The Female Choir Voice: important considerations

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Summary
The human singing voice changes throughout the lifespan and there are also gender-specific variations that need to be taken into account when working with females. Life changes in terms of voice are different for females and males and this chapter concentrates on the female singing voice in the context of choral singing. Data are presented relating to the changing female voice during puberty as part of a longitudinal study of female choristers in a major English Cathedral Choir School. In addition, discussion is presented on important considerations with respect to the female choral singing voice in the context of specific choral aspects during rehearsals and performance.

Introduction
Singing is something that provides great pleasure and satisfaction to many people, whether they sing in the privacy of their own home, sing in a choir or sing solos in public audiences. For many such singers, singing is simply something that they can do without realising that, with some added knowledge, vocal improvements could probably be made quite readily.

Our understanding of the way in which the human voice works in terms of its underlying anatomy and physiology, how best to 'play' the voice as an 'instrument' and the nature of the resulting acoustic output, has moved on hugely over the last 20-30 years. This is primarily as a result of the ubiquity of personal computers (PCs) and their ability to carry out acoustic signal analysis fast enough to enable real-time displays to be presented on-screen when singing. Many young singers now expect to make use of their PCs and other portable technology in their everyday lives, and these can be included as part of their voice training as a means to understand better the underlying principles of voice physiology and voice acoustics (e.g., see Welch et al, 2005; La, 2014).

There are male/female differences that are important in the context of the singing voice, particularly in terms of the pitch ranges covered, some of the voice qualities that are employed in performance and the absolute sounds of the vowels produced as a result of differing female/male vocal tract sizes. These are important considerations with respect not only to the solo voice, but also for the choral voice in terms of intonation and blend; two core aspects of improving excellence in choral performance. In this paper we explore acoustic aspects over five years of longitudinal development of a female chorister in an English Cathedral Choir.

Acoustics of the female singing voice
The human singing voice can be considered in terms of three elements: the power source, the sound source and the sound modifiers (Howard and Murphy, 2009). These

three elements relate to the physiology of the vocal instrument as well as a basis upon which the contribution of their acoustic function to the overall acoustic output can be considered.

The *power source* provides the energy for vocal sound production and, in singing, this is the control of airflow from the lungs, which in turn, affects the nature of the acoustic output from the vibrating vocal folds. Developing an appropriate breathing technique is basic to a good singing technique, but is beyond the scope of this chapter; further information can be found in Watson (2014).

The *sound source* for pitched notes is the vibrating vocal folds in the larynx. Their regular vibration at a controlled rate results in an acoustic output that is perceived at a specific pitch (related to fundamental frequency, F0). For example, if a singer's vocal folds are vibrating 440 times a second, they are singing the note A above middle C (this is the reference pitch that a struck orchestral tuning fork produces and the note that an oboist plays as a reference when a Western classical orchestra is tuning up, and it is usually indicated as A4). A pitch increase of an octave results in a doubling of the F0 of vocal fold vibration, so when a soprano sings the note A5 (an octave above the A4 discussed above), her vocal folds are vibrating 880 times a second, usually reported as 880 Hertz or 880 Hz. Because the sung vocal ranges of female singers are very approximately between a sixth and an octave above those of male singers, a female singer's vocal folds will vibrate up to twice as many times as her male counterpart. Noting that the vibrating vocal folds collide at the midline in every vibratory cycle and that this results in an arresting of the airflow as the glottis closes, provides an explanation of the origin of the acoustic excitation to the vocal tract during singing and speech. In order to assure that these collisions can occur in a healthy manner without damaging the tissues of the vocal folds (an action that is often quite reasonably compared to a hand clap), indulging in healthy vocal practice is particularly important for vocal performers (e.g. see Howard, 2015). One of the main requirements for prolonged vocal health is to keep the folds themselves well lubricated by drinking plenty of water; the presence of bottles of water with vocal performers is therefore quite commonplace.

Assured control of the vibration of the vocal folds is critical for holding a note at a steady pitch. Overall control of pitch is a skill to be attained by a singer when singing the different notes of a melody by changing pitch (changing the vibration rate of the vocal folds), changing the overall loudness of a note to create musical dynamic variations from pianissimo (*pp*) to fortissimo (*ff*), increasing or decreasing the amount of vibrato (pitch undulation), as well as starting and ending notes whilst maintaining their pitches throughout no matter what the text set to the note is.

In addition, there are major variations between females and males during voice change from pre- to during puberty. At that point in life, there are major physical changes and, in the case of voice production these occur in speech as well as singing, because the larynx changes considerably in size under the impact of hormonal changes. Given that the larynx is the sound source in singing and speech, changes in its overall size causes significant changes in the nature of its acoustic output. At pre-puberty, the female and male larynxes are approximately the same size. Pubertal change results in an approximate doubling in linear dimensions of the larynx for boys and a linear dimension increase of around 20% for girls. In female singers the vocal folds are shorter than those for male singers as shown in table 1 (data from Roers et al; 2007), and they vary directly as a function of the reducing pitch range of the sung parts as one would expect. When singing, the vocal folds close and open to create the pitched sound source for the vocal tract, and the time for which the folds remain in contact during each cycle changes with singing experience and training. Howard (1995) found that there is a difference between trained and untrained female singers such that this contact time increases with sung pitch for trained singers but not for untrained singers. Earlier, Howard et al (1990) suggested that increased contact time provides a singer with three advantages: (1) less lung air is used overall (meaning the singer's breath lasts longer and breaths can be taken less often), (2) a greater amount of acoustic energy is produced into the performance space via the mouth and/or nostrils since less is lost to the lung spaces ('known as 'sub glottal damping') because the vocal folds are apart for a shorter time in each cycle, and (3) the perceived voice quality is less breathy.

Table 1: Mean vocal fold lengths for female and male singers (data from Roers et al., 2007).

part	sopranos	mezzos	altos	tenors	baritones	basses
length (mm)	14.9	16.0	16.6	18.4	19.5	20.9

Pitch control develops with age and experience and it starts when we learn to speak, when we take on board the intonation of the language that surrounds us, mostly at home (Welch, 2005). Singing with someone else poses a different scenario, in that the starting note to sing is likely to be set by an external pitch reference, such as another human voice, or an individual note from a piano, or other instrument, or, for example, an introduction played on a piano, organ, band, or by an orchestra. For a small proportion of people, making the link with an external pitch reference and getting the starting note (and other notes) in-tune is a really difficult thing to do, and often this is referred to (completely inappropriately in our view) as being 'tone deaf'; 'tone dumbness' is a better term. This inability to sing in-tune can be changed with some guidance and practice on pitch focussing to an external reference note as opposed to the internalised pitch reference used when speaking; there is nothing to prevent in-tune singing ability to flourish (Welch, 2006; 2009). Furthermore, a landmark study seeking to understand singing proficiency in the general adult population (Dalla Bella et al., 2007) reported that the majority of adult participants could, when prompted, sing a recognisable tune from memory with relatively few pitch deviations. Furthermore, these adult participants—termed 'occasional singers'—were more pitch accurate if they performed the well-known target melody at slower tempi, being generally as accurate as a comparison group of professional singers.

It has been noted that choirs tend to sing descending passages accurately, but that they have a tendency to sing sharp when singing ascending passages (Sundberg, 1989). This effect was investigated further in terms of tempo by Jers and Ternström (2005) for all four sung parts (soprano, alto, tenor, bass) when singing the Canon *Laudate Dominum* by Praetorius in unison. They calculated the standard deviation in fundamental frequency for a specific recurring note in the Canon and found a similar variation across all four parts (the overall ranges were: 23-28 cents when singing faster and 16-18 cents when singing slower), In all cases, intonation was more accurate when singing slower.

Howard and Angus (1999) looked at the ability to sing in-tune by boys and girls in Years 3-6 inclusive (approximate ages 8-11 years old) in a UK Primary school. They found through that girls develop accurate absolute and relative pitch matching skills earlier than the boys from approximately the age of 9 years (school Year 4). In addition, for both boys and girls, they found that unisons were always pitched very accurately and that pitching accuracy decreased as a function of the extent of the musical interval being tested (in their case the intervals were: unison and rising and falling minor third, major third, perfect fifth). They further found that all ascending intervals were pitched too narrow; all falling intervals were pitched too wide, but that intervals were generally pitched more accurately when ascending.

Singers monitor their pitch constantly against any relevant external reference (accompaniment or other singers) and this feedback process is basic to a singer's ability to remain in-tune. The role of this feedback mechanism has been explored by Burnett et al., (1998). Their listeners were asked to produce a vowel ('ah') on a sustained pitch while wearing headphones over which a pitch signal was played back, based on their phonation. Listeners were asked to take no notice of the feedback in the headphones and to hold their pitch and intensity levels. At a point in the experiment, the feedback pitch was increased by a semitone. Two responses were observed: (1) the minority of listeners moved their pitch *towards* the change, while (2) the majority of listeners moved the opposite way as if to compensate for the pitch change. Larson et al. named these two responses as *following* and *opposing* respectively. Their conclusions suggest that when a singer monitors their F0, it is not affected much by changes in the level of feedback or local acoustic noise. Larson et al. further suggest that this F0 monitoring may be mainly used for making small F0 adjustments relating to 'aberrations in the neuromuscular control, fatigue, or biomechanical changes in the cover of the vocal folds'. They suggest that the difference between a *following* and *opposing* response is perhaps related to listeners either relying on an external F0 reference and therefore they *follow* the F0 change – this would be relevant when singing in a choir by tuning to other singers – or relying on *pitch memory* of an internalised F0 and therefore they *oppose* the change to bring the F0 back to its expected value.

The effect of the stages of the monthly menstrual cycle in regard to pitching accuracy is also an important consideration. Lã and Davidson (2005) report that singers have reported a number of symptoms, including vocal fatigue, hoarseness, decreased range, problems singing pianissimo and difficulties controlling intonation and vibrato. Lã et al. (2012) looked at variation in intonation accuracy and vibrato control during the menstrual cycle in a six month double-blind randomized placebo-controlled trial involving two groups of female singers, where one group took an oral contraceptive pill and the other took a placebo. Neither the researchers nor the subjects knew which group any individual participant was in. Eight sopranos and one mezzo soprano completed the study, which involved singing a short exercise in which an octave change from F4 to F5 and from B4 to B5 was recorded in each of three phases of the menstrual cycle in the third month of the trial and analysed. The expected changes in pitch control with the placebo were not found across the three phases, although the expected variations in hormonal concentrations were confirmed. Taking the oral contraceptive pill did not stabilise intonation compared with the placebo, but there was a difference in the F4 to F5 octave accuracy between the three phases. The study confirms that there is likely to be an interaction between hormonal changes and pitch control and Lã et al. suggest that perhaps the specific finding in relation to the F4 to F5 octave might relate to passaggio change.

Development of *sound source* control in the female choir voice

The ability to control pitch in a manner appropriate for choral singing involves a degree of control over the vibration of the vocal folds that is normally greater than it is during speech in terms of the requirements of singing individual notes and changing between notes in a musical manner. In addition, the pitches of individual notes have to be maintained during any consonants associated with the words being sung when those consonants are themselves voiced or pitched (such as those in *“me”*, *“no”*, *“love”*, *“ding”*, *“rang”*, *“bring”* and *“though”*).

In order to observe changes in the pitch control of the developing female voice, a series of recordings of a girl chorister taken between May 1999 and June 2004 are presented below at two yearly intervals between 1999 and 2003 and then in the final version 13 months later in June 2004. During these sessions, a number of items were recorded including a read passage, spoken and sung isolated vowel-consonant-vowel utterances, a two-octave G major scale and a sung verse of either the carol “*This is the truth sent from above*” or the nursery rhyme “*Baa baa black sheep*”.

To explore changes in pitch control, the second line (*“the truth of God the God of love”*) of the carol *“This is the truth sent from above”* has been used; its score is shown in Figure 1. Fundamental frequency (F0) plots for this target melody fragment are shown in Figure 2 for four recording covering the overall time range of the recordings, in May 1999, May 2001, May 2003 and June 2004. Note that the Y-axis is in cents above F4 (100 cents is one semitone and so the starting note is B4 as shown in the score in Figure 1, which is 600 cents above F4).

Figure 1: Score as sung for the recordings of the second line (*“the truth of God the God of love”*) of the carol *“This is the truth sent from above”.*

The F0 contours shown in Figure 2 can be compared directly with the score in Figure 1 to identify individual notes and words. Observation of the four F0 contours shows that the individual notes become steadier (shown horizontally) in terms of their F0 over time; a feature that is commonly associated with the developing chorister voice. This is particularly apparent on comparing the plot for the May 1999 recording with the other three. For the May 1999 recording there is considerable variation in F0 in each individual note; sometimes this is over one semitone. For the following three F0 plots, individual notes have steadier F0 contours year-on-year, and that for June 2004 is the steadiest of all, which is what one might expect, as it was the latest, i.e., most experienced one. In addition, there is considerable overshoot in the starts of notes in the May 1999 recording and to a lesser degree in the May 2000 recording. By the final June 2004 recording, the onsets are generally well-defined; where there are swoops at note onsets and offsets, these relate to the consonants involved, as described next.

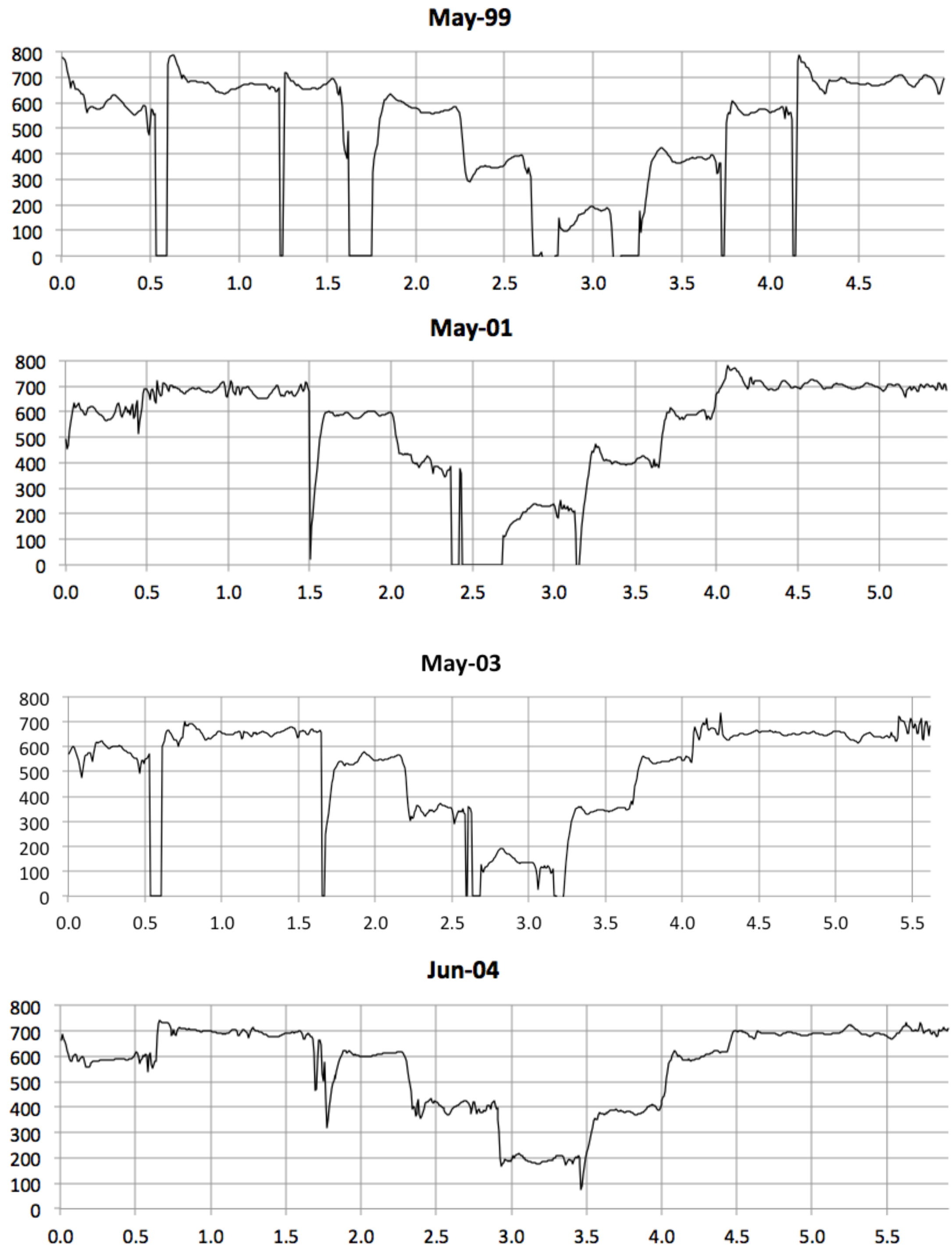

Figure 2: Fundamental frequency (F0) contours for four sung renderings by one girl cathedral chorister of *'the truth of God the God of love'* (the second line of the traditional carol *'This is the truth from above'*) recorded in May 1999, May 2001, May 2003 and June 2004. Note that the X-axis is time in seconds and varies for each plot since the singer set the tempo at the time, and the Y-axis is in cents from F4 for convenience (100 cents equals 1 semitone giving a starting note of B4).

The second note for the word "*truth*" starts with a voiceless alveolar plosive followed by a voiced alveolar approximant. Any closure in the vocal tract between vowels during continuous singing has the potential to pull the F0 to a lower value unless it is compensated for; this is normally something that improves with experience. In these four examples, there are two (the 1st and 3rd) that exhibit a break in the F0 contour (shown as vertically changes in the trace), while the other two have no break. Having no break implies that the alveolar plosive has been changed from voiceless to voiced (a /d/ instead of a /t/) – a choral technique that is very appropriate for *legato* singing of a phrase, and which is probably the interpretation that was familiar to this chorister from her past experience, either of this piece or of other music being rehearsed around the time of the recording. It is also noteworthy that the 2nd recording has rapid F0 fluctuations at the end of the first note and at the start of the second note. These are a result of the /r/ being sung as a rolled /r/; something that is common in this choir. The 3rd recording matches the 1st in terms of the break at this point in the F0 contour, while the 4th recording exhibits a clean well-defined F0 transition between these two notes.

The word "*truth*" is followed by "*of"*, and in the 1st recording, these are sung as two clearly separated notes. For the other three recordings, there is no break between these two notes. The next word is "*God*" on the 4th and 5th notes (see the score in Figure 1), and the /g/ is sung with a break in the F0 contour, but this break becomes less marked over time, which could relate to attempts to make the sung line more *legato*. In all cases, the word '*God*' is stressed and this is part realised by making the break itself. The next word is "*the*", which in speech would be fully voiced. For these four sung versions, there is a breath just before this "*the*" in all but the 4th version, suggesting the development of a musical phrasing that is more appropriate to performance of this particular line.

The second "*God*" tends to be stressed, causing a strong voicing on the voice velar plosive /g/. As this occurs, the airway is very narrow and, therefore, there is a tendency for the F0 to be reduced during the /g/ followed by a swoop in F0 to the note itself as the vowel starts. Such a swoop is visible in all four plots; in the first, there is an obvious break before the word "God", whereas for the other three, there is a swoop from below. This swoop is least marked in the final recording, suggesting that attention is being paid to the phrasing of a legato line in keeping with what can be observed for the remainder of the phrase.

The remainder of the phrase is "of love', and in all cases, there is an F0 join visible at the start of both notes for the final three recordings; the first recording continues with small breaks between notes. In this case there is a voice alveolar plosive at the end of the word "God" and a voice lateral approximant at the start of the word "love".

Voicing remains intact and the F0 contour is maintained in the last three recordings, but with an F0 overshoot during the lateral; a sound where the vocal tract is not constricted and there is possibly an over-compensation being made for the consonant.

Comparing the score in Figure 1 with the F0 plots in Figure 2, it can be seen that the ability to tune a note appropriately changes with time and experience. Note that the Y-axis in Figure 2 is in cents (100 cents is equal to one semitone) above the arbitrary reference note chosen for the plot, F4; thus the starting note B4 is at 600 cents because it is 6 semitones above F4. Looking at the first note in each of the four recordings, it is close to G4 (200 cents above F4), suggesting that the piano used (which was the same instrument in each case) remained in tune. Observing individual notes in the phrase across the recordings indicates that they are not close to their scored pitches in the first three recordings. Indeed, there is evidence of a certain amount of pitch gliding at the starts of some of the notes, especially the G4 sung to the second ‘the’.

Most important of all in these F0 plots is evidence of pitch control development during thee snapshot recordings for this chorister. A comparison of the first and last recordings makes it clear that there is a move from the words being sung separately to a smooth F0 line where the words are joined as a music phrase appropriate for this piece, and appropriate to the singing expected of a chorister for the interpretation of cathedral music repertoire.

Development of *sound modifier* control in the female choir voice

The sound modifiers form an integral part of the human voice production mechanism and, in the context of singing, there is an expectation that choir members listen to each other and modify their pitch (sound source) as well as their timbre (sound modifiers) in a manner that is appropriate to their contribution to the overall choral sound. This is something of a ‘balancing act’, since the sung output is a combination of the sound source being changed acoustically by the sound modifiers and either of these can be responsible for changes in the perceived output.

The main aspect that is controlled by the sound modifiers during speech and singing is the sound of the language – the vowels and consonants. This we learn early in life, but the individual sounds are not identical from speaker to speaker, even within one language, since there are regional accent variations. Acoustically, it is the underlying resonances of the vocal tract that act as the sound modifiers because the overall shape and volume of the vocal tract changes as different sounds are articulated. Any shape or volume variation within the tract will move the resonances of the vocal tract in terms of their position in frequency (their centre frequencies) and the range over which they have an effect (their bandwidths). When we perceive or analyse different spoken or sing sounds, the frequency peaks in the output that appear as a result of the positions of the vocal tract acoustic resonances are known as ‘formants’ (Titze et al., 2015). The formants provide the basis upon which listeners identify the vowels and other sounds of language.

In choral singing, the overall sound of a choir changes greatly if, for example, the vowels produced by individual singers are not closely matched, due to an audible mismatch between individual singers as a result of their voal tract resonance settings being different. This matching is one element of choral 'blend', and it makes a clearly perceivable difference to the overall sound of a choir if singers match their sounds well or not (Killian and Basinger, 2007; Ternström, 1012). In terms of technique, the main requirements for achieving good choral blend are excellent musically honed critical listening skills on the part of each singer, in conjunction with appropriate physical placement of singers so they can hear each other readily as well as themselves at appropriate levels. This latter requirement has been quantified as the 'self-to-other ratio' (Ternström, 1999) and has, for example, been studied for singers in a professional opera chorus (Ternström et al., 2005)

For the developing singer, especially during voice change, these listening skills are particularly important as the individual comes to terms with the sound of their new, emerging voice as vocal change advances. Less has been written about sound modifier control, but it is a critical aspect of a singer's skill if they are to contribute professionally to the overall choral blend of their choir.

In sung acoustic terms, an analysis that is commonly applied is the long-term average spectrum (LTAS), such as those shown in Figures 3-5 for the same recordings for which F0 tracks are plotted in Figure 2. An LTAS enables the distribution of energy with frequency to be observed for an acoustic signal, in this case a sung line of a carol. Change over time can be tracked in such plots, and this can be observed in Figure 3 where the individual LTAS plots for the four recordings are clearly different, particularly in the 3-4 kHz region and the 6-11 kHz region. Acoustically, vowels are distinguished essentially by the frequency positions of the lowest two acoustic resonances of the vocal tract, known as the first and second formants, or F1 and F2. The first and second formants are typically found in the frequency region below 2 250 Hz (Baken and Orlikoff, 1999).

The frequency positions of the higher formants (F3, F4, F5 …) in the region above 2.5 kHz relate to the overall *timbre* or *quality* of the perceived sound, and this is a particularly factor in singing in terms of the overall quality of the voice and how it blends in with other singers in the context, for example, of choral singing. Changing the shape and volume of the epilarynx tube - the space above the vocal folds that ends at the upper margins of the aryepiglottic folds (Moisik et al., 2010) - particularly affects the frequency positions of F3, F4 and F5 and can result in an enhanced overall acoustic resonance peak in the 2.5 kHz to 4 kHz region that is referred to as the 'singers formant' or more commonly nowadays as the 'singer's formant cluster' (Sundberg, 1989), based on the idea of it being a clustering of the 3rd, 4th and 5th formants (Sundberg, 1974). Trained tenors have been shown to have a second energy peak in the 8-9 kHz region in addition to the singers formant cluster in the 3 kHz region that has been attributed to the second acoustic resonance of the epilarynx tube (Titze and Jin, 2003). In the context of the children's singing voice, evidence suggests that the perceived 'ring' relates to their singers formant cluster around 4 kHz (higher than that for adults since their epilarynx tube dimensions are smaller), and a strong second acoustic epilarynx tube peak in the 7.5-11 kHz region that may be the main acoustic cue to 'ring' (Howard et al, 2014). It is also worth noting the acoustic effect of the piriform fossae, which are located just above the oesophagus. They act to help define perceptually the upper frequency margin of the singer's formant cluster by adding an acoustic anti-resonance in the 4-5 kHz region (Delvaux and Howard, 2014).

Apart from the sound that one is singing in terms of whether it is a vowel or a consonant, which in itself is important for blend in terms of all singers focussing on the same end result, other aspects of the overall sound are also important. In particular, there is the ability to project the sung output that is something Western classical individual singers typically learn in the context of solo singing. This is a function of changing the volume and shape of the space immediately above the vocal folds where there is a tube that is often referred to as the ‘epilarynx’ tube.

In a choral context, vocal projection is usually something that is typically rather inappropriate, since it can result in individual voice standing out in the overall sound of the choir in a very obvious manner. In a solo singing context, the ability to project the voice is important, especially when microphones are not being used, but even then it must be employed with musical sensitivity. Many soloists are able to control the degree of vocal projection in a sensitive manner, enabling them to contribute to performances as both solo and choral singers as required. The ability to make this change is something that emerges with listening, guidance from singing teachers and conductors and experience.

In the context of a cathedral choir, the issue of choral blend is extremely important and something that is usually worked on explicitly during rehearsals. The change in overall spectral shape in the frequency region above 2.4 kHz, the *timbral* region, will relate to the extent to which an individual’s singing voice will stand out within the overall choral sound and the degree to which a singer can blend in with the other voices. Basic to being able to do either of these is the ability to modify in a controlled manner the frequency content in the timbral region (above 2.5 kHz), specifically the singers formant cluster.

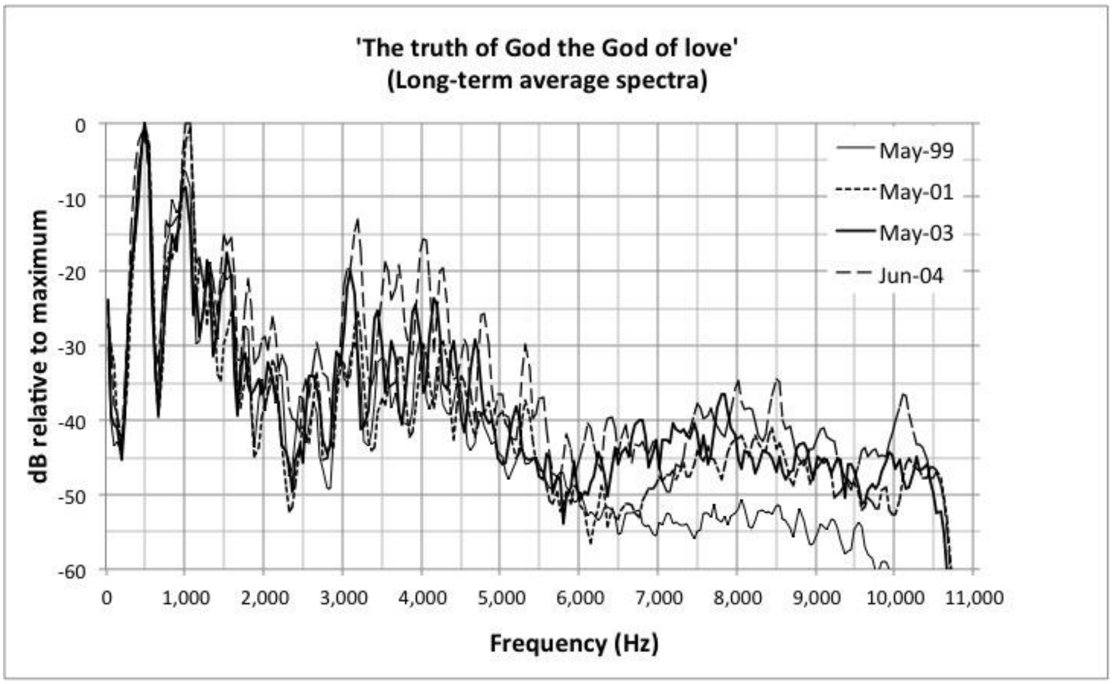

Figure 3: Long-term average spectra (LTAS) for four sung renderings by one girl cathedral chorister of *‘the truth of God the God of love’* (the second line of *‘This is the truth from above’*) recorded in May 1999, May 2001, May 2003 and June 2004. Note that all four plots are

normalised with their lowest peak being fixed at 0dB to enable differences in the LTAS plots to be observed.

Figure 3 shows long-term average spectra (LTAS) for four renderings by one female cathedral chorister of *'the truth of God the God of love'* (the second line of *'This is the truth from above'* – see Figure 1) recorded in May 1999, May 2001, May 2003 and June 2004, where the lowest frequency peak has been normalised for all four plots to 0dB to enable direct comparison of spectral differences. Over the period of time within which these recordings were made there is considerable spectral variation of up to around 12dB, especially in the frequency regions 3-4 kHz and 6-10 kHz. Such changes will be readily heard by listeners and being in these frequency regions, will relate primarily to overall projection of the sound in the formant cluster frequency region, as well as adding sense of 'ring' to the output as described above (Howard et al, 2014). Whilst such additions might not be welcomed in all choral situations, what is particularly important is the singer's ability to control these in a musically appropriate manner.

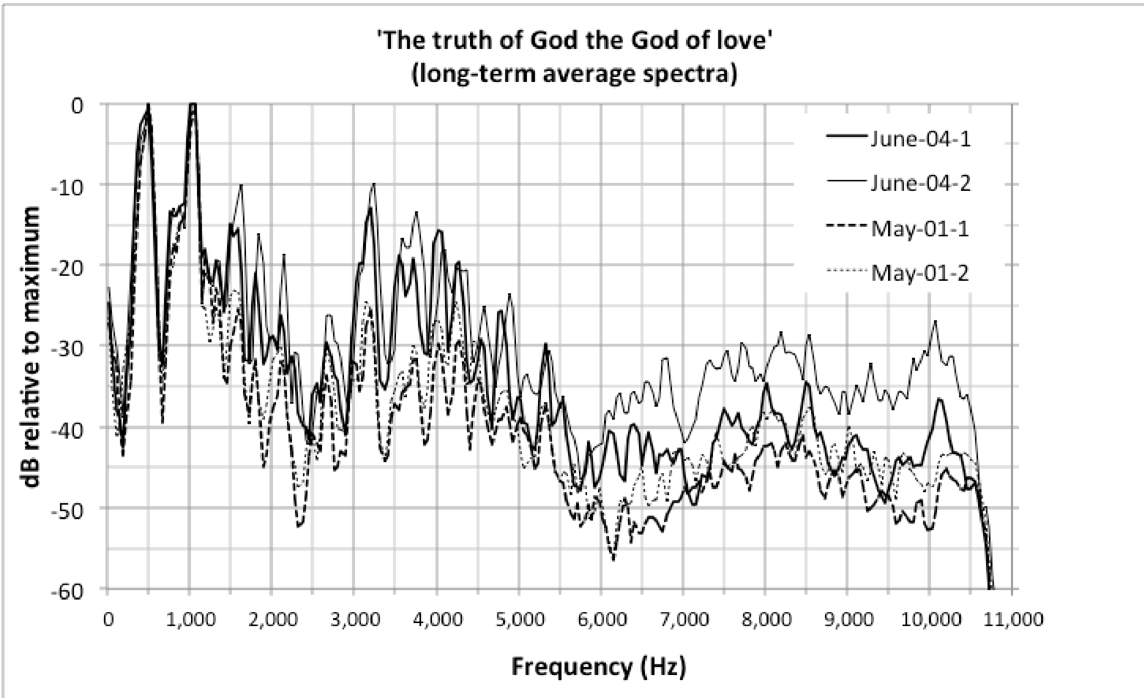

Figure 4: Long-term average spectra (LTAS) for four sung renderings by one girl cathedral chorister of *'the truth of God the God of love'* (the second line of *'This is the truth from above'*) recorded 3 years apart in May 2001 and June 2004. On each occasion, the 'normal choir' recording (indicated as 'May-01-1' and 'June-04-1') was followed by a 'solo performance' version (indicated as 'May-01-2' and 'June-04-2'). Note that all four plots are normalised with their lowest peak being fixed at 0dB to enable differences in the LTAS plots to be observed.

Figure 4 shows that this chorister is indeed able to control the degree of change in these *timbral* spectral regions. Here, LTAS for four renderings by the girl cathedral chorister of *'the truth of God the God of love'* (the second line of *'This is the truth* *from above'*) are plotted for recordings made 3 years apart in May 2001 and June 2004. On each occasion, the 'normal choir' recordings (indicated in the figure as 'May-01-1' and 'June-04-1') were followed by a 'solo performance' version (indicated in the figure as 'May-01-2' and 'June-04-2'). Again, the lowest frequency peak has been normalised for all four plots to 0dB to enable direct comparison of spectral variation. It can be seen that on both occasions, she is able to alter the spectral content in the 'ring' region (7.5-11 kHz) in particular in a manner that is rather modest in the earlier 2001 recording compared to the much greater very obvious change produced in the 2004 recording. This provides direct evidence of a developing vocal and choral skill in the context of singing regular daily rehearsals, as well as services approximately every other day (alternately with the boys' choir). Direct evidence of vocal development is also shown in the singers formant cluster region in terms of the difference between the 2001 and 2004 recordings, where there is around a 15dB difference between the peaks across the recordings, but very little change between the 'normal choir' and 'solo performance' versions on either occasion.

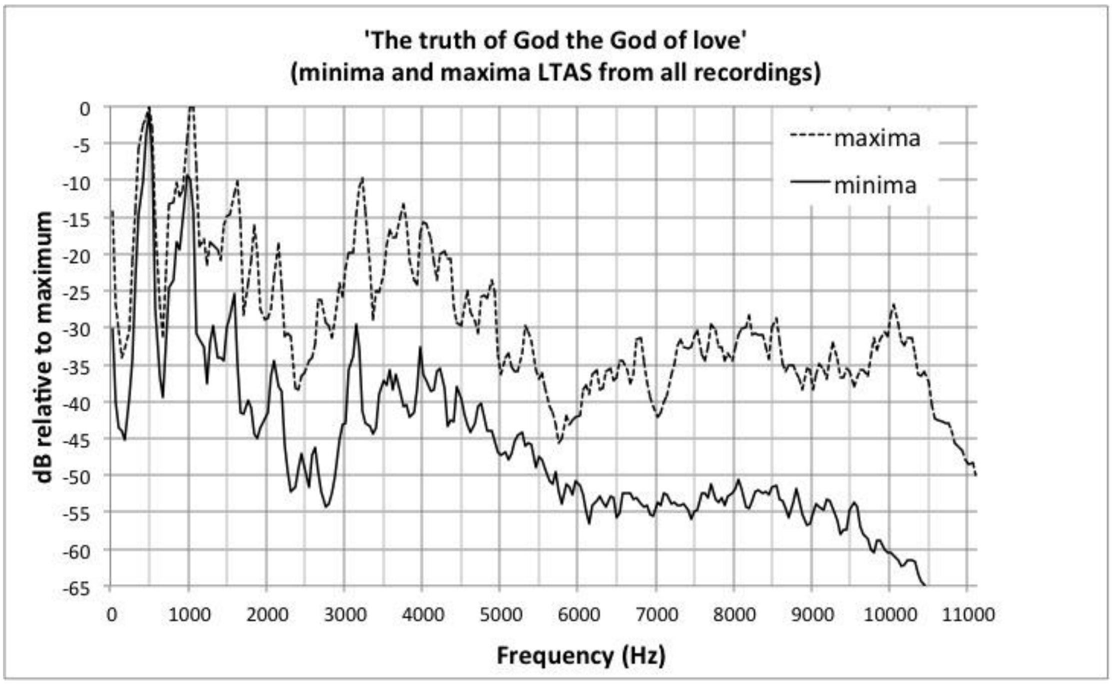

Figure 5: Plot of the minimum and maximum values from long-term average spectra (LTAS) for all sung renderings by one girl cathedral chorister from eight recordings of *'the truth of God the God of love'* (the second line of *'This is the truth from above'*) recorded between May 1999 and June 2004. Note that all four plots are normalised with their lowest peak being fixed at 0dB to enable differences in the LTAS plots to be observed.

In order to provide a clear picture of the potential to modify her sung output across all the recordings that have been considered, Figure 5 shows the minimum and maximum values from the LTAS plots for all the sung renderings by one girl cathedral chorister from eight recordings of *'the truth of God the God of love'* (the second line of *'This is the truth from above'*) recorded between May 1999 and June 2004. Once again the plots have been normalised such that the lowest peaks are set to 0dB to enable comparison between the plots. Here it can be seen that there is a huge variation evident in the *timbral* region between the minimum and maximum values achieved by this girl chorister across both the overall time period and the ‘normal choir’ and ‘solo performance’ recordings.

Conclusions

The overall in-tune and blended sound of a choir requires sensitive musical input that is based on individual critical listening from each and every member. These two aspects of choral singing (tuning and blend) are often rather neglected in terms of detailed work by singers and their director during rehearsals, and yet they are probably the most critical in terms of the providing an exceptional and noteworthy overall audience listening experience.

This chapter has considered the developing choral singing voice of a girl chorister in an English Cathedral Choir over 5 years. It has demonstrated her changing pitch control over this period, as illustrated by fundamental frequency plots over time. These have shown improvements in tuning as well as note onsets, and improvements over time with regard to appropriate pitch control during consonants. In terms of blend, of singing as part of a group, experimental results show that she develops considerable control over the output spectrum of her voice, particularly in what we describe as the *timbral* region (above 2.5kHz). In addition, her ability to change her vocal output between a ‘normal choral’ and a ‘solo performance’ voice is far more marked in the last of the recordings than the first recordings, suggesting that this aspect of timbral vocal control is available to her to an increasing degree over time in her contribution to an overall choral blend within the choir.

In particular for this girl chorister, the data suggest that the highly engaging musical setting in which she finds herself is very conducive to encouraging a high degree of versatility in being able to control the pitch and the timbre of her sung sound; both vital aspects that underpin some of the main differences between the outputs of professional and amateur choirs.

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