5	Tenor	3 years
Singer 6	Baritone	single session
Singer 7	Baritone	1 year
Singer 8	Bass	single session

Since the students were at various stages of their training but were all undergraduates it was expected that there would be a certain amount of contradictory/inconsistent outcomes in resonance qualities. At such an early stage of training it was thought to be unlikely that students would have the necessary skills, experience, and established muscle and nerve memory which are required for consistent results. However this turned out to be only partly true. Whilst it can be seen that resonance characteristics changed over a period of time for those whose recordings were not taken at a single session, all students showed a high degree of consistency in spectrographic and EGG signals in single sessions. This would tend to indicate that at whatever point of development a student had reached, the coordination of vocal resources was habitual and probably the result of muscle memory and proprioceptive control, whether conscious or not. So to that extent, there was a somewhat surprising level of consistency.

There are five main areas of discussion, with some cross-over between these topics:

- Student resonance characteristics developing over time
- Other aspects of student resonance
- The challenge of finesse in vowel modification
- The apparent unification of 'registers'
- Electroglottogram rates and student voices: questions arising

In considering the development over time of student voices there is an issue for researchers: there is no possible equivalent of the 'control group' which can be used to contrast and compare results for longitudinal studies in medical research. We do not have access to a group of singers who remain outside of training over a period of years to compare with others who are trained during the same period. The inability to duplicate with singers the predominant medical research model for development over time has meant that examining progress made in voices in training over a sustained period has languished somewhat in classical singing research.

Two points are pertinent in relation to this. First, any reference to a 'control group' of singers who were not being trained in contradistinction to others would be likely to be unreliably meaningless. The concept of the 'control group' simply does not transfer meaningfully to classical singing voice research. How would one really know what influences the singers in the control group had been subjected to? How would any such elements, whether subtle or more obvious, be identified, verified and assessed? Would singers in the control group be required not to read about or discuss singing in any way? As one starts to consider what the concept of a 'control group' might mean in this context it becomes obvious why this concept is not appropriate here.

Secondly, it is illogical to assume that simply because there is no equivalent of a ‘control group’ that developments which can be identified in singers being trained are not worthy of examination, assessment and comment. The reader is invited to use his/her own judgement to decide whether what is being offered as comment seems reasonable and sustainable in relation to the quality of evidence. On these grounds it is asserted that there are tentative conclusions and ideas that can be offered in relation to student development which have some probable validity. This springs from the foundation of the study being in the ‘ecology’ of singing, rather than in the ‘laboratory’. It is unsatisfactory that no research at all is the outcome of not having an equivalent of the medical research model’s ‘control group’ for studies in classical singing which have longitudinal developmental aspects.

7.2. Student resonance characteristics developing over time

Since f_1 is the strongest of the formants in the vocal tract it is logical to assume that H2 would be significantly boosted once it enters the area of pitch influenced by f_1, even if in the case of an un-trained voice this might amount to blundering into that pitch zone and the f_1/H2 resonance link.

In examples taken at the commencement of training Student 1 showed that H2 did not strengthen particularly in the passaggio zone of D4 – F#4, achieving only c.3 dB stronger than H1. This was associated with modest CQ measurements which were c.45-47%. Partials in the SF zone were weaker than H1, 2, 3 and 4 in all areas of pitch. It may be surmised that with such a relatively low contact quotient the vocal tract was unlikely to be acting as an efficient resonator, since the acoustic signal would be dissipated and damped passing through the somewhat lengthy open glottal phase, then to be damped in the sub-glottal trachea and lungs. Without some clean or reasonably firm adduction of the vocal folds it would be unlikely that any partials could be enhanced significantly by the formants available in the shaping of the vocal tract vowels. Though this study does not directly address the skilled coordination of air/breath with the glottis, it is clear that in this relatively untrained voice this aspect needs training for progress to be facilitated in resonance enhancement.

There is a very noticeable change towards a professional quality looking at examples from the same singer after three years of training. All CQ figures had increased to the range of 56 – 69%, indicating a much finer control of air passing through the glottis and probably firmer adduction of the vocal folds. Partials in the SF had strengthened, often exceeding H1 by c.8 dB. Instead of H1 and H2 being almost of equal strength in the upper range there was a clear change from f_1/H2 tuning in the passaggio to f_2/H3 resonance tuning after approximately G4. As mentioned earlier these characteristics are far closer to a professional model. The voice also exhibited much greater finesse in a strong f_1/H2 relationship in the passaggio, where momentarily H2 was c.24 dB stronger than H1.

The change from f_1/H2 resonance to f_2/H3 resonance is a recognised professional characteristic in most tenor voices (except the Charaktertenor) which singers themselves describe with various terms, but often as the ‘turn’ of the voice. Indeed the Italian term ‘girare la voce’ (literally, ‘turn the voice’), which is in frequent use, refers to this concept. Though at the commencement of his training Student 1 shows characteristics which appear to be somewhat distant from professional quality, the development after three years of study is very noticeable. This does also suggest a question for further investigation. How common would the modest CQ rates be in other comparable untrained singers, and would they also show the same resonance characteristics, such as almost equal levels of H1 and H2?

Also noted in the earlier recorded examples was the weakness of partials in the SF zone. Since classical singers are training to be able to be heard clearly without electronic amplification it is essential that they develop resonance which permits the voice to be heard in orchestral contexts, in large auditoria, and often with other competing voices (whether solo or chorus). The acoustic strengthening of upper partials in the male voice is crucial to achieving this. Yet at the same time, in many choruses a voice with soloistically strong upper partials would stand out individually and therefore may be considered to be undesirable for chorus work (unless all members of the chorus were singing with 'trained' quality, as might be the case in professional operatic choruses). If research showed that prior to training some, or even most, male voices had relatively low CQ rates with undistinguished strengths of upper partials, this might influence vocal pedagogy to ensure that phonation efficiency was seen as a primary task. The examples here suggest that this could well be the case.

The examples presented from Student 5 were also collected over a period of three years, in this case covering most of the student's undergraduate training years. As with Student 1, there is a clear change in the resonance qualities offered.

The earlier recordings, dating from the student's second year of study, showed that f_1 engaged with H2 in the passaggio zone from E4 onwards, reaching a maximum of H2 on G4, but continuing to show f_1/H2 tuning on higher pitches such as A4. This is too high for Italianate classical voice production, though we have noted that Charaktertenors retain this resonance tuning in the higher range.

A year later there seems to have been a significant development towards more sophisticated resonance management. The epicentre of the strengthening of H2 by f_1 has shifted to the pitch of F4 and the student shows that he is able to sing F#4 with both f_1/H2 and f_2/H3 resonance adjustment. Though it was noted that in January 2010 pitches in the upper range were showing quite equal H2 and H3, a year later in 2011 the same pitches were sung with secure f_2/H3 tuning which was evenly distributed through the vibrato pitch cycle. This accurate formant tracking was associated with some fairly subtle vowel modifications which allowed the [ʌ] vowel to modify [a] so that f_2 could rise to track H3 as it ascended with rising fundamental pitch in scales and arpeggios.

The ability to alter resonance tunings by choice from f_1/H2 to f_2/H3 at the secondo passaggio point greatly enhances the artistic possibilities of a tenor, in addition to facilitating easier and more economic singing in the higher range beyond. There are very many contexts in which the quality of tone resulting from f_1/H2 on secondo passaggio pivotal pitches or higher is inappropriate, causing as it does a strong ‘yelled’ quality. For example Don Jose’s aria from Carmen opens with the weak syllable, ‘La’ placed on a downbeat for a whole crotchet within the moderate tempo on the upper passaggio pitch of F4. Clearly the second word ‘fleur’ is of more importance poetically than the definite article. But since ‘fleur’ is placed on the weak second beat of the bar it sits in an unusual rhythmic placing. Using f_2/H3 resonance on the initial ‘La’ makes it possible to sing this cleanly and warmly but without the weight and volume of f_1/H2 which might add to the downbeat impact of the rhythmic position of the word. Later in the aria the word ‘car’ appears on a sustained note of passionate climax, Ab4. Carrying f_1/H2 tuning to this note might cause some involuntary constriction for many tenors, since this would involve raising the level of

f_1 which would probably cause some lifting of the laryngeal positioning or constriction of the pharynx. However, with accurate f_2/H3 tuning the note can be sung with full tone and a free pharynx retaining the low resting laryngeal position which contributes importantly to the Italian ideal of 'chiaroscuro' tone quality. There are very many examples of this sort in operatic and concert repertoire.

As student 4 already was in his third year of training at the time of taking his first set of examples, he was clearly further advanced than students 1 and 5. This shows in the way that vowel modifications were used to seek f_2/H3 tuning from the pitch of F4 upwards. Ironically though, at that stage the vowel modifications employed also show that this is still a student voice in training, rather than a professional quality instrument. The [a] vowel is modified to such an extent that it would be disturbing to a listener if the target vowel (ie the vowel indicated in the setting of the text) was supposedly [a]. This vowel modification could not be regarded as something which a singer would tend to do naturally; it must be the case that either the student has been encouraged to modify the vowel in this way, or has heard other singers doing this and is imitating that element. However at this stage of his skill-set, the modifications are too extreme both in artistic matters (in that the language would sound unacceptably distorted) and in terms of vocal efficiency and resonance.

This student tends to use the same modification on all pitches from F4-Ab4. This is not necessary since it is likely that the pitch of his f_2 would already be appropriate for singing G4 with very little modification at all. Some subtle rounding of the [a] vowel towards [ɔ] would lower f_1 and thereby assist in ensuring that a potentially troublesome link between f_1 and H2 would not occur on the pitch of G4.

The maximal strengthening of H3 on the lower portion of the vibrato pitch cycle showed that with the modified vowel f_2 was taken too low to be efficiently used.

It was noted that f_1 was likely to be around 735 Hz and this would suggest that it is simply not necessary to lose the f_1/H2 resonance which is easily available on the pitch of F4. The spectrographic detail (see Chapter 6.5, p.204) also unsurprisingly suggested that f_2 was too low for optimum effect on the pitch of Ab4.

The crudeness of vowel modification had become far more refined and subtle in the examples taken 21 months after the earlier ones. The F4 instead of being manipulated for f_2/H3 resonance acquired even distribution throughout the vibrato pitch cycle with the easier f_1/H2 engagement which also preserves a more accurate [a] vowel, thereby sounding more 'natural' to a listener. The CQ had been noted as 72% when singing F4 with f_2/H3 resonance and this remains the same when that is supplanted with f_1/H2. This is interesting because it so strongly suggests that the difference in quality between these two contrasted examples is very largely due to formant/harmonic alignment and not due to a change in phonatory mechanism.

This is a robust young tenor who, when mature, is likely to be a full lyric voice and consequently for such a tenor it is important that he is not misled by looking for a lighter, more 'floated' sensation when crossing from his secondo passaggio point into singing in the upper range. The change in timbre is predominantly one caused by formant/harmonic alignment, not by an abrupt letting-go of the adjustment of vocalis muscle involvement in phonation. His secondo passaggio point is shown in the later recordings as consistently occurring from F#4-G4 as is appropriate for this voice type. In his negotiation of the passaggio zone and sustaining of strongly resonant high pitches such as Bb4 using f_2/H3 tuning coupled with a CQ rate that is often around

72% the student leaves behind the transitory clumsiness of the earlier recordings and demonstrates professional finesse.

Some of the most useful information about the management of resonance in the passaggio and beyond in tenor students can be seen in the examples from student 3. Most of the examples from this student were taken at the same time, when he had been studying for eighteen months. There are four files which were recorded one year later, which demonstrate a significant change in his skills. The bulk of the material gives a ‘snapshot’ view of the level of development of this student, and show reasonably clearly a range of challenges and issues of vocal technique which experience suggests are common.

It was noted that the student tends to allow his [a] vowel to drift a little towards the brighter sounding [æ] vowel, (referred to by Vennard, 1967, as the ‘bad’ vowel). Many young male students who believe their voice to be too dark and wish to have access to a brighter, more quasi-professional sound, mistakenly try to mix these two vowels. Whilst it is the case that the [ae] vowel can create stronger activity in the SF partials of the voice (especially when slightly nasalised), it is not necessary to try to retain that vowel in singing an [a] vowel in order to retain that strength in the SF partials. This is demonstrated by almost all professional voices and more advanced students. Unfortunately, mistaken use of the [æ] can lead to pulling the larynx upward since the vowel is made with a lift of the blade of the tongue and in young students the body of the tongue is often stiff, including the deepest part connected to the hyoid bone. This leads easily to accidental raising of the larynx, thereby shortening the vocal tract and raising all formants. The consequence of this is that the much desired Italianate ideal of ‘chiaroscuro’ tone is not possible, since the warmth of tone facilitated by f_1 (with low resting larynx) on an [a] vowel is compromised. This student was constantly advised in lessons to use the long Italian [a] vowel, though the habit of resorting to a vowel with some aspects of [æ] was a persistent one.

It was possible to identify by reference to a variety of partials and 'shadow' indications in the spectrographic information from this student that f_1 was most influential around 775 Hz and f_2 at 1134 Hz when he sang a scale from E3 – E4. These could be regarded as relatively normal for a tenor. They give a useful starting point for observations in higher scales and pitches which suggest further laryngeal rising. Whilst it looked as though there may have been some aesthetic balancing of the strengths of H2 and H3 during the singing of F4 as achieved by some professional singers (thereby disguising any sudden change of timbre at the top of the passaggio), the retention of f_1/H2 tuning on all higher pitches (see Chapter 6.4, pp.190-197) indicates that what occurred on F4 was probably accidental. Both f_1 and f_2 climbed in tandem with the fundamental (H1). This enabled some resonance to be achieved, in a situation where the strength of partials in the SF zone was only at the level H1, therefore not assisting in creating professional resonance.

The other aspect of this vocalism was that the student only achieves CQ levels which are generally below 50% and sometimes as low as 39% (on E4, see Chapter 6.4, p.188). There was an unusual loop visible (described, as has become conventional in descriptions of EGG signals, as a 'knee') in the first portion of the open phase of the EGG signal. This is something normally associated with female EGG phonation signals, which generally exhibit considerably lower CQ rates than males (for logical reasons, associated with the phonatory mechanism). Hampala et al, (2015) has pointed out that the lower the CQ rate, in association with less than full-voiced, firm singing, the less reliable these rates tend to be. In this case the figures at least seem credible, in that the lack of resonance and the very gentle somewhat unphysical vocalism are logical in relation to low CQ rates. When the student attempted an A4 the CQ was noted as 45% and the EGG had the appearance of a sine wave, possibly indicating that the phonation was approaching the lightness of falsetto adjustment (though it is not possible to be certain about this without further investigation, such as using video-kymographic analysis). To achieve the ringing resonance and tone quality required for the generally accepted international tonal model of Italianate singing, (able to serve the musical requirements of a wide range of repertoire), three major inter-associated changes would be needed in this student's singing.

1. The larynx needs to be in a stable low-resting position, creating a longer and consistent tract for resonance (see Sundberg, 1987, pp. 113-124 for a basic discussion of this aspect, also Bozeman, 2013, pp.37-48). Sundberg and Askenfeld, 1983, assert that a raised laryngeal position is associated with pressed-phonation. Pressed phonation itself is '…a rather poor affair in terms of vocal economy; one expends a high subglottic pressure plus strong adduction force without gaining anything in sound level' (Sundberg, 1987, pp.80-81). On the continuum which is feasible in phonation, ranging from breathy at one extreme to pressed phonation at the other, the most efficient and acoustically beneficial is what is termed 'flow phonation' (Sundberg, 1987, pp.49-92).
2. The adduction of vocal folds needs to be somewhat firmer to create the conditions which can yield the advantages of a higher CQ rate and flow phonation (see Miller, 2008, pp.55-58 for a discussion reinforcing the importance of achieving optimal CQ rates).

3. Formant tuning needs to be more accurately achieved for easy production of available aesthetically desirable resonance. This cannot be achieved if the larynx is being allowed to rise unintentionally.

The question was raised as to whether the vocalism demonstrated by this student could have professional contexts functioning as it did (see Chapter 6.4, p.195-196). This may be considered not relevant at this stage, because though this vocal coordination may have been appropriate, for example, in some Baroque repertoire, the ascent of the larynx implied by our observations was probably associated with an undesirable increase in muscle tensions in the neck and laryngeal suspensory system. This would not be healthy over time. It seemed that these resonance outcomes were the result of not having any other options available. Therefore at this stage of a student's development it was far preferable to explore whether improving the coordination habits leading to resonance could be achieved. The four examples from the same student eleven months later are therefore of great interest.

The student volunteered to show examples of what he considered to be an improvement in his singing. He was familiar with spectrographic signals and had been working on experimenting to see if he could locate a stronger H3 whilst singing the pitch of G4 on [a]. The recorded example shows him successfully targeting that partial, achieving gradually a clear emphasis on H3. He manages to maintain this consistently through the note with H3 stronger than H2 by c.7 dB and 11 dB stronger than H1. The student himself thought this was significant because it enabled him to identify proprioceptively the 'feel' of singing the [a] vowel in the upper range which was not using f_1/H2 resonance, and he was able to hear and identify the nature of the slight modification of the [a] vowel associated with this. He then demonstrated in three further examples that he was able to locate this resonance on A4, each time showing clear f_2/H3 tuning. There was also an improvement in the strength of his resonance in the SF zone. Though there is no EGG for these examples, given the resonance characteristics it is likely that the CQ level was considerably higher as part of the coordination producing these notes. In terms of the resonance quality, at this stage of research it is not possible to state which element might be causative in relation to the other.

This intelligent and highly self-aware student was a cultivated musician and was enthusiastic about the possibilities for his own career and repertoire base, which this development in his resonance management might facilitate.

The only other student for whom there exists examples which are significantly separated in time was student 7. The scale to a ninth from D3 – E4 which was recorded two years earlier than the other files employs a noticeably rounded [a] vowel which sounds closer to [o] or [ɔ] and it was noted that since this lowers f_1 and f_2 there is a somewhat earlier than expected entry to the passaggio as defined by f_1/H2 engagement. At the top of the scale on E4 f_1/H2 is replaced by f_2/H3. The later recorded examples do not exhibit the fairly obvious vowel change, and the consequence is that F4 becomes a pivotal pitch with f_1/H2 resonance strongest during the lower pitch of the vibrato cycle, then replaced by f_2/H3 when pitch is highest. This, oscillation in the strengths of the resonances of f_1/H2 and f_2/H3, together with reasonably strong partials in the SF zone is sufficient to avoid the note sounding too blatantly 'open'. The arpeggio of F#3 – F#4 has clear f_2/H3 engagement on the uppermost note. This therefore achieves a smoothly graded transition from one timbre to the next in traversing the passaggio, which was not the case in the earlier recording.

Taken together the examples from these students show the effects of training in developing professional resonance qualities. In one instance at least (student 3) this work was undertaken with an intelligent awareness on the part of the student of formant/harmonic alignment, though it is not therefore possible to state that such an approach would suit all students.

7.3. Other aspects of student resonance

Where students were able to use non-periodic phonation ('vocal fry') (Miller, 1997) to establish estimates of the position of f_1 and f_2 for their habituated [a] vowel these could be used to predict the most challenging moments in the management of the [a] vowel in their passaggio. It was then possible to see how these challenges were met in practice.

Though student 2 was not able to consistently de-voice his vocal fry, he nevertheless was able to provide consistent results showing the approximate position of f_1 as 760 Hz and f_2 as 1150 Hz. It was noted that these values for f_1 and f_2 would mean that on F#4 H2 at 740 Hz and H3 at 1110 Hz would be very well positioned to strengthen those partials. Though H2 and H3 of G4 were slightly higher than the established f_1 and f_2 values, they would be close enough to remain engaged. However a semitone higher on Ab4 there would be a challenge since f_1 and f_2 would now be too low for boosting H2 and H3 respectively.

The recorded examples showed as expected a strong link between f_1 and H2 on F#4, and slight boosting of H3. However the modification of the [a] vowel towards [ʌ] which subsequently occurs when sung pitch reaches G4 (in a scale from C4 – G4) raises f_2 too far for it to influence H3. Looking at other partials in the scale whilst this modified vowel is being used, there are indications that f_2 may now be as high as 1320 Hz (or even higher as the exact position cannot be determined in this way).

The response to the challenge predicted on Ab4 can be clearly seen in Fig 8 (see Chapter 6.3, p.184), where the loss of tuned formant resonance is obvious in the waveform envelope and colour spectrogram windows. f_2 cannot engage with H3 on the Ab4 (because it is probably c.150 Hz too high) and so there is a sudden change of timbre and reduction in perceived loudness. The fairly strong partials in the SF zone also suddenly weaken for this pitch.

A more subtle point emerges from the examples of this student singing up to his high A4. When this is tackled as a scale the result is very similar to the problems noted in the scale ascending to Ab4, with poor resonance available on the highest pitch. The A4 shows considerably better engagement between H3 and f_2 when this note is part of a triad rather than a scale. This may be because once a particular resonance tuning is established it tends to persist, most especially when notes are conjunct since the singer naturally carries the sensation of one pitch close by to the next. This is especially so in inexperienced students who have not yet learned that the semblance of unity of voice across the entire range for the listener requires the singer to make subtle changes, rather than attempting to maintain one vocal position/sensation throughout. When there are greater melodic leaps as occur in non-conjunct patterns the psychological effect of having a leap involved appears to enable a student to 're-think' a high pitch, rather than extending the pitch and sensation of the previous note.

The baritone voice of student 6 offered vocal fry in association with his habituated [a] vowel which showed f_1 as c.680 Hz and f_2 as c.970 Hz. In all his examples there were strong partials in the SF zone. The high estimates of his CQ illustrate the fact that the long closed phase in the glottal cycle produces a stronger sound in the higher frequency zones (Herbst and Švec, 2015). The values for f_1 and

f_2 are low enough to create the darker vocal quality of the baritone voice, with f_2 seemingly particularly low.

Again it is possible to predict where the greatest challenge in the passaggio is likely to occur. The low f_2 means that it is unlikely to be able to boost H3 of E4 and F4, where baritones traditionally make the change from f_1/H2 tuning to a different viable alternative. On Eb4 f_2 would be too high to help with H3 which would be around 935 Hz. It requires very subtle adjustments to the vowel to achieve the formant tuning which would enhance resonance in this area. This is a clear example of exactly why the [a] vowel is a challenge for vocal technique in the male passaggio. This singer has the advantage of strong partials in the SF zone and so when singing Eb4 the partials H2 and H4 are strong but equalled by a higher band of partials, H8, 9, and 10. As all of these partials were noted as nearly 20 dB stronger than H1 this creates a very impressive sound which projects easily in auditoria.

This student attempted to modify his [a] vowel for pitches on E4 and beyond. The use of [ʌ] and [ʊ] in a composite sound for E4 resulted in a drop of f_2 which had been boosting H4 previously. As this was a powerful link, the loss of that element in the radiated sound is very noticeable, creating a discontinuity in timbre which was probably not necessary, or at least, rather too crude. When he attempted the same pitch, without the vowel change, H2 and H4 were stronger than in the modified vowel version (indeed more so than the partials in the SF). It is also significant that when the resonance was less successful his usually high CQ dropped to 60%, but in the unmodified version producing stronger resonance on H2 and H4, the CQ reverted to slightly below 70% (see 6.7, pp.218-221).

The singer's attempts at F4 all used a marked change from the [a] to [ʌ] which though it had the effect of dropping f_1 desirably so that it began to disengage with H2, also probably accidentally raised f_2 too far so that it was not effective in relation to H3. Only on the upper side of the vibrato pitch cycle on an F#4 can it be seen that H3 starts to strengthen, showing that f_2 is too high for maximum benefit.

Singer 8 was the other singer whose examples were all recorded at one time. The signals from singers 2 and 6 showed that there was a tendency when modifying the [a] vowel to raise f_2 too high, and singer 8 also appears to exaggerate vowel changes too much, thereby negating some of the value of that approach. However, as with the others, there are strong signs that he is developing his skills in an appropriate way, simply needing more finesse.

This singer also used vocal fry to establish approximate positions for f_1 as 635 Hz and f_2 as 985 Hz. These low values were indicative of his bass voice timbre. He also tended to have high CQ rates which, as with singer 6, produced strong activity in the SF zone. The student questioned whether his D4 sung with strong f_1/H2 resonance was aesthetically too 'open'. There was some evidence amongst the partials to suggest that f_2 was higher than in the vocal fry version(s) of the [a] vowel. However the alternative offered with the [a] vowel changed very noticeably and suddenly to [ʊ] caused an unacceptable loss of sense of continuity of timbre and did not locate f_2 accurately enough to boost H3. (The very abrupt reduction in waveform envelope was shown in Chapter 6.9 pp.239-240.) As with the comparable moment described above with student 6, at the moment when resonance efficiency is compromised the CQ rate drops significantly from 72% to 67%.

The E4 sung at the top of the triad, though not quite stable, managed at some moments a strong engagement between f_2 and H3, but it appeared that both f_1 and f_2 were a little too high. With a little more refinement in vowel management (and successfully evading the muscular constrictions which can bedevil attempts at singing the highest notes in the male range), this would be a note of impressive professional quality. The student showed a high degree of self-awareness in demonstrating his onset with glissando for F4 with the vowel modified towards [ʌ]. This high note (for a bass singer) of F4 demonstrated a strong f_2/H3 resonance and disengagement of f_1 from H2. With a strong CQ level of 69%, again this presents very good professional potential.

Overall, these students show that it is possible to predict where the greatest technical hurdles will be in conquering the transition through the passaggio, and singing notes on the [a] vowel in that area and on higher pitches. This can be achieved readily and simply, using vocal fry to find approximate locations of f_1 and f_2 which are sufficiently accurate to be of use in practice. Where a singer finds this not easy to achieve, there is the other possibility of closely examining all partials in scales (preferably chromatic) covering the interval of a fifth. Providing the vowel is constant this will give an idea of the location of where a formant is maximally effective, even if its exact position is still not certain. For a singer, the pitch of where maximal interaction between formant and partials takes place is of more use than the actual exact position of a formant.

There is a considerable amount of evidence here that student vowel modification can be too approximate or crude. It may be that in this respect at least, training of the student ear to respond to very small adjustments in vowels can be enhanced by use of spectrographic real-time feedback. This perhaps links to the view expressed by Tomatis (1988) that what the ear of the singer cannot hear, his voice cannot reproduce.

7.4. The challenge of finesse in vowel modification

Miller, R., (1986) states that it is necessary to use vowel modifications in achieving a unified voice across the passaggio (pp.157-159). This view was not new, and had been the subject of intensive investigation, thoughtful analysis, and writing by pedagogical authorities such as Appelman (1967, pp.126-140 and pp.216-375) and Coffin (1976). Appelman sought to clarify what was needed by using photographs and saggital 'X ray' views of the head showing mouth, tongue, jaw and pharyngeal positions. There are many others who have written about the need for vowel modification, (variously referred to as vowel modification, migration, or adjustment).

The evidence here from the group of students both illustrates the need for vowel modification and at the same time shows why this approach may sometimes be unsuccessful, and even acquire a negative reputation. This is because some of the attempts to modify a vowel are too exaggerated and fail to achieve the intended alliance between a formant and harmonic.

Any singer who can manage reasonably clear vocal fry can discover very rapidly how drastically the frequency location of formants can shift when a vowel changes. What is clear from the student (and professional) examples given in this study is that skilled modification of the [a] vowel can enhance resonance qualities and greatly assist a singer in traversing the passaggio zone and singing in the higher range. The examples show both the aesthetic and functional advantages of such technical accomplishment.

As is clearly shown by some of the student attempts to manipulate vowels, it is all too possible for exaggerated or crude attempts in vowel modification to result in very poor resonance outcomes. This may partly explain, even when the evidence is clear, why there are still some pedagogues and singers who eschew any form of vowel modification. It may also be that neurological processes as described by Westen et al (2006) in another context, showing that once an opinion about an issue is established the brain seeks ways of avoiding revising such an opinion, also play a role here.

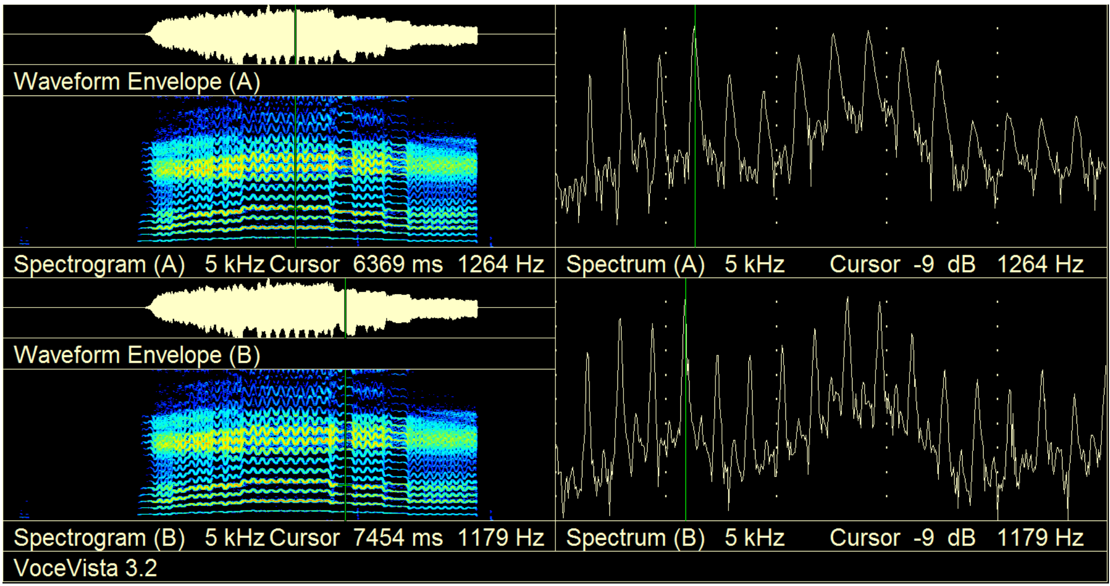
Though using vocal fry can help to establish the likely whereabouts in pitch of formants 1 and 2, this tool can arguably be problematic when it comes to finely tuning vowels for passaggio and higher notes in the male voice. It may well be that the detailed position of the larynx and pharynx is not quite consistently stable when making a substantial difference in phonatory mode. That is to say that changing from normal, ‘modal’ (Hollien, 1974) phonation to non-periodic phonation may cause some differences which would affect resonance. This needs skilled monitoring by singer and tutor. If the position of the larynx and the configuration of the pharynx changes slightly during swapping between sung pitch and vocal fry in attempting to establish, as precisely as possible, the effective location of a formant in relation to nearby harmonics[35], the value of vowel-guidance gained is compromised. However, the spread of pitch which occurs during normal vibrato and observation of all nearby harmonics can greatly assist in determining the likely most favourable position for a lower formant (ie f_1 or f_2).

In Figure 7.4.1 (student 6) it can be seen that on the uppermost note in the short sung scale from A3-E4, H4 is at its strongest when at the lowest point in vibrato pitch cycle, at 1264 Hz. At that point it is momentarily shown in the power spectrum as -9 dB (Fig 1, upper window). When pitch ascends this strength weakens showing a lessening influence from f_2. Immediately after, as pitch descends to D4, H4 is strengthened again by f_2 but now at the top of the vibrato pitch cycle at 1179 Hz,

[35] Not the actual location of the formant, but where a formant is most influential on harmonics.

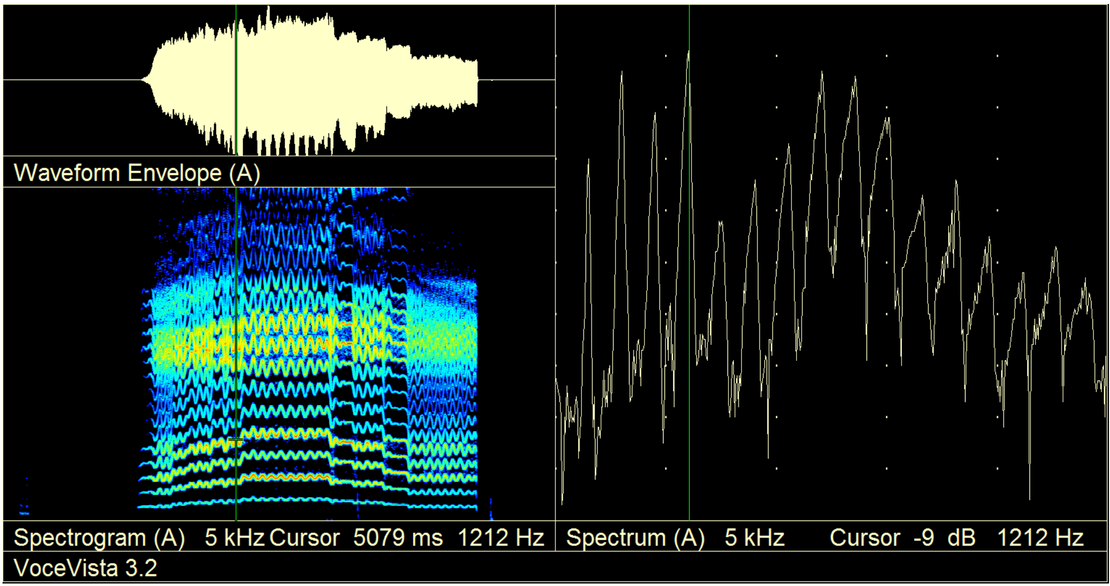
again reaching -9 dB (Fig 1 lower window). This leaves a gap of 85 Hz (derived from 1264 – 1179) wherein f_2 must be somewhere located.

Figure 7.4.1: Student baritone (6) A3 – E4 scale [a]



In Figure 7.4.2 the green cursor is placed at an earlier moment of the same example showing the end of the sung D4 before ascending to E4. At this point the upper moment in vibrato pitch cycle causes H4 at 1212 Hz to strengthen attaining -9 dB, but immediately thereafter weakening as pitch descends. It therefore seems extremely plausible that f_2 will be located at c.1210-1220 Hz.

Figure 7.4.2: Student baritone A3 – E4 scale [a] 2



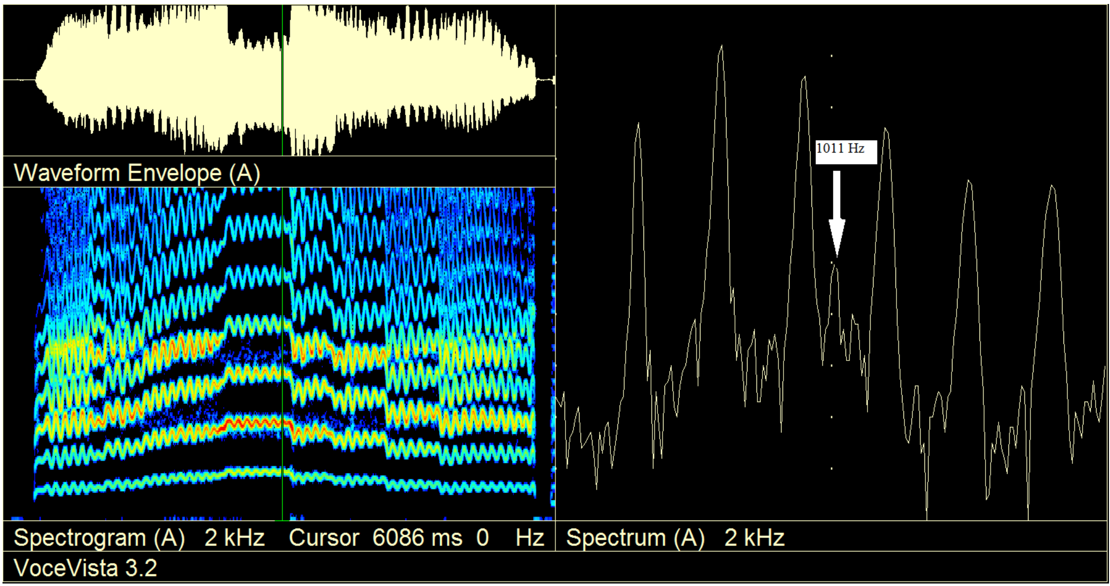
On the sustained E4 in this example the singer would therefore have to lower f_2 by c.150 Hz to enable it to engage effectively with H3 of the sung pitch. As previously explained, when this student attempted a vowel modification to achieve f_2/H3 resonance on the sung pitch of E4, he did not manage to find a suitable vowel to locate f_2 advantageously and it was possible to conclude that in his case, to do so would have been unnecessary and probably cause distorted text beyond an acceptable level. By examining the spectrographic views more closely (as above) it is possible to see some detail of why this was the case.

Student 2 adjusted his [a] vowel in singing a scale from C4-G4 (see Chapter 6.3, p.113) towards the [ʌ] vowel when this was not necessary. This could partly be because the developed internal model for tenorial timbre in the upper range, which this enthusiastic student had acquired through his attentive listening to mature professionals, had suggested to him (even if subconsciously) that this would be necessary to achieve the tone which he ambitiously desired. This is not surprising in a 20 year-old young singer, but again illustrates a crudeness in the execution of vowel modification. As most Conservatoire voice tutors are themselves mature singers, it can also be that an inappropriate vowel adjustment results from the student copying the timbre and apparent vowel adjustments of the tutor. In fact it may be that the tutor is not adjusting the vowel significantly, but that his own formants are at differing pitches to those of the student.

Slightly differently, student 4 showed that he could find f_2/H3 resonance on his F4 in a scale ascending to that pitch from Bb3, and even though f_2 was not ideally located he manages some alignment between f_2 and H3 on subsequently higher pitches. When, 21 months later, the vowel changes are more subtle not only would text seem more natural (because any occurring [a] vowel would be less distorted), but the strengthening of H3 by f_2 is more marked. There was also an increase in the strength of partials in the SF zone. These changes created both a brighter and fuller sound, approaching the ideal of Italianate 'chiaroscuro' tone.

There are further examples given in Chapter 6 from students 5 and 7 demonstrating a tendency to over-modify the [a] vowel for a period of study, before finding a more successfully subtle approach. This general tendency to exaggerate what is needed may be a warning to pedagogues that even the mention of the concept of 'modification' to a student can accidentally contribute to misguided exaggeration in practice. Student 8 illustrates one of the more complex set of characteristics in this regard. When singing a scale up to D4 the student thought that it might be better to sing this note with a modified vowel, but when he demonstrated this the [a] vowel was actually replaced, rather than modified, by the [ʊ] vowel (see Chapter 6.9, pp.239-240). The attempted vowel does not facilitate f_2/H3 resonance, with f_1/H2 remaining dominant. The waveform envelope window clearly shows the effect of the disengagement of f_2 which is lowered by this vowel change (see Fig 3 below). On the C4 either side of D4 in the upwards and downwards scale H4 is the strongest harmonic. This strength is suddenly lost because of the marked change of vowel. It is probable that f_2 has dropped to c.1011 Hz, as shown in Figure 7.4.3. (The pitch range has been reduced to a limit of 2000 Hz for greater clarity here.) The white arrow in the right-hand screen view of the power spectrum shows the likely whereabouts of f_2 revealed by the tract's amplification of non-harmonic 'noise' at the pitch of 1011 Hz.

Figure 7.4.3: Student bass (8) G3 –D4 scale [a]



This student did demonstrate that he was on a good path to finding the resonance of f_2/H3 on both E4, where it was partially successful and also on his high F4. The latter he sought to demonstrate using an aspirated glissando for the onset in order to attempt to reduce the muscular tension associated with high effort level which otherwise arose from his somewhat pressed phonation. This was a good demonstration of how success in seeking specific resonance qualities may be achieved by skilled breath management and an acute kinaesthetic awareness of keeping tensions at bay, as well as vowel adjustments which guides formants beneficially.

7.5. The apparent unification of 'registers'

There are a number of factors which combine to produce the semblance of the existence of a 'register' which seems to change in quality once its upper limit is reached and surpassed at the top of the male passaggio. The perceived change in quality of texture and timbre for listener and singer can be varied, depending on how the gradually ascending pitch when singing the [a] vowel is managed. It is logically of considerable benefit for both singers and pedagogues to understand the causes of this apparent register, in order to help avoid unnecessary strategies seeking to combat elements which do not exist in reality, and to respond conversely with well-founded coordination of the vocal resources.

The two main factors which combine to produce the sense (both for the ear of the listener and in the inner sensation of tone for the singer) of there being a register in the passaggio are the pitch and strength of f_1. As this strongest of the formants of the [a] vowel very frequently sits close to the pitch of H2 at the top of the passaggio zone, it produces a powerful ring in the timbre of the sung tone when H2 is ideally situated in relation to f_1 for optimal resonance. As pitch continues to ascend the singer is faced with a choice, which is to either continue to amplify H2 by finding a means of gradually raising the pitch of f_1, or to allow f_1 and H2 to disengage. When the latter happens there is the obvious consequence that an element of the timbre of the voice will be significantly weaker.

It has already been noted that there are two common strategies for this challenge to unifying the quality of sound in relation to the [a] vowel ascending through and beyond the passaggio. In voices which have a strong SF zone the loss of strength in H2 is less significant, since the SF harmonics are dominant anyway, and providing that strength is maintained reasonably consistently the listener hears a satisfactorily unified quality. In voices which do not have this quality, the loss of overall strength from the weakened f_1/H2 engagement needs to be supplanted by strength from another formant/harmonic interaction. Though f_2/H3 engagement does not produce a timbre which is the same as f_1/H2, it has become a desired hall-mark of what singers tend to refer to as the ‘turn’ of the voice. The slightly ‘darker’ tone which this causes avoids the very bright, blatant tone (often referred to as the ‘yell’ of the voice) which results when carrying f_1/H2 beyond the position where f_1 is simply at the pitch of the particular singer’s freely produced [a] vowel. In classical singing this is usually in association with a low resting laryngeal position. If the singer allows the larynx to rise and/or constricts the internal dimensions of the vocal tract in another way, f_1 can be raised and this approach is accepted as desirable in some other singing styles.

There is also a musico-psychological challenge, in that the singer will have experienced the strong ringing sound caused by f_1/H2 interaction in the passaggio; consequently in seeking to maintain a consistent quality he may accidentally allow laryngeal raising or other physical events to occur in order to maintain what was perceived as desirable whilst singing passaggio pitches.

It has already been shown that some considerable subtlety is needed to successfully situate f_2 so as to achieve what has been described above. All of the students considered here illustrate the nature of the task of managing registration through and beyond the passaggio, and their responses to that challenge. Students 2, 4, 6 and 8 tended to modify the vowel either too early or too excessively which resulted in the likely location of f_2 being inaccurate in relation to H3. This also caused a loss of strength either from the f_1/H2 link or/and (as in the case of student 6) a rather abrupt loss of strength of H4 being strengthened by f_2.

Whilst the above students made excessive/early changes to try and evade the sense of carrying f_1/H2 too high, the tenor students 3 and 5 showed f_1/H2 carried up into the high range (beyond expected secondo passaggio pitch) which is reported by many pedagogues as being a common challenge in training young male voices (Bozeman, 2013) to maintain a classical Italianate chiaroscuro tone quality as the voice ascends. In the case of tenor 5 f_1/H2 resonance was still dominant as high as A4. However, examples given by these students later in their training showed that they had developed some skill in finding f_2/H3 resonance in the upper range. In the case of student 5 this became reliably available in his coordination, and he showed that he could sing his 'pivotal' secondo passaggio pitch with either f_1/H2 engagement, or f_2/H3. Student 3 had only three files which illustrated this development, and in his case it remained an open question as to whether this voice was predisposed to the type of resonance which is distinctive for Charaktertenor voices, or whether, with further training and exploration, this voice could establish the more Italianate approach to the top of the passaggio and beyond. As mentioned previously, the student himself was very self-aware about this aspect and intended to work on consolidating his skill in finding f_2/H3 resonance.

The baritone student 6 was a clear example of a singer who had very strong activity in the SF zone of his voice and his attempts to adjust the [a] vowel in order to achieve a sense of avoiding taking the power of f_1/H2 too high seemed to be too soon in ascending pitch and too exaggerated also. Bearing in mind that most of these students were continuing their vocal education, it may be that he might eventually show the same kind of outcome as illustrated by tenor student 4 in unifying the upper voice. This latter student tended to make vowel modifications which were both too exaggerated and too early in ascending pitch in his earlier examples. The exaggeration of vowel modification caused inaccurate formant tracking and therefore compromised timbre, but also would have had the effect of making any text which was supposed to be using the [a] vowel sound considerably less intelligible. However, the examples from later in his development showed more subtlety and very well balanced strong resonance across the top of the passaggio and into the high tenor range.

There are facets of each student's use of available resonances which very strongly show that they were all concerned about the quality of resonance and how this could help to achieve a sense of consistent unity across the passaggio and into the upper range. Though the basic aesthetic principles of what was being sought seem to be common to the whole group, there was a wide variety of individual differences and responses which we have noted.

7.6. Electroglottogram rates and student voices: questions arising

The CQ figures obtained are generally not surprising for anyone accustomed to male classical singer's CQ rates. Miller, D., (2008) lists three advantages of a relatively large closed quotient. These are:

- facilitation of increased air pressure at the glottis creating stronger sound pressure levels
- facilitation of improved resonance because the glottis being closed for longer in each glottal cycle creates a more efficient resonator tube
- facilitation of stronger harmonics in the acoustically valuable singer's formant zone of pitch (pp.40-41)

The EGG results depend on some skilled judgement on the part of the operator in order to identify the likely point of glottal opening within the longer descending slope shown in the VV EGG display. Some purist voice scientists might question the exactitude of figures obtained using the EGG in this way. However there is broad agreement that when singing at mezzo forte (or stronger) dynamic levels in the operatic aesthetic the results can be broadly trusted. Herbst

(2016) also thought that this was likely in discussing the various methods available for examination and analysis of vocal fold contact.

Student tenor 1 shows very marked development in his CQ levels. His earlier examples had CQ rates which were consistently below 50% and these rates unsurprisingly were associated with weakly resonated partials. H1, H2 and H3 are often of equal levels and the SF harmonics are also generally weaker than H1. Three years later his CQ levels sit at a much more productive 56-59%, even touching 69% for a fully voiced Ab4. This underlines the significant development during this time of his vocalism.

Student tenor 3 shows somewhat low CQ rates sometimes as low as 39% and rarely attaining more than 49%. As suggested by Miller, D., (2008) this may indicate a voice which can transition to lighter registrations (as would be appropriate in some Renaissance and Baroque repertoire) with greater ease. It would require a more extended set of examples over time to ascertain whether this was the case with this particular voice or whether, like student 1, the voice simply needed more skill and development.

Student tenor 5 showed CQ rates which were comparable to professional singer 3, in the range of 58-62%. As was the case with professional singer 3, this student demonstrated that he could use efficient resonance with formant/harmonic alignment to create the qualities desired in the operatic Italianate tradition.

The other student voices all display strong CQ rates which were comparable with published rates (and those mentioned here also in Chapter 4) for successful professional operatic singers. The most promisingly substantial voices are students 4, 6, and 8, with CQ rates that are often above 70%. On very strongly vocalised higher pitches the CQ touches 79-80%. Students 2 and 7 show CQ figures which are nearly all in the range of 61-69%. The high levels of CQ rates tend to support the view that singing in the upper male voice in classical full-voiced singing does not cause, or require, a substantial change in the phonatory mechanism.

As some time has now elapsed since these figures were taken in the recorded examples (in all cases more than three years) it can be reported that the subsequent repertoire and Fach destinations of all of these singers very strongly support the indications suggested by the CQ figures. It would need a longer separate study to confirm these findings authoritatively but the tentative conclusion at this stage would be that monitoring CQ rates in students with non-invasive EGG is informative and pedagogically useful.

There are some intriguing details about CQ levels which pose questions for further research. When student tenor 4 employed a somewhat overly modified [a] vowel to achieve the quality of timbre associated with f_2/H3 resonance on the pitch of F4, his CQ level was 72%. Eighteen months later singing the same pitch of F4 it is sung with f_1/H2 resonance, but the CQ level is unaffected remaining at 72%. To what extent therefore does resonance tuning enhance or affect CQ levels? Are these levels inborne or are they achieved by a period of development? Is breath control and pressure at the glottis more significant in attaining higher CQ rates than resonance tuning? How does a high level of skill in resonance tuning assist in achieving an acoustic standing wave in the vocal tract and what impact does that in turn have on subglottal pressure?

The same tenor also shows interesting results in his uppermost range. Singing Ab4 the CQ rate is 80%, but the rate for a note a whole tone higher at Bb4 was lower at 72%. Though this is clearly a voice of considerable strength, which might be appropriate in professional work for Lyric, bordering Spinto Fach, it seems that this singer achieves a healthy slight reduction in the otherwise very high CQ rate of the Ab4 as pitch ascends further. This suggests that there may be a reduction in the tensed mass of vocalis muscle which is strongly engaged on the Ab4 but which has probably reached its limit at that point. These remain important open questions for further investigation with significant potential for vocal pedagogy.

Chapter 8: Conclusion

8.1. Introduction

Both singers and vocal pedagogues express a wide variety of views on the passaggio and especially about the [a] vowel in the passaggio. There appears to be confusion in some quarters about whether the passaggio even exists (Striny, 2007), perhaps because there is even greater confusion about defining it. The examples which have been collected here offer some clear explanation for these contradictions and seemingly-opposed views. It is hoped that by way of a broader consideration of factors affecting the passaggio it will be possible to understand in more depth what is meant by the term itself, and to suggest professional parameters and the implications for pedagogy.

In exploring the complexities of the management of the [a] vowel in the male passaggio there are four interacting elements which need to be borne in mind, if conclusions are to be truthful and valid. In no particular order of importance, these are:

1) The physiological and acoustic capabilities of the vocal mechanism and tract
2) The established professional aesthetics of classical singing
3) The ingrained proclivities of any singer to produce his [a] vowel in his own particular way
4) The fact that a skilled singer may be able to deliberately manipulate the factors which affect the qualities of his [a] vowel in the passaggio

These factors constantly interact. In drawing conclusions about how student singers and professional singers manage the passaggio [a] vowel it is necessary to keep these influencing variants in mind if the conclusions are to avoid simplistic generalisations. Defining what is really meant by 'the male passaggio' has often proved difficult simply because one or more of these factors have been omitted in offering a definition.

It can be further argued that there are two modes of knowledge which concern definitions of the passaggio. Failing to acknowledge this has led to entrenched disagreements between experts (reported by Henrich, 2006 and earlier by Hollien, 1983, 1984) about registers in singing as well as the characteristics of the passaggio. These two modes of knowledge are:

1) That which is concerned with 'practice' (including real-time vocalising, performing, teaching, and aesthetics of classical singing)
2) That which is concerned with 'theory' (including factual information about vocal function and theoretical constructs based on voice science)

That this is so interestingly mirrors the pre-occupation in recent years with the division in so many skill-based areas of education between 'declarative' and 'procedural' work. These two differing approaches for pedagogy have been in evidence in theories about teaching of skills for sports education for some while. In singing the relevance of this information has been articulated by several authors including Verdolini-Abbot (2012) and Helding (2016).

'Declarative' knowledge in singing relates to the established facts of physiology and acoustics. These are fixed elements which do not rely on social constructs such as aesthetic judgements. Conversely 'procedural' may be crudely characterised as 'what someone does'.

This study replaces one of the standard popular tools of qualitative enquiry, the interview (and subsequent analysis), with the recorded examples of singing (and subsequent examination) as these examples represent a more accurate way of discovering a particular singer's 'opinion' on how to sing the [a] vowel through and beyond the passaggio. Singers own words attempting to describe what they do would be a poor substitute for this material. The conclusions presented here offer substantially new insights into the complex reality of professional and student singing, partly because they are rooted in the real world (rather than theoretical) ecology of a singer, each singer having providing examples of their craft/art. We are thereby forced to consider the reasons for the wide range of variable results by acknowledging the factors (discussed briefly above) which may have influenced each singer and each recorded example. It is necessary in presenting the conclusions below to refer to the broad range of interacting factors which may have guided the vocalism offered by each singer in each example.

8.2. The Charaktertenor(s)

The resonance characteristics shown by the group of Charaktertenors here considered have not hitherto been reported in any published sources. They are strikingly different from those of their Lyric and Helden/Spinto colleagues.

One singer (Tenor 2) showed a highly unusual engagement with a strengthened H3 that remained the strongest partial traversing the entire traditional zone of the passaggio and beyond. Only on reaching B4 did H2 become the dominant partial. This is the reverse of the more familiar Lyric/Helden/Spinto passaggio resonance which moves from f_1/H2 strengthening in the passaggio zone to f_2/H3 in the upper voice (or enhanced SF partials). It seems likely that this tenor achieved the extraordinary boost of H3 over a wide range (commencing around B3) by approximating formants 1 and 2 to create a 'super-formant'. This creates a very strong, bright-sounding timbre which can project in all parts of the range with clarity. Most educated listeners would probably describe the timbre of this voice as 'open', or more pejoratively, 'blatant'. Ironically however this is not the result of carrying f_1/H2 higher in pitch, beyond the top of the passaggio, which is described by some authors as a 'register violation' (Miller, 2000, pp.136-137). The very particular timbre of this voice type is sought-after for the special roles which it undertakes and this particular singer has a long and distinguished career singing in this Fach for over thirty years, engaged by the world's most prestigious opera houses. It is therefore not possible to dismiss how this voice functions as though it were of no artistic interest or defective.

Both of the other Charaktertenors exhibited a traditional engagement with f_1/H2 in the passaggio zone but continued with this well beyond what would be conventionally considered the top of the tenor passaggio. All three Charaktertenors exhibited H2 as the strongest ‘vowel partial’ on the high note of B4. No Lyric/Helden/Spinto voice offers this.

Moreover it seems that these resonances were not due to freakish CQ rates as Tenor 9 showed a modest CQ of c.55% on his B4 whereas Tenor 10 on the same pitch had a CQ of c.74%. Also it needs to be borne in mind that at least one of these singers (Tenor 9) was able to offer a different resonance coupling for F#4 – A 4 which he himself described as ‘more lyric’ and which indeed did show the more usual emergence of f_2/H3 at F#4. In other words, we cannot simply assume that the resonance employed by these tenors was due to poor vocal technique or inadequate vocal training. Both Tenor 2 and Tenor 9, having had long and distinguished careers, it would in any case seem highly unlikely that their singing could be the result of poor vocal technique or inadequate vocal training.

These tenors do not have a passaggio zone in the commonly accepted meaning of the term. They have a totally different approach to traversing this area of pitch. The voices have a particular aesthetic quality which is valued by those who cast singers in roles for the brightly assertive and projecting quality of their tone, which is able to cut through high levels of orchestral sound and compete effectively with large stage ensembles. Their roles often have a tessitura which is higher than that of Lyric/Helden/Spinto roles and an additional feature is the frequently encountered rapidity and quantity of text in their music.

These features illustrate very well some of the arguments discussed in the Introduction above. The better-founded instructional books about how to treat the male passaggio would suggest that these singers do not conform to what is desired. Yet they show that (in one case by very deliberate choice – and it may be the case that this applies to the other singers also) the way they use the potential of the vocal mechanism and acoustic laws answers to a specific aesthetic. This is as required by composers and the opera houses which perform particular repertoire and which contrasts very markedly to the aesthetic of 'bel canto'.

It may well be argued that such singers have an in-built proclivity to coordinate their voices in this way. Further research is needed to explore this aspect, but it is often the case that those who sing Charaktertenor roles tend to be of shorter height (less than 1.7 metres). This may mean that the vocal tract is shorter and therefore would be easier to retain f_1/H2 relationship at higher pitches. A 'natural' proclivity to do a thing in a particular way may be regarded as an element of 'talent'. Should formal training enhance what is there already or seek to replace it more radically? This is a crucial question for all those who teach or coach singers. Student 3 showed a natural inclination to sing with a resonance quality that in some respects was similar to the group of professional Charaktertenors. (Though his very low CQ figures suggested that the energy and physical firmness in his singing was below both the norms of his peers and certainly below professional norms.)

The evidence here is perhaps a warning that pedagogues need to be aware that there is a potentially successful professional 'Fach' for those who sing through the passaggio zone 'unconventionally'. Conversely, at least for Student 3 it did become clear that he could learn to engage with f_2/H3 tuning and that this was in association with a likely improvement in CQ rates. Pedagogical decisions about voice type (and to what extent it is appropriate to teach a voice to access different resonances to those with which they initially present) are likely to remain a subtle art, but the foregoing information is new and useful.

8.3. Longitudinal Aspects of Student Examples

The examples collected over extended periods of time from Students 1,3,4,5,and 7 offer some new, specific insights into student progression from their initial proclivities of resonance for the [a] vowel in their passaggio zones towards a more professional model.

Two of these students had low CQ rates of less than 50% in their earlier examples which would probably make it unlikely that they would be able to achieve what Miller (1986; 1993) calls 'voce piena in testa[36]', which (whatever one calls it) is a desirable/necessary professional goal. Both tended to carry the f_1/H2 link up through the passaggio zone and into upper voice, as high as A4. Neither had SF partials which were stronger than H1. This was also the case with Student 5. Yet all three tenors showed marked changes (Student 1 over three years, Students 3 and 5 over one year) and were subsequently able to use f_2/H3 resonance in upper voice. As with the professional tenor Singer 9, Student 5 was able to choose whether to use f_1/H2 or f_2/H3 on the pivotal pitch at top of his passaggio, F#4. The ability of a trained classical singer to choose different resonances in their treatment of the [a] vowel in the passaggio zone and above raises a serious challenge for anyone who seeks to establish how this area of the voice functions. Future research would ideally need to interrelate recorded examples (using any appropriate method) with

[36] Meaning, 'full voice in the head'. This refers to a resonant 'forte' quality in the upper voice.

questions/interview to ensure that what is offered by a singer is fully representative of their craft/art.

Students 4 and 7 were both slightly more advanced when this study commenced and their initial examples demonstrate that they tended to exaggerate the modification of [a] towards [ɔ]. In both cases this meant that any intended text would sound somewhat distorted and also that their change from f_1/H2 resonance to f_2/H3 was earlier than necessary. Approximately two years later, they show less obvious modification of [a] and the change to f_2/H3 resonance is higher in both singers and more clearly and strongly achieved. Singer 7 shows a particularly smoothly managed change from f_1/H2 to f_2/H3. On his pitch of F4 the lower frequencies of the vibrato cycles change to f_1/H2 resonance and the upper frequency within his vibrato conversely exhibits f_2/H3. This prepares the way for his F#4 which has f_2/H3 resonance throughout the frequency change caused by vibrato. The later examples from Student 4 show in the distribution of partials in upper voice a quality which compares very well indeed with well-established professional singers in the lyric tenor Fach (at the age of 22).

There is almost a complete dearth of published material showing student progress. The issues here discussed and illustrated demonstrate (for the first time) how students can definitely make progress over a period of time towards being able to sing through the passaggio zone benefiting from the strong f_1/H2 link and learn to disengage from that powerful relationship, replacing it with f_2/H3 at the top of the passaggio and beyond into upper voice. This ability is a highly important skill for any male singer who wishes to engage with repertoire written later than the Baroque era, and which is essential for most of the core operatic repertoire. (In much modern performing Baroque repertoire is often also sung with this approach to the passaggio and upper voice.) It also enables voices which have a stronger, fuller timbre to negotiate the upper range without accidental or deliberate constrictions created by the necessity of allowing f_1 to rise with rising tessitura, so that it can continue to track H2.

The question may arise in considering the changes in resonance discussed above as to how these changes were engineered. Clearly a detailed description of that is beyond the scope of this study, but in each case students were instructed using traditional Italianate methods with the added advantage of some supervised work with the *VoceVista* spectrogram, enabling them to see what was happening to partials as they made vowel changes and to a limited extent to see what happens to formants when vowels are modified.

Already mentioned above is a recurrent feature of the student examples, whether visible in the student examples taken over a period of time or in examples taken only at one session. This would be best described as clumsy or crude attempts at vowel modification which results inevitably in a lack of success in finding the sought resonances. Six of the eight students showed that they had a tendency to over-exaggerate vowel modifications. The most common result was that both f_1 and f_2 were lowered too far for the intended improvement in resonance to be attained. These students were not all being taught by the same tutor, so it is unlikely that the sole cause of exaggeration of intended vowel modification was because of misdirection from a particular tutor.

Students in Conservatoire environments acquire ideas and attitudes to the technical aspects of their singing, magpie-like, from a wide variety of sources. It would be logical to assume that the main influence comes from their personal vocal tutor. But the starting point for any tutor will not be a ‘blank sheet’. The student will already have habituated an approach to resonance in his voice to a greater or a lesser extent.

Students enter a highly competitive environment in Conservatoires and are usually very strongly motivated to progress, as measured in exams, competitions, and a myriad variety of performing situations. This can engender a competitive and highly critical working environment in which singing students seek to achieve vocal maturity as rapidly as possible. Recorded examples of established artists offering what is considered to be highly successful timbre in their voice types are more easily accessed than ever before. The result is that a highly aware, intelligent, ambitious and diligent student singer may attempt to copy the vowel modifications which they think they can hear in the work of mature voices, hoping to achieve the same quality as rapidly as possible themselves. However often what students are hearing in recordings are the consequences of successful vowel modifications ('vowel tracking') rather than the modifications themselves. That is to say, they hear the outcome of the vowel modification rather than the precise detail of the actual modification used.

It has already been pointed out that it is not possible to identify reliably the exact location of a formant by observing the relative strengths of partials. It is even less possible to guess reliably the location of a formant by simply listening to a singer. Those who work frequently with spectrographs and singers over a sustained period may be able to offer an educated guess, but no student singer is in that category. The observations on the examples provided by Student 2 (Chapter 6.3, pp.177-186) showed very clearly these aspects of student resonance. Only armed with the detail of multiple spectrographic views and the information about the likely position of that student's f_1 and f_2, coupled with the audible change in vowel for the scale from C4-G4 it is possible to assess reasonably accurately what has occurred in the lack of resonance on G4.

When a student has some background understanding of the relevance of positioning of f_1 and f_2 and has the benefit of seeing how rapidly formants move with vowel changes, it becomes possible to refine their ear. The students for whom there are examples collected over a period of time (rather than at one session) all were able to see spectrographically how formants and partials were interacting, and to improve their finesse of vowel modification/tracking thereby.

One more aspect emerged from studying the sung examples given by the student group, which was that the results suggested some priorities for the pedagogical process. In the examples provided by students 1,2,3 and 5 there was some evidence that laryngeal position was not stable and that when pitch rose so did the larynx position. (It was noted that this was also likely in some of the examples provided by the professional singers, the Charaktertenors aside, the result was a loss of resonance in the upper range.) In addition, the CQ figures from Students 1, 3, and 4 showed these singers at the earlier stage of training as sometimes less than 50%. Though it would be speculative to attempt to identify the exact reasons for these CQ figures, it is not speculative to say that achieving a low resting laryngeal position (and therefore a longer vocal tract tube which is not compromised by contraction when ascending in pitch) coupled with skilled breath management is a pre-requisite for tackling refinement of resonance in the passaggio and beyond. It is therefore desirable to tackle breath management skills, onsets and offsets of phonation, the ability to offer clear, firm-voiced phonation, and freedom from pharyngeal or lingual constrictions, all prior to working on the passaggio.

8.4. Fach type and f_1/H2 resonance

The extent to which Fach type was demonstrated by the details of f_1/H2 resonance in the passaggio [a] vowel was an unexpected result of close examination of the recorded examples. This is an area which has not been commented on in published studies concerning the passaggio. Though the number of singers studied here is not sufficiently high to merit an authoritative conclusion in this area, the consistency of the details does suggest that the behaviour of f_1/H2 can be at least to some extent Fach-defining.

The group of Helden/Spinto voices all showed earlier engagement with f_1/H2 (around C#4) and exhibited a difference between the relative strengths of H1 and H2, peaking at c. 25dB on Eb4. This was also true of the two baritones both of whom sing Wagnerian Helden repertoire. It was also noted that H2 greatly exceeded the strength of H3 at this peak moment. The two voices which perform a mixture of both Lyric and Helden/Spinto repertoire had slightly higher sung frequency fundamental for the peak difference between H1 and H2. For Tenor 5 this was E4 and for Tenor 4 F4. This group of tenor voices also all showed strong levels in the SF zone.

Those who sing in the Lyric Fach showed strongest engagement between f_1 and H2 on F4. The biggest difference between H1 and H2 at such moments was c.15dB. A second difference was that at the same moment H3 tended to also be strengthened to the extent of being only c. 5-9 dB weaker than H2. This was part of the visible tendency for the lyric voices to show a more equal balance between H2 and H3 at the secondo passaggio point. This was unsurprising in that the higher pitch of F4 would be nearer the influence of the likely position of f_2.

These results were interesting for the detailed way in which the relative strengths of H1, H2 and H3 consistently suggested vocal Fach type. The Helden/Spinto voices had more isolated stronger resonance on H2 around Eb4, whilst the more Lyric voices had somewhat weaker H2 levels occurring a whole tone higher. The voices which performed in both Fachs showed midway results, compared with their peers.

Professional Tenor 4 commented that he tended to treat the top of his passaggio slightly differently in varying repertoire. He gave the example of the aria 'Celeste Aida' from Verdi's opera, *Aida*. He pointed out that there are a number of musically prominent F4 [a] vowels in the aria, for example at the end of the first phrase. In this repertoire he would be cautious not to sing these pitches too 'open' (his word) and showed via demonstration that he would modify the [a] vowel in order to engage f_2/H3 tuning earlier than he normally would in more lyric repertoire. No recording was made of this example as it was simply offered spontaneously in conversation at the end of the main recorded session. However, there are commercial recordings of this tenor singing the aria which are easily accessed and which tend to confirm his assertions.

These tenors also showed clear differences in where the passaggio zone appeared to end in that the Helden/Spinto group moved to f_2/H3 resonance around F4 or F#4 whereas the Lyric group showed that change most clearly occurring on G4 or Ab4.

These tentative conclusions relating strengths of particular partials in the passaggio and beyond for the [a] vowel could be of use in a number of situations when deciding a likely Fach type is not simple or clear.

8.5. The effect of ‘context’ on resonance for particular pitches

Singers were asked to sing short sections of scales from tonic to dominant, and also triads and arpeggios in providing their examples. This had the unintended consequence of demonstrating that the position of a particular pitch within a phrase or pattern of notes sometimes appeared to change/influence the resonance quality which the note attained. This may seem obvious to anyone that sings professionally but it is rarely acknowledged in the literature which seeks to establish and analyse how particular pitches are resonated.

When F#4 was the highest pitch in a short five note scale sung by Professional Tenor 1, the F# showed f_1/H2 tuning. However, when the same pitch occurred in a medial position (in a five-note scale from D4 – A4), f_2/H3 resonance was clear. The logic and possible reasons for this have already been discussed (see Chapter 4.3, pp.95-97).

Almost all notes which occurred as the highest note in examples sung by Tenor 8 showed different resonances when they occurred as intermediate pitches in a phrase/pattern. (Again the reasons for this have already been discussed.)

Tenor 9 showed in examples that he could opt to use differing resonances, changing the predominant resonance on F#4, G4 and A4 from f_1/H2 to f_2/H3 depending on what type of repertoire he was singing. Similarly student 5 showed that he also could choose whether to use f_1/H2 or f_2/H3 resonance in his examples of F#4.

Conversely, the detail of the spectrographic information showed that Tenor 5 was deliberately guiding the resonance of his F#4 so as ensure that it was always sung with f_2/H3 tuning regardless of where the pitch was situated within a phrase.

8.6. Consequences of inadequate formant/vowel management and singer's formant levels

Bozeman (2013) points out that if the laryngeal position is stable and vowel integrity is maintained a voice will 'naturally' change its timbre (sometimes referred to by singers as 'turn over') as H2 rises beyond the influence of f_1. It is therefore suggested by some that the singer should simply allow these events to take place and not attempt to guide them with formant manipulation achieved by vowel modification.

The examples provided by both students and professional singers suggest that the outcome of this approach is often that efficient, optimal resonation in the higher range is lost. (There is also the danger for pedagogues and students who are working to gradually conquer an extended range that the change of timbre, caused as described, gives an illusion that all is well for proceeding to higher pitches. See below under 'Further conclusions relevant to vocal pedagogy'.)

Tenors 1, 6 and 8 showed some change from f_1/H2 giving way to f_2/H3 resonance around F#4/G4 as partials moved into the orbit of the apposite formant. This looks like quite sophisticated resonance management. However, all three tenors subsequently lost the potentially easily available resonance on increasingly higher pitches because they did not allow f_2 to rise with rising fundamental pitch. The adverse consequences of this seemed particularly clear in the spectrographic information of Tenors 1 and 8.   This seems especially important where a singer does not have strong SF levels which can at least partially obviate the need for careful management of the change from f_1/H2 to f_2/H3 at the top of the passaggio and beyond for the [a] vowel. It may be worth commenting that those professional singers who had the most prestigious careers showed care in guiding this resonance change even though they also had very high SF levels.

There are many examples from the student group which suggest that when resonance is not efficiently managed at the top of the passaggio (the 'secondo passaggio' point) the result is weaker timbre in the upper range which can cause tensions and unnecessary effort.

These are crucial issues, since they can make or break a career. A male singer who cannot sustain singing in the upper range without excessive effort and strain is clearly a singer whose career may be foreshortened, or who may not achieve his full potential.

8.7. Further conclusions relevant to vocal pedagogy

Chapter 7 discussed three areas which are directly relevant to vocal pedagogy:

1) Remaining alert to the professional potential of students who do not have a 'conventional' passaggio.
2) The usefulness of obtaining an indication as regards a student's CQ in the upper range.
3) The necessity of achieving a stable low resting larynx position.

The issue mentioned here of laryngeal positioning is an important one. The significant issue is to what extent the spectrographic examples suggest laryngeal instability and especially whether there are signs of laryngeal raising coupled to rising sung pitch. There is very broad agreement that a stable resting larynx is a basic requirement in vocal technique. Authoritative sources for both voice science (Sundberg, 1987, pp.113-124) and vocal pedagogy (Miller, 1993, pp.123-126) assert and explain this importance.

Whilst it is possible to incorrectly infer laryngeal raising when looking at spectrography, there are some circumstances where it is highly likely that the signals do indicate a rising larynx with consequent general raising of formants. It is necessary to be able to discriminate between sub-harmonics (or artefacts) shown in the signals and the likely proximity of a formant as revealed by a combination of factors, including strength of partials and a ‘shadow’ trace caused by a formant amplifying the vocal bi-noises (such as trans-glottal air-flow). These are masked to the human ear by the much louder sounds of the fundamental and partials. Some voices create more of these ‘bi-noises’ than others, depending on the efficiency and clarity of phonation. Secondly, where the strength of partials above the sung fundamental frequency appear to remain consistent as the fundamental frequency rises, without this aspect being managed via vowel adjustments, there must be an aspect of the singing which causes this to be so. That could include increased buccal opening, and lip-spreading, either separately or in combination. However, if the pattern of the particular partials which are visibly strengthened remains quite consistent as sung fundamental pitch ascends it may well be that (where buccal opening and lip position remain fairly static) a rising larynx is causing the vocal tract to shorten and therefore formants to rise. Miller

(2004, pp.159-160) mentions that laryngeal elevation at the top of the passaggio is a common problem in training young tenors and baritones.

Figure 4.4.5 (p.116) shows, in the colour spectrogram of professional tenor 1, blue 'shadow' traces across the screen appearing to continue at the frequencies of partials strengthened by F1 and F2. It was noted that as fundamental frequency continued to rise in the scale of D4-A4, the strengths of H2 and H3 was lost. Potentially available formants simply remained static. Though in this instance it was likely that the larynx was stable, there was no formant-tuning strategy to assist resonance as fundamental frequency of sung pitch rose.

Conversely Figures 4.4.11 and 4.4.12 (professional tenor 3 singing first a scale from D4-A4 and then F4-C5, p.121-122), show blue 'shadow' traces which are most likely explained as caused by formants amplifying vocal bi-noises. (Especially clear in 4.4.12, where the white arrow in the power spectrum indicates the probable position of the raised F1.) It seems at the very least possible, and more likely probable (since this singer used neither marked buccal opening nor lip spreading) that the rising of the formants caused by a degree of laryngeal elevation explains the signals shown.

The situation of formants as suggested in association with Figure 6.4.8. (p.193) show that both F1 and F2 have risen significantly and again it is quite probable that the cause of this for this young, relatively undeveloped voice, is laryngeal raising. This particular example illustrates the commonly found 'locking' of F1 and H2 above the top of the passaggio zone. This will be very familiar territory for anyone who teaches young male voices in Conservatoires.

These observations remain a matter of opinion, however there are many instances where the colour spectrum shows a clear trace of the presence of a formant with a blue 'shadow' line, easily seen because of its relation to surrounding partials and their strengths (eg Figures 6.2.7 and 6.2.8, p.175-176). In such instances it seems highly likely that the blue ‘shadow’ does indeed reveal the frequency of a formant, in the same way as occurs when deliberately employing non-periodic phonation such as vocal ‘fry’. Such information can help to make an assessment of resonance issues clearer in pedagogical situations.

Three further issues emerged through considering the examples which students recorded:

1) Conjunct scales which traverse the passaggio pose the greatest challenge in achieving apparent unity of voice and management of resonance at the top of the passaggio and beyond.
2) The ability to 'predict' likely moments of greatest vocal challenge via establishing the pitch positions of f_1 and f_2 creates an extra layer of awareness for pedagogues and student singers.
3) The need to be wary of practical demonstrations in a pedagogical context, since the location of formants in mature singers may be different to those of a student.

A clear example from student 2 showed how on ascending in a scale of a fifth from D4-A4 resonant quality was lost after the f_1/H2 relationship was relinquished after G4, because of rising pitch. No substitute for this timbral enhancement is found for the highest pitch of A4. However when a triad is then sung on D4, the A4 in that triad does find a new f_2/H3 resonance (Chapter 6.3, p.186). (Though the effect of f_2 is strongest at the top of the vibrato cycle). There are further instances of this effect in the student recorded examples. Though it is conjectural, it is likely that this is simply the way less trained voices tend to cling to a resonance quality which they perceive in some way as 'good'. When there are melodic leaps rather than conjunct motion singers appear to find it easier to 'reset'. That can of course mean a negative result, commonly, raising the larynx (and head position too) for rising pitch. The implication for pedagogues is that in the earlier stages of exploring the upper range it would not be productive to attempt this using conjunct scale passages. Interestingly this small finding echoes an established pedagogical approach to registration in the upper voice which was to deliberately separate the 'registers' until the student was certain of the proprioceptive sensation of the higher pitches and only subsequently attempt to build smooth overall unity. This approach has languished in general international pedagogy, (whilst retaining some advocates) because superficially, deliberately separating registers sounds so contrary to the intended final goal.

Some experience is needed to estimate formant locations using vocal fry, and the vowel the student uses must be the same as the intended sung vowel (as far as possible) to obtain approximately valid results. For those students who were able to do this, it was worthwhile since it made it possible to predict where there might be the most demanding moments for resonance. For a pedagogue to do this would obviously assist in giving students accurately targeted advice. It is also easier to diagnose why a particular pitch in, or beyond, the passaggio a student might find difficult. This was illuminating in examining the examples given by students 2, 6, 7 and 8. In each case it was possible to see why difficulties in resonance management occurred and diagnosis for improvement would have been enhanced by the extra detailed information obtained.

The third point, above, does not need amplification beyond saying that students tend to imitate the models to which they are exposed. Since formant positions of the 'models' may well be different from those of the students, this approach to instructing a singer may be misleading.

8.8. Questions concerning the contact quotient

Throughout the study, where possible and convenient, an EGG was used in conjunction with the spectrographic information, to estimate contact quotients. Herbst (2016) believes that this can give a reasonably useful estimate when singing is full voiced, tending towards operatic quality, rather than light, airy phonation or falsetto. All of the professional singers were working successfully in opera houses, though it was not possible to obtain properly functioning EGG signals from most of them. The students were all being trained towards eventually entering the operatic milieu, even if for some of them this was likely to be years into their futures. Student necks were more EGG-friendly, tending to have less insulatory subcutaneous material, prominent larynges, and less bushily obstructive beards.

Only two students showed CQ levels of less than 50%. The earlier recordings of student 1 (whose CQ levels subsequently became reliably higher as his technique developed) and student 3, showed levels which appeared to be extremely low – to the point where they might not have been trustworthy. However, the latter student's singing also sounded somewhat enervated, and so the signals did appear to make sense.

In general, findings were consonant with what is already established. In particular that the more resonant and more robust voices, likely to be cast in at least the lyric Fach, had CQ levels that very often exceeded 60% and sometimes were around the 70-74% levels noted by Miller, (2000, 2008) as obtained from established operatic voices. It was also noted often that CQ rates did not change significantly when a voice traversed the top of the passaggio and ascended into the upper range. Indeed rather than reducing there was a general tendency for CQ to be higher in the upper range. This concurs with Miller (2000, 2008), even though Miller was not writing specifically of student voices.

Professional Tenor 3 had very clear EGG signals which suggested that this was a moderate light lyric voice, with his CQ often around 55%. This seems quite modest for a regularly working operatic voice, but the singer demonstrated skilled manipulation of formant/vowel relationships.

Nonetheless, the observations did raise a number of very important questions for any voice research which is aimed at helping singers in their vocal production.

1) Can a low CQ rate be improved by training? If so, how is this best accomplished?
2) Are high CQ rates, over 70%, potentially damaging to the health of a voice?
3) Can CQ rates be influenced by changes in formant/vowel alignments in resonance?
4) Noting that many of the voices which showed high CQ rates, also had very rapid initial vocal fold closure rates, could this indicate that this element is in-borne in a 'talented' singer rather than achieved by training?

As these questions were not a primary aim of this project, the necessary rigorous material for properly discussing them was not obtained. They are, however, questions of significant interest for all those concerned with the professional male classical singing voice. It may be that studies investigating vocal dosage would have useful information which could partly at least answer questions such as [2] above. If the amount of time spent in full, sustained (loud) singing in the upper voice were shown to be only a small percentage of total vocal dose of an operatic role, this would suggest that singing with high CQ levels is part of a thrilling ‘only-just-possible’ display of art and craft from an elite group of singers. There is also the view that where resonance achieves a ‘standing wave’ in the vocal tract it is possible for a singer to have a high CQ level without the need for excessive effort, since the ‘standing wave’ is acoustically highly efficient.

8.9. Summary of main points

The management of the [a] vowel in the classical singing voice of the male is not required by a mechanical change in the function of the vocal folds, but by an acoustic issue caused by the second harmonic engaging with the first formant. The audible change in timbre which may occur at the top of the passaggio may give the impression of a change in register, whereas it is primarily a change in resonance. The established aesthetics of the repertoire, as exemplified in live performances and recordings of artists who are acknowledged to be amongst the best exponents, play an important part in the strategies which singers use in response to the acoustic issue. A skilled singer may be able to use differing strategies for the same pitch(es) according to artistic need. Charaktertenors appear to use an approach which contrasts strongly with that of all other Fach types. Student voices early in their Conservatoire level training find the link between second harmonic and first formant quite easily, but have some difficulty in achieving the more subtle skills needed at the top of the passaggio and in the higher range, where it may be desirable to find the link between the third harmonic and the second formant. Over a period of time they can be helped to achieve this accurately, and technology can play a part in this. Ultimately, how a singer resonates a particular pitch in the passaggio zone, especially pitches towards the top of the passaggio zone, will be influenced a wide variety of factors. These may include position and duration of the pitch within the musical phrase, volume, the intended emotional quality, the singer's vocal Fach, external factors such as orchestral forces and acoustic of hall/opera house, the particular singer's personal concepts of what constitutes best timbre, and the particular singer's level of skill.

In the end traversing the passaggio and ascending into, and maintaining, the upper range in male classical voices is a question of artistic judgement, rather than simply complying with the facts of physiology and acoustics. It is not possible, therefore, to give a definition of how the passaggio should/must be treated by a singer, as there exists a plurality of professionally justifiable differing solutions.

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Appendices

Appendix 1

Glossary of Terms

Body type: Three differing body types for males are identified by Sheldon (1954) and Vertinsky (2007). These are: **Mesomorph**, tendency to muscularity; strong/solid; square shaped physique; neither underweight nor overweight with even weight distribution. **Endomorph**, higher proportion of body fat; rounded physique and bone structure; tendency to gain weight. **Ectomorph**, small light body frame; tendency for long lean muscle with little mass; does not gain weight easily.

Chest Voice: Despite efforts from various sources to replace this traditional term for the lower area of pitch in a voice, this term remains very much in use, as does **Head Voice** (q.v.). Singers can feel vibration in the upper wall of the thorax. The vibration sensed there by the singer plays no role in the radiated sound which the voice produces and is not the source of the sound. The term is in very common usage, so much so that even some voice scientists continue to use it. In male voices chest voice is considered to be the lower pitch zone of the range up to the passaggio.

Chiaroscuro: Meaning, bright-dark, is an Italian term which refers to a balance between the relative strengths of low and high harmonics in a voice, creating the ideal cultivated Western classical singing voice timbre.

Closed vowel/Closed voice: Closed vowels have a low first formant such as [i] and [u]. In traditional vocal pedagogy the Italian term 'voce chiusa' (Austin, 2005) refers to a voice having a balanced richness of strength in upper and lower harmonics. It is not a reference to 'cover' or a physical closing of the throat. (Miller, 1996, pp.10 – 12)

Contact Quotient: The amount of time in a glottal cycle in which the glottis is effectively acoustically closed. Some inferences may be made about the depth of vocal fold contact, though this is not always reliable.

Covered tone/vowel: A term used by some singers to describe the 'darkened' tone sometimes deliberately employed at the top of the male passaggio zone. There is no consistent definition in traditional vocal pedagogy to describe the precise means by which this is achieved. This term may mean different things in differing languages, for example German 'Deckung' is quite different to Italianate 'Copertura'.

Electroglottography (EGG): Two non-invasive small electrodes are placed on either side of the thyroid flanges of the larynx. By using a very small electric current between the two it is possible to measure the conductivity and thereby estimate the level of vocal fold contact. Estimates can then be made as to the amount of time the glottis is closed. As a percentage of the glottal cycle of opening and closing this produces the contact quotient (CQ). (see Baken, 1992, for a basic explanation of electroglottography.)

Fach: Fach is the German word for categorising voice types. It is in use world-wide by opera houses, agents, singers, and pedagogues. This is mainly because the German speaking world of Germany, Austria and Switzerland combined have such a large number of professional opera houses (c. 95). Elements which contribute to voice categorisation may include vocal timbre, range, repertoire base, strength and stamina, physique, age and experience.

Formant: A formant is a resonance at a particular area of pitch caused by the shape of the vocal tract. Formants 1 and 2 are the most variable/tunable and are significant in defining a vowel. The singer's formant is a clustering together of at least two of formants 3, 4, and 5. This can strengthen harmonics in the region of 2,300 – 3,500 Hz (in the pitch zone of the top octave of the piano).This enables Western classical voices – particularly male operatic ones – to project over large orchestras. In some voices the strength of resonance of harmonics in the singer's formant zone constitutes the most prominent element in the overall sound pressure level.

Head Voice: Despite efforts from various sources to replace this traditional term for the highest area of pitch in a voice, this term remains very much in use, as does **Chest Voice** (q.v.) for the lower range. Singers can often sense vibration in the skull and face when singing in the higher range hence the use of this term. The vibration thereby experienced does not enhance the resonance of the radiated sound of the voice, nor is the head the source of the sound. The term remains in very common usage, even by some voice scientists.

Open vowel/Open voice: An open vowel is one with a high first formant such as [a] and [æ]. This should not be confused with open voice/timbre which the Italian term, ‘voce aperta’, describes in referring to singing tone which lacks balanced strength in harmonics.

Sound Pressure Level (SPL): this is the scientific measurement of the pressure within a sound wave relative to the surrounding air pressure. The SPL is measured in decibels (dB). Other commonly used terms such as volume, or loudness, depend on the perception of sound by the human ear and brain.

Standing wave: This is said to occur when a prominent harmonic can be seen in the audio signal to persist in strength through the open phase of the glottal cycle with very little loss of energy. The spectrum shows one harmonic as dominant at the frequency of the standing wave.

Vocal Dosage: Refers to the amount of time actually spent singing. For example, though an opera may last several hours, the vocal dosage of a particular role may only be quite small within that opera. Equally an aria may last five minutes, but the vocal dosage of the highest range could be as little as ten seconds. This measurement can therefore be helpful in assessing the likely consequences for vocal health of a particular sung element in an aria/opera.

Vocal Fry: This is the sound of air popping slowly through an otherwise closed glottis so that very nearly individual ‘clicks’ can be heard generating a sound which is also sometimes called vocal creak. The rate of such clicks is usually between 15 – 50

Hz. This non-periodic sound can produce a continuous spectrum revealing the approximate positions of formants 1 and 2 of the vocal tract. (See, Miller et al, 1997)

Voce piena in testa: Meaning, full voice in the head, is an Italian term used to denote full toned timbre of mezzo forte level or louder in Western classical singing of males. This is required in many classical vocal genres but especially in Opera.

Vowel modification: Is a very traditional tool for adjusting vowels by allowing one vowel to be subtly influenced by another in order to achieve a desired timbre. This is essentially what happens when a singer deliberately tunes a formant to obtain an acoustic advantage.

Appendix 2

Informed consent forms

<u>INFORMED CONSENT for STUDENT SINGERS</u>

Royal Conservatoire of Scotland

CONSENT TO PARTICIPATE IN A RESEARCH STUDY

<u>An anonymised study of male student classical voice development in the passaggio and higher range with particular reference to the [a] vowel, using spectrographic and electrolottographic examples.</u>

The following information describes the research study in which you are being asked participate. Please read the information carefully. At the end, you will be asked to sign if you agree to participate.

Purpose of the study:
The purpose of the study is to improve understanding of how vowels and resonance factors function in the male voice in the passaggio zone and above both at student and professional levels. The study is intended to generate acoustic information which is factual, rather than based on reported verbal description.
You are being asked to be in the study because you are a Conservatoire student training towards eventually becoming a professional singer.

Procedures:
You will be asked to sing a series of scales (either covering a whole octave or the interval of a fifth) and arpeggios, at pitches which are professionally normal for your voice. The vowel for these will mostly be [a], with some more limited use of [e]. Any adjustments to vowels which you would normally make in order to sing well you should continue to do so, singing 'normally'. These scales and arpeggios will be recorded using a head microphone in a stable position and an electroglottogram. The files are encoded electronically for further observation and analysis.

Risks and/discomforts:
We do not anticipate that you will experience any personal risk or discomfort from taking part in this study. The method of recording the data is non-invasive and well proven/established. If you wish to re-record any scale/arpeggio because you are personally not satisfied that the previous version was representative you may request a repetition. If you feel tired at any point you may request that the session be terminated.
If you feel uncomfortable at any point the procedure can be terminated at your request.
It is our aim that you should feel entirely at ease during the procedure.

Benefits:
No benefit can be promised to you from your participation in this study. The study is expected to benefit the larger singing and pedagogical community.

Confidentiality:
The recorded and encoded samples will be only identified as student tenor 1, student tenor 2 etc.
Samples will be securely kept on Mr Stephen Robertson's personal laptop and external hard drive (back up copy).
No other persons will have access to these samples, without your specific consent.
Participant/subject names will never appear in association with this study or its data/samples.

Publication:
The study will result in suitable articles for professional Journals such as the Journal of Singing and the Journal of Voice, plus presentations at specialist conferences.
Where exemplar material from your samples are needed, such material will be visually presented (as spectrograph or glottogram images), making it not possible to identify a particular singer.
For presentation at conferences, short examples of no more than five seconds may be used in addition to spectrograph and glottogram images.
In addition the results may be used to provide source material for a PhD dissertation by Stephen Robertson on the subject of the male passaggio and upper range of the male voice.

Costs:
There are no costs associated with your participation in this study.

Right to decline or withdraw:
Your participation in this study is voluntary. You are free to decline to participate or withdraw your consent at any time during the study.

Contact information:
Stephen Robertson (s.robertson@rcs.ac.uk tel., 00447931 317749) will gladly answer any questions you have concerning the purpose, procedures and outcome of this project. This study conforms to the advice given by British Educational Research Association governing research studies and ethics.

Participant agreement:
I have read the information in this consent form and agree to participate in this study. I have had the chance to ask any questions I have about this study, and they have been answered for me. I am entitled to a copy of this form after it has been read and signed.

Signature of participant

…………………………………..date……..

Signature of person obtaining consent

……………………………..……date……..

INFORMED CONSENT for PROFESSIONAL SINGERS

Royal Conservatoire of Scotland

CONSENT TO PARTICIPATE IN A RESEARCH STUDY

An anonymised study of current professional performance practice in operatic male classical voice production, as revealed in alignment of formants with harmonics, and in electroglottogram closed quotient levels, with particular reference to the 'passaggio' zone and beyond.

The following information describes the research study in which you are being asked participate. Please read the information carefully. At the end, you will be asked to sign if you agree to participate.

Purpose of the study:
The purpose of the study is to improve understanding of how vowels and resonance factors function in the male operatic voice in the passaggio zone and above. The study is intended to generate acoustic information which is factual, rather than based on reported verbal description.
You are being asked to be in the study because you are a professionally distinguished operatic singer.

Procedures:
You will be asked to sing a series of scales (either covering a whole octave or the interval of a fifth) and arpeggios, at pitches which are professionally normal for your voice. The vowel for these will mostly be [a], with some more limited use of [e]. Any adjustments to vowels which you would normally make in order to sing well you should continue to do so, singing 'normally'. These scales and arpeggios will be recorded using a head microphone in a stable position and an electroglottogram. The files are encoded electronically for further observation and analysis.

Risks and/discomforts:
We do not anticipate that you will experience any personal risk or discomfort from taking part in this study. The method of recording the data is non-invasive and well proven/established. If you wish to re-record any scale/arpeggio because you are personally not satisfied that the previous version was representative you may request a repetition. If you feel tired at any point you may request that the session be terminated.
If you feel uncomfortable at any point the procedure can be terminated at your request.
It is our aim that you should feel entirely at ease during the procedure.

Benefits:
No benefit can be promised to you from your participation in this study. The study is expected to benefit the larger singing and pedagogical community.

Confidentiality:
The recorded and encoded samples will be only identified as tenor 1, tenor 2 etc. Samples will be securely kept on Mr Stephen Robertson's personal laptop and external hard drive (back up copy).

No other persons will have access to these samples, without your specific consent. Participant/subject names will never appear in association with this study or its data/samples.

Publication:
The study will result in an article on the subject of the male passaggio and upper voice which will be offered to a suitable Journal (eg Journal of Singing, published by NATS), and/or presentations at professional conferences. Where exemplar material from your samples are needed, such material will be visually presented (as spectrograph or glottogram images), making it not possible to identify a particular singer.
For presentation at conferences, short examples of no more than five seconds may be used in addition to spectrograph and glottogram images.
In addition the results may be used to provide source material for a PhD dissertation by Stephen Robertson on the subject of the male passaggio and upper range of the male voice.

Costs:
There are no costs associated with your participation in this study.

Right to decline or withdraw:
Your participation in this study is voluntary. You are free to decline to participate or withdraw your consent at any time during the study.

Contact information:
Stephen Robertson (s.robertson@rcs.ac.uk tel., 00447931 317749) will gladly answer any questions you have concerning the purpose, procedures and outcome of this project. This study conforms to the advice given by British Educational Research Association governing research studies and ethics.

Participant agreement:
I have read the information in this consent form and agree to participate in this study. I have had the chance to ask any questions I have about this study, and they have been answered for me. I am entitled to a copy of this form after it has been read and signed.

Signature of participant

…………………………………..date……..

Signature of person obtaining consent

……………………………..……date……..

Appendix 3

Ethical Statement and Discussion

The [a] vowel in the male passaggio and upper range

This project is dependent on several different types of people who, it is proposed, would be participants in the sense that data and other material would be derived from their input. The two principal types of information would be, first material derived from surveys/interviews/questionnaires and secondly material derived from the use of the computer voice analysis system called *VoceVista*. There are four distinct groups of persons envisaged.

Recorded established professional singers

In current voice research it is not practice to seek the permission of this category of singers before proceeding with analysis. However, respect and consideration for the persons concerned must be duly exercised in accordance with the normal ethical considerations of those whose research involves humans. The analysis of published commercial recordings is well established in voice research. It does however behove researchers to present findings and analytical results fairly and without bias, using balanced, reasonable language that avoids personal comment. Findings must seek to be objective and factual. This project will be limited to examining the harmonics and implied formant characteristics of these singers via Long Term Average Spectra and will consequently be entirely factual.

Undergraduate and first level Post-graduate singers (probably aged 19-23)

In this category the ethical position is more complex and it will be necessary to have an appropriate system in place to deal with these aspects. The project as a whole will have to be clearly explained to students in terms which they can understand and the nature of the final written document (ie the dissertation) made clear. Volunteers will be sought and their written permission(s) obtained for use of material and data derived from their input. (The manner of seeking volunteers will need to be one which does not produce any kind of pressure to agree to volunteering.) The written permission(s) needs to include a statement about the use of materials derived from participants and protection of privacy mechanisms. Clearly the ethical concerns for this group of students is more complicated since the author occupies a position not only as tutor to some students who will be invited to volunteer, but also as someone who occupies a position of authority within the vocal department of the Academy, thereby causing the students to be in the category best described as having 'diminished autonomy'. Students must not feel compelled, or under pressure, to volunteer and must understand and genuinely feel that they are at liberty to cease being participants in the project at any stage and without having to explain their reason for wishing to withdraw. The design of the project will try to ensure that students time and bureaucratic commitment level as participants is minimised. Similarly the overall student learning experience must not be adversely affected by the project in any way. Crudely stated this means that normal individual lesson time(s) may not be diverted to the project unless such work is necessary and desirable for a student in any case. Nor must any student be caused to feel uncomfortable about their singing or general ability because of the project. Sensitivity will be required where complex issues become apparent. For example where a student who has volunteered to take part and who is not a student of the author produces results which show negative qualities, or even elements which might threaten overall vocal health, it will require tact and diplomacy to deal with the resultant situation, possibly requiring the cooperation and input of the relevant voice tutor. As the equipment can only produce factual information, it will be important that students understand such information in so far as it may help them. The equipment itself is non-invasive and extremely comfortable to use. There are no safety issues.

Mature Post-graduate singers (probably aged 25-31)

Many of the same issues outlined above are still relevant to this group but as these singers are older, more experienced adults they are more able to take decisions without feeling unduly influenced by others – such as the author in his position of authority. Nevertheless the same information, permissions and safeguards will be necessary.

Professional Singers (probably aged 35 and older)

These persons will be approached with a full explanation of the nature of the project and asked if they are willing to participate. If the result is positive they will be asked to sign a fairly simple disclaimer about the use of the material derived from their input and to show that they approve the overriding privacy policy arising from their input and cooperation.

Anonymity of material

The Australian *National Statement on Ethical Conduct in Research Involving Humans* (March 2007, ISBN 1864960434) identifies three different levels for data as regards anonymity; identified, potentially identifiable, and de-identified (not re-identifiable ie fully anonymous). For the purposes of this study it will be necessary to record some basic data about each singer (age and level of experience and training) and short computer based recordings of their singing and vocal fold behaviour. This material will be presented in the final dissertation without names, but labelled singer 1, 2, 3, etc. The storage of such information (including names) will be held as a private file not accessible to any third party. There is a very small chance that someone who already knew the distinguishing characteristics of a voice would be able to re-identify a singer. This is clearly not applicable to the section on internationally recognised artist's recordings.
In addition the design of any interviews/surveys/questionnaires will also safeguard personal identification so that people may speak and answer freely. Interviews will not be presented as recordings in the final dissertation but as transcripts (where necessary) which will have to have the approval of the person concerned.

The Data Protection Act 1998

This act states that people are entitled to know how and why personal data is stored. Permission is required for any disclosure of personal data to third parties. It will therefore be necessary for students and singers who become participants in this research project to be shown the proposed method of data storage and for them to agree that this is acceptable. Mostly this will be electronic storage with appropriate back-up copies in held on two sites in secure situations (ie locked) in order to avoid catastrophic loss eg from fire or theft. Not only will data be physically locked but it will also be protected by electronic passwords. Some intermediate processing of data will require hard copies which will also need to be secured.

In preparing this discussion the author has taken into account the RSAMD *Research Ethics Policy* (session 2007/08 currently pending revision), The British Educational Research Association's *Revised Ethical Guidelines for Educational Research* (2004), the *National Statement on Ethical Conduct in Research involving Humans* (2007) from Australia, the *Context of Ethics* issued by the Canadian Institute for Higher Education and available on the web site of the Government of Canada, and the *Code for Research Involving Human Subjects* (2007) issued by the University of Cape Town.

Professor Stephen Robertson.
September, 2008.

Appendix 4

Pilot study

Resonance Characteristics in Upper Passaggio Tenor Singing

One of the few areas of almost unanimous agreement amongst classical singers and teachers of singing is the desirability of achieving an ‘equalised scale’. This term is commonly used to refer to the aesthetically pleasing quality of a voice being able to produce a recognisably consistent sound throughout its musical range, without sudden marked changes in the sound quality perceived. Garcia’s definition of vocal register is often still the starting point for discussions of this aspect of the singer’s craft:

> ‘By the word register we mean a series of consecutive and homogenous tones going from high to low, produced by the development of the same mechanical principle, and whose nature differs essentially from another series of tones equally consecutive and homogenous produced by another mechanical principle. All the tones belonging to the same register are consequently of the same nature, whatever may be the modifications of timbre or of force to which one subjects them.’ (Paschke, 1984)

In all classical voice types the physiological mechanics of how registers work mean that achieving such an ‘equalised scale’ is a major challenge to the singer. For sopranos and mezzos perhaps the most awkward area is moving between areas of pitch which have been traditionally described as ‘chest’ and ‘middle’ voice. For the baritone and tenor the most difficult zone is that which by tradition has been labelled the ‘passaggio’ and the tenor in particular is called upon by the demands of the repertoire to spend a considerable amount of time in this zone. Many would argue that the successful negotiation of the range of the tenor (and baritone) beyond the passaggio depends greatly on how the passaggio zone itself is accomplished. Lyric tenor operatic roles make sophisticated demands on the singer within the pitch range of approximately D4-F#4, ie the range traditionally designated the passaggio. Even if it is not so called, the immutable physiologic and acoustic facts and laws will necessitate a strategy that successfully copes with the changes in registration and resonance which occur in this area of pitch.

There has been some significant research which seeks to examine this area in the last ten years. Miller (2000) began the process of closer analysis of resonance factors as determinants in registration processes, notably establishing a clear link between the strength of particular formants on open vowels in the male passaggio zone. Subsequently Miller (2008) sought to demonstrate how this information could be used in a practical context. Henrich (2006) summarised the current multiplicity of views on vocal registers, pointing out in conclusion the necessity of being precise about the means which are required to identify differing vocal registers. In discussing the differences between establishing registers as a purely laryngeal mechanism and secondly, as associated with differing resonance strategies Henrich helps make clear how it is that a multiplicity of views manage to co-exist. Sonninen et al., (1992) had previously attempted to examine the detail of vocal fold length changes and how this related to registration issues by the use of roentgeonological techniques. This showed a useful difference between what is described (in the study) as 'open' as opposed to 'covered' singing quality based on differing vocal cord behaviour, and associating vocal fatigue with retaining 'open' quality at higher pitches. In so doing this study tended to confirm a widely accepted major pedagogical aim, which is the avoidance of 'open' quality in the upper range of the singing voice. However, though this study observed and differentiated usefully in vocal cord behaviour, even establishing that some forms of behaviour might be considered as less effortful than others, it did not attempt to assess how such differing behaviour could be achieved.

In another approach the vocal tract was examined using Magnetic Resonance Imaging techniques for evidence of changes in configuration associated with registers (Echternacht et al, 2008). This work has not yet progressed very far, in that this study merely established that it was possible to observe changes in vocal tract shape in ascending scales. Schutte et al, (2005) examined how differing resonance strategies were employed in a particular context of recorded tenor high notes which suggested a possible approach for examining other areas of pitch within singing voice behaviour in order to try and establish what would seem to be preferred desirable characteristics. Neumann et al., (2005) further tested the assertions of Miller (2000) and in discussing the relationship of harmonics (especially those described as H2, H3 and H4) and how these are strengthened (or not) by coinciding (or not coinciding) with nearby formants (especially f_1 and f_2) confirmed Miller's earlier findings. The conclusion states that, "In 'chest' both H2 and H4 dominate because they are resonated by f_1 and f_2. During the passaggio the spectral energy of H2 is reduced because it loses the resonance of f_1 whereas f_2 is now tuned to H3. Simultaneously, H4 decreases its amplitude because it is not supported by f_2 any longer." (Neumann et al, 2005 p.326.)

A potential weakness in this study was that the singers were recruited from an opera chorus. Such singers would not necessarily demonstrate what could be subsequently regarded as the highest available levels of professional expertise. However the findings of both Miller (2000 and 2008) and Neumann et al, (2005) offer a reasonably clear basis for further examination of the spectral characteristics of the male voice in the passaggio zone.

This is clearly an area of prime concern for all those who either sing or teach. This pilot study seeks to determine what strategies are employed by singers of well-established high repute who are either living and performing currently, or very recently. The material used was limited to examining two very exposed and revealing moments from the aria 'Una Furtiva Lagrima' from Donizetti's opera 'L'Elisir d'Amore'.

Extract 1

Extract 2

The first of these extracts (bar 20/21) shows an exposed prolonged F♮4 (349 herz if A tuned to 440) on the Italian word ‘vo’. The second extract (bar 44-48) includes a cadenza scale which traverses the entire passaggio zone on the first syllable of the word ‘chiedo’. These two moments were selected for presentation here because they show the resonance strategies at particularly crucial moments and also because these moments are relatively free from any orchestral crowding of audio signals.

Method

Each extract was examined using the ‘VoceVista’ voice analysis computer software programme. The readings for each harmonic were taken from the power spectrum using an average spectrum setting of 200 ms, which setting is long enough to give a representation of what the human ear hears rather than a shorter setting which could give rise to erratic results depending on the vibrato rate of the singer.

For extract one, using the coupled time scrolling cursor available which links the spectrogram to the power spectrum (offering a detailed slice from a particular point in time of the spectrogram) it was possible to scroll through the extract to identify highest points of differences between H1, H2 and H3. These were generally noted to be consistent for each note examined, (exceptions are discussed below). (The procedure was tested on three different computers to see if there would be inconsistencies in results caused by differing sound cards installed on computers. This was found to not be the case; results were extremely consistent. The signal from each recording was passed directly to VoceVista electronically by the sound card of each computer – not acoustically via a microphone.)

For extract two a measurement was taken late in the ascending scale passage, (for most of the performances, on the brief F♮4), and then a second reading a moment later on the more sustained high A♮4. Timings are given in each case showing the length of time between the two measurements.

Schutte et al., (2005 p.304) argued for the validity of recorded samples as source material for analysis stating that,

> 'The strongest argument for taking recordings as evidence of the actual resonance strategies of the singers comes from the f_2-H3 effect, used by the large majority of singers represented'.

Their study used some 80 examples gathered from throughout the 20th century and therefore was working with material that had been produced by widely differing technologies ranging from early primitive recordings through to relatively modern digital ones. In so far as the f_2-H3 affect seemed to be a constantly clearly discernible feature often represented by a significant dB difference they point out that,

> "While it is technically possible for an artificial adjustment of harmonic levels to reach that magnitude, it seems quite unlikely in the absence of a widespread awareness of this strategy among singing teachers." (Ibid)

They also pointed out that,

> 'Insofar as such experts find the distinctions still present in recordings, the acoustic signals of these are authentic'. (Ibid)

In other words where experts such as singers, singing teachers and critics can clearly identify individual voices from seemingly very short snippets of recordings it follows logically that these recordings have some kind of validity as encoding such individual characteristics which it should be possible to identify and analyse.

In recent years the rapid development of easily accessed recordings available via internet sites such as 'YouTube' has made it much easier to access recorded material. Discretion has to be exercised regarding the quality of the recordings, but almost any modern recording is clearer than some of the extremely old technology which has been hitherto regarded as admissible in published research (7). The material here presented is easily accessed and the analysis can be similarly easily repeated and therefore checked by anyone with the necessary equipment.

The internet site 'YouTube' lists currently (as of 22/4/2009) 569 video entries with the heading 'Una Furtiva Lagrima'. Over 200 hundred of these videos were considered for inclusion for this study. Only video performances by very well established artists of international repute with clear audio signals were used. Not all videos give exact dates and venues of performances, which is a pity as it would be of interest to compare performances by the same artists (eg Pavarotti) covering a span of time. (Though it would of course be possible to organise a separate study for that purpose.)

Results (Spectral harmonic data derived from recordings.) **Extract 1 'vo'** (IPA [ɔ])

For further details about each recording (where these were available) see appendix 1. H1 = harmonic 1. H2 = harmonic 2 etc. The numbers show the strength of each harmonic in decibels. These decibel readings show thereby the differences in the strength of the various individual harmonics.

It should be noted that the dB scale runs from minus figures, getting stronger towards 0. (Hence in the first example shown Domingo's second harmonic is clearly 14dB louder than H1 and 6dB louder than H3 meaning that it predominates in the overall sound.)

These figures are taken from an instant of the long held F♮ on the syllable 'vo', as described above. The relevant differences in the various harmonics can be easily discerned.

Placido Domingo 1

H1 -28

H2 -14

H3 -20

Placido Domingo 2

H1 -32

H2 -18 (when moving up to Ab H3 becomes much more dominant at -12.)

Luciano Pavarotti

H1 -26

H2 -17

H3 -5

(When vowel changes to a in following bar but same note of F♮ 349 herz, H1 -32 H2 -4 H3 -17.)

Ramon Vargas1

H1 -28

H2 values as high as -7, but consistently higher than -11.

H3 -26

Ramon Vargas2

H1 -34

H2 -12

H3 -31

(H1, 2, and 3 remain unchanged when vowel changes to ‘a’ in first syllable of ‘mama’.)

Jose Carreras 1

H1 -35

H2 -19

H3 -28 (though in some places H2 and H3 erratically more equal)

Jose Carreras 2

H1 -26

H2 -15

H3 -28

Jose Carreras 3

Shows some moments where H2 and H3 balanced in strength, both significantly stronger than H1.

Juan Diego Florez

H2 and H3 almsot balanced with H2 marginally stronger. However H2 clearly stronger on change to ‘a’ vowel in first syllable of ‘mama’.

Alfredo Kraus

H2 -13

H3 -28.

Marcelo Alvarez

H3 stronger by small margin, changing to H2 becoming stronger on syllable ‘ma’.

Analysis – extract 1 ‘vo’.

The vowel for the Italian word vo in the sentence ‘Che piu cercando io vo’ is an open vowel represented in the International Phonetic Alphabet as [ɔ]. Miller (2000 and 2008) has shown that when a male singer enters his passaggio zone on an open vowel this is clearly indicated by a spike in the level of the second harmonic, caused by the first formant (f_1) resonating the second harmonic (H2). As fundamental pitch (F0) ascends at some point it will rise beyond the ability of f_1 to follow H2 at which point if the singer persists with the same strategy a register violation (for a full discussion of this term Miller, 2000 pp. 129-138) will occur. The most often encountered sign that the singer has successfully negotiated changes in resonance and registration that avoid undesirable forcing of the voice is that H2 drops back in prominence and another harmonic(s) takes over the limelight – very often the third harmonic (H3) being resonated by the second formant (f_2), (though even at this stage it may be pointed out that some singers strengthen the so-called third formant area at the point that H2 gives up its locked relationship to f_1). For the present study these events are a very convenient way to observe the upper passaggio strategy as exemplified by the chosen singers/performances. Singers would tend to describe these events as either ‘chest/open’ or ‘head/closed’, such terms being in very common use in performing and teaching of singing.

Of the eight singers examined here, four (Domingo, Vargas, Carreras [in two recordings], and Kraus) sing the sustained F at 349 Hz in extract 1 with significantly strengthened H2 –ie in ‘chest/open’ voice. Three singers (Pavarotti, Alavarez, and Alagna) exhibit H3/f_2 resonance indicating where H3 is significantly stronger than H2 or any other harmonic, and thereby showing an earlier arrival in ‘head/closed’ voice quality than the first group.

The recording by Alavrez is interesting in that he opts to begin the sustained F♮ on ‘vo’ with H3 prominent but as a crescendo takes place he alters the vowel gradually towards ‘a’ and as this occurs nearly losing the dominance of H3 until in the next bar the vowel change is complete and the voice reverts to H2 being the strongest harmonic.

In one of the three recordings by Carreras (from 1986 film) H2 and H3 seem mostly equal throughout the F♮ on ‘vo’ with H2 becoming dominant at the word change in the next bar. It seems therefore probable that H2 and H3 are close enough to f_1 and f_2 to pick up some benefit from their presence.

There are some interesting striking further features that are worth noting. Domingo shows complete consistency in the two different recordings examined in that both times there is a 14dB differential between H1 and H2 even though absolute overall levels are not the same. The two different recordings of Vargas (the first when he was young and the second mid-career) show a consistent approach. Many of the singers show a difference of more than 12dB between the chosen dominant harmonic and the next strongest harmonic, which is sufficient for the voice to be substantially carried by the resonated harmonic. All of the chosen group showed that on reaching the Ab4 415 Hz in bar 3 on the vowel ‘a’ of extract 1, that H3 has become clearly the strongest harmonic. This clearly suggests that whatever change of registration (in association with resonance change) is in progress at some point at the top of the passaggio area, it is distinct by the time pitch has ascended to Ab4.

One further remarkable feature is that Pavarotti appears to manage the biggest dB differential between harmonics with for example a 21dB difference between H1 and H3 on ‘vo’ and a very striking 28dB difference between H1 and H2 on ‘ma’ in the next bar. This would suggest very decisively executed resonance strategies which one might reasonably interpret as meaning that the singer uses an economic (in effort terms) and cleanly acoustically efficient voice.

Results Extract 2 ‘chiedo’ (middle vowel, IPA [ɛ])

Showing two sets of figures for each singer, the first taken just before the leap from F♮4-A♮4 in the cadenza scale (mostly taken from the F♮4) and then secondly, immediately after the leap, a measurement on the pitch A♮4. The time gap between measurements is stated in milliseconds. Some extra measurements are given of higher harmonics where these are interesting/revealing (discussed below). Figures in brackets are the pitch in herz of harmonics, given in some examples to make it possible to see the relationship of higher harmonics to the area of acoustic strength usually referred to as the 'singers'formant'.

Luciano Pavarotti 1

@**351 Hz** (if A is tuned to 440, F4 is 349 Hz)

H1 -30

H2 -3

H3 -31

H4 -25

H6 -23

H7 -9 (2382 Hz)

367ms later @ 449 Hz

H1 -15

H2 -22

H3 -24

H4 -8

H5 -11 (2255hz)

Luviano Pavarotti 2 (1991)

@ **351 Hz**

H1 -34

H2 -18

H3 -29

H4 -22 (1455 Hz)

279ms later @439 Hz

H1 -29

H2 -32

H3 -30

H4 -16

H5 -21

H6 -23 (2636 Hz)

H7 -26 (3066 Hz)

H8 -24 (3496 Hz)

Ramon Vargas 1 (2007)

@292 Hz (D4 is 294)

H1 -32

H2 -5

H3 -29

H4 -21

H5 -25 (1503 Hz)

988ms later @351hz (F4 is 349 Hz)

H1 -21

H2 -22

H3 -25

H4 -14 (1494 Hz)

150ms later @ 419 Hz

H1 -14

H2 -22

H3 -19 (1250 Hz)

194ms later @ 439 Hz

H1 -19

H2 -22

H3 -8

H4 -31 (1757 Hz)

Ramon Vargas 2 (identified as 'young')

@ **332 Hz**

H1 -28

H2 -7

H3 -39

H4 -28

Note H9 -10 (2988 Hz)

644ms later @ 449 Hz

H1 -25

H2 -24

H3 -18

H4 -18

H5 -17 (2246 Hz)

H6 -15 (2744 Hz)

H7 -15 (3144 Hz)

Roberto Alagna

@302 Hz (294 Hz is D4, 311 Hz is D#4)

H1 -29

H2 -15

H3 -45

H4 -19 (1220 Hz)

1462ms later @ 453 Hz

H1 -16

H2 -29

H3 -7

H4 -22

H5 -13 (2382 Hz)

('Third formant' levels also look high at mostly stronger than -10dB)

Jose Carreras

@**351 Hz**

H1 -25

H2 -11

H3 -25

H4 -19 (Though scrolling shows that for most of scale passage H2 clearly strongest)

Note: Interestingly **387ms later** Carreras inserts a brief strongly aspirated neutral vowel with a very strong H3 predominant at -4dB before ascending to the high A♮.

430ms later @439 Hz

H1 -23

H2 -27

H3 -18

H4 -5

Note: Scrolling shows H4 as generally predominant through the high A♮4 , but there are some moments where H5 takes over at the top of the vibrato pitch cycle.

Placido Domingo

@**351 Hz**

H1 -29

H2 -11

H3 -21

H4 -16

345 ms later @449 Hz

H1 -27

H2 -30

H3 -11

H4 -9

H5 -13 (2275 Hz)

H6 -12 (2734 Hz)

Analysis – extract 2 ‘chiedo’.

This cadenza-like scale culminating in the leap of a third, from F♮4-A♮4, whilst maintaining the same vowel, was chosen because it traverses the entire passaggio zone of the tenor voice and is unaccompanied, thereby affording clear acoustic signals uncluttered by orchestral sound. The vowel which is used is the vowel printed as ‘e’ in the word chiedo, and pronounced in Italian as an open vowel, represented in the International Phonetic Alphabet as [ε] . It is an important moment in the aria as it comes prominently at the end, creating a climax of both emotion and pitch (it is the only A♮4 in the aria, that being the highest note).

Of the seven performances under consideration six have strongly emphasised second harmonics through the passaggio zone up to and including the F♮4 (349 Hz). This is extremely important information for those who teach this voice type and repertoire, since it suggests that these singers choose to remain in ‘open’ registration as late as possible even though this particular pitch of F♮4 is often pivotal and one on which tenors are often advised to 'close', (given the information above, presumably by unlocking the acoustic emphasis on H2). It would be extremely easy to allow the open vowel [ɛ] to modify towards the closed vowel of [e], which would effect a change of registration in the terms discussed here. It might even be thought desirable, as logically, this would prepare the way for the high A♮4. It is therefore very significant that this strategy is largely eschewed here.

The exception to this is the Vargas 1 performance, which shows strongly 'open' registration on the D♮4 as the passage ascends. It seems then that the second formant strengthens H4 around the F♮4, and as pitch further ascends, (in a rapid glissando barely 150 milliseconds later), it briefly strengthens H3 around the pitch of G# (here at 419 Hz) after which H3 further strengthens and is clearly the strongest harmonic. To achieve this, Vargas moves away from the strategy of slightly closing the [ɛ] vowel towards [e] for the A♮4 which is what the other six performances show (to a greater or lesser degree). Instead he modifies his vowel towards [a] which has the effect of dropping the second formant sufficiently so that it tunes to H3 efficiently. This is clearly either an instinctive or deliberate decision on his part, either way it is a matter of aesthetic taste. It should be noted that in Vargas2 (recorded when he was much younger) harmonics are tuned in the manner exemplified by the other tenors here discussed.

Pavarotti in both performances shows cleanly efficient tuning of harmonics with striking changes from strong H2 on the F♮4, to H4 on the high A♮4. Alagna is clearly using 'open' registration in his passaggio region and then utilizes H3 for the A♮4, employing the same vowel strategy as Vargas1 for the A♮4. Carreras is interesting because although scrolling through the scale passage within the passaggio zone shows that he locks onto H2, he disrupts this locked relationship with a brief aspirated repetition of the vowel, (modified towards the neutral vowel [ə]), with a suddenly strengthened H3, before proceeding to the more conventional tuning of second formant/H4 for the A♮4 . Domingo (like Pavarotti) exhibits a cleanly rapid change, accomplished in less than half a second, from strongly 'open' registration on the F♮4, to emphasized H4 on the A♮4. (Note also the comparative strengths of H3, and the singer's formant area shown above by the strength of H5 and H6. The important point remains that H2 is far weaker than any of these, indicating that 'open' registration has been quitted.)

The most significant fact here is that all these singers (including the younger Vargas) prefer to stay in 'open' (or 'chest') registration up to and including the F♮4, before seeking an alternative strategy for the A♮4.

Conclusions

The aim of this pilot study was to further refine and make clear what resonance strategies we should be guided by for higher passaggio notes on open vowels, as demonstrated by singers of well-established high repute. Very often both singers and voice teachers speak of F♮ 349 Hz as being the pivotal pitch between what they call chest/open voice and head/closed voice. However what is clear here is that the professional tenors show that this F♮ 349 Hz can be sung in two different ways – either chest/open or head/closed (to use singer's vernacular), with the suggestion in one case (Carreras) that it might be possible also to achieve the impression of neither area being predominant. There is always the possibility that in the latter case this could be seen as less efficient singing with indecisive or poorly executed resonance. The fact that (in extract 1) all the singers moved to H3 dominant resonance for the higher Ab4 pitch would strongly suggest that the change from H2 to H3 resonance is a feature of successful passaggio execution and that the current study of one particular note exposes the pitch where the options and vocal challenge are most complex. Extract 2 shows that again though all singers had distinctively strengthened H2 levels in the passaggio, all quitted this relationship on moving to the A♮4. The fact that in six out of seven performances singers chose to remain in 'open' registration up to and including F♮4 when it would theoretically have been easy to move towards 'closed' registration in preparing to move to A♮4 is of pedagogical significance and merits further investigation.

There are some factors which we have not taken into account here and which it may be fairly argued could be influential in the strategies adopted by individual singers.

For example what dynamic/volume level was the singer aiming to achieve? Was the singer looking to achieve a particular emotional quality on the note chosen? What did the singer believe to be the relative demands of preserving the absolute integrity of the language as opposed to merely vocal considerations? Such complexities are beyond the scope of the current article but cannot be dismissed as irrelevancies for such considerations could seriously influence the choices made by singers.

As a final note it is relevant to remember that for the vast majority of tenors and voice teachers most of the conclusions offered above as regards the available options for coping with a pivotal moment in vocal registration would bring no surprise. However not many would be aware of the detail of the acoustic facts that surround this known technical hurdle. By becoming more aware of such detail it may in time be possible to suggest that some strategies are to be preferred. Certainly it would be interesting to compare the results presented here with a second group of singers all drawn from a student level of expertise to discern differences in results which could help identify desirable learning skills.

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Appendix 1a

Spectral harmonic data derived from recordings with additional information about recordings.

Placido Domingo 1 (unidentified commercial recording) H1 -28 H2 -14 H3 -20

Placido Domingo 2 (c. Pritchard) H1 -32 H2 -18 (when moving up to Ab H3 becomes much more dominant at -12.)

Luciano Pavarotti (live recording from Albert Hall Royal Gala Performance c.Adler 1982) H1 -26 H2 -17 H3 -5 .(When vowel changes to a in following bar (but same note of F 349 herz) H1 -32 H2 -4 H3 -17.)

Ramon Vargas1 (broadcast concert from Baden-Baden August 2007) H1 -28 H2 values as high as -7 but consistently higher than -11, H3 -26.

Ramon Vargas2 (unidentified recording from early 90s) H1 -34 H2 -12 H3 -31.(H1, 2, and 3 remain almost unchanged when vowel changes to ‘a’ in first syllable of ‘mama’.)

Jose Carreras 1 (Liceu Barcelona Feb 1982) H1 -35 H2 -19 H3 -28 (though in some places H2 and H3 erratically more equal)

Jose Carreras 2 (listed as telecast, undated) H1 -26 H2 -15 H3 -28

Jose Carreras 3 (soundtrack from film ‘Romanza Final’ 1986) shows some moments where H2 and H3 balanced in strength, both significantly stronger than H1.

Juan Diego Florez (recording made for professional broadcast Teatro Cuyas Las Palmas May 2005) H2 and H3 almost balanced with H2 marginally stronger however H2 clearly stronger on change to ‘a’ vowel in first syllable of ‘mama’.

Alfredo Kraus (broadcast concert with Orchestre Sinfonica de Bilbao Sept 1991) H2 -13 whereas H3 -28.

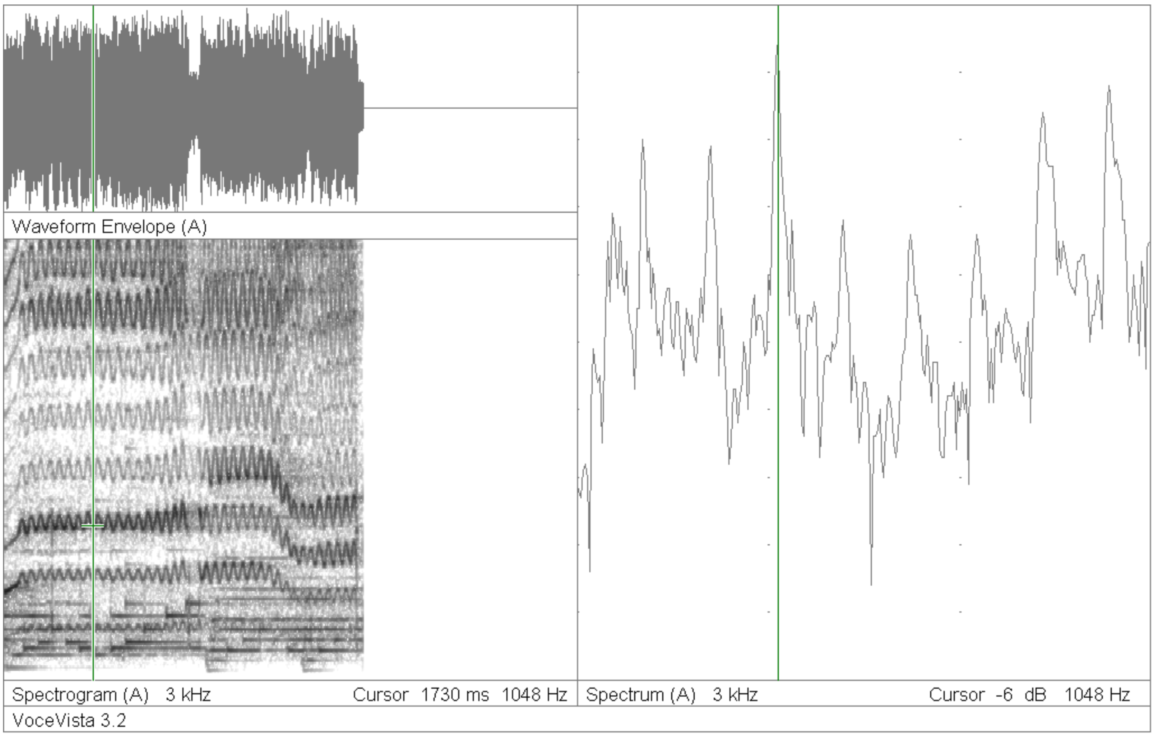
Marcelo Alvarez (Faenol Festival broadcast by Artsworld August 2000) readings show H3 stronger by small margin changing to H2 becoming stronger on syllable ‘ma’.

Roberto Alagna (Filmed by Opera national de lyon in 1996, released by Decca in 1997)
H2 -34 H3 -22

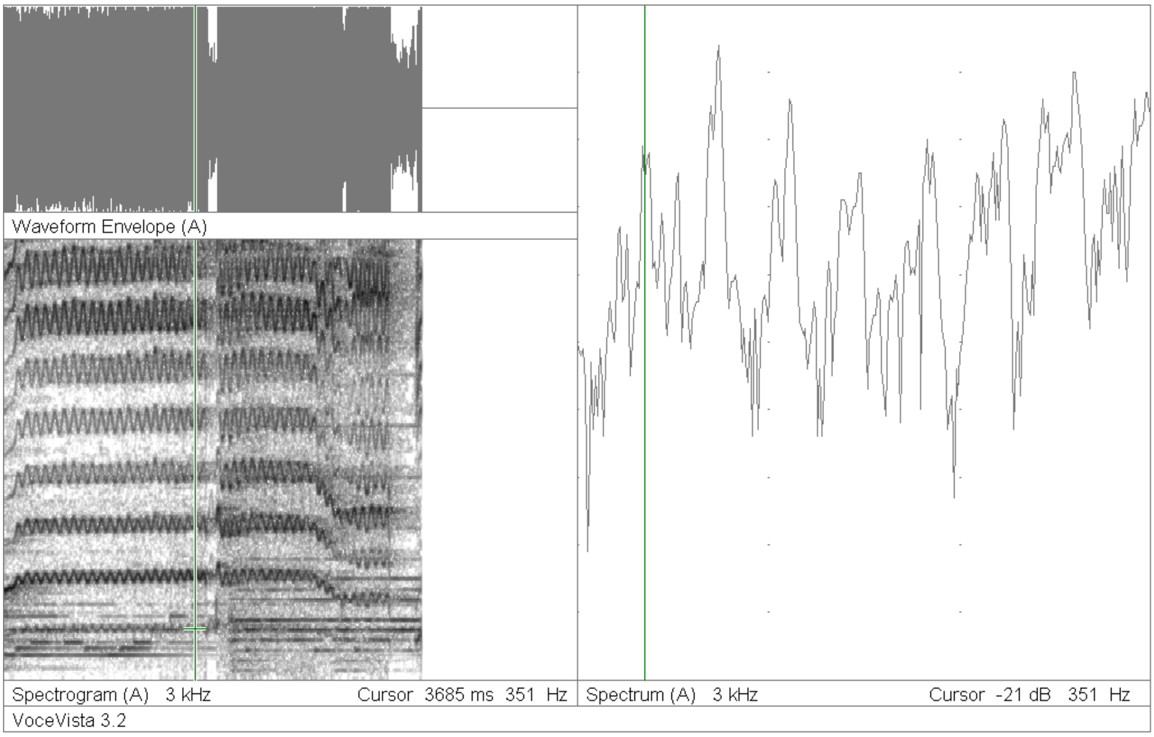
Appendix 2

Examples taken from VoceVista screens relevant to extract 1.

Pavarotti (Albert Hall performance) singing on the syllable ‘vo’, clearly showing much strengthened H3.



Domingo1 singing ‘vo’ showing dominant H2.



Vargas1 singing ‘vo’ showing very dominant H2.