The implications of intensive singing training on the vocal health and development of boy choristers in an English cathedral choir

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Abstract

Boy choristers who sing in UK cathedrals and major chapels perform to a professional standard on a daily basis, with linked rehearsals, whilst also following a full school curriculum. This research will investigate the impact of this intensive schedule in relation to current vocal health and future development.

This research reports the findings of a longitudinal chorister study, based in one of London's cathedrals. Singing and vocal behaviour have been profiled on a six-monthly basis across three years using data from a specially designed perceptual and acoustic assessment protocol. The speaking and singing voice data have been analysed using a selection of techniques in current usage in both laboratory and clinical settings. Evaluation and comparison of these methods has enabled a range of effective assessment protocols to be suggested. The behaviour of the voice at the onset of adolescent voice change has been observed using electroglottogram data. The boarding choristers numbered thirty-four in total, eleven of whom were selected for longitudinal analysis. Similar acoustic data have also been collected from three other groups of boys, a total of ninety individuals, for comparative purposes.

It has been possible to quantify the possible influence of both school environment and vocal activity on overall vocal health. Significant differences have been noted between the vocal health of the boys in the chorister group and the non-choristers; the boarding choristers, although having the highest vocal loading, have the lowest incidence of voice disorder. This would in itself suggest that either the voice is being athletically conditioned to support such activity, or that the chorister group employs some self-regulation with regard to overusing the voice. The comparison with various other groups of boys implicates the cultural and social influences of peer groups in voice use.

The longitudinal observations of the choristers illustrate the development of vocal skills and the impact of increased choral responsibility on the vocal health of the individuals. It has also provided insights into the vocal behaviour during the onset of adolescent voice change with particular information about the vocal skills employed in the upper pitch range; the nature of phonation in the upper pitch range of trained boy singers entering voice change

resembles that of trained adult countertenors, rather than the usual adult male falsetto phonation.

The results of this study enable us to understand better the effects of such training and performance on underlying vocal behaviour and vocal health in boy choristers.

I hereby declare that, except where explicit attribution is made, the work presented in this thesis is entirely my own.

Jenevora Williams 25.03.10

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List of abbreviations used in this thesis

A4	A note with a F_0 of 440Hz; the letter defines the musical note, the number denotes the octave and it changes when ascending from B to C. C1 is the lowest C on a piano keyboard.
ANOVA	Analysis of variance
C1-C7	Cervical vertebrae; C1 is located at the top of the cervical spine
CQ	Closed quotient: the percentage of each vocal fold vibration cycle for which they remain in contact
CRB	Criminal records bureau
dB	Decibels: used to quantify sound level based on a reference level (see dBSPL)
dBSPL	Sound pressure level: Commonly used dB scale for sound level referenced to 20 micro Pascals (μPa) which is the average threshold of hearing.
EAIS	Equal appearing intervallic scale
F_0	Fundamental frequency: the lowest frequency component of a sound signal. It is the rate of cyclic vibrations per second, in a sound, measured in Hertz (Hz)
F1	The first formant in a sound; F2 is the second formant etc.
GRBAS	Grade, roughness, breathiness, asthenia and strain
HNR	Harmonic to noise ratio: a comparison of the amplitudes of harmonics and inharmonic spectrum components
Hz	Hertz: the rate of cyclic vibrations per second in a sound
LTAS	Long-term average spectrum: the distribution of sound energy at different frequencies within the signal, averaged over time
Lx	Electrolaryngograph
RV	Residual lung volume: the volume of air remaining in the lungs after complete expiration
SATB	Soprano, Alto, Tenor, Bass: the voice parts in western classical choral music
SLT	Speech and language therapist
SPL	Sound pressure level: see dBSPL

SPSS	Statistical package for the social sciences
TLC	Total lung capacity: the total volume of air which can be contained within the lungs
VAS	Visual analogue scale
VC	Vital capacity: the total lung volume available for respiration (the total lung volume minus the residual lung volume)
VPA	Voice profile analysis

Chapter 1

The boy chorister in British cathedrals – history and contemporary practice

1.1 Introduction

This study was initiated as a result of the author's involvement as a singing teacher to cathedral choristers in all three major London cathedrals (St Paul's Cathedral, Westminster Abbey and Westminster Cathedral) at various times from the 1980s to the 2000s. This teaching comprised individual singing lessons for all of the choristers on a weekly or fortnightly basis. For these the author drew upon her professional experience as an operatic soloist, oratorio and choral singer. At the time when this teaching work was undertaken, there were no vocal pedagogy courses available in the UK. Teaching knowledge was based on personal experience and observation of other teachers. The nature of the singing teaching given to the choristers by the author was broad and varied. It incorporated technical and developmental guidance within the context of choral singing as well as training the boys to a high standard for professional solo work. Selected boys were coached for operatic solos with The Royal Opera House, Covent Garden; Glyndebourne Festival Opera and Les Arts Florissant (Paris). The work with the choristers also included choral warm-ups, group technical guidance and technical consultation during rehearsal. It did not include artistic direction of the group or any work with the adult members of the choirs. Twenty years of experience and accumulated knowledge regarding the singing voices of boys between the ages of 8 and 13 resulted in the author having some authority in the pedagogical aspects of this type of vocal activity as well as an experienced ear for assessing vocal behaviour.

There had been a brief flurry of media speculation (*St Paul's: Me or the Music,* transmission 11/07/1999 BBC2) that intensive training could be seen as 'exploitation', with a disproportionate occurrence of vocal disorders arising from this. On brief investigation, following the TV broadcast, it appeared that there was no published research on the vocal health of choristers. This is most likely due to the difficulties researchers may have had gaining access to these boys, not because of a lack of interest. The cathedral foundations tend to be protective of the boys; not wanting to subject them to any extra activities, such as participation in research, which will take more of their time. They have also expressed concern about the implications of any negative outcomes of research involving the boys in their care (see 5.5.5).

It should be pointed out that this research is only on boy singers. This does not mean to suggest that girls cannot train to sing at such a high standard, or that girls' voices are not as worthy of study. It is a particular cultural artefact that the professional cathedral choirs in the UK, which require children to perform at the highest levels of performance (see 1.5), mostly have only male singers. It is not appropriate for this study to comment on whether this use of boys alone is socially fair or artistically justified. The concern of this study is to assess the voice use of the professional child classical singers in the UK who have the highest levels of vocal loading.

1.2 The history of the chorister in British cathedrals

Although this research concerns the activities of a particular cultural and historical cohort within the Christian community in the UK, it is fundamentally concerned with vocal health from a clinical perspective and voice assessment methods from both clinical and pedagogical aspects. These are primarily scientific and educational subjects and are not dependent on a thorough historical investigation of the *raison d'être* of the professional boy chorister. For general interest to the reader, Appendix 1 is a summary of the history of the chorister in UK cathedrals.

1.2.1 More recent developments

The twentieth century has seen some changes in chorister education. Many choirs have seen the introduction, from the 1980s, of a specialist singing teacher to complement the work of the choirmaster in training the singers. In the 1980s the Choir of Westminster Cathedral employed the wife of the Organist and Choirmaster, who was herself a professional singer, to give singing lessons to the boys. In 1989, Westminster Abbey employed the author as a singing teacher for the choristers. These are probably the first two cases of professional employment of singing teachers to work alongside the choirmaster in an English cathedral choir. From the 1990s many choral foundations have introduced girls, either to join the boys or to form a parallel choir. Salisbury Cathedral introduced a girls' choir in 1990, which was the first of its kind. Manchester Cathedral and St Mary's Cathedral, Edinburgh, both have mixed choirs of boys and girls. All but one of the designated choir schools (Westminster Abbey Choir School) have opened their classrooms to non-choristers. This means that the choristers have their daily school curriculum classes in a mixed environment of both choristers and non-choristers.

Some recent changes have also, arguably, increased the pressure on the boys involved. They are no longer automatically awarded places at senior independent schools purely on the basis of their chorister training; they now have to sit the rigorous academic entrance examinations alongside their non-chorister peers. The previous informal arrangement for the awarding of school places, between head teachers of the choir schools and the senior independent schools, was rarely documented but has been confirmed in discussions between the author and the head teachers of more than one choir school.

The high-profile events in the more public cathedrals such as Westminster Abbey and St Paul's Cathedral now are often broadcast live on radio or television. Towards the end of the twentieth century, the listening public became much more familiar with the standard of performing exhibited on commercially available recordings. These standards were often the result of studio editing which can remove most inaccuracies and give an apparently flawless end product. There is an argument that recordings have had an impact on the performers and standards expected of them.

> 'recordings have not just changed the behaviour of musicologists. They have also changed how performers behave. For one thing, it is harder to be singled out from peers, since many performers sound like recordings, and the performer is faced with the ideological residues of earlier performing generations and constantly bombarded with the desires of a media-controlled public that consumes in order to resemble and no longer, as in the older regime of representation, to distinguish oneself.'
>
> (Gritton, 2008)

Finally, we have seen a drop in the age of onset of puberty in both boys and girls since the middle of the twentieth century. In addition to this, boys in present-day cathedral choirs will expect to stop singing the treble or soprano line in the choir when their voice moves to stage ll or the early part of stage lll (see 3.8.5). During the early and mid-twentieth century it was not uncommon for boys to remain on the soprano line for two or three years beyond the onset of voice change. It is now considered unwise to encourage this prolongation of soprano singing. This is described more fully in 7.3.3. The implications of this earlier departure from the soprano part are many. Firstly, the senior members of the choir have duties both practical and musical. They are more experienced and have higher levels of confidence and ability than the junior choristers. As a result, they are relied upon to exhibit leadership qualities such as prompt and accurate musical entries, advanced sight-reading skills, and exemplary discipline and behaviour both in public performances and also during choir practice. The senior choristers are occasionally called upon to lead part of a choir practice. Whereas these duties would previously have fallen to boys of the age of 13 and 14, as a result of the earlier onset of puberty, it is now more common for boys of 11 and 12 to have this responsibility. The older boys are more likely to have 'retired' from singing as trebles (child sopranos) in the choir as a result of adolescent voice change causing the pitch of their voice to drop.

Any increase in pressure both in terms of academic attainment and the expectations of maturity and leadership can raise the anxiety levels of the boy and increase the possibility of vocal dysfunction (see 3.9.4). It has been suggested that the choristers of the early twenty-first century may have higher levels of academic requirement, more performance strain (larger audiences and live broadcasts), and an increase in responsibility for younger boys. All of these changes could potentially have increased the emotional and vocal loading of the choristers. In the absence of any evidence to quantify the effects of these possible additional strains on the boys it was considered necessary to establish some more concrete evidence of choristers' vocal welfare.

1.2.2 Current liturgical foundations in the UK

There are currently 712 boy choristers and 208 cathedral and collegiate girl choristers in the UK (Capon, 2009). The majority of these are educated in designated choir schools, some of which are boarding schools; 40.33% of UK choristers are boarders (Milton, 2010). Their education is often subsidised by the cathedral and choir school foundations: in 2009 the total subsidy was £7.4m of which £200,000 was from the Government's Music and Dance Scheme chorister fund (Capon, 2009).

Boys are members of cathedral and collegiate choirs, of which there are a total of thirty-eight in the UK, from the age of eight to thirteen (school years 3 or 4 to 8). The boarding choristers in this study were from a school at which the education for choristers was fully funded by the choir school foundation. The non-boarding choristers were from a school with some discretionary bursaries for chorister places. In both schools, if the boys showed an aptitude for singing at the age of 7 or 8, they would be given a place in the choir school regardless of their parents' ability to pay private school fees. Although the UK chorister entry requirements are purely on musical and vocal aptitude, the socio-economic and cultural background of choristers is predominantly white (92%) and middle-class (95.6%)(Milton, 2010).

1.3 Current cultural comparisons – Leipzig and Dresden

For this study, it was considered most relevant to investigate the boys from a London Cathedral (see 1.2.1). In order to assess the vocal loading of these boys and to put this in the context of other similar choirs throughout the world, it was decided to undertake a field study of similar choirs within the European tradition of Christian worship. The author visited the cathedral choirs of Leipzig and Dresden in 2003 in order to obtain information on chorister training and vocal welfare.

The tradition of using boys to sing in cathedral foundations extends throughout much of Europe and now into North America, Australia and New Zealand. In 1850, Sir Frederick Arthur Gore Ouseley, a curate of St Barnabas', Pimlico, witnessed the severe anti-popery riots and the subsequent closure of his choir's residence. In his distress he resigned his curacy and toured Europe for a year to rethink his vocational future (Shaw, 1986). The two churches which impressed him the most were the Thomaskirche in Leipzig (where Bach had been Cantor) and the Kreuzkirche in Dresden. He was astonished by the quality of the boys' singing and was determined to try and replicate this in England. He went on to found St Michael's College at Tenbury, a model choir school with purpose-built premises, later used as a model for the new choir school of St Paul's Cathedral (Prestige, 1955).

1.3.1 Introduction to the German tradition

The tradition that boys' choirs should perform the music of the Liturgy in German churches dates from the thirteenth century (Williams, 2004, 2004 - see Appendix 16). Unlike the tradition in the UK, with adult voices on the alto, tenor and bass lines (this evolved as musicians replaced clergy as singers (Mould, 2007)), the German choirs have boys up to the age of 18 years old singing all four choral parts. Sopranos are unchanged voices, altos are naturally low unchanged and early stages of changing, tenors and basses are young adult voices (Williams, 2004 - see Appendix 16).

The daily routine of each tradition had a similar workload in terms of the number of hours, however, the German choirs performed only at weekends, allowing more time for preparation in the weekday rehearsals. They seemed to have a comparatively large number of concerts and tours and fewer recordings (Table 1.1).

Since the Reformation, the choirs have belonged to the city and not to the church. This suggests that the responsibility for the education and welfare of the boys lies with the City Council or the State. In the UK this responsibility lies with the cathedral foundation. This may or may not have implications concerning any recommendations for changes to the regime.

1.3.2 The Dresden Kreuzchor

The conductor of the choir from 1996 to the time of interview in 2003 was Roderick Kreile. He had been originally based at the Munich Hochschule, teaching choral conducting. The choir, founded in 1216, had, in 2004, 140 boys in total: 48 sopranos, 18 altos, 18 tenors and 24 basses. This was a relatively large choir, enabling them to perform bigger repertoire such as the Brahms Requiem. They reduced their numbers to 80 for touring and sometimes to 40 for early music performances.

The main performing venue was the Kreuzkirche. This was bombed severely during World War II and was one of the few buildings to be re-built by the German Democratic Republic. As a consequence of limited funding for renovation it has a rather austere interior. The church seats 3,200.

1.3.3 The Leipzig Thomanerchor

This originally belonged to the monastery of St Thomas, founded in 1212. After the dissolution of the monasteries it became a municipal school. In Bach's time there were 55 pupils including residential and external. The Choirmaster was expected to teach three hours a day of vocal and instrumental music (Bach chose to pay a deputy to teach academic subjects such as Latin). He also had to find the time in order to compose a new cantata for each Sunday, plus occasional motets.

The Leipzig choir of 2003 was smaller than the Kreuzchor, with 30 sopranos, 15 altos, 8 tenors and 17 basses. The school had moved to larger premises on the other side of Leipzig but the choir still sang in the Thomaskirche, which had been beautifully restored in time for the 250^{th} anniversary of Bach's death in 2000.

1.3.4 The rehearsal schedule

Unlike UK cathedrals, there was no early morning rehearsal as German schools begin lessons at 8am. The rehearsals for the choir were during the afternoon, as were the individual singing and instrumental lessons.

The comparison in Table 1.1 suggests that the ratio of rehearsal to performance time in the German choirs is 10:1; in the UK it is 3:1. Choristers from a major London cathedral were selected for analysis in this study; the cathedral itself could not be named for ethical reasons (see 5.5.5). More information on the weekly schedule of the boys in this major London cathedral is included in 1.4.2.

Table 1.1 A summary of rehearsal and performance hours in an average week (Williams, 2004 - see Appendix 16)

	Kreuzchor	Thomanerchor	The major London Cathedral
Rehearsal per week	SA 8 hrs, TB 5 hrs SATB 9 hrs S total 17 hrs	SA 9 hrs, TB 6 hrs SATB 8 hrs S total 17 hrs	S 12 hrs
Performance per week (music content only - not including spoken parts of the service)	1.5 hrs	1.5 hrs (+ 1 hour on one Sunday in three)	4.5 hrs (some repertoire is repeated during the week)
Concerts Recordings	70 (may tour the same programme) 1 in two years	Not known	10 (comprising different repertoire) 2 per year

There is no day off in the week for the younger boys; they have no significant rest time from singing activity (see section 3.8.4 on muscle growth and development). The Kreuzchor had a weekend off every four to five weeks, the Thomanerchor had two out of every three Sundays as rest days from singing activity.

The conductor of both German choirs had trained as a choral conductor and was usually a professional singer; he was able to make use of an assistant, as well as of senior boys who were required to assist with musical training of the younger boys. This was contrary to the UK tradition, where the choral director had generally trained as an organist. When the Thomanerchor had a conductor during the 1940s who had trained as an organist and not as a singer, there was a significantly greater number of voice disorders during this time than either before or after.

1.3.5 Probationers (junior choir members, new to the choir)

The boys entered as probationers for one year and auditioned for the choir at the end of this. Each year some failed to become choristers, due to an inability to fulfil the requirements of musicianship and vocal skill tested at the end of the preliminary year. In the UK this rejection of a probationer after a year is a possibility but it is almost never carried out (from author interviews with several UK cathedral music directors). The German probationers had a 45-minute rehearsal each day, comprising hymn singing and learning basic music theory. In addition to this, they had a half-hour singing lesson each week. Probationers entered at the age of 7 or 8; there were no members of the choir who had been admitted at a later age.

1.3.6 Individual training for choristers

Choristers have an individual singing lesson of 45 minutes each week. There were 8-10 singing teachers in each school, both male and female, all of whom were professional singers; they never worked with the whole choir, only with individual boys. All singing teachers in German choirs were required to learn teaching techniques at university, although there was no specific Child Voice Pedagogy available. The choirs have employed singing teachers for the choristers for the last 20–30 years. Before this time, if a boy developed long-term vocal problems he was required to leave the choir.

"we are trained so that nothing is happening to us, we are getting the technique before and after voice change. If you have the right technique you can sing for much longer"

Lutz, Kreuzchor member (Williams, 2004 - see Appendix 16)

Instrumental tuition was seen as a supporting skill for the boys' overall musical development. Only one instrument was studied: most boys learned piano in half-hour lessons with not much expectation of practice. If a boy showed real potential as an instrumentalist, he left the choir. The period of rest during voice mutation was often seen as a time to devote more hours to regular instrumental practice. Within the UK choir schools, boys were required to learn two instruments. The general level of expectation was of a pass in at least one Grade 5 Associated Board music examination by the leaving age of 13 years.

1.3.7 Adolescent voice change

Boys moved to alto during pre-mutation and then left the choir during mutation. This period could be for anything from six months to two years. During this time they continued with singing lessons. They then returned at the discretion of their teacher to sing either tenor or bass. All the tenors and basses in the choir had sung as trebles and all the trebles went on to sing either tenor or bass. Countertenor singers were considered to be extremely rare, there was maybe one every five years.

It was considered, by the choir director, that the earlier onset of voice change had implications for the balance of the choir, as this resulted in a greater percentage of tenors and basses. One answer to this situation was to allow boys a longer period of voice rest during mutation. The tenors and basses would still be taken from the older two or three years of the school; boys who may have ceased singing alto at the age of 13 may have had a further two or three years without singing. The other implication of this shift is that younger boys (maybe aged 11 or 12 years instead of 13 or 14 years old) were expected to lead the soprano and alto sections; they may have advanced physical maturity but possibly did not have the musical maturity of the older boys. This was reported as a cause for concern by both of the musical directors.

The end of singing as a treble was not generally perceived by the boys as any sort of loss, musically or psychologically, as the boys had plenty of tenor and bass role models amongst the older members of the choir. According to the choir director, the only time when a boy may have tried to disguise voice change (by artificially raising the speaking voice perhaps) is if there were to be an exciting tour in the immediate future. Otherwise, voice change was accepted as inevitable and most boys appeared to enjoy the opportunity to devote more time to their academic work and instrumental practice. Boys during this time were responsible for programme selling and organisation of performances; they were able to remain in the community of the choir.

1.3.8 Voice disorders (see 3.9)

On a rough analysis, in line with the author's own personal experience, the percentage of voice disorders appeared to be consistent with those of choristers in the UK, If a boy in the Leipzig Thomanerchor had a long-term or recurring problem (three months or more) he was required to leave the choir as chorister places were limited in numbers. Boys with a suspected viral infection would see a phoniatrician if the infection persisted for more that one or two weeks. Boys who were 'off singing' did not attend rehearsals because of the phenomenon of 'inner singing': it is known that the vocal folds move when you listen to music, therefore listening to rehearsals was not considered to be vocal rest. They had a specified programme of vocal exercises and rehabilitation with a singing teacher when they began vocal recovery.

According to estimates based on personal experience of the author and discussion with the Thomanerchor phoniatrician, it would appear that the incidence of asthma appeared to be lower than in London choristers, but the incidence of allergies appeared to be higher. It is possible that this could have been merely due to differing diagnostic criteria within the medical professions in each country.

1.3.9 General schooling

Both of the German schools were large day schools for up to 800 pupils. The choristers were, however, taught in their own classes and had the option to board.

Academic achievement was stated to be important: there were exams to pass at the end of years 10 and 13. If the year 10 (age 14-15 years) exams were not passed, the boy had to leave school to pursue vocational training. The smaller class sizes for the choristers, and the resulting increase in individual attention, made success in these examinations a more easily attainable target.

There was provision made for play and for sport: one hour after lunch and time in the evening after dinner. Structured physical exercise was for two periods a week as German school children normally pursue sport after school (from lunchtime onwards). The choristers were not allowed to play football if they had an upper respiratory tract infection (common cold) or if the weather was too cold; there was an indoor facility for sport in cold weather.

The boarding choristers in the Thomanerchor could see their parents from Friday evening to Saturday lunchtime and for two out of every three Sundays.

1.3.10 Cultural and political context

The existence of the communist German Democratic Republic for forty years had a mixed effect on the choral tradition. The funding for the choirs was still maintained and generous financial support was given to those arts organisations which were at a level that was on show to the international community. There was great competition to enter the choirs as it offered boys a chance to travel abroad. In the 1970s the Thomanerchor had approximately 250 applicants for the 10 places available each year.

The state tried to introduce what they considered to be 'Socialist Music' into the choral repertoire; however, according to the directors of both choirs, the tradition of performing music written specifically for the choir was too strong to be altered in any significant way. In Leipzig the music of Bach and Mendelssohn predominated, as in Dresden did the music of Schütz.

According to the choir directors, the culture of the former East Germany in 2003 still had differences from the west. For example, the school lunch given to the author in the Thomanerchor was more similar to English school lunches of the 1960s than to her experience of meals served to school children in the UK in 2003.

1.3.11 Comparative standards and priorities in the choral singing

From the author's experience of listening to boys' choirs, the standard of the choirs appeared to be high; the quality of choral singing was impressive. On hearing the individual sections and some individual voices, the level of ability and training was possibly not as great as that in the equivalent London choirs. In the opinion of the author, the vocal technique was less detailed: for example, breathing was allowed to be predominately clavicular (see 2.2.2), the 'singer's formant' was not developed to any noticeable extent and the soprano boys did not have a particularly strong mid to low pitch range. The articulation of text was, however, exemplary; the German style of singing requires strong consonants and real clarity of vowel colour. It was observed in the individual singing lessons that great attention was paid to articulatory and not phonatory techniques.

Most of the repertoire was in German or German Latin. This gave a contrast between bright and dark vowel sounds, increasing the range of harmonics in the sound and giving it a naturally rich timbre.

It was evident in the rehearsals of both German choirs that although the pace was efficient and disciplined, it did not have the speed of that of the UK choirs. This attention focus in the UK is considered necessary to facilitate the larger proportion of performance time and to accommodate the rehearsal habits of the predominately adult presence. The comparative luxury of a greater number of rehearsal hours did not necessarily result in a more polished performance.

The lack of mature adult voices in the German choirs is possibly what gave them a distinctly different timbre. Young boys singing soprano were not required to match the power of mature adult voices which would have been found in the alto, tenor and bass sections of a UK choir. Secondly, the altos are naturally high voices singing at the lower end of their range rather than naturally low voices singing at an artificially high pitch (which is the situation in the UK choirs who employ adult male altos); this possibly gave an overall feel of balance to the four-part choral sound. It is possible that the adult male alto sound, which is an integral part of the UK cathedral choir, may influence the boy sopranos in the UK choirs with unfavourable results. It could influence them to the extent that they subconsciously mimic the sound: a direct, piercing, sometimes 'hooty' sound.

When compared with the author's experience of London cathedral choirs, the overall impression of the choral singing on the author was an easier sound: lighter and more facile. Although this may be considered to have been a safer way of training developing voices; in terms of vocal loading, see 1.4.2), it did not necessarily have the excitement and fullness of tone which could be produced by some English choirs.

In the light of all these comparisons, it seems that although the German choirs demonstrated a high professional standard of training and performance for the choristers, the UK choirs may have been subject to higher levels of vocal loading. To summarise; the UK choirboys were required to match a mature adult sound from the alto, tenor and bass sections, achieve a greater proportion of performance time for the available rehearsal and attain higher standards in their musical instrumental study.

1.4 The choice of a major London cathedral for this study

1.4.1 Twenty-first century musical performance expectations

Many British cathedrals have introduced separate girls' choirs to perform a share of the weekly sung liturgy. This has meant that the singing responsibility of each choir (boys and girls) is less than those foundations with a single group of children performing. Of those which have only one group of singing children, the two major Anglican cathedrals in London have not only the daily services in which to sing, but also a number of additional events. These may be royal, corporation (linked to the City of London), cultural (concert performances) or society (weddings, memorials, thanksgivings or anniversaries) occasions. Due to the central location of the cathedrals, these events tend to be high-profile occasions with large congregations. They are often broadcast on radio or television, normally going out as live transmissions. This has the effect of increasing the audience size by a large factor. The viewing figure for the television broadcast of the wedding of Prince Charles and Lady Diana Spencer, with the London cathedral choir (which was used in this study) singing, was 28.4million (BBC, last accessed March 2009). Listening figures for choral evensong on Radio 3 are 250,000 (Timesonline, last accessed March 2009).

There is evidence to suggest that the common availability of commercial recording in the latter half of the twentieth century has altered the expectations of both performers and audiences during live performance (see 1.2.1). This situation is most likely to have increased the performance pressure and the corresponding performance anxiety of the choristers, when compared with the general level of requirements faced by previous generations of boys.

1.4.2 Vocal loading

Vocal loading is defined as the stress inflicted on the vocal apparatus during periods of usage. This may be when speaking or singing. Factors known to increase levels of vocal loading are the proportion of time (within a given time frame) for which the voice is operating, the intensity (loudness) level at which the voice is operating and the level of psychological stress of the vocalist (Artkoski, Tommila, & Laukkanen, 2002; Sala et al., 2002; Titze, 1994). Many of the vocal performances of these boys will have high levels of expectation with the resulting increase in the possibility of performance anxiety or nervous tension. It is likely that they are also singing for more hours per week than any other boys' choir in Europe (see Table 1.1).

Table 1.2 shows the weekly schedule for the London choristers taking part in this study. In an average week there are 12 hours of rehearsal and 9.3 hours of performances. In more than half of the weeks there will be additional concerts or services. The maximum number of formally timetabled singing hours in any week is 25 as regulated by the Dean and Chapter. The table shows desk allocation of 1, 2 and 3: these denote the position of seniority within the choir; 1st desk are the most senior boys. In addition to the details shown on the weekly schedule, 3rd desk boys have no singing on Friday and two weekends at home with their parents every term, and 1st and 2nd desk boys have one weekend at home with their parents every term (coinciding with 3rd desks). The probationers go home every Friday at 16:00 returning to school Sunday evening / Monday by 07:40.

Table 1.2 weekly schedule for the choristers in this study

	Schedule for 1st and 2nd desk choristers
Mon – Fri	
07:00	Wake up (sleeping is in dormitories of between two and six boys per room. The accommodation building is separate from but adjacent to the school and the cathedral)
07:20	Breakfast (this is in the school dining hall)
07:50	Choir practice in the cathedral rehearsal room, a designated room in the crypt of the cathedral. On Thursday (a day off from cathedral singing activities) instrumental practice for 30 mins, then free time before school day begins at 08.55)
08:55	Assembly – then lessons until 15.40 These follow the accepted school day, familiar to all UK school children
	20 min break during the morning and 20 min break for 3rd desks in the afternoon)
	40 min break for lunch (1 hour for 3rd desks)
	40 mins PE / 80 mins games / 40 mins swimming each week (no swimming for Year 8)
15:40	Snack
16:10	Cathedral practice (extra-curricular clubs on Thurs when there is no cathedral singing activity)
17:00	Evensong – a 45-minute service with 15-20 mins of singing within it
18:00	Supper
18:40	Prep (private study)
19:40	Instrumental practice
20:10	Free time within the school buildings and grounds
20:30	Bedtime (21:00 for senior boys / 20:00 for probationers) + 30 mins for lights out
	Parents allowed in school to help supervise prep / practice but must leave premises by 20:00 (junior choristers' bedtime)
Saturday	
07:40	Wake up
08:00	Breakfast
08:30	Cathedral practice
10:00	Leave – free time when the boys are allowed off the school premises with their parents
15:15	Cathedral practice
16:15-16:30	Break / snack
17:00	Evensong
18:00	Supper – then free time until bed at 21:00 (no overnight leave allowed)
	Parents allowed in school until 20:00 (very few ever drop in)
Sunday	
08:15	Wake up
08:35	Breakfast
09:15	Cathedral practice
10:15	Matins – a church service with 15–20 mins of singing
11:00	Break / snack
11:30-12:50	Eucharist – a church service with 20-30 mins of singing
12:50-13:15	Break
13:15	Lunch
13:45	Free time
14:30	Cathedral practice
15:15	Evensong
16:30	Free time / leave (overnight leave permitted – boys must return to school by 07:40 Monday)
18:00	Supper
20:30	Bedtimes (as Mon–Fri)

The singing rehearsals are highlighted in green, performances are in red.

1.5 Occupational health of professional musicians, dancers and athletes

Any person training to perform a physical activity to a high level of achievement will be stretching the capabilities and limitations of their body. The acquisition of an appropriate technique will help to prevent injury (Cram, 2001); nevertheless, performers will always strive to achieve more than their predecessors. With every individual there is a tipping point at which the level of performance is detrimental to health (Hardy & Fazey, 1987). This is generally only discovered when it is exceeded by the individual. This expectation of injury may be part of the personal progress of an Olympic athlete or a professional dancer; it should not be integral to the training for a child. Children who perform to a high level, whether they are gymnasts or swimmers, despite a high level of enthusiasm and commitment, are not consenting adults. They have often been persuaded into such activities by their parents or teachers and there is a moral obligation for all adults concerned to provide a duty of care to ensure that they do not suffer physical injury or emotional trauma as a direct result of their training (Sklaire, 1997).

1.5.1 Children as dancers or gymnasts

In the last twenty years, there has been a considerable amount of research into children who perform at high levels in physical activities. There is concern about potential negative influences of intensive training on the growth and maturation of young athletes. Growth is defined as changes in stature and body weight; maturation is the progress towards the mature state (skeletal and secondary sexual maturation) (Malina, 1994). The natural height and weight of children can initially influence their selection for certain sports. For example: in sports such as basketball and volleyball, a higher than average stature is preferred; in gymnastics, a lower than average stature is preferred. It would appear that, in most sports, an average height and slightly below-average weight is maintained throughout adolescence. Most children training in sports do not suffer any delay to the onset of puberty (Geithner, Woynarowska, & Malina, 1998). In some activities, most notably gymnastics and ballet, sexual maturation is often delayed by two or three years (Malina, 1994). Although the sisters and mothers of female ballet dances tend to attain menarche later than the average population, this is not as late as that of the girl dancers. This delay may be due to dietary practices which place an emphasis on thinness, which may result in nutritional energy deficiency for prolonged periods (Malina, 1994). Any prolonged dietary limitation may result in amenorrhea (lack of menstruation) and subsequent osteoporosis (lack of bone density) as a result of the hormone imbalance (*The challenge of the adolescent dancer*, 2009). Because catch-up growth commonly occurs when training is reduced or ceases, final adult stature is unlikely to be compromised (Daly, Bass, Caine, & Howe, 2002). It has not been possible to separate the effect of the training itself from nutritional or stress factors (Rogol, Clark, & Roemmich, 2000).

1.5.2 Children as professional singers in other genres

A number of children in the UK perform in professional musical theatre productions. They are often pupils at specialist performing arts schools and receive vocal training appropriate for the style of music they are performing. There appears to be little, if any, research into the health of the voices of children who perform as professional singers in this genre.

1.5.3 Professional adult musicians

There has been much research in the field of performing arts medicine, some of which addresses the issues affecting professional adult singers. It is evident that considerable attention must be given to physical posture and body use while practising and performing (Wynn Parry, 2004). In order to achieve this, the knowledge and direction of the teachers is of paramount importance (Brandfonbrener, 1997; Williamon & Thompson, 2006). Many injuries experienced by professional musicians are related to repeated activity (repetitive strain injuries). In singers, the causes are often less easy to pinpoint, due to the physically internal situation of the mechanical parts involved in vocalizing (see Chapter 2). There is, however, plenty of well-documented research into the vocal health of professional adult singers (Garfield Davies & Jahn, 2004).

It has been suggested that, considering factors such as environmental noise, musicians are perhaps not as unhealthy as they should be. Orchestral musicians have to rehearse and perform in environments which often exceed Control of Noise at Work UK Government Regulations. Musicians have been shown to have a significant bilateral notch in their audiogram at 6kHz, suggesting the presence of noise-induced hearing loss (Backus, Clark, &

Williamon, 2007). When the degree of hearing loss is contextualized within the known data relating hearing loss to levels of background noise, the levels of hearing loss are not as great as would be expected. It is possible that the musicians are able to control or regulate the effect of the noise levels: if they know that, for example, a loud chord is imminent, it is possible subconsciously to reduce the impact on the auditory mechanism (Backus et al., 2007). This possibility of self-regulation is a key finding of this research on boy choristers (see 9.5.7).

1.5.4 Levels of training for both children and their teachers

For the boys involved in this study, their prime musical and vocal influences are provided by the cathedral music staff. These include the director of music who conducts the choir, two or three assistant staff, and the boys' singing teacher, based in the school. In general, cathedral directors of music in the UK have been trained as organists. Although they will have had a great deal of exposure to choral music, their individual knowledge of singing technique and of children's voices in particular can be varied. It is not usual for the director of music to have had any formal training as a conductor or any specific training in vocal pedagogy.

The training provided by the conductors for the boys tends to be primarily musical, without any specific reference to vocal technique. Singing teachers in the UK are not formally trained, licensed or regulated; specific knowledge of children's voices is generally gained through personal experience rather than formal training. It has been shown that the attitude and effectiveness of the conductor are key elements for the effort, self-worth and success of boys' choir members (Daugherty & Hedden, 2006; Durrant, 2000). Thus it can be surmised that the level of training offered to choristers in UK cathedrals is variable; their individual vocal progress is left largely to chance. Although the conductor is appointed on the basis of choral-training skills assessed at interview, the training offered for potential candidates is based on organ-playing skills.

There is information available on the internet relating to the vocal health and behaviour of teachers, whether these are classroom teachers, or other leaders of children's activities. There is very little information available to teachers regarding the vocal health and behaviour of children. Again, knowledge of this among the singing teaching profession is generally through personal experience, although there are some continuing professional development courses available to teachers who choose to pursue them.

There has been no study to date and there is no information available to teachers relating to the vocal health and training of children who are singing at a professional level.

1.5.5 The relationship between levels of vocal activity and vocal health

It could be proposed to consider levels of vocal behaviour on a linear scale, from subnormal (inefficient or pathological voice, for example) through normal to supranormal (an exceptional level of technical and artistic achievement). There is evidence to suggest that if physiological arousal (a measure of the heart rate of the individual) and cognitive anxiety (the degree of anxiety relating to performance expectation of the individual) increase to a critical level, then performance levels will rapidly deteriorate (Hardy & Fazey, 1987; Hardy, Parfitt, & Pates, 1994); see 3.9.5). If this model is taken into account, a significant number of individuals will, at some point in their performing career, suffer from the vocal collapse illustrated in the model (Figure 3.8). This collapse of performing levels at the upper end of the scale suggests that a circular rather than linear model would be more appropriate (Figure 1.2). If supranormal performance expectations are taken higher than is possible for the individual, the resulting collapse renders their performance level subnormal.

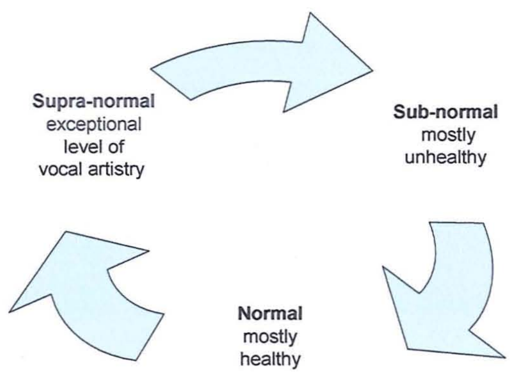

Figure 1.2 Schematic diagram of the cyclical relationship between vocal activity and vocal health

1.6 Research questions

1.6.1 Methods of assessment

In order to address the questions, it was necessary to establish the most appropriate tool for measuring the vocal behaviour. There was no such assessment specifically designed to assess children who are trained professional voice users. The design of the assessment method embraced perceptual and acoustic measures in current usage in clinical settings. These were combined and adapted in order to give a thorough and relevant way to evaluate the voice use of the boys in question.

1.6.2 Vocal health of intensively trained boy choristers

Sections 1.2.1 and 1.4.2 highlighted some reasons why this particular group of boys in the London cathedral may be the most likely to develop voice disorders, if this type of vocal loading were to be a contributing factor in this. These are summarised below.

- They have a high level of voice use required to meet rigorous professional standards (see 1.1; this statement also reflects the professional experience of the author whilst teaching these boys).
- They perform for more hours per week than the two European choirs selected for comparison; these could be considered as generally representative of the genre (Table 1.1).
- They perform in a large reverberant building, requiring a high vocal intensity level to fill the acoustic.
- They have other, high-level academic and musical expectations to fulfil (1.2.1).
- They are influenced by the legacy of commercially recorded repertoire, and may have greater pressure to achieve higher standards more often (1.4.1).

These statements suggest that a study of the vocal health and overall vocal behaviour of these boys could illustrate whether the high probability of voice disorders amongst them is actually the case. This would indicate a possible link between vocal activity and vocal health.

1.6.3 Vocal development of intensively trained boy choristers

There has been little published research to investigate the vocal health or development of intensively trained boys as they undergo adolescent voice change. Pearce (Pearce, 2007) has tracked choristers' longitudinal vocal behaviour but without any specific evidence regarding the vocal health of this cohort, in the context of the vocal behaviour of boys of this age.

This current research looks at the acquisition of singing and general voice use skills as the boys progress through their chorister career. It also looks at patterns of fatigue throughout their training, with reference to increased choral responsibilities and musical expectations. The second main section of the research investigates the voice use during the early stages of puberty. In particular, it looks at the singing technique used in the upper pitch ranges. This appears to employ a phonatory pattern closer to that used by adult female singers, than to one used by young adult male singers. This information could have relevance for future training of young male singers.

This research is primarily concerned with the learners and not the teachers or policy makers. It could, however, have important implications for all adults involved in the training of child singers.

1.7 Research aims and questions

The aims of this research are to investigate the impact of the choristers' intensive schedule of rehearsal and performing in relation to current vocal health and future development.

This study set out to investigate answers to these three questions:

- What is the vocal behaviour of boys who experience an intensive, performance-focused training?
- How does such behaviour change over time?
- Is the nature and incidence of vocal dysfunction (self-perceived and/or quantifiable by others in some way) different from what might be found in boys of a similar age and school environment?

Chapter 2

The anatomy and physiology of the human voice

2.1 Introduction

This chapter will give an overall account of the anatomical structures involved in the functioning of the adult human voice. This includes the breathing mechanism, the larynx and the vocal tract. There is much more detail in the published literature on the adult voice than in that on the child voice. A full understanding of the functioning of these systems in the adult is necessary in order to enable us to appreciate the similarities and differences found in the developing voice. Furthermore, an understanding of the functioning of the 'normal' voice is an essential starting point from which to assess any deviations from this.

2.1.1 Background to human vocalisation

The ability to use the voice as a means of communication is one common to many mammals. Barking, roaring and crying are all ways of attracting the attention of other animals, friend or foe; many species can communicate aggression, fear or sexual intent with their voices. Humans, however, possess a unique alignment of the larynx (voicebox) within the vocal tract (throat) that enables them to access a much wider variety of sound qualities that any other animal (Lieberman & Crelin, 1971). These can be used for much more subtle communicative messages and their function has enabled humans to evolve speech and song as an integral part of their social existence in every culture. The most primitive larynx can be observed in the early lungfish (Protopterus and Neoceratodus). They possess sphyncteric musculature, the action of which can enable air to enter the lungs during periods of drought. The phonatory function of the larynx appears to be a late phylogenetic acquisition (Sasaki, 2006). It can be argued that the vocal function of the larynx is as a direct result of the social needs of the species. There are many species with sophisticated larynges (other primates, for example) which do not rely on vocalising in a correspondingly sophisticated way. Conversely, there are species with a relatively simple laryngeal structure (for example, the frog) for whom voicing is an integral part of their inter-species communication. It is most likely that the development of the brain is the prime factor influencing the use of the larynx. If the human species had the larynx of a marsupial, without a moveable cricothyroid joint, it is likely that we would still be able to communicate in a human language (Hast, 1983).

The vocal sound is normally considered to be produced with three related systems: the energy source (breathing mechanism), the phonator (larynx) and the resonator (supra laryngeal spaces or vocal tract).

2.2 The breathing mechanism

This utilises the lungs, the ribcage and the muscles of respiration.

2.2.1 Tidal breathing

Tidal breathing, or automatic breathing, is a habitual action, occurring between twelve and seventeen times per minute in an adult at rest (Titze, 1994). In this primarily reflex action, inspiration is caused by the contraction and subsequent lowering of the diaphragm, combined with the contraction of the external intercostal muscles, causing the raising of the ribcage. This creates negative pressure within the thoracic cavity, thereby pulling air in through the mouth or nose. As the diaphragm contracts, it also may raise and expand the lower part (ribs 7–12) of the ribcage (J. Rubin, 1998).

In tidal breathing, expiration is passive. The lung tissue and the ribcage have elastic properties and will automatically recoil to their deflated state after being stretched with the inhalation of air. In an upright position this action is combined with the downward movement of the ribcage, due to gravitational pull, which generates an expiratory force. (There is also a small *in*spiratory force exerted by the gravitational pull of the abdominal content in upright position.) This will expel air from the lungs, causing them to return to their resting volume. They remain in this state for the greater portion of the breathing cycle until the concentration of carbon dioxide in the blood reaches the critical level to trigger the action of inspiration again. During breathing at rest, the volume of air entering and leaving the lungs is about 10% of the total volume available (vital capacity - VC) (Proctor, 1980).

2.2.2 Phonatory breathing – inspiration

For speech and singing, it is necessary to alter this pattern to one of more rapid inspiration and prolonged expiration. If expiration is not consciously controlled, the outward flow of air will be rapid at the start, dwindling to a trickle (Lieberman, 1968). This is not suitable for singing, an action that requires a controlled subglottic pressure over an extended time period (Hixon, 1987). In singing (and to a lesser extent in speech) the expiration time is dictated by the length of the phrase and may be as long as 15 to 20 seconds. In conversation, a typical phrase or sentence lasts 1 to 5 seconds (Titze, 1994).

Inspiration for singing primarily uses the diaphragm and the external intercostals (Hixon, 1987; Proctor, 1980). Certain vocal pedagogues tend to recommend the singer to conceive the use of the diaphragm as the primary muscle of inspiration (Chapman, 2006; Thyme-Frøkjær & Frøkjær-Jensen, 2001). One reason for this may be that there is a resulting tracheal pull on the larynx, causing it to move to a lower level in the neck (Sundberg, Leanderson, & von Euler, 1989). A lower larynx gives a longer vocal tract which may be advantageous to the singer in Western classical music performance (see 2.4.3 Phonation) (Iwarsson, Thomasson, & Sundberg, 1996).

The other muscle groups responsible for raising the ribcage (levatores costarum, pectoralis minor, serratus anterior, serratus posterior inferior, quadratus lumborum and serratus posterior superior) (J. Rubin, 1998) may have some function in singing. Recent studies of professional singers have shown that other muscle groups are active during either inspiration or expiration (Pettersen, Bjørkøy, Torp, & Westgaard, 2005; Pettersen & Westgaard, 2002, 2005). These include the sternocleidomastiodeus, the trapezius and the scalenus. Their function may be to stabilise the ribcage during exhalation, or their use may be an unnecessary habit (Pettersen & Westgaard, 2002). Their use is not generally recommended in vocal pedagogy (Bunch, 1997; Chapman, 2006; Emmons, 1988; Miller, 1986; R. C. White, 1988). These accessory muscles may be used in times of respiratory distress, e.g. asthmatic attack or extreme athletic activity.

As the diaphragm lowers, as well as the lower ribs expanding and raising, the abdomen may be observed to protrude. It is generally considered important by singing teachers for the singer to release the abdominal muscles during inspiration to allow a quick and easy descent of the diaphragm (Bunch, 1997; Chapman, 2006). Despite this agreement of contemporary vocal pedagogues, research literature tends to find that singers in fact use quite a variety of inhalatory and exhalatory techniques (Callaghan, 2000; Thomasson, 2003; Watson & Hixon, 1984) that may relate to a number of pedagogical methods (Foulds-Elloitt, Thorpe, Cala, & Davis, 2000; Garcia, 1840; Husler & Rodd-Marling, 1965) and there is very little research evidence to shed insight into what singers themselves believe that they are doing when breathing for performance, or believe that they should be doing (Hixon, 1987).

2.2.3 Phonatory breathing – expiration

Expiration for singing involves some relaxation of the diaphragm and contraction of abdominal muscles. The diaphragm will remain in a state of partial contraction, especially in the initial part of expiration, to counteract the expiratory forces caused by the elastic recoil of the lung tissue. This is considered to be essential in order to control the subglottic pressure for singing (Bunch, 1997; Chapman, 2006; Tom Harris, Harris, Rubin, & Howard, 1998; Miller, 1986). A high subglottic pressure can result in a high level of adductory action in the vocal folds and consequently louder phonation. This can result in 'pressed phonation' (Sundberg & Gauffin, 1979) or a rise in pitch in the untrained singer (Sundberg, Andersson, & Hultqvist, 1999). In order to enable appropriate laryngeal abduction, diaphragmatic contraction during phonation can assist in maintaining a lower subglottic pressure (Leanderson & Sundberg, 1983).

The abdominal wall muscles whose contraction can diminish thoracic volume are the transversus abdominis, internal oblique and external oblique (see Figure 2.1). Activity is greater in the lateral abdominal area (obliques) than in the medial (transversus abdominis) (Watson, Hoit, Lansing, & Hixon, 1989). Other muscles may be used to stabilise the system, such as the postural muscles of the back, pelvic floor and the intercostal muscles (Draper, Ladefoged, & Witteridge, 1959). Figure 2.1 shows the main muscles of human respiration.

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Figure 2.1 The muscles of respiration (Netter, 1997)

Muscle groups such as the trapezius, sternocleidomastoideus and scalenus have been shown to be active to a varying degree during singing (Pettersen & Westgaard, 2005), although their action may be detrimental to efficient postural balance in the head and neck region (W. Barlow, 1973).

There is some disagreement over the role of the external and internal intercostals. Taylor (Taylor, 1960) demonstrated that both internal and external intercostals muscles are active during inspiration and suggested that their role is to prevent the chest wall from being sucked in or pushed out during inspiration and expiration respectively and not to alter lung volume. There is, however, evidence to show that breathing activity remains possible after diaphragmatic paralysis (Raval & Byrd, last accessed 2009) and, therefore, that the intercostal muscles can be responsible for actively altering lung volume.

2.2.4 Lung capacity

When the lungs are fully inflated (reaching total lung capacity – TLC), there is an expiratory force from the elastic recoil of the lung tissue and the ribcage. This increases with the amount of air inhaled. When all the air possible has been expelled from the lungs, there is an inspiratory force from the ribcage, striving to return to its ideal resting position. This force also increases with the amount of air exhaled. The resting position, of partial inflation between the two extremes, is known as functional residual capacity – FRC (generally close to 35% of the vital capacity – VC). After maximum exhalation there is a small amount of air remaining in the lungs, this is the residual volume – RV. This volume of air will remain in the lungs even after death. The difference between total lung capacity and residual volume is known as vital capacity: approximately five litres in the adult male (Sundberg, 1987).

During rest the volume of air inhaled and exhaled is typically between 35% and 45% of the *vital capacity* (using mainly diaphragmatic contraction for inhalation and elastic recoil for expiration). During gentle speech this is between 10% and 50% (occasionally people use lung volumes below the FRC and therefore some abdominal muscle contraction (Sundberg, 1987)) and during singing this can be between 5% and 100% of the vital capacity (using a more extreme range of muscular action and coordination). Singers tend to have learnt to reduce their FRC rather than increase their overall lung volume; in other words, they have learnt to squeeze their lungs more efficiently (Gould, 1977). Trained singers can get two to three times greater peak air flow than non-singers: it is likely that the singers learn to adjust their glottal or vocal tract configurations for optimum transfer between the vibrator and resonator (Titze, 1992). This may due to be additional thickening of the vocal folds, a loosening adjustment of the vocal ligament, or greater air flow (Doscher, 1994).

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Figure 2.2 Lung volumes and lung capacities (Hixon, 1987)

During both inspiration and expiration there are passive forces (striving to return the lung volume to the FRC) and active forces (striving to work with or against these forces, to vary subglottic pressure and move air in and out of the lungs). In order to maintain a controllable air flow through the larynx, the muscles of both inspiration and expiration have to coordinate their synergistic action at all times. The respiratory system of the singer has to judge the degree of muscular effort needed in order to counteract the passive forces and result in a controllable subglottic pressure on expiration (as if one were riding a bicycle in a slow, controlled way; one could use both pedals and brakes at the same time).

2.2.5 Subglottic pressure

Subglottic pressure is the air pressure measured immediately below the vocal folds. This is regulated by the breathing mechanism of the singer. There are mechanoreceptors in the subglottal mucosa that are extremely sensitive to air pressure. They exert reflex effects on the activity of the laryngeal intrinsic muscles and are particularly important as air pressure rises during expiration (J. Rubin, 1998). On the other hand, subglottic pressure variation was achieved with almost the same accuracy in three subjects where the subglottal mucosa was anaesthetized, suggesting that it is not necessarily the case for the mucosa to be involved and that they may be overridden/replaced by other mechanisms (Sundberg, Iwarsson, & Billström, 1995).

Louder phonation requires higher subglottic pressure, as does – to a certain extent – higher frequency phonation. However, as a rise in subglottic air pressure can result in both a rise in loudness and a rise in pitch (Van den Berg, 1957) (e.g. the untrained speaker will tend to raise the pitch of the voice when speaking more loudly), the singer must be able to control frequency with a varying amplitude and to control amplitude with a varying frequency (H. J. Rubin, LeCover, & Vennard, 1967). The untrained male singer will use a much higher subglottic pressure than the trained singer for the same loudness (Titze, 1994), suggesting that the trained singer employs a higher closed quotient (see 2.3.4) than the untrained singer, in order to increase the amplitude. Coordination between the laryngeal muscles and breathing muscles is necessary in order to stabilise the relationship between pitch and loudness. The minimal level of glottal adduction for efficient vocalisation is defined as flow phonation (Titze, 1994).

2.3 Phonation – the larynx

2.3.1 Basic physical structure (Zemlin, 1988)

The larynx is a collection of cartilages and bone, suspended by muscles and ligaments, situated at the top of the windpipe. Its position can be felt at the front of the neck as a prominent lump also known as the Adam's Apple. There are several groups of muscles that connect the cartilages and move their positions relative to each other and as a whole unit within the throat (see 2.4.1). Suspended from them on the inside are the vocal folds: two flaps of tissue (comprising muscle, ligament and mucosa) that can be pushed or pulled together to close the gap at the top of the windpipe. The length of these is about 16mm in the adult male and 10mm in the female.

2.3.2 Basic function

The larynx is essentially a sphincter; the adductory action of the vocal folds enables the closure of the top of the windpipe. The main reasons for having this ability are to prevent particles from entering the lungs when we swallow and to enable us to build up pneumatic pressure within the torso for assisting us with straining i.e. lifting, defecating, giving birth etc. Attached to the inside front edge of the thyroid cartilage is a cartilage flap (*epiglottis*) which also assists in closing the windpipe when we swallow.

The intrinsic structure of the vocal folds is much more complicated than any other sphincter in the body (Zemlin, 1988). This is to enable a by-product of the closing action of these two vocal folds; if they are brought together more gently as we are breathing out, they make a sound. The basic sound made by the larynx alone is a buzzing noise (Titze, 1994).

N.B. The human voice is capable of producing a huge variety of vocal qualities. Each quality is due to a particular 'recipe' of vocal fold muscle use, subglottic pressure and vocal tract alignment and configuration. One particular voice quality can often be produced with a variety of alterations in the 'recipe'. In other words, there is often more than one way in which to achieve a general vocal quality.

2.3.3 Detailed structure

The larynx has many constituent and inter-relating parts (Netter, 1997).

Bone - the hyoid bone is situated at the top of the larynx and the base of the tongue. This provides the root of the tongue with an anchor point.

Cartilage - The cricoid cartilage is effectively the top cartilage of the trachea. It is the only complete ring in the laryngo-tracheo-bronchial tree and has limited mobility relative to the rest of the trachea (Kirchner, 1988). It is the structure about which the other laryngeal cartilages move. The thyroid cartilage hinges on either side of the cricoid; the possible movement is down/forward or up/back. The arytenoid cartilages are hinged at the back of the cricoid and have a rocking *and* sliding movement. The cuneiform cartilages are at the tip of the arytenoid cartilages. They support the soft tissues of the aryepiglottic folds that connect the arytenoid cartilages to the epiglottis.

The thyroid, cricoid and articulating surfaces of the arytenoids are hyaline cartilage and therefore subject to ossification (becoming more bone-like) with age. In middle-age this can result in a more robust laryngeal frame, able to withstand a greater degree of muscular contraction. This is one reason why dramatic singers (the strongest voices) are at their peak when they are in their forties and fifties. This ossification can eventually lead to inflexibility and may result in a 'hardening' of the sound quality and a reduction of the upper pitch range. The hyoid bone and thyroid cartilage tend to move together as one unit, any variation in relative position is due to vowel alteration ((Söderberg, 1978); cited in (Vilkman, Sonninen, Hurme, & Körkkö, 1996). This collection of cartilages provides a rigid opening to the top of the trachea. The vocal folds and the epiglottis enable closure when necessary for swallowing.

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Figure 2.3 The cartilages of the larynx viewed from the front (Netter, 1997)

Figure 2.4 The cartilages of the larynx viewed from the back (Netter, 1997)

Muscles – The muscle groups of the larynx have four main functions:

1 To open the glottis

2 To close the glottis

3 To lengthen the vocal folds

4 To shorten the vocal folds

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Figure 2.5 Intrinsic muscles of the larynx and the movements of the laryngeal cartilages (Netter, 1997)

The **extrinsic musculature** of the larynx is influential on laryngeal function by maintaining the position of the larynx in the neck. This is essential to a singer as this stability enables the intrinsic muscles to work effectively (R. Sataloff, 1998). The infrahyoid muscles, those below the hyoid bone, are the thyrohyoid, sternohyoid and omohyoid. The suprahyoid muscles, those above the hyoid bone, are the digastric, mylohyoid, geniohyoid and stylohyoid. In addition to these, the sternothyroid, hypothyroid, cricopharyngeal and thyropharyngeal have a direct effect on the position of the larynx, the hypoglossus and genioglossus have an indirect effect via tongue position. The larynx, hyoid and the base of the tongue need to be considered as a physiologic entity. Their action cannot be observed without consideration of their interaction (Kenyon, 1922); cited in (Vilkman et al., 1996).

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Figure 2.6 Diagram of lines of pull of the extrinsic laryngeal muscles (Bunch, 1997)

Connective tissue – this is primarily evident as the vocal ligament arising from the conus elasticus. It runs through the vocal fold, attaching to the arytenoid cartilages posteriorly and to the thyroid cartilage anteriorly. It is also evident on the articulating surfaces of the cartilages and at the point of muscle insertion into the cartilages.

Nerves – The motor coordinations of the laryngeal muscles are controlled by the vagus nerve. The cricothyroid is triggered by the superior laryngeal nerve, the other laryngeal muscles by the recurrent laryngeal nerve.

Space – the glottis: this is the gap between the vocal folds.

Vocal folds – The vocal folds comprise many layers: the more superficial the layer, the more pliable (Hirano, 1988).The vocalis muscles are supported on the conus elasticus which arises from the upper edge of the cricoid cartilage. The vocal fold comprises, from the deep layer towards the superficial,

- the vocal ligament (the free upper border of the conus elasticus);
- the vocalis and thyroarytenoid muscles;
- layers of elastic fibres and dense connective tissue (Kahane, 1988).

These layers comprise three different tissue types. Innermost is the deep lamina propria consisting of collagenous fibres and fibroblasts (cells that cause scar formation). This is the stiffest and least mobile of the connective tissue layers of the vocal fold. Where these intermingle with the intermediate layer is the location of the vocal ligament. The next layer is the intermediate lamina propria comprising elastic fibres and some fibroblasts. Finally one can observe the superficial lamina propria which comprises loose fibrous components, a matrix that can accumulate fluid and contains very few fibroblasts (Reinke's space). This is covered with stratified squamous epithelium (this can withstand the trauma of frequent vocal fold contact due to its ability to regenerate damaged cells quickly). The various layers have different mechanical properties, enabling a variety of combinations of elasticity and mobility (Titze, 1994).

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Figure 2.7 A cross-section through the vocal fold to show the tissue layering (Hirano, Kurita, & Nakashima, 1983).

Larynx tube – This is the cavity immediately above the vocal folds, but within the larynx. It is bordered by the sinus Morgagni at the sides and the aryepiglottic sphincter at the top. It has an acoustic function, acting as a low-pass filter for the frequency components of the glottic source (Van den Berg, 1955). The resonating features of this ventricle have been demonstrated to be involved in the generation of the 'singer's formant' (Sundberg, 1974). It also provides a location for mucous glands to lubricate the vocal folds (Kutta, Steven, Kohla, Tillmann, & Paulsen, 2002) as the vocal fold epithelium is not itself mucus-producing.

<u>2.3.4 Detailed function of the larynx</u>

The intrinsic laryngeal muscles have a predominance of Type llA fibres. This type are both able to contract quickly and are fatigue resistant (R. Sataloff, 1998)(see 3.4.2).

Glottal opening (abduction)

Posterior and lateral cricoarytenoid muscles contract, pulling the muscular processes of the arytenoids towards each other, therefore swinging the vocal processes out and away from each other and causing abduction of vocal ligaments (Tom Harris, 1998). These muscles are contracted all the time that we are not phonating or swallowing. This allows the free movement of air in and out of the lungs for respiration.

Glottal closing (adduction)

Lateral cricoarytenoid muscles contract with the interarytenoid muscles (transverse arytenoids and oblique arytenoids) as a unit – this pulls the arytenoid cartilages towards each other, closing the posterior glottal chink and adducting the vocal ligaments almost as far as the mid-line of the glottis.

The vocalis (internal thyroarytenoid muscle) and external thyroarytenoid muscles contract. This shortens the distance between the arytenoid and thyroid cartilages (possibly relaxing the vocal ligaments slightly and stabilising the position of the arytenoid cartilages) and gives the vocal folds a stiffer body. This gives a firmer and thicker surface for impact, resulting in a stronger sound. The thyroarytenoid has some oblique-running fibres that enable the muscle to 'bulk up' (in a similar way to the biceps) and enable a greater area for contact.

Vocal fold vibration

When the vocal folds are adducted, sub-glottic air pressure builds up. Air pushes through from bottom to top until there is space between the folds, air passes over the folds and through the glottis. On exhalation supra-glottic pressure is lower than sub-glottic. Therefore, the lower edge of the fold is pulled inward even while the upper edges are still separating (this is the Bernoulli effect). The upper edges are more elastic and therefore snap back together when the lower edges are pulled together (Titze, 1994; Van den Berg, 1957).

A mucosal wave is caused by this rippling movement from bottom to top and is essential to the basic quality of the sound. It generates a pulsating air flow, creating the upper partials in the frequency spectrum and contributing to the vocal timbre. Irregularities in this vibratory pattern caused by inflammation of the lamina propria can lead to vocal hoarseness (see 3.9).

The false vocal folds are fleshy folds situated within the larynx tube; above the true vocal folds and the sinus Morgagni. They contain mucous glands, whose main role is to generate mucus to keep the surface of the vocal folds moist, enabling effective contact in each vibratory cycle and preventing frictional damage (Bunch, 1997). The surface of the vocal fold itself does not contain mucous glands as mucosa would be too delicate to withstand the trauma of vibration and collision. They are reliant on the presence of mucous from the surrounding tissues. The false vocal folds can be pushed together by the contraction of the lateral thyroarytenoid and the interarytenoid muscles. This action is part of the sphincteric ability of the larynx, used in defecation or coughing. However, it restricts the free vibratory movement of the true vocal folds and is detrimental to good singing.

Vocal onset

A clear and precise start of a note depends on the coordination between respiratory and laryngeal muscular contraction. The adductory and pitch-regulating muscles engage about ⅓ second before phonation (Hirano, 1988).

Glottal onset (sometimes called attack) is caused by the complete adduction of the vocal folds before the air begins to travel through the glottis. As the air then builds up and bursts through there is an audible click. This can be used with varying levels of effort ranging from a slight click (for example, used at the start of German words beginning with a vowel) to a potentially abusive level of constriction (heard, for example, when sportsmen vocalise during exertion).

Breathy onset occurs with aspirated consonants (/h/, /p/, /f/ etc). Unwanted breathy onset is caused by either unnecessarily high air pressure preventing effective closure of the folds or inefficient muscular control so that the folds are not brought together properly. For example, air can escape through a posterior glottal chink caused by ineffective contraction of the transverse arytenoids, or a medial glottal chink caused by ineffective contraction of the lateral cricoarytenoids.

Glottal Closed Quotient or Contact Quotient (CQ) is the percentage of each cycle for which the vocal folds are in contact (see also 4.5.3). It is greater, for example, in trained voices, speech register and pressed voices (Howard, 1995, 2007). It increases with vocal loudness.

The muscles of the larynx engage about a third of a second before phonation. The vocal folds close slightly on exhalation; this is probably to control the outflow of air and maximise gas exchange.

When considering the neuromuscular system used in vocalising, there are two caveats to bear in mind. Firstly, any analysis of the voice must acknowledge the whole human in whom the voice is located. Vocal performance is the end product of a thought – feeling – speech interface (Morrison & Rammage, 1995). A thought consists of both intellectual and emotional elements. These expressed through the personality of the speaker will affect the muscular patterns of usage. This particular study deals primarily with the physical outcome of this web of influences: whilst acknowledging the complexity of this situation, it does not contain any specific analysis of underlying emotional effect.

Secondly, the neuromuscular system used for speech initially evolved for swallowing, breathing and airway protection. These powerful instincts may often override or affect the muscular usage during speech (Morrison & Rammage, 1995).

2.3.5 Changes in pitch

Although this is primarily enabled by the intrinsic laryngeal muscles (Hirano, Ohala, & Vennard, 1969), the cricothyroid is mechanically more effective than its antagonist, the thyroarytenoid (Shipp, 1982); cited in (Vilkman et al., 1996), suggesting that the external laryngeal musculature is also involved in pitch control. The strap muscles (thyrohyoid, sternohyoid and sternothyroid) show greater activity at high and low pitches than at pitches in mid-range of speech (Roubeau, Chevrie-Muller, & Saint Guily, 1997).The vocal folds will vibrate at a higher frequency if they are thinner or tighter.

Vocal fold lengthening

Longer vocal folds are generally thinner and therefore vibrate at a higher pitch. The cricothyroid muscles contract – this tilts the thyroid cartilage forwards and down and the cricoid cartilage backwards and up, thereby lengthening the vocal ligaments and thinning the vocal folds. Vocal fold lengthening can also be achieved by contraction of the thyropharyngeus which approximates the thyroid laminae and thus moves the anterior fixation point of the vocal folds forward. There is some gliding action between these two cartilages, especially observed in younger, more mobile cartilages (Zenker & Zenker, 1960); cited in (Vilkman et al., 1996).

Increased sub-glottic air pressure will also cause a higher frequency of vibration (Gramming, Sundberg, Ternstrom, Leanderson, & Perkins, 1988). Singers have to balance these two actions of muscles and air pressure with the adductory force, as increased air pressure also increases loudness which may not be desired (H. J. Rubin et al., 1967). Thinner vocal folds tend to produce a quieter sound.

Non-singers – in the sense of non-educated or experienced – tend to raise the larynx with raised pitch (Shipp, 1975), whereas singers endeavour to maintain a more consistent laryngeal height (Sundberg, 1987). This relative consistency is also dependent on the musical genre and style of singing and also singer classification (for example, sopranos singing in their highest register have to shorten the resonating tube, including raising the height of the larynx). Non-singers, therefore, have a direct relationship between vocal fold length and pitch. Whilst this is also true for singers, they also have developed the option of being able to thin the vibrating mass of the vocal fold to provide some flexibility in the relationship between vocal fold length and pitch (see 2.3.6). The vocal folds are observed at their longest during deep inspiration (Pfau, 1961); cited in (Vilkman et al., 1996).

Vocal fold shortening

Shorter vocal folds are generally thicker and therefore vibrate at a lower frequency. To shorten the vocal folds the cricothyroid muscles relax and thyroarytenoid muscles contract (Titze, Luschei, & Hirano, 1989). Pitch may also be lowered by tracheal pull (see 2.2.2), the downward pull on the cricoid cartilage results in a shortening of the vocal folds. However, any downward pull of the trachea tends to result in an increase in contraction of the cricothyroid (Sundberg et al., 1989). This would be needed in order to counteract this vocal fold shortening (Sonninen, 1956).

If the head is positioned back, the contraction of the sternothyroid can result in a lowering of pitch (Sonninen, 1956) although severing of the sternothyroid in thyroid surgery can result in a loss of high pitches, suggesting that the sternothyroid has more of a stabilising role in pitch alteration.

2.3.6 Changes in register

Register changes are directly related to pitch. Modal register (also known as speech quality, or chest voice) is made using relatively thick vocal folds. This is the voice quality most commonly used: as there is a greater area of contact, the possibility for strain is reduced (as long as the pitch is appropriate). There is generally a larger amplitude (movement away from the mid-line) in modal phonation. The use of modal register, by the singer, as high as is physically possible results in a potentially thrilling and dramatic sound, one which could be described as 'shouting at a controlled pitch'. This is believed to be the mechanism used by tenors singing A4 to C5 in full 'chest', or by female singers 'belting' above about B4 (Lovetri, Lesh, & Woo, 1999; Miles & Hollien, 1990; Schutte & Miller, 1993; Sundberg, Gramming, & Lovetri, 1993).

Modal register will only feel comfortable for both the male and female up to about E4 to G4. If the pitch is raised beyond this, the vocal folds cannot lengthen further without considerable effort and the method of phonation will naturally change into falsetto. In uncultivated falsetto phonation the thyroarytenoid releases and become relatively flaccid (Lindestad, Fritzell, & Persson, 1994), the lateral crico-arytenoids contract, pulling the arytenoid cartilages back and tightening the vocal ligament (Tom Harris, 1998). The vocal fold is more rigid, glottal closure is brief and incomplete, the folds only close completely every so often and the sound is caused by the vibration of the outer mucosal layer only. This is a fluttering action, not a wave motion as observed in other phonation. The sound cannot be made with increased air pressure as there is insufficient glottal closure (Murry, Xu, & Woodson, 1998; Sundberg & Högset, 2001) and so has limited dynamic range. It can be hooty or breathy and it is often used by inexperienced singers in the upper part of their range. A cultivated falsetto phonation, such as is used by countertenors, uses a combination of both uncultivated falsetto and thin-fold phonation, from contraction of the cricothyroid muscle.

If the singer wishes to vocalise at higher pitches with a greater degree of flexibility than falsetto will allow, it is possible to use head register or thin-fold phonation (n.b. much of the literature refers to this quality as falsetto; (Keidar, Hurtig, & Titze, 1987). This uses thinner, longer vocal folds created by a greater degree of contraction in the cricothyroid and with some level of contraction in the thyroarytenoid (Lindestad et al., 1994). This thyroarytenoid activity gives enough tension in the vocal fold body to prevent the singer slipping into a falsetto production. It is normally used by trained singers at a higher pitch (Colton & Hollien, 1972). The transition from thick (modal) to thin-fold is normally between D4 and G4 in both male and female voices (Thurman, Welch, Theimer, & Klitzke, 2004). This shift is often relatively uncoordinated in the untrained vocalist. For a smooth change to occur, it is necessary to learn coordination of the antagonistic actions of the lengthener and shortener muscles,as well as regulating the glottal closure (Steinhauer, Grayhack, Smiley-Oyen, Shaiman, & McNeil, 2004). The vocal quality is lighter, with fewer partials in the lower part of the spectrum (200–400Hz; (Colton, 1972).

If a singer moves from thin-fold to falsetto on the same pitch, the vocal folds will be observed to shorten (Welch, Sergeant, & MacCurtain, 1989). A move from modal to falsetto on the same pitch will result in a lengthening of the vocal folds.

For centuries, singing teachers have argued in support of the existence of a middle register or 'voix mixte'. Only recently has some acoustic evidence to support this phenomenon been demonstrated (Sundberg & Kullberg, 1999; Titze, 1988).

Reverberating sound waves in the trachea could be influencing the vibration of the vocal folds at certain pitches, when this corresponds with the resonance frequency of the trachea. This causes interference in the vibratory pattern and results in subconscious adjustments to the muscle activity (Thurman et al., 2004). This could explain the difficulty encountered by singers in taking modal voice from F4 to C5 (Titze, 1988).

The change from one vocal register to another is known as a passaggio. There is at least one other passaggio in the vocal range, in addition to the transition from thick to thin-fold phonation (Thurman et al., 2004). This is experienced by the singer as a change in sensation as well as an audible change in voice quality. A skilled singer will attempt to conceal any noticeable quality change.

<u>2.3.7 Changes in loudness</u>

According to Rubin (H. J. Rubin et al., 1967), at low pitches this is controlled more by glottal resistance, i.e. the force with which the vocal folds are adducted. Stronger adduction leads to louder phonation (like clapping hands). At higher pitches, loudness is controlled more by subglottic air pressure, i.e. the expiratory muscles. Later research suggests that higher subglottic pressure results in louder phonation (Sundberg, Titze, & Scherer, 1993). One longitudinal study of a professional baritone showed that, through deliberate alteration of his vocal technique over a period of thirty years, he managed to reduce his subglottic pressure by about 50% with very little change in overall sound pressure level (SPL) (Schutte, Stark, & Miller, 2003). Increased adduction can result in pressed phonation which can be injurious to the vocal folds. A slightly spread posture of the vocal folds will reduce the phonation threshold pressure (Titze, 1994).

2.3.8 Vibrato

Vibrato is a natural phenomenon giving simultaneous fluctuations of F_0, loudness and timbre. The contraction of a muscle is triggered by a message from the nerve. As this has to travel from the brain, there is a slight time delay for this message to reach the muscle. When two antagonistic muscles contract simultaneously at a particular effort level, the message to one muscle (A) will result in a slightly stronger contraction while the message to the other muscle (B) is still travelling. When the message reaches muscle B, it will contract slightly more strongly than muscle A. This periodic shifting of balance between the two results in a type of tremor movement with about 5 to 7 cycles per second (Shipp, Leanderson, & Sundberg, 1980); (Shipp, Sundberg, & Haglund, 1984).

In the larynx, the lengtheners (cricothyroid) and shorteners (thyroarytenoid) work antagonistically (Shipp, Leanderson, & Haglund, 1982) and can produce a fluctuating fundamental frequency (pitch). In the breathing mechanism, the muscles of inspiration (diaphragm) and expiration (abdominal wall) will do likewise, resulting in fluctuation of intensity (loudness).

A vibrato at the optimum degree of fluctuation can be a symptom of well-balanced laryngeal function (Rothman & Timberlake, 1984); it is not advisable to try consciously to create this effect. An inappropriate vibrato may sound like a bleat (too rapid) or a wobble (too slow and wide). A giggle uses the same oscillation between these two sets of muscles (Titze, Finnegan, Laukkanen, Fuja, & Hoffman, 2008).

2.4 Resonance and articulation

The vocal tract consists of the pharynx, the mouth and, to a lesser extent, the nasal cavity. The vocal tract is an extremely flexible resonating chamber. It can be lengthened or shortened. It can be widened and narrowed in different regions simultaneously. These adjustments of alignment alter the quality of the sound by enhancing certain harmonics in the acoustic signal. This gives the sound timbral qualities such as warmth, brightness, depth and ring (Bunch, 1976; Estill, Baer, Honda, & Harris, 1984), as well as articulating all the different vowels. Closure in some form by the tongue or the lips will produce consonants.

2.4.1 The structure of the vocal tract

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Figure 2.8 Sagittal section of the vocal tract (Bunch, 1997)

The vocal tract is essentially a tube with the vocal folds at one end and the lips at the other. In the adult male this is about 17cm (D. B. Fry, 1979). There is an optional addition of the nasal cavity, controlled by the opening or closing of the velopharyngeal port (soft palate).

2.4.2 Basic vocal tract function

Swallowing

The pharynx is a muscular sleeve attached to the skull at the top and the larynx at the bottom. Its primary function is to create an action that will enable us to swallow food – passing the food from the mouth into the oesophagus whilst the soft palate closes the back of the nose and the larynx closes the top of the windpipe. This swallowing action is achieved by the closing of the jaw, the tongue pushing the food into the oral pharynx, and the contraction of the three pairs of pharyngeal constrictor muscles, superior, middle and inferior, to push the food down the pharynx, past the closed larynx and into the oesophagus. (Zemlin, 1988).

The closure of the larynx is achieved by the upward pull of the longitudinal muscles, stylohyoid, stylopharyngeus and the palatopharyngeus, pulling it up and forward against the epiglottis at the same time as the laryngeal muscles close the glottis, a double 'belt and braces' effect. The closure of the nasal passage is achieved primarily by the raising (levator palati) and a small element of tensing (tensor palati) of the soft palate (Zemlin, 1988); see Figure 2.6).

Yawning

This is a reflex action designed to open the throat, allowing easy inhalation to raise our oxygen intake if we are tired. The soft palate raises and the root of the tongue pushes the larynx down and back (Zemlin, 1988). This second movement opens the throat to enable more air to enter but also 'fixes' the larynx and restricts mobility. A complete yawning sensation whilst singing is therefore detrimental (try speaking and yawning simultaneously). There is limited kinesthetic awareness of the position of the soft palate (Morris, 2006).

The instinctive actions of the muscles that raise the palate are connected to reflex actions (swallowing and yawning); these actions in their complete form are not helpful for good sound production. The singer has to learn discrete use of the muscles to raise the soft palate. Raising the soft palate whilst vocalising increases the length of the throat (vocal tract) and prevents vibrating air from entering the nasal cavity (which can produce a nasal tone quality and dampens the intensity of the sound).

In the trained singer, the velopharyngeal port will remain closed significantly longer than in speech (Austin, 1997) unless it is lowered as a choice related either to sound quality (a 'nasal' characterization, for example) or language (French nasalized vowels). Employing a limited degree of velopharyngeal opening can enhance the singer's formant on certain vowels, notably /a/ (Kent & Vorperian, 1995; Sundberg et al., 2007).

Chewing

The muscles of mastication are the most powerful muscles of the head (Bunch, 1997). The masseter, temporalis and medial pterygoids are elevators of the jaw used in biting and chewing. The jaw can move up and down, forward and back, and side to side (Zemlin, 1988). It is hinged at the temporo-mandibular joint (the hinge action felt just in front of the ears)

2.4.3 Vocal tract function – enhancing phonation

There are many factors that enable the shape of the pharynx to alter. Sound waves travel in straight lines; if sound is bounced off relatively hard surfaces it will carry further than if it is absorbed by softer tissues (Paget, 1930); cited in (Bunch, 1997). Harder surfaces include the raised (stretched) soft palate, the back of the throat (the upper cervical vertebrae) and the hard palate. Softer surfaces include the anterior part of the pharynx, the tongue and lips.

The larynx can move up and down (affecting the length of the vocal tract) and the cartilages can tilt independently of each other to aim the sound waves at different parts of the pharynx. A high larynx will result in higher frequencies for all formants (Lindblom & Sundberg, 1971), a lower larynx will correspondingly lower the formant frequencies (Sundberg & Nordström, 1976). The soft palate can move both up and down and can be raised in a wide arch or a taller, narrower arch. The base, middle or front of the tongue can be used to direct sound. The position of the jaw is important in determining the position and flexibility of the tongue, larynx and soft palate (Morris, 2006).

Finally, maintaining a stable position of the head and neck is advisable in order to enable all of these parts the freedom to function at their optimum (W. Barlow, 1973). According to Laver (Laver, 1980), it has been observed that singers may 'tuck in' the chin in order to enhance lower frequencies. This may facilitate the lowering of the larynx by minimizing any potentially antagonistic mechanical stretch on the suprahyoid musculature. It is also the case that singers may raise the chin to facilitate singing at high pitches (Morris, 2006). Both of these actions may involve a reduction in the flexibility of the laryngeal mechanism, resulting in negative consequences for the singer.

2.4.4 Vocal quality or timbre

Singers and speakers may alter the sound quality by altering the dimensions of the vocal tract. Pedagogical literature refers to 'covered' and 'open' qualities (Lehmann, 1924; Miller, 1986). The 'covered' quality will tend to be produced with a lower larynx and a higher soft palate, thereby lengthening the vocal tract (Bunch, 1976).

Harmonics are multiples of the fundamental frequency. Some are stronger than others due to the vibratory pattern in the vocal folds. Modal and falsetto phonation have different vibratory patterns and as a result they generate a different distribution of harmonics in the sound (2.3.6).

The sound energy leaving the larynx, with its own family of harmonic distribution, passes into the vocal tract. This is a tube with an almost infinitely variable shape. The length is determined by the height of the larynx and the opening of the lips (wide or pursed). The length is therefore limited to within these parameters. The smallest width is zero – mouth closed, soft palate raised and larynx raised and constricted – this happens with each swallow. The largest is determined by the dimensions of the individual physiology of the singer. Within these limits of length and width, the shape is very flexible.

The cavities and constrictions formed by the height of the larynx, position of the pharynx wall, tongue, soft palate and jaw will create smaller spaces, each with their own formant frequency. This is a resonant phenomenon meaning that a particular group of frequencies will be amplified within this space (any hollow chamber has a formant frequency; an open-topped bottle will have a variable resonant frequency depending on how much fluid is in it, and how much air remains). The vocal tract has the ability to form more than one cavity within it, enabling a number of formants to be amplified on any given note or vowel. A singer will be working with up to five formants. The first two formants will determine the vowel and the next three will determine vocal quality or timbre.

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Figure 2.9 The British English vowel formants (Doscher, 1994)

The chart shows that vowels with a high tongue position, [i] and [u], have a low F1; [æ] and [ɑ] have a higher F1. Vowels with a forward tongue position, [i] and [y] , have a high F2. Vowels with a backed tongue position, [ɔ] and [ɑ] have a low F2. As the tongue moves from raised to flattened the F1 rises; as the tongue moves forward within the mouth, the F2 rises.

For a vowel to be sung at a particular frequency, the resonators need to reinforce a sound which has partials of the fundamental and also partials within both vowel formants. The vowel formants have to be altered to accommodate the harmonic series. Articulators need to remain flexible and responsive so that they can instinctively seek the position for the best resonance for each vowel and each pitch.

If the resonators are 'out of tune' with the harmonics, the sound may be dulled or the fundamental pitch may appear to be out of tune. Alternatively the singer may mis-tune the formants, giving the singer the impression (due to the selective nature of the internal conduction of the sound) that the fundamental is in tune when it is not.

2.4.5 Twang, ring or the singer's formant (Sundberg, 1995)

A trained singer or speaker can learn to enhance the frequencies in the level near 3 kHz in the spectrum (Bartholomew, 1934), 2–4 octaves above the sung pitch (Howard & Angus, 2001). This particular band of frequencies is not observed as a peak in the orchestral spectrum. The singer, as a consequence, can be heard above the sound of an orchestra, even though the sound pressure level of the orchestra far exceeds that of the singer's output. The method to determine the presence or otherwise of a singer's formant is normally to compare the level of F3-5 with F1 (the formants or harmonic clusters observed in the sound frequency spectrum; (Schutte & Miller, 1985).

One explanation (Sundberg, 1974) is that this phenomenon is facilitated by a particular relationship between the dimensions of the larynx tube and the pharynx. The larynx tube is about 2cm long. It is bordered on the bottom by the vocal folds, on the posterior wall by the arytenoid cartilages and on the anterior wall by the epiglottis. If the cross-sectional area of its aperture is smaller than one sixth of that of the pharynx, an acoustical mismatch occurs and the larynx tube acts as a separate resonator.

In order for the singer to achieve phonation with the singer's formant, the cross-sectional area in the pharynx can be at least six times wider than that of the larynx tube opening, the sinus Morgagni must be wide in relation to the rest of the larynx tube and the sinus piriformes wide in the pharynx (Sundberg, 1974). This particular frequency 'rings' in our ears when we hear it as the resonance frequency of the larynx tube is the same as that of the ear canal (ReSound, 2007).

If we assume that the 1:6 ratio is an important factor determining the presence of the singer's formant, this could conceivably be achieved by either the narrowing of the larynx tube or the widening of the pharynx, or both. The former action has been identified in some cases observing the contraction of the oblique and transverse arytenoid muscles, collectively known as the aryepiglottic sphincter (Yanagisawa, Estill, Kmucha, & Leder, 1989).

This timbre can be also associated with pharyngeal narrowing (Titze, Bergan, Hunter, & Story, 2003), rather than aryepiglottic narrowing. There is more than one way to enhance particular frequencies. This would also provide an argument against using terminology such as 'open throat' for optimal vocal performance (Mitchell & Kenny, 2004). This timbre can also be connected with the pedagogical direction of 'forward placement' which will generally result in the enhancement of higher frequencies and the singers' formant (Vurma & Ross, 2003). The result is a 'ringing' quality. This acoustic effect occurs in variable quantities in the speaking voice, for example, a Southern-States North American speaker generally has more twang than an English one (Chapman, 2006).

2.4.6 Articulation

Articulation can be defined as the manoeuvres made in order to adjust the shape of the vocal tract during phonation (Sundberg, 1987). The moving parts responsible for articulation are the jaw, tongue and lips; these work in relation to the skull posture (especially hard palate and teeth) which remains relatively stable.

The Lips

These can be rounded to lengthen the vocal tract and lower the formant frequencies (sounds darker) or spread to raise the formant frequencies (sounds brighter) (Sundberg, 1987).

The Jaw

Opening the jaw will increase the frequency of F1 (Sundberg, 1987). Opening the jaw too much reduces soft palate and tongue flexibility (Morris, 2006).

The Tongue

The tongue is not flat, it is a ball of muscle. If you put out your tongue, you only see the front third. The position of the tongue in the mouth and pharynx will alter the distribution of the formants and therefore the perceived vowel colour (Titze, 1995; Vennard, 1967). The extrinsic muscles of the tongue show connections with the jaw (mandible), the soft palate, the pharyngeal wall and the hyoid bone. In vocal pedagogy, the use of the tongue is restricted to the articulation of the text. It is a common habit for the tongue to become involved as a larynx depressor. This can have disastrous long-term consequences for efficient singing. The pressure of the hyoglossus on the hyoid bone and indirectly on the thyroid cartilage can limit the movement of the cricothyroid joint. The lowering of the back of the tongue can also limit the functioning of the palatoglossus in raising the soft palate. There is a suggestion, however, that the geniohyoid contracts at high pitches, especially on vowels with a raised tongue placement ([i] and [u]), pulling on the front of the hyoid bone and indirectly on the thyroid cartilage, and assisting in the lengthening of the vocal folds (Honda & Fujimura, 1991). This may be one reason why tenors find it easier to sing loud, high pitches on bright vowels.

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Figure 2.10 Muscles of the tongue and soft palate (Bunch, 1997).

2.4.7 Vowels and consonants

Vowels are formed by the position of the tongue and the lips. As a very basic generalization, the [i] vowel is formed with a raised and fronted tongue; this lowers through [ɛ] to [ɑ]. The vowels from [ɑ], through [ɔ] to [u], are formed by bringing the lips forward; the back of the tongue will tend to rise again through these darker vowels (Sapir, 1989).

Consonants are formed by the action of the tongue and lips against each other or the teeth and palate. They fall into two categories, voiced and un-voiced. The articulation of consonants inevitably has an effect on vocal function. The movement of the jaw and tongue will affect the configuration of the vocal tract and therefore alter the acoustic properties of the sound. The closure of the vocal tract with the articulators as consonants are formed will cause alterations to the subglottal air pressure and to the transglottal air flow. As F_0 regulation depends on regulated air flow and pressure, one would expect the introduction of consonants into a vocal line to have an effect on pitch. This is evident from studies (Baken & Orlikoff, 1987). However, it would appear that our ears accept this, and both singers and listeners seem to be unaware of these pitch changes. Although articulation has an effect on the behaviour of the vocal folds, this can be considered as a secondary influencing factor in vocal fold behaviour. A detailed description of articulation has not been included in this account.

2.5 Overall vocal quality

This is partly dependent on the natural shape of the vocal tract, partly dependent on the learnt coordination of the relevant muscles and partly dependent on imagination, musicianship and personality. In other words, everyone can learn to be a better singer but not everyone can learn to be a great singer.

2.6 Summary

This chapter has given a description of the physical functioning of the adult human vocal mechanism. It is relatively long and a fairly comprehensive summary of the available literature on the functioning of the adult voice. This wide base is necessary in order to support the degree of specialisation and subsequent narrowing of the pyramid as the nature of the child professional singer is investigated.

An understanding of vocal function is also essential information for the application of voice assessment, both perceptual and acoustic. The final product – spoken or sung sound, is a complex amalgamation of interacting elements. Any one vocal gesture can often be obtained from more than one combination of these elements. In order to make an informed judgment regarding voice use, it is necessary to have an awareness of the possibilities of the vocal system and how these can affect the resulting sound.

Chapter 3

Child and adolescent voice development

3.1 Introduction

This chapter presents the anatomical and physiological alterations from pre-birth to adult. The vocal mechanism of the child is not simply a smaller version of the adult system. In order to understand the differences between the various stages of development, it is necessary to investigate the nature of the infant voice and why this may be so fundamentally different from that of the child and adolescent. The final section of this chapter gives an account of voice disorders found in children. This information is necessary to enable informed assessments of the health and functioning of the voices occurring later in the study.

Many aspects of the infant vocal mechanism are structurally and functionally different from that of both the child and adult. This is explained by the fact that the infant larynx is primarily designed to aid suckling, crying and efficient valving; not speech. In order to appreciate the changes to the child voice during growth, it is important to understand how fundamentally different the infant vocal mechanism is from that of the adult (Bosma, 1975). The structures grow and develop in order to adapt for the onset of speech from the age of one year (Kent & Vorperian, 1995).

3.2 Evolution of the vocal mechanism

The human voice has evolved to be capable of producing a wide range of sounds (Lieberman & Crelin, 1971). Not only is this much broader than any observed in other mammals, it is also more than that which would have been produced by earlier humanoid species (Lieberman, 1993). When observing the stages of evolution, one can see the links with the stages of development of the embryo. These parallels between embryology and phylogeny can give strong indicators of how the vocal mechanism has evolved for its present function (Henick & Holinger, 1997). In the embryonic development of the vocal mechanism it is observed that the diaphragm is evident by 33 post-ovulatory days. The diaphragm is the first and most fundamentally important structure to form. The evolutionarily more sophisticated structures of the larynx develop later during gestation. The structures of the larynx appear initially as an outgrowth of the pharynx (Eavey, 1995): they are distinct by 47 days and the ribs are identifiable by 50 days (Jirásek, 2000). By 56 days most of the major laryngeal muscles are present and their innervation follows closely the adult pattern (Muller, O'Rahilly, & Tucker, 1981; Zaw-Tun & Burdi, 1985); although at this time the median part of the soft palate is not yet formed (Muller, O'Rahilly, & Tucker, 1985). The epiglottis and soft palate are in close contact by the 24th week. In the 5 or 6 week-old embryo, the larynx lies at the level of the basi-occiput, but descends by birth to the level of the 3rd cervical vertebra (C3)(Negus, 1962).

3.3 The breathing mechanism

Respiratory function begins pre-natally, as early as 21 weeks gestation, with both 'breathing' and swallowing of amniotic fluid (Jansen & Chernick, 1983). At birth, the first response to the air encountered outside the birth canal is for the diaphragm to contract and for the baby to inhale (C. A. Smith, 1963).

3.3.1 Lung capacity

The newborn infant has relatively small lung capacity. The lungs and trachea are between quarter and half of adult proportions, with relatively few bronchioles. By the age of seven the bronchioles have reached adult numbers and the structures are merely proportionally smaller overall (Eichorn, 1970). The infant does not need the lung capacity to facilitate sustained aerobic activity or speech, therefore lung volume is proportionally smaller in favour of a larger digestive tract. Lung size and vital capacity increase not only with overall growth of the body but also relative to the amount of aerobic activity in childhood (Cotes, 1979b). This has implications for the lung function of physically disabled children, for example, who may never reach their full potential lung volume.

The growth of relative lung capacity can be observed in the frequency of maintenance breaths. The newborn takes about 87 breaths per minute, at 1 year 47, and as an adult 16–20 (Thurman, 2000). As well as the relative growth of the lungs, during the first year the infant begins to learn to develop voluntary control of breathing ready for use in speech. Speech requires not only larger volumes of air than maintenance breathing but also uses significantly longer expirations than inspirations (Sundberg, 1987).

3.3.2 Respiratory function

At birth and while the infant is mostly in a horizontal position, the breathing is largely diaphragmatic. The ribs are horizontal circles, without the option of the lifting movement observed in adult ribcage expansion. They are mostly cartilaginous, not rigid enough to enable intercostal movement to affect lung volume significantly (Kent & Vorperian, 1995). The use of diaphragmatic contraction (observed as abdominal movement) and rib excursion is individually variable and does not necessarily correlate with vocal activity. It is as if the infant is 'trying out' different sensations (Boliek, Hixon, Watson, & Morgan, 1996).

Tidal or maintenance breathing gradually changes to a mixture of diaphragmatic and thoracic movement from one to five years, the ribs assuming a more adult contour by the age of seven; by the age of eight it follows the adult pattern of both thoracic and abdominal movement for maintenance breathing (Eichorn, 1970; Thurman, 2000). This area of research has produced discrepancies in the results of various studies. Some have found that children terminate utterances with the ribcage in a higher position than that of its position at rest (Hoit, Hixon, Watson, & Morgan, 1990), others have found the reverse to be true (Stathopoulos & Sapienza, 1997). It is known that by this age, breathing can be learnt to be voluntarily controlled using particular muscle groups advantageous to advanced vocal production.

Children tend to use rib displacement more than abdominal movement during speech (Stathopoulos & Sapienza, 1993). Paradoxical breathing (in which the abdomen is pulled in rather than allowed to expand during inspiration) is not unusual in children up to the age of ten years (Solomin & Charron, 1998). Children have a higher subglottic pressure than adults

(Stathopoulos & Sapienza, 1993). This could be as a result of the relatively smaller vocal tract size. Children also use a larger percentage of their vital capacity during speech: they tend to terminate speech utterances at a lung volume below that of resting expiratory level. This is most extreme in toddlers (not infants); terminal lung volumes decrease during childhood until in adults they match those of resting expiratory levels (Stathopoulos & Sapienza, 1993). Children may be less efficient at managing their laryngeal airflow as they have relatively smaller, thinner and less elastic vocal folds (see 3.5). Adults have been observed to use higher subglottic pressures at higher pitches, where the vocal folds are thinner (Sundberg et al., 1999). It is likely that, as children have greater airway compliance than adults, it is easier for them to speak at higher and lower lung volumes (Solomon & Charron, 1998).

Air flow is reported to be lower in children than in adults (Stathopoulos & Sapienza, 1997). As adults are known to have a stronger elastic recoil in the lungs (Mansell, Bryan, & Levinson, 1977) this additional expiratory force may enable a measurably higher air flow. Lung growth continues throughout childhood and adolescence, changes continue into senescence. The lung budding also continues with about seven more branchings occurring after birth (Eavey, 1995).

3.4 The larynx

3.4.1 Laryngeal cartilages (Eavey, 1995)

The infant larynx is approximately one-third the size of the adult larynx (Rahbar & Healy, 2003). The infant vocal folds are 6–8mm, in the adult female they are 8–11.5mm and in the adult male 11–16mm (Morrison & Rammage, 1995). The infant larynx is proportionally much smaller and more rounded than angular. The cartilages are softer and more pliable, and are more compact in their connection to each other; the thyroid cartilage and hyoid bone almost meet at the front (Fried, Kelly, & Strome, 1982; Tucker & Tucker, 1979). The relative proximity of the laryngeal cartilages is much closer in the infant. The hyoid bone often overlaps the thyroid cartilage. The cricoid and thyroid cartilages are so close to each other that the cricothyroid membrane appears as a slit.

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Figure 3.1 Anterior comparison of the infant and adult larynx (Eavey, 1995)

Figure 3.2 Posterior comparison of the infant and adult larynx (Eavey, 1995)

This system is much less flexible than the mature larynx. The robust structure enables relatively loud and efficient vocalising, the lack of flexibility limits the pitch range. These shorter vocal folds, higher in the vocal tract will give an acoustic advantage (see 3.6.3) (T Harris, 2007). The sound produced is much more piercing and is suited to the infant whose tools for survival include being as loud as possible. The sophistication of increased pitch range and more expressive vocalising comes with the onset of speech (Morrison & Rammage, 1995).

The cartilaginous portion of the infant larynx is proportionally longer: the ratio of cartilage to membrane in the infant is about 1:1, in the adult it is about 1:4. This enables the larynx to alternate rapidly as a valve during swallowing and then open rapidly for respiration (Morrison & Rammage, 1995). The coordination of the muscles of the infant is less advanced (see 3.4.2); a rapid response to the danger of foreign bodies entering the airway is of greater importance than subtle manipulations of the laryngeal cartilages needed for speech. Another suggestion for this difference is that cartilage does not suffer from oedema which could block the relatively small airway (Aronson, 1990; Holinger & Green, 1997).

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Figure 3.3 Transverse comparison of the infant and adult larynx (Eavey, 1995)

The epiglottis is tilted more posteriorly than in the adult (Holinger & Green, 1997). It is relatively thicker and omega-shaped in cross section (the adult is a more gentle curve) (Morrison & Rammage, 1995); (Fried et al., 1982) and is able to couple with the soft palate to facilitate suckling and breathing simultaneously (Crelin, 1973). As the larynx position lowers with age, this coupling ability ceases.

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Figure 3.4 Sagittal comparison of the infant and adult larynx (Eavey, 1995)

3.4.2 Laryngeal muscles

In the infant larynx the cricothyroid is relatively large compared with the other intrinsic laryngeal muscles (Kahane & Kahn, 1984). The vocalis muscle is relatively thin in newborns (Hirano et al., 1983). This would suggest that the ability to raise the pitch of the vocalisations is advantageous for survival from the start of life; other more subtle variations of vocal tone are developed later.

Muscles in children are known to relax at a slower rate than those in adults (Lin, Brown, & Walsh, 1994) this will affect the response time of finer muscle coordination. Type l muscle fibres are characterised by prolonged contraction, Type ll fibres have a short and fast contraction. The intrinsic laryngeal muscles of the infant are more Type ll than Type l, enabling the sphincteric action of the larynx to operate effectively. As a result, infant vocalisation is brief and unvaried. Gradually, the proportion of Type l muscle fibres increases, enabling more prolonged vocalisation (Verhulst, 1987). It has been noted that trained athletes have a higher proportion of Type ll muscles. With studies on monozygotic twins, one of whom is an athlete and the other not; this has been shown to be as a direct result of training, not a genetic predisposition (Malina, 1986). Although there has not been a specific study of this type on laryngeal muscles, one may hypothesise that training has the same effect on the muscles of vocalisation; allowing a slower, more controlled action of these muscles in the adult and possibly in the child singer. This has not been confirmed and other sources consider it unlikely (Bailey, Malina, & Mirwald, 1986).

3.5 Vocal fold structure

3.5.1 Development of the vocal fold lamina propria

At birth there appears to be a monolayer with a diversity of cell forms within it (Hartnick, Rehbar, & Prasad, 2005). By two months of age, there appears to be a movement towards a bi-laminar structure. The superficial, hypocellular layer has no mucin (a complex protein found in the substances secreted by mucous membranes). The deeper layer has plumper, less spindly cells with more mucin present. By eleven months, a three-layered structure is evident. However, these layers each contain elastin and collagen fibres, unlike the differentiation of adult layering where these are separated in the middle and deep layers (Hirano et al., 1983).

3.5.2 Vocal ligament

There is no defined vocal ligament within the vocal folds, meaning that the possiblity for sustained quiet vocalising is reduced in favour of shorter bursts of loud vocalising. As the child grows, by the age of three or four the internal structure of the vocal folds becomes more defined with the development of the vocal ligament and observable layering of the mucosa. By the age of seven years, the lamina propria contains three distinct layers. The deeper layer is more hypocellular than the middle layer; it does not, however, resemble the vocal ligament which becomes evident in a more adult form by the onset of adolescence. By ten years the tissues are considerably developed but do not assume adult configuration until after puberty (Hirano, Kurita, & Nashashima, 1981).

3.5.3 Distribution and development of the elastic fibres in the vocal folds

Early in development, the elastic fibres within the vocal folds consist of little amorphous material and numerous microfibrils. With growth, these proportions reverse, resulting in increased elastic properties of the vocal folds (Bonnaure-Mallet & Lescoat, 1989)(see 2.3.3).

3.6 Vocal tract

Due to the infant ability to couple the epiglottis with the soft palate, the location of the larynx in the infant vocal tract is much higher; the infant has a larynx level with the third cervical vertebra (C3), resulting in a relatively short vocal tract (Holinger & Green, 1997; Verhulst, 1987)(see Figure 3.5). The larynx drops to C5 by five years and the vocal tract assumes a configuration which by this age is relatively similar to the adult (ibid.).

The shorter vocal tract in the infant and subsequently in the child means that the formants are closer together; higher formants are reinforced but individual vowel sounds are less discernible. The size of the larynx and length of the vocal tract are generally in proportion to the height of the individual (Titze, 1994). Skeletal length will nearly always reflect vocal range; basses and altos tend to be taller than tenors and sopranos (Titze, 1994). However, there are individual idiosyncrasies in growth and eventual adult proportions. These lead to voice type anomalies such as the short but very loud Heldentenor (small, robust larynx, long and wide vocal tract), or the tall and willowy soubrette (small larynx and vocal tract). The effect of the vocal tract dimensions (width, length and shape) on the overall sound (individual vowels not considered) can be seen in the long term average spectrum (LTAS) (see 4.4.3).

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Figure 3.5 An illustration to show the relative proportions of the infant and child vocal tract (Kent & Vorperian, 1995)

3.6.1 Soft palate

The soft palate grows and thickens significantly in the first year (Subtelny, 1957). There is an alteration in the role of the palatal muscles between infant and child. The levator palatine is a palatal tensor in the infant but becomes an elevator in the child; tensor veli palatine is a palatal depressor in the infant but a palatal tensor in the child (Fletcher, 1973). The position of the soft palate in relation to the pharyngeal wall will determine the level of nasality in vocalisation. In the infant, the soft palate does not function to separate the oral and nasal cavities during phonation, therefore infant vocalising tends to have a nasal quality (Fletcher, 1973). There are observed changes in velo-pharyngeal valving with age (Thompson &

Hixon, 1979), and females tend to develop palatal muscle coordination sooner than males. Velopharyngeal valving alters through childhood as the adenoid (pharyngeal tonsil) atrophies (Fletcher, 1973). Velopharyngeal closure is velar-adenoidal in the young child. The adenoids can be at their largest at the age of about four years, leading to inefficient opening of the velo-pharyngeal port resulting in mouth breathing and denasal speech. Velopharyngeal closure changes to more adult forms during puberty (Croft, Shprintzen, & Ruben, 1981). Children's voices may have a greater degree of either hyponasality or hypernasality than adults'.

3.6.2 Jaw

Development of the jaw and articulatory mechanism is gradual throughout childhood. It would seem that the oral motor reflex responses of children at the age of seven to eight years are still in a transitional stage, they become more similar to adult reflexes by the age of twelve years (Qvarnstrom, Jaroma, & Laine, 1994; A. Smith, Weber, Newton, & Denny, 1991).

The development of the cranio-facial bones in relation to each other is partly dependent upon use, as this determines regions of resorption and apposition of bone (Kent & Vorperian, 1995). For example, children with an open-mouth posture have a slower pattern of maxillary growth than children with a closed-mouth posture (Gross et al., 1994). This open-mouth posture can be acquired as a result of over-enlarged adenoidal tonsils preventing nasal breathing.

3.6.3 Tongue

The structures in the cranial region of the infant nearest to adult size are the brain, tongue, inner ear and eye. The advanced maturity of these structures represents their importance for immediate survival (Eavey, 1995). The relatively large proportions of the infant tongue limit its function to merely thrusting and rocking (Fletcher, 1973): the intrinsic musculature is not capable of finer articulatory gestures. The development of lingual coordination is a gradual one, similar to the development of the laryngeal muscles.

In the infant the fat pads in the cheeks stabilise the suckling action but limit mandibular mobility. The tongue lies entirely in the oral cavity; this is however, not a suitable position for varied lingual articulation. The posterior third of the tongue is located in the pharynx by four years and the vocal tract is longer and more curved. The average dimensions of both male and female vocal tracts increase at about the same rate throughout childhood. From the age of seven to the onset of adolescence, the development of the larynx mirrors the overall growth of the child. There is no particular change in proportion or alignment (Kent & Vorperian, 1995).

To summarise, the infant voice is designed for crying to attract attention, vital for the survival of an immobile baby. The child larynx is better suited to speech, a more effective long-term solution for survival.

3.7 Speech and singing development through childhood

The infant can be identified from others by the sound of its cry, suggesting that there are already individual differences in neural control and structural properties (Gustafson, Green, & Cleland, 1994).

3.7.1 Pitch range of children's voices

The speaking fundamental frequency (F_0 – see Chapter 4, 4.3) will drop gradually through development from ages 6 to 16 and the range will increase gradually. No sudden changes are evident until mutation (van Oordt & Drost, 1963).

Male average speaking fundamental frequency (F_0 – see 4.3; (Pearce, 2007)

age 8 250Hz

age 9 236Hz

age 10 235Hz

age 11 222Hz

age 12 206Hz

Puberty: during which the larynx will grow to adult proportions and the F_0 will drop correspondingly (See 3.8 and Figure 3.6)

Adult male 103 – 169Hz

Children experience register changes in their singing in the same way that adults do (see 2.3.6). The pitch of these changes is, however, not the same as adults. The lower passaggio occurs at about G4 in children (C4 to G4 in adult females, depending on skill and training). The upper passaggio occurs at about D5 in children as opposed to E5 – F5 in adult females (Wurgler, 1990). These characteristics are outlined in Table 3.1.

Table 3.1 Register terminology

Singer Age	Gender	Physiological Characteristics	Acoustic Properties	Approx Range	Commonly Used Descriptors
3–5	M & F	Relatively small, thin vocal folds (thick/thin transition is less)	Difference between speech/chest and head/upper are less obvious	C4 – C5	Speech/chest/ lower
		No vocal ligament	'falsetto' not possible	G4 – E5	Head/upper
		Muscular coordination is relatively clumsy	Accurate pitching/control of register transition is approximate		
6–8 (Sargeant & Welch, 2008)	M & F	General growth of vocal folds, vocal ligament emerging Intrinsic laryngeal muscular coordination developing	Accurate pitching/control of register transition is more likely LTAS shows higher spectral energy in 6–10kHz range	A3 – C5 G4 – G5	Speech/chest/ lower Head/upper
9–11	M & F	General growth of vocal folds, vocal ligament emerging Intrinsic laryngeal muscular coordination developing	Accurate pitching/control of register transition is expected LTAS shows higher spectral energy in 2–5kHz range (NB trained voices still peak at 7–10kHz also (Howard & Williams, 2009))	G3 – C5 E4 – A5 C6 – G6	Speech/chest/ lower Head/upper Whistle can be observed in some individuals
12–14	F	Larynx growing, vocal folds thickening, vocal fold mucosa responding to female pubertal hormones (oedema)	Transition between thick and thin vocal fold phonation becomes more obvious Breathiness, pitch instability etc ? possible emergence of falsetto (rather than breathy 'head' voice)	F3 – A4 D4 – A5/C6 C6 – G6	Speech/chest/ lower Head/upper Whistle can be observed in some individuals

Singer Age	Gender	Physiological Characteristics	Acoustic Properties	Approx Range	Commonly Used Descriptors
15–18	F	Laryngeal growth stabilizing, larynx functioning closer to young adult model	Breathiness disappearing, phonation clearer	F3 – G4 D4 – A5/C6 D6 – G6	Speech/chest/ lower Head/upper Whistle can be observed in some individuals
12/13	M	Rapid growth of larynx in observable growth spurts. Thickening and lengthening of vocal folds	Huskiness Upper range can be clear and strong or can be more breathy (depends on training and experience)	E3 – E4 D4 – G5	Speech/chest/ lower Upper/Head/ emerging falsetto
13/14	M	Rapid growth of larynx in observable growth spurts. Thickening and lengthening of vocal folds	Huskiness Upper range can be clear and strong or can be more breathy (depends on training and experience)	C3 – D4 D4 – D5	Speech/chest/ lower Upper/Head/ emerging falsetto
14/15	M	Rapid growth of larynx in observable growth spurts. Thickening and lengthening of vocal folds	Huskiness reducing More resonant developing baritone phonation Upper range becoming less accessible in most individuals	A2/C3 – D/F4 E/G4 – D5	Speech/chest/ lower falsetto
15/16-18	M	Laryngeal growth stabilising	Emerging possibility of clearer range classification (tenor/bass) Register transition into upper thick-fold phonation (head)	G2/B2 – A3/B3 A3/B3 – E4/F#4 E4-E5	Chest/full/ speech Head/upper Falsetto

Children have a higher phonation threshold pressure (the minimum subglottic air pressure needed to enable the vocal folds to activate for phonation), and as the age of the individual increases, subglottic pressure (Ps) decreases. Further increases in Ps will result in louder phonation in children than the same increase of Ps in adults: a doubling of Ps yielded a 16dB increase of the sound pressure level (SPL – see 4.3) in eight-year-old children and a 11dB increase in a group of adults (Stathopoulos & Sapienza, 1993). At normal loudness and habitual pitch, SPL values are similar in children and women (McAllister & Sundberg, 1996).

3.7.2 Sexual dimorphism

Differences are evident from the age of three years, the male larynx being larger and longer (Crelin, 1973; Kahane, 1978, 1982). There is a difference in timbre between male and female from the age of three and noticeable by the age of six (Sargeant, Sjölander, & Welch, 2005). This is evident in the third formant (P. J. White, 1999; Yang & Mu, 1989).

3.7.3 Control of pitch

Approximately 65% of seven-year-olds and 93% of eleven-year-olds sing 'in tune' (Welch, 2009). Within this one can observe sex differentiation: girls tend to pitch match more accurately than boys, in a ratio of about 2:1 of girls to boys (Welch & Murao, 1994).

3.8 Speech and singing development through puberty

The average age of onset of change has been observed to be dropping over the last fifty years; mid-change from 1890 to 1940 was generally at the age of fourteen (Curry, 1946; Paulsen, 1899). In 1950, onset was between ages thirteen to fifteen (Weiss, 1950). Recent research suggests that the age of onset is nearer to twelve and a half years for boys and ten years for girls (Gackle, 2000)

There are many possible reasons for this. All hypotheses at present are (Thurman & Welch, 2000):

- Improved diet
- Warmer climate
- Hormones in water supplies/ beauty products
- Increased psycho-sexual stimulation
- Increased overall exposure to light, due to the use of artificial lighting during the hours without natural sunlight

Duration of puberty can be from eight months to over four years (Whiteside, Hodgson, & Tapster, 2002) as well as commencing at any time between the ages of eleven and sixteen (for boys). Physical growth through adolescence is in growth spurts or stages. The growth of the larynx mirrors the observable overall growth of the individual (Hollien, Green, & Massey, 1994). If the individual is undergoing a growth spurt with a noticeable height gain, the larynx and its associated skeletal and muscular anatomy will be undergoing similar enlargement. This is then followed by a period of stabilisation (Tanner, 1964). This growth pattern is caused by hormonal levels and cannot be accelerated or decelerated except by artificial hormonal input.

Delay to puberty can also be caused by severe malnutrition or severe emotional deprivation (Pozo & Argente, 2002). It has been argued that extreme physical exercise, as has been observed in some child dancers and gymnasts, could delay puberty (Malina, 1994). More recent literature suggests that the children and the body types for these activities are self-selecting (Cram, 2001). Accelerated puberty has been observed in obese children: recent research suggests that obese girls are more likely to have early pubertal onset, but that obese boys are more likely to have delayed pubertal onset (Wang, 2002). In a normal healthy individual it is an unstoppable process.

3.8.1 The lungs

During the pubertal growth spurt, the lungs approach adult size and vital capacity (Cotes, 1979a; Mansell et al., 1977). However, due to variability in growth rates of both lung tissue and of the chest wall, establishment of adult dimensions, vital capacity and total lung volume can only be estimated to occur by the age of eighteen to twenty (Hixon, 1987).

3.8.2 The larynx

The height of the larynx in the vocal tract drops to C6 (level with cervical vertebra number 6) by puberty and C7 by about twenty years (Kent & Vorperian, 1995). Pubertal development includes an increase in muscle strength; in the larynx this can be seen in the adductory muscles and cricothyroid. Thyroarytenoid bulk may increase with laryngeal muscle conditioning as a result of extensive and vigorous use in voicing (Thurman, 2000). Skeletal growth is not affected by exercise although motor skills are (Malina, Bouchard, & Bar-Or, 2004). This fact could have important implications for trained child singers who rely on finely coordinated motor skill development to enable their vocal skills to mature.

In the male, the thyroid cartilage grows primarily in the front-to-back direction, particularly at the anterior tip, forming the 'Adam's apple'. In the female, the thyroid cartilage growth remains more rounded. The male vocal folds undergo nearly twice the growth of those of the female: 63% increase in the male and 34% in the female (Kahane, 1982). The growth of the vocal folds during puberty is mainly in the membranous portion. The length of the cartilaginous portion of the vocal folds is the same in the adult male and female.

3.8.3 Vocal fold tissues

The vocal ligament and vocalis function as a unit, the vocal ligament providing longitudinal stability. Growth affects the temporo-spatial properties of the movements of the vocal folds, also factoring cricothyroid growth. The result of this can be instabilities causing breathiness, roughness or hoarseness (Kahane, 1982). By the age of eleven or twelve the cellular layering resembles the classic pattern seen in the adult lamina propria.

3.8.4 Muscle and cartilage growth

Skeletal growth and muscle mass are directly related (Bailey et al., 1986; Malina, 1986). An increase in skeletal size will result in increased muscle mass. This increased muscle mass precedes increased strength. Physical training of the endurance type leads to significant increases in the relative area of muscle composed of type 1 fibres or slow-twitch; these contract slowly and are resistant to fatigue; (Bailey et al., 1986; Malina, 1986). Vocal fold muscles are predominately muscle type llA (able to contract quickly and fatigue resistant; (R. T. Sataloff, 2005). The reverse cannot be said to be true: increased activity will not affect skeletal growth, although it will affect the type and distribution of muscle fibres (Malina et al., 2004).

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Figure 3.6 The thyroid cartilage of a child (bold line) and adult (dotted line) superimposed to show the relative increase in size in both male and female (Kahane, 1978)

Although the vocal folds have essentially reached adult length at the end of puberty, the connective tissue of the vocal folds continues to increase in size and quantity into adulthood, at which point ossification of the laryngeal cartilages begins (Linville, 2001). This process begins in the mid-twenties and is completed by the sixties. This means that a singer aged in their forties has the greatest vocal stamina, as the relative rigidity of the laryngeal cartilages enables effective muscle action. After this, continuing ossification results in reduced flexibility of pitch range and timbre. The structure of the larynx is changing continuously throughout life.

3.8.5 The male voice during puberty

For the purposes of this study, male vocal mutation through puberty will be referred to as 'changing' and not 'breaking'. The term 'breaking' voice can be construed as a negative or destructive process. It may describe the pitch instability of some boys in adolescence who may be observed to flip into falsetto phonation intermittently. This tends to be observed during emotional upset or rapid changes of subglottic pressure, e.g. laughter. The term 'changing voice' is more commonly used to describe the period of male adolescent voice mutation. The most noticeable laryngeal growth and therefore the mid-point of voice change occurs mid-way through an invariable sequence of developmental stages, although individual stages will vary in duration (Tanner, 1964).

Tanner's five stages of male development are clearly outlined with relation to genital development (Marshall & Tanner, 1986). These stages have been demonstrated to have a significant correlation with the five stages of voice change given by Cooksey (Harries, Griffith, Walker, & Hawkins, 1996). The maximum change in pitch occurs at the same time as the maximum growth; between stages 3 and 4. Although F_0 is mainly dependent on vocal fold length; the sudden drop in pitch observed between stages 3 and 4 is largely due to increased vocal fold mass more than sudden elongation of the vocal folds (Harries, Hawkins, Hacking, & Hughes, 1998).

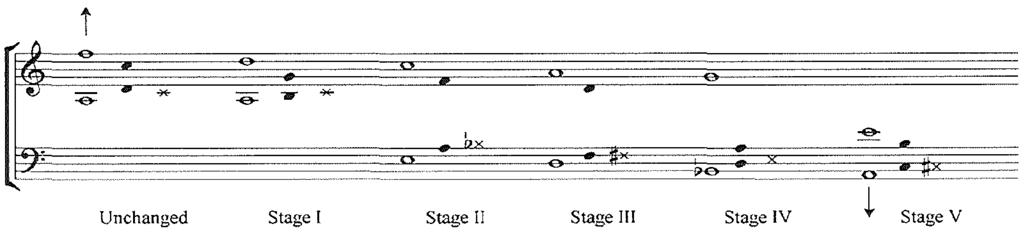

Figure 3.7 The pitch ranges of each stage of male voice change (Cooksey, 2000)

Key: x = speech F_0, • = speech range, o = singing range

The pitch ranges show:

Extended singing range (unfilled note). This is the pitch range possible with no observable sign of strain and without using falsetto.

Comfortable modal singing range (filled note).

Speech fundamental frequency (cross). This can be ascertained simply by asking the boy to count backwards from 20 and observe the pitch at which his voice settles most comfortably. This is usually three to four semitones above his lowest comfortable singing pitch (Böhme & Stuchlick, 1995).

Observable signs of strain may be visual (increased jaw or neck tension) and aural (voice becoming hoarse, scratchy, breathy or constricted) (Sederholm, McAllister, Dalkvist, & Sundberg, 1995). These seemingly subjective criteria will nonetheless become increasingly evident beyond certain pitches.

Possible signs of change to Cooksey Stages I and II (Cooksey, 2000)

- Growth spurt
- Change of timbre in the mid-range of the singing voice
- Decrease in control at the top of the singing range
- Change in timbre of speaking voice
- Increased variability; more 'off' days

There tends to be more stability and less individual variation in the lower pitch range limit throughout the different stages of voice maturation than in the upper pitch range limit. Therefore, it is more reliable to judge the developmental stage by the lower singing range and by the fundamental frequency of speech.

3.9 Voice disorders in children and adolescents

This section, drawing on the research of several authors (Andrews, 2002; Morrison & Rammage, 1995; Rahbar & Healy, 2003; Rammage & Sakeld, 1994; Strome, 1982), will give a summary of common voice disorders found in young voices, the environmental and psychological associations.

There are five characteristics that can be used to define a problem voice (Wilson, 1979):

1. Disturbed voice quality caused by laryngeal dysfunction,
2. Hypernasality or hyponasality,
3. Voice too soft to be heard or unpleasantly loud,
4. A speaking pitch too high or too low for the age, size and sex,
5. Inappropriate inflections of pitch and loudness,

Voice disorders are common among school-age children. Studies vary somewhat in the reported incidence of hoarseness from 6% (P Carding, Roulstone, & Northstone, 2006), 7% (Baynes, 1966), 10% (F. W. White, 1946) to 20% (Bonet & Casan, 1994) and 23.4% (Silverman & Zimmer, 1975). Up to half of these cases may have nodules (Shearer, 1972). Most of these cases are never referred for clinical treatment, which would imply that they nearly all get better in time, presumably because the child is growing and so use and function are continually altering.

The voice disorders discussed below are specifically those which could occur in otherwise healthy children who may sing regularly. This rules out conditions such as webs, stenosis and vocal fold paralysis – for example. These are conditions which could possibly have been experienced by any of the children participating in this study.

3.9.1 Organic voice disorders

Inflammation (common but temporary)
This can be acute laryngitis or croup. The symptoms can range from a croaky or breathy voice to complete voice loss. Unless the symptoms are severe and threaten the airway, the treatment is voice rest, humidification, reduced physical activity, and analgesics. Other inflammations such as pharyngitis, tonsillitis, sinusitis and rhinitis will not directly affect the action of the vocal folds unless there is considerable post-nasal drip.

Allergies (common, generally need ongoing treatment)
Allergic responses can result in inflammation of the tracheobronchial tree as well as the nasopharynx. The inflammation results in swelling and excessive secretions of mucus. The symptoms can be hoarseness and hyponasality as well as nose-blowing and sneezing. Allergens can be pollen, mould spores, dust, foods or cigarette smoke.

Cysts
These are fluid-filled dilated mucosal ducts; the etiology is unclear. Symptoms may be hoarseness or coughing. Treatment is surgical removal.

Gastroesophageal reflux
Reflux is common in infants and young children. In a few instances it continues and can cause problems with increased acid levels in the laryngeal area causing inflammation and leading to hoarseness. Treatment is to prescribe antacid to neutralise the pH, and/or to raise the bed head.

Papilloma (uncommon)

These are benign lesions with an etiology that is normally viral. The symptom is hoarseness and the treatment can be surgical removal or waiting until puberty when they will most probably disappear.

Malignant tumor (very rare)

The symptoms are dysphonia followed by respiratory distress. Tumors are very unusual in children.

Endocrinopathies (very rare)

Abnormalities in the functioning of the pituitary, thyroid or the adrenal glands can result in distorted growth of the laryngeal cartilages or tissues. This can present as early or delayed pubertal change, or deepening or coarseness of the voice.

3.9.2 Functional voice disorders

Polyps

These are associated with vocal trauma: a break in the epithelium is followed by an exuberant granulamatous healing response. Voice therapy can be beneficial; surgery is only a last resort.

Nodules

These occur more frequently in boys and are associated with stress, anxiety or aggression (see Psychological factors 3.9.4). They are a mass of fibrous tissue, similar to callouses. They tend to occur at the most mobile area of the vocal fold, at the junction of the anterior and middle third, and on the free upper edge. Treatment is voice therapy, although there is a spontaneous tendency towards symptom regression during puberty (Von Leden, 1985). After six months of speech therapy, two thirds of children will have healthy larynxes (Deal, McClain, & Sudderth, 1976), although Toohill suggests that this is not necessarily due to the treatment (Toohill, 1975); see Psychological factors 3.9.4).

Foreign objects

Objects which block the airway have to be dealt with as an emergency situation. Smaller objects which become lodged in the larynx (such as pieces of apple or carrot) can result in a coughing spasm which may not dislodge the object. Inflammation develops with increasing vocal dysphonia. The inhalation of small objects such as pins, bits of glass, eggshells or parts of toys can result in vocal fold scarring or damage to the muscles or ligaments of the larynx.

Caustic ingestion

This can be ingestion of caustic fluids, passing through the pharynx, or inhalation of powder such as dishwasher powder. Site and severity depends on the amount and type of substance.

Psychological dysphonia

The larynx on examination will appear normal; coughing will have the associated phonatory response but the speaking voice will appear dysfunctional. This tends to be stress-related and a detailed history will be necessary. Psychological therapy will often be the necessary treatment. Complete voice loss may indicate conversion hysteria (extremely uncommon in children, especially boys). Voice hoarseness or discomfort may indicate muscle tension dysphonia (much more common – see 3.9.4).

Trauma

Intubation of the neonate can result in contusions, lacerations and dislocation of the arytenoid cartilages. The symptoms when speech later develops are breathy or hoarse voice. There is the possibility of trauma occurring as a result of a direct blow to the neck, for example in a serious road traffic accident. Fracture of the larynx is less likely in children as their laryngeal cartilages are more flexible.

Disordered growth patterns

In general, craniomandibular disorder and discomfort are linked to articulatory disorders in children. In particular, boys with speech disorders have a pattern of poorly controlled movements of the oro-facial muscles. Children with articulatory disorders have a smaller maximal opening but larger maximal laterotrusion and protrusion (Ettala-Ylitalo & Laine, 1991). Children with an open-mouth posture have a slower pattern of maxillary growth than children with a closed-mouth posture (Gross et al., 1994). This may have implications for singing training (see 5.6.1)(A. Smith et al., 1991; Thompson & Hixon, 1979). Certain studies have shown links between voice disorder and body type. The ectomorph is more prone to voice disorder and the mesomorph the least susceptible (Weiss, 1955).

3.9.3 Voice disorder due to inefficient or idiosyncratic vocal habits

Deviant vocal behaviours can be as a result of gradual habituation of abusive patterns (Andrews, 2002). These may be adopted during illness. In order to enable phonation with inflammation of the vocal mechanism, the child may overadduct, strain or repeatedly clear the throat. These compensatory habits may then remain beyond the duration of the illness. Recurrent coughing can be associated with voice disorder (Senturia & Wilson, 1968). Children are very socially adaptive and will alter their vocal behaviour to fit their environment, whether that is their family, social group, or school environment. This can result in poor or inefficient voice use. For example, a child may exhibit patterns of hyponasality if a parent does so, regardless of their own physiognomy (Brandell, 1982). Children may also persist in hyponasal voicing even after surgical removal of the adenoid tonsils has removed the obstruction (Greene & Mathieson, 2001).

3.9.4 Context or environmental factors (DeVito, 1980)

Physical

Acoustic environments with a high level of background noise will cause the child to speak loudly or shout for prolonged periods of time. These may include: noisy playgrounds, school dining hall, swimming pool, sports stadium or even an unsupervised or poorly supervised classroom.

Social

This element includes status and hierarchy and the use of appropriate levels of voicing, both in amount and loudness (see Psychological factors below). Hours spent per day in large groups and a family history of voice problems are significant factors in incidence of dysphonia (Sederholm, 1996a; Sederholm et al., 1995).

Temporal

The time of day, stage of the school year or the child's past history of behaviour will all affect voice use (Wilson, 1979).

Psychological factors

Personality type would appear to be the single most influential factor on the occurrence of voice disorders in children (Brandell, 1982; Moses, 1954). Several studies have suggested that the occurrence of nodules is more prevalent in children with anxiety symptoms (Brandell & Filter, 1973; Green, 1989). This can present as aggressive personalities (Greene & Mathieson, 2001) or as unnecessarily withdrawn, repressed personalities (Glassell, 1972). Children with a breathy or whiny voice may be more submissive and emotionally unstable (Moore, 1939). Children who have unattainable goals (academic, musical or sporting), either as a result of parental pressure or sibling rivalry, are more likely to develop nodules (Renfrew, 1972). Children assessed in a music conservatoire in Montpellier, France, were shown to have a higher incidence of voice disorders than the control group (Arnoux-Sindt et al., 1993). Treatment of psychogenic voice disorders (which may include most functional voice disorders at some level) will often require psychotherapy as well as speech therapy. Toohill (Toohill, 1975) even suggests that parental counselling is a more effective treatment for the vocal nodules of children than professional speech therapy.

3.9.5 Performance expectations, anxieties and Catastrophe theory

There is evidence to suggest that if physiological arousal (a measure of the heart rate of the individual) and cognitive anxiety (the degree of anxiety relating to performance expectation of the individual) increase to a critical level, then performance levels will rapidly deteriorate (Hardy & Fazey, 1987; Hardy et al., 1994). Figure 3.8 illustrates the interaction of three variables: physiological arousal, cognitive anxiety and performance (the level at which the individual is able to perform) at any single point in time. Catastrophe theory suggests that once this critical level of cognitive anxiety is exceeded, it is not possible to regain performance levels with small adjustments to the predictor variables, physiological arousal and cognitive anxiety. This is illustrated by the sudden dip and further collapse of the performance level as the cognitive anxiety increases. If cognitive anxiety is kept to a low level, then physiological arousal and performance level can have a positive correlation.

Figure 3.8 Catastrophe model of performance (Hardy & Fazey, 1987)

This work comes from the field of sports and sporting achievement. There could be similarities with singing; they both rely on the systematic training of a specific group of muscles to perform a complicated task at an expert attainment level. There is a link between performance anxiety and achievement in both musical skill and performance, dancing and sporting skill and performance (Baker, 2002; Brinson & Dick, 1996; Cram, 2001).

This theory has a relevant application to the performance achievements of professional child choristers who are expected to achieve high performance levels on a daily basis. If these requirements are made of an individual who may have a personality profile making him more prone to cognitive anxiety (see 3.9.4 Psychological factors), the possibilities of performance collapse are increased.

3.10 Summary

This chapter provides a physiological and anatomical background to the study. It can be inferred that the structure and function of a child's voice develops from the specific role of the larynx of the newborn infant. The voices of children are 'in transit' between the vocalisation possible by the infant and that of the adult. The vocal functioning of adolescents, especially boys, is affected by the relatively rapid changes taking place as a result of pubertal hormonal secretions.

It is important to note that the voice of the child is not that of a small adult: the requirements both socially and developmentally result in function as well as dysfunction which are specific to the child voice.

Chapter 4

Measurement of voice: perceptual and acoustic perspectives

4.1 Introduction

This chapter gives an account of the two types of assessment which are conventionally used in both laboratory and clinical settings. The main type of assessment used is perceptual. The expert listener hears any deviations from an accepted standard of 'healthy' or 'normal' (Paul Carding, Carlson, Epstein, Mathieson, & Shewell, 2000); these are qualified and quantified in order to reach a conclusion. Acoustic measurements can be applied as a way of reinforcing and validating these perceptual judgements. This study investigates any possible deviations from 'normal' voice behaviour. In order to assess this, a baseline model of normal voice use had to be established using the same methodology as that used to measure any deviations from the expected norm. This chapter uses examples of 'normal' voice, these were recordings of a healthy non-chorister aged 10. The recordings were made specifically for illustrative use in this chapter, as there appeared to be no similar examples in the literature available. The recordings were made under similar conditions to those of the choristers.

This chapter outlines a basic summary of the methods of acoustic measurement of sound that are used in both clinics and laboratories. The perceptual methods outlined are all in current clinical usage.

4.2 Perceptual evaluation

This type of assessment is based on judgements from experienced voice professionals who are accustomed to listening to voices in order to identify and evaluate vocal qualities. The assessment is intended to give a good indication of the type and severity of any voice disorder. Instrumental evaluation is also beneficial, providing an objective system for rating the accuracy and consistency of the perceptual evaluations, as has been shown by similar evaluations of boys' voices in Dresden (Pabst, 2000). However, the human ear is not to be underestimated as the most highly refined analytical tool of human vocal behaviour (Howard, 2005; Ma & Yiu, 2006). Perceptual judgements made by expert listeners tend to agree on types of voice qualities but not necessarily on the magnitude of these (McAllister, Sundberg, & Hibi, 1998).

The terms used to describe voice qualities are many and often subjective. Several attempts have been made to refine the terminology. Laver lists a selection of adjectives used to describe voice which have absolutely no phonetic specificity: dulcet, sonorous, hollow, educated, metallic, melodious, ingratiating, sepulchral and so on (Laver, 1974). It is possible to attribute labels to voice qualities based on the physical settings of the larynx and vocal tract (Laver, 1979). These are useful to those whose knowledge of vocal anatomy and physiology enables them to recognise specific vocal attributes as resulting from particular types of usage. Even so, there is still much room for variation amongst experienced professionals (see 6.8.1).

Table 4.1: Tentative definitions and acoustic correlates of voice parameters recommended for the perceptual evaluation of Swedish pathological voices (from (Sederholm, 1996a), reproduced with the author's permission; adapted from (Hammarberg & Gauffin, 1995)

Voice quality parameter	Tentative definition	Acoustic correlate
Aphonic / Intermittently aphonic	Voice is constantly or intermittently lacking phonation – there are moments of whisper or loss of voice	Lack of phonation: F_0 and other voicing signals are missing in the signal
Breathy	Audible noise created at the glottis, probably due to insufficient glottal closure; vocal folds are vibrating, but somewhat abducted	Low spectral level in formant region, suggesting a steep spectral slope; noise in spectrum above 4–5 kHz; sine-wave source waveform
Hyperfunctional / Tense	Voice sounds strained, as if the vocal folds are compressed during phonation	Low level of fundamental relative to first formant level

Hypofunctional / Lax	Opposite to hyperfunctional. Insufficient vocal fold tension, resulting in a weak and 'slack' voice	Higher level of fundamental relative first formant level as compared to hyperfunctional voice
Roughness	Low-frequency aperiodic noise, presumably related to some kind of irregular vocal fold vibrations	Noise in the formant region; waveform perturbation
Gratings / High-frequency roughness	High-frequency aperiodic noise, presumably related to some kind of irregular vocal fold vibrations	Noise in high frequency region; waveform perturbation
Unstable voice quality / pitch	Voice is fluctuating in voice quality or pitch over time	Large standard deviation of fundamental frequency; waveform perturbation
Voice breaks	Intermittent frequency breaks	Abrupt stepwise changes in fundamental frequency
Diplophonia	Two different pitches can be simultaneously produced	Bimodal distribution of fundamental frequency waveform perturbation
Modal / Falsetto register	Modes of phonation; falsetto usually weak in timbre due to short insufficient closure, as opposed to modal register, which is rich in timbre due to more efficient vocal fold closure vertically as well as horizontally	In falsetto the fundamental is dominating the spectrum, whereas in modal register there is greater amount of energy in the formant region
Pitch	The chief auditory correlate of fundamental frequency	Fundamental frequency
Loudness	The chief auditory correlate of sound pressure level of speech	Sound pressure level

Dysphonia is a general term referring to any unusual or unhealthy vocal behaviour. Hoarseness is a more common term. It has been defined as the presence of hyperfunction, breathiness or roughness and seemed to be reasonably well defined and unequivocal between judges (Sederholm, McAllister, Sundberg, & Dalkvist, 1993). Sederholm used the measurements of 'hoarseness' and 'chronic hoarseness'. Chronic hoarseness would be an indicator of possible vocal fold pathology and would generally be followed-up with medical examination. From a medical definition, chronic hoarseness would persist for more than three weeks.[1]

4.2.1 Rating schemes

Perceptual evaluation tends to rely on rating scales: these give quantifiable results suitable for comparison, either with other individuals or with the same individual over time. There are numerous systems for the rating of voice qualities (Paul Carding et al., 2000; Kreiman, Gerratt, Kempster, Erman, & Berke, 1993). These include the Hammarberg Scheme (Hammarberg & Gauffin, 1995), the Buffalo Voice Profile (Wilson, 1979), Voice Profile Analysis (Laver, 1980) and the GRBAS scale (Hirano, 1981). Perceptual rating of voice quality is routinely used in the clinical setting. It is necessary in order to give a baseline assessment of the vocal behaviour and to monitor development during and after treatment (Hirano, 1981). For this study, the main influences on the structure of the ratings used were the Voice Profile Analysis (VPA) and GRBAS. The main reason for this was that these are most commonly used in voice clinics in the UK; the judges used to validate the assessments of the recordings would be most familiar with these types of ratings (Eadie & Baylor, 2006).

4.2.2 GRBAS (Yamaguchi, Shrivastav, Andrews, & Niimi, 2003)

The five letters in this scale stand for Grade, Roughness, Breathiness, Asthenia and Strain. The overall impression of abnormality in the voice is the Grade: this is a quantitative judgment. Roughness is indicated by audible low-frequency noise and measurable

[1] In the case of this study, the boys were only measured twice a year and it would not have been possible to establish whether the hoarseness was chronic. Quantitative measurements of jitter and shimmer will give an indication of the levels of hoarseness. These, however, do not take into consideration short-term (0.1–0.3 second) but significant irregularities in the phonation which can only be seen by examining narrowband spectrogram (Titze, 2008).

irregularities in pitch and amplitude. This is often caused by swollen vocal folds and/or laryngeal constriction. Breathiness is an audible escape of air during phonation, measured as mid-frequency noise. It is caused by incomplete closure of the vocal folds. Asthenia is a weakness to project the voice, often characterised by a fading amplitude contour. It is caused by hypofunction or use of thin vocal folds. Strain may be indicated by a higher overall pitch in the voice, a reduced pitch contour and noise in the higher frequencies (Fukazawa, Blaugrund, El-Assuooty, & Gould, 1988). It is caused by hyperfunction, stiff vocal folds or increased vocal fold mass. A four-point scale from 0 to 3 is used for each parameter, 0 indicates normal, 1 – slight, 2 – moderate and 3 – severe. The GRBAS scale has been the subject of many inter- and intra-judge reliability ratings (Bhuta, Patrick, & Garnett, 2004; De Bodt, Wuyts, Van de Heyning, & Croux, 1997; Dejonkere et al., 1996; Hakkesteegt, Brocaar, Wieringa, & Feenstra, 2008; Kreiman et al., 1993), and seems to withstand the scrutiny.

4.2.3 Voice Profile Analysis (VPA)

This system for voice quality analysis, devised by Laver et al in 1988, is a descriptive system that allows the listener both to describe and to analyse conversational or reading voice quality (Paul Carding et al., 2000). The aspects of voice use are divided into categories and individual settings of the larynx and vocal tract. Each feature is compared with a neutral baseline setting. It is a comprehensive and detailed system of analysis and is a potentially more useful tool for analysing normal voice use.

4.2.4 Rating scales

Ratings can be numeric, known as EAIS (equal appearing interval scales) or they can be continuous, VAS (visual analog scale) (Kreiman et al., 1993). EAIS assume that the points on the scale are equidistant and so parametric statistics can be applied, although this may not necessarily be the case. Other methods can be used, such as paired comparison, but these are less common. There seem to be advantages in either system and the EAIS was chosen for the first two of the analyses in this study, purely to simplify the management of the scores during the assessment process, and as it is the most commonly used. The judges were asked to allocate one score per auditory stimulus to represent given parameters. Some studies suggest that it is easier to obtain good inter-judge reliability using EAIS (Wuyts, De Bodt, &

Van de Heyning, 1998). The disadvantage of EAIS is that in statistical analysis it is assumed, often erroneously, that the points are equidistant. It is also possible that the judges are susceptible to 'pigeon-holing' voices according to personal parameters (Sederholm et al., 1993). The VAS uses a single line, 100mm long, with the extreme conditions at each end of the scale. Judges are asked to mark the line at a point which corresponded most closely with their perception of how the rating of the stimulus falls between two given extremes.

4.3 Acoustic measurement of sound

The pitch of the voice, whether we perceive it as high or low, is measured as fundamental frequency (D. B. Fry, 1979; Howard & Angus, 2001; Sundberg, 1987). This is the number of events (disturbances, collisions, vibrations) per second. The pitch A4 has a frequency of 440 Hertz (Hz); vocal folds producing this pitch will be colliding 440 times per second. The vibrating frequency of an object is determined by its mass, length and tension (ibid.). Vocal folds will vibrate at higher frequencies if they are thinner (longer), or tighter.

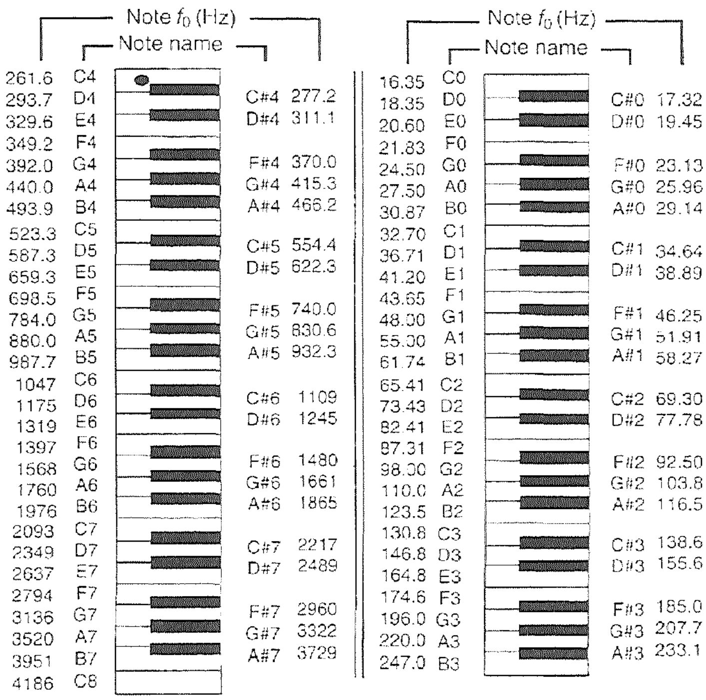

Figure 4.1 Fundamental frequencies as they relate to a piano keyboard tuned to A4=440Hz (Howard & Angus, 2001)

The loudness of the voice is referred to as amplitude (the size of the sound pressure change) or sound pressure level (SPL), which is measured in decibels (dB). Vocal folds colliding with a greater movement at the midline of the glottis will produce sound of greater amplitude (produced by higher subglottic air pressure and a greater rapidity of vocal fold closure)(Howard & Angus, 2001).

Table 4.2: Typical sound pressure levels in decibels, or dB (SPL) values, along with the equivalent sound pressure levels in microPascals (μPa) and Pascals (Pa), and typical sounds for each level listed (D. Howard & Murphy, 2008)

pressure (μPa)	pressure (Pa) ($P_{measured}$)	dB(SPL) $20 \times \log_{10}\left\{\frac{P_{measured}}{0.00002}\right\}$	typical sound
200,000,000	200	140	Jet take off at 10 m.
63,200,000	63.2	130	Threshold of pain – jet taking off at 40 m.
20,000,000	20.0	120	Threshold of feeling
6,320,000	6.32	110	Peak level: opera singer fortissimo *(ff)* at 1 m.
2,000,000	2.00	100	Shout or yell at 1 m.
632,000	0.632	90	Heavy diesel engine (high throttle) at 1 m.
200,000	0.200	80	Vacuum cleaner at 1 m.
63,200	0.0632	70	Opera singer singing piano *(p)* at 1 m.
20,000	0.0200	60	Conversational speech at 1 m.
6,320	0.00632	50	Background level in office.
2,000	0.00200	40	Whispered speech at 1 m.
632	0.000632	30	Background level in a quiet home.
200	0.000200	20	Quiet in a well designed performance hall
63.2	0.0000632	10	Wilderness on a still day
20.0	0.0000200	0	Threshold of hearing – complete silence

All pitched or periodic vocal sounds (with a regular fundamental frequency) will have harmonics (these are the additional vibrating frequencies in the harmonic series). The relative strength of these is determined by the sound source (rapidity of vocal fold closure and disturbances set up by the movement of the mucosal wave across the vocal fold) and enhanced or dampened by the sound amplification (vocal tract dimensions). Harmonics at some frequencies are stronger than others; this gives the sound its unique timbre (Howard & Angus, 2001) (A4 on an oboe is recognizably different from A4 on a violin, A4 sung by a tenor has a different timbre from A4 sung by a soprano.)

A vocal tract resonance is called a formant. Every resonating chamber has one or more natural resonant frequencies (this can be illustrated if one blows over the top of an empty bottle; its resonant frequency will sound). If the dimensions of the resonating chamber can be altered, the relative strength and frequency of these resonant frequencies (formants) will be altered. Figure 4.2 illustrates how the shape of the vocal tract can alter the frequencies of the lower formants (F1 and F2) and determine the vowel (Fant, 1960; Story, Titze, & Hoffman, 2001).

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Figure 4.2 A diagrammatic representation of the relationship between vocal tract shape and the frequency spectrum for the vowels [i] and [ɑ] (D. Fry, 1979).

Formants 3, 4 and 5 are relevant to voice timbre, or personal voice quality (Sundberg, 1987). It is possible to vary the timbre of the voice whilst maintaining the intelligibility of the vowel sounds (Fant, 1960; Story et al., 2001).

4.4 Using acoustic measurements for voice quality analysis

There is some precedent for acoustic assessment of children's voices (Sever, 1982; P. J. White, 1999), although this is still a relatively under-researched area. The existing studies tend to assess sustained vowels as they give a regular vibratory pattern, with a steady distribution of harmonics (Murry & Doherty, 1980). In a comparison of the results of analysis of sustained vowels with running speech, the running speech gives higher perturbation values in children (McAllister, Sederholm, Ternstrom, & Sundberg, 1995). It has also been shown that children have higher jitter (see 4.4.1) values than adults (Steinsapir, Forner, & Stemple, 1986).

4.4.1 Spectrum Analysis

The distribution of partials in the sound can be seen in a *spectrogram,* where time is on the horizontal axis, frequency on the vertical axis and grayscale for sound level. This can be either wideband (predominantly displayed as vertical lines or striations, useful to observe cycle-by-cycle irregularities over time) or narrowband (predominantly horizontal lines or harmonics, useful to observe partials or timbre) (Howard & Angus, 2001). This gives a visual representation of the acoustic signal. The interpretation of the information illustrated in a spectrum is in itself still a subjective measurement. The term *spectrogram* is normally used for the graph. From the spectrogram it is possible to isolate moments for comparison in a spectrum section which can be analysed further by more objective measurements such as LTAS or VPA. The spectrogram can show the relationship between the first and second formant (F1 and F2), although this becomes less clear at higher F_0 values (Doscher, 1994). This relationship determines the timbre of the vowel. Vowels with a high tongue position, [i] and [u], have a low F1; [æ] and [ɑ] have a higher F1. Vowels with a forward tongue position, [i] and [y] have a high F2. Vowels with a backed tongue position, [ɔ] and [ɑ] have a low F2.

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Figure 4.3 Spectrograms of nine English vowels (written under the horizontal axis) showing the relationship between first and second formants and how these (seen as dark horizontal bands) vary over time (D. Fry, 1979)

The spectrum will also show formant clusters such as the 'singers' formant' (see 2.4.5).

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Figure 4.4 Narrowband spectrograms (upper images) and long-term average spectra (LTAS, see 4.3.6) of the whole spectrogram of an entire sound passage (lower images) of commercial CD recordings of three professional tenors singing the last three syllables of the second (unaccompanied) "*(vit)toria*" from Act 2 of *Tosca*. The singer's formant region is indicated in each plot as "SF" (D. Howard & D. Murphy, 2008)

The spectrogram will show the relationship between clear vowels (regular harmonic distribution) and perturbation (irregular harmonic distribution); voiced sounds (vowels and voiced fricatives), unvoiced sounds (unvoiced fricatives), silence (stopped consonants) and other perturbations such as breathiness or roughness (de Krom, 1995). Trained singers tend to greater stability and consistency between the vowels. As the larynx is lowered, the velum raised and the jaw opening is stable (resulting in a larger vocal tract), the upper formant frequencies are lowered (Welch & White, 1993).

4.4.2 Harmonics to Noise Ratio (HNR)

This compares the amplitudes of harmonics and inharmonic spectrum components. Inharmonic spectrum components will arise from irregularities in the vocal fold vibrational pattern (Sever, 1982; Shrivastav, 2002). This could be caused by any localised mucosal swelling, asymmetric contact pattern or additional collisions of the false vocal folds. It applies only to steady sounds with even defined harmonics (i.e. sustained vowels); the 'noise' is extra to these. This method of instrumental acoustic analysis is often used in speech therapy evaluations in order to give a baseline for follow-up assessments. It has not, however, been shown to give a greater level of diagnostic success as perceptual evaluation (Mathieson, 2005).

4.4.3 Long-term Average Spectrum (LTAS)

The LTAS shows the distribution of sound energy at different frequencies within the signal, averaged over time (P. J. White, 2000). With a spoken passage such as 'Arthur the Rat' (see Appendix 3), the vowels are evenly distributed. In the LTAS the spectral variation from the vowels is smoothed and the peaks and troughs show the overall characteristics of the sound. Analysis of the LTAS can show if the singing samples have, for example, enhanced higher frequencies (for example, the singer's formant).

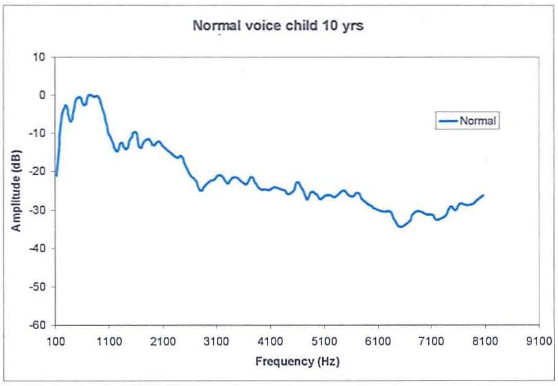

Figure 4.5 LTAS of normal speech, child aged 10 years, linear frequency scale

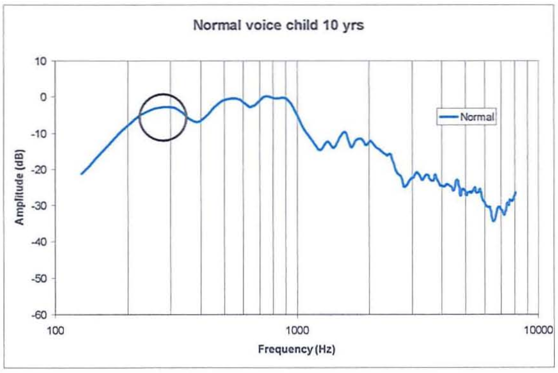

Figure 4.6 LTAS of normal speech, child aged 10 years, logarithmic frequency scale

Figures 4.5 and 4.6 show the LTAS of normal speech in a child aged ten years. It is more common to see this graph illustrated with a linear frequency scale. The logarithmic frequency scale shows more detail in the region of the first 1000Hz, expanding the lower frequency region and compressing the higher frequency region: this focus is closer to the receptive priority at the level of the basilar membrane of the ear. This visual scale represents our aural perception more closely and provides more detail regarding the lower frequencies. The average fundamental frequency is circled on Figure 4.6 in the region of 200Hz (approximately the pitch of Aflat3). The next two peaks will reflect the mean of the first and second formants, these show the resonant properties of the vowels within the spoken passage. The upper frequencies (1000 to 10000Hz) show the other spectral properties in the sound, these tend to be idiosyncratic to the individual person. These upper frequencies are more clearly observed in the linear frequency scale.

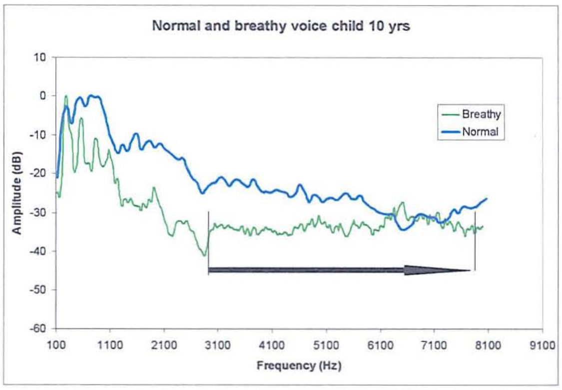

Figure 4.7 LTAS of normal and breathy speech, child aged 10 years, linear frequency scale

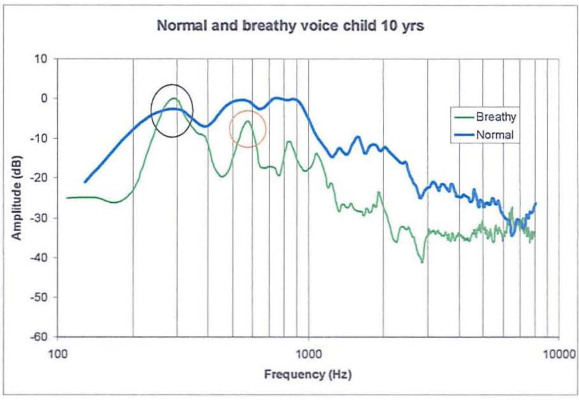

Figure 4.8 LTAS of normal and breathy speech, child aged 10 years, logarithmic frequency scale

Breathiness in the vocal output (see 5.6.1) can be seen in the spectrum as a relatively weak F_0 with additional 'noise' in the upper components. This 'noise' is the result of high frequencies generated by the fricative action of the air travelling through the narrowed glottis, producing turbulence. Figure 4.7 shows the breathy component of the sound as indicated by the arrow. Figure 4.8 shows unusually strong fundamental frequencies shown by the grey and orange circles. These can also be seen on the DFx1&2 Speech Studio plot of this signal, Figure 4.22. These arise as this particular voice was fairly monotonal in the delivery of the speech passage. There was not the usual even spread of pitches.

A similar range of frequencies to those of breathy voice can be observed on the spectrum in unvoiced fricative consonants such as [s] and [f].

A creaky voice, or one with vocal fry (see 5.6.1) shows a degree of instability in fundamental frequency and vocal fold closure. The LTAS for this will show an increase in intensity of the higher frequencies: this can be seen in Figure 4.9 in the region of 6000 to 7000Hz (green circle). In creaky voice there are four main peaks between 500 and 1000Hz; in normal voice there are only two. This may be due to the diplophonic effect at the voice source (see 5.6.1).

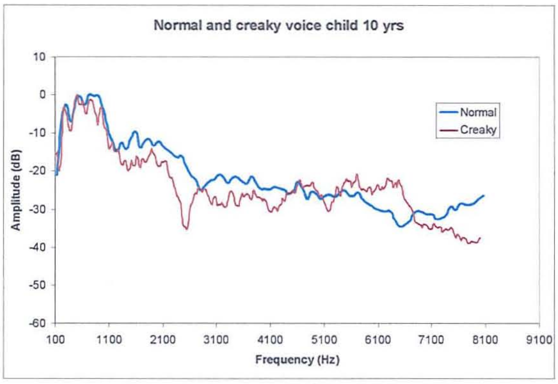

Figure 4.9 LTAS of normal and creaky speech, child aged 10 years, linear frequency scale

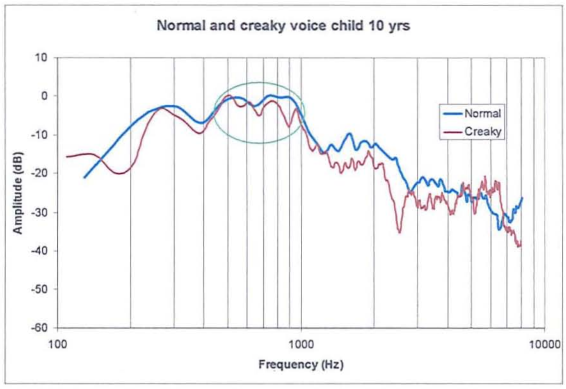

Figure 4.10 LTAS of normal and creaky speech, child aged 10 years, logarithmic frequency scale

Harshness in the voice will show an increase in higher frequencies, in this example from 5500 to 7000Hz. There is less energy between 2000 and 6000Hz, this may be due to the vocal tract constriction altering its resonant properties.

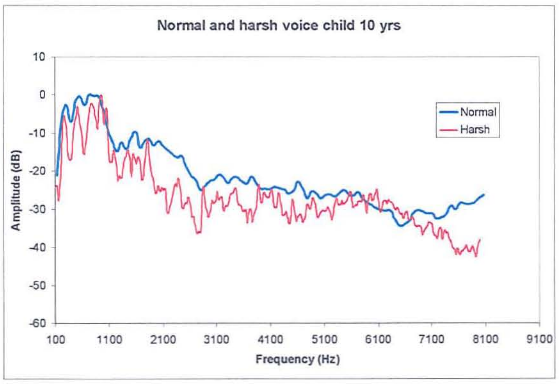

Figure 4.11 LTAS of normal and harsh speech, child aged 10 years, linear frequency scale

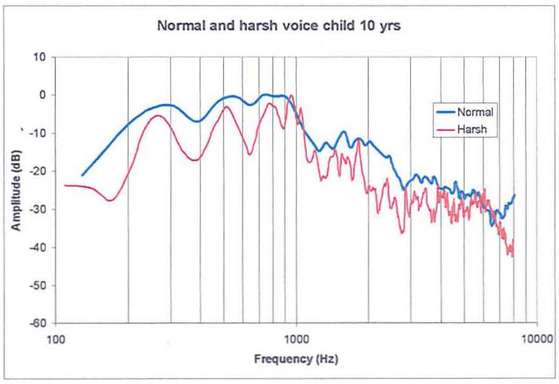

Figure 4.12 LTAS of normal and harsh speech, child aged 10 years, logarithmic frequency scale

There is evidence to show that the higher formants become relatively stronger at higher intensity levels (Fant, 1960; Gauffin & Sundberg, 1989). If the LTAS for the Messa di voce (see Appendix 2) with the evenly varying intensity level were analysed, it would smooth out this effect also. Conversely, in falsetto phonation, the higher formants are weaker than the F_0 (Neiman, Robb, Lerman, & Duffy, 1997).

The LTAS of children's singing voices alters with age, in older children the lower frequencies (2–5 kHz) are stronger and the higher frequencies (6–10kHz) are weaker (Sargeant & Welch, 2008); see Figure 4.13. This will most likely be due to a combination of the acoustic properties of the lengthening vocal tract and the acoustic excitation generated by the more abruptly closing vocal folds in the younger child.

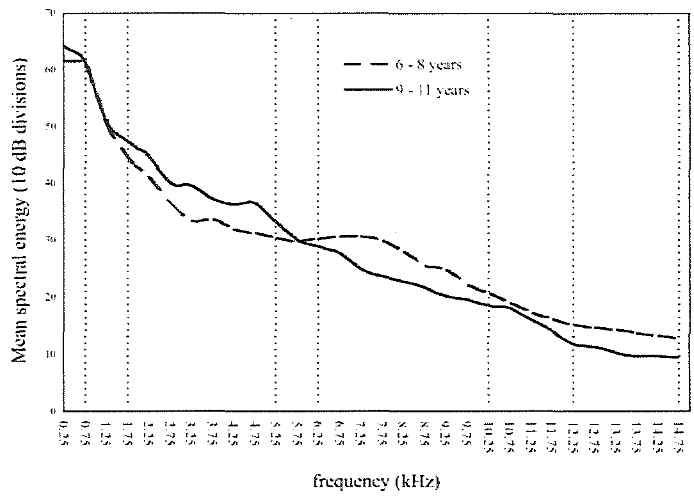

Figure 4.13 Areas of significant differences in mean LTAS curves in children's singing voices aged 6–11 years (Sargeant & Welch, 2008)

4.4.4 Voice Range Profile

The voice range profile (VRP) or phonetogram is a graphical representation of the relationship between pitch and intensity and is suitable for use on children's voices (Heylen et al., 2000; McAllister, Sederholm, Sundberg, & Gramming, 1994). Generally speaking, the higher intensity sounds will allow production of higher pitches and the lower intensity sounds will enable lower pitches. A 'healthy' voice will have a smooth upper contour to the VRP (Pabon, McAllister, Sederholm, & Sundberg, 2000; Pabon & Plomp, 1988).

4.5 Laryngography (Electroglottography)

The Portable Field Laryngograph (Appendix 5.2, picture 5.1) uses a pair of electrodes to measure current flow across the larynx. When the vocal folds are together, the current flows between the electrodes. An increase in current flow between the electrodes is plotted as a positive change on the vertical axis; as the area of vocal fold contact becomes greater, the inter-electrode soft tissue contact increases (Abberton, Howard, & Fourcin, 1989). A display of this current against time gives an indication of the degree and duration of glottal closure with each cycle. The signal from the laryngograph can be analysed to give an accurate reading of the fundamental frequency (F_0) of the sound (see 4.2) (Fourcin & Abberton, 1971; Gilbert, Potter, & Hoodin, 1984).

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Figure 4.14 Idealised electrolaryngograph output waveform showing closed and open phases (Howard, Lindsey, & Allen, 1990)

The laryngograph is commonly used in clinical settings (Greene & Mathieson, 2001), to evaluate vocal health in patients presenting with vocal fold pathology or other dysfunction. The quantitative nature of the assessment provides both the therapist and the client with tangible evidence of changing voice use over time.

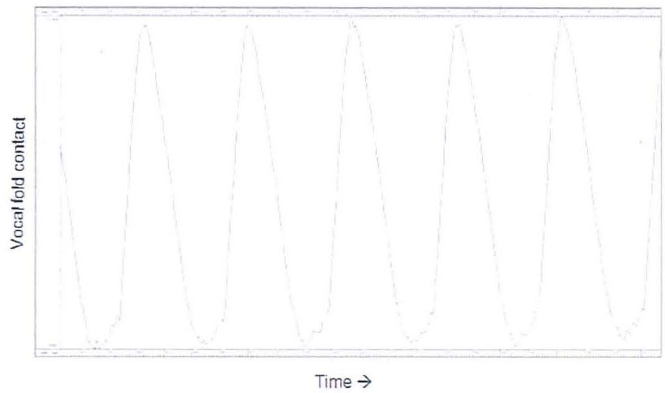

Figure 4.15 Lx waveform of normal voice, child aged 10 years, F_0 260Hz

The laryngographic waveform of normal child voice shown in Figure 4.15 shows a regular cycle by cycle waveform (see Figure 4.14). In the adult with thicker vocal folds, the closing slope (the rise on the left of the peak) would be similar but the opening slope (the fall on the right of the peak) would have a slower initial opening and a more rapid follow-on (see Figure 7.38 for the emergence of the young adult waveform). This example of normal speech can be heard on track 4.1 on the accompanying CD.

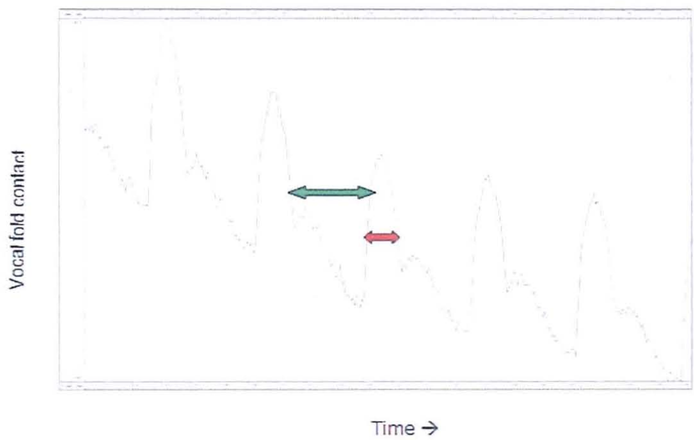

Figure 4.16 Lx waveform of breathy voice, child aged 10 years, F_0 260Hz

The Laryngographic waveform of child breathy voice in Figure 4.16 shows a longer open phase (green arrow) than closed phase (red arrow). This is indicative of the inefficient vocal fold closure resulting in air escaping through the glottis. The downward direction of the overall waveform is due merely to the movement of the larynx during the recording. This example of breathy speech can be heard on track 4.2 on the accompanying CD.

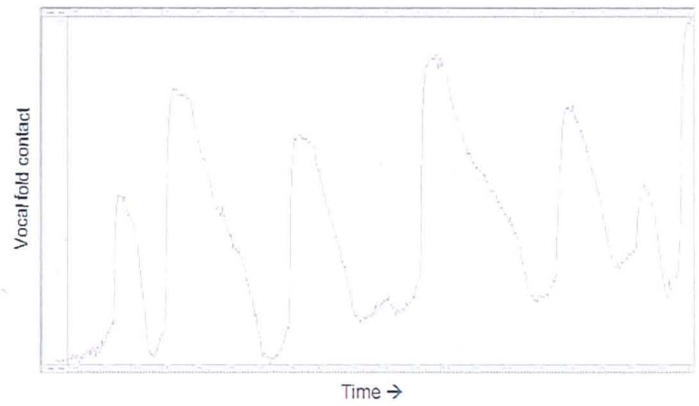

Figure 4.17 Lx waveform of creaky voice, child aged 10 years

The laryngographic waveform of creaky voice in Figure 4.17 shows a cycle by cycle irregularity. The variation in each cycle gives the diplophonic effect. This example of creaky speech can be heard on track 4.3 on the accompanying CD.

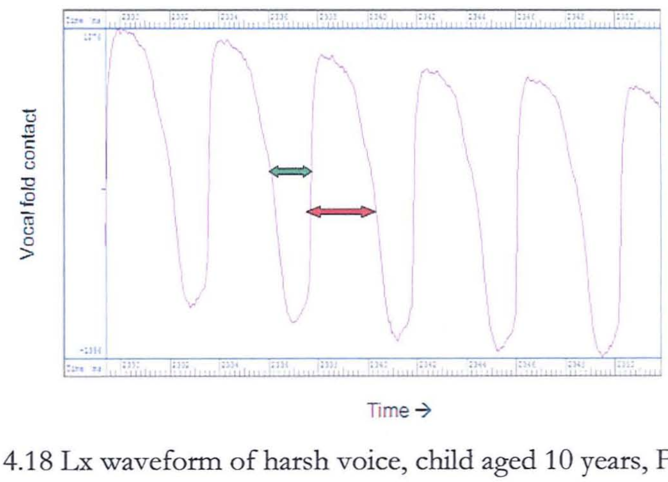

Figure 4.18 Lx waveform of harsh voice, child aged 10 years, F_0 250Hz

The laryngographic waveform of harsh or pressed voice in Figure 4.18 shows a regular cycle by cycle waveform, but with a greater portion of the cycle with the vocal folds in contact (red arrow) than open (green arrow). This example of harsh speech can be heard on track 4.4 on the accompanying CD.

The regularity of these measures, from cycle to cycle, can be calculated by plotting, in separate distribution curves on a graph, the reading of consecutive pairs of vocal fold cycles and the F_0 reading of all the cycles. These two curves can be matched to indicate degrees of perturbation of vocal fold cycles. For this purpose the Laryngograph® Speech Studio was used in this study (Greene & Mathieson, 2001).

4.5.1 Jitter

This measures the F_0 period time difference from cycle to cycle in a sustained vowel. There is always some differential here, possibly due to an inherent neuromuscular condition (Baer, 1980), or due to the chaotic potential of vocal fold vibrational patterns (Titze, Baken, & Herzel, 1993). Deviations in periodicity are often greater in pathological voices than in healthy ones (Greene & Mathieson, 2001).

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Figure 4.19 Speech Studio reading of irregularity (F_0 perturbation) in a healthy voice. This shows first and second order vocal fold frequency distributions, DFx1 and DFx2, and the agreement between the two (coherence) (Greene & Mathieson, 2001)

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Figure 4.20 Speech Studio reading of irregularity in an unhealthy voice (Greene & Mathieson, 2001).

4.5.2 Shimmer

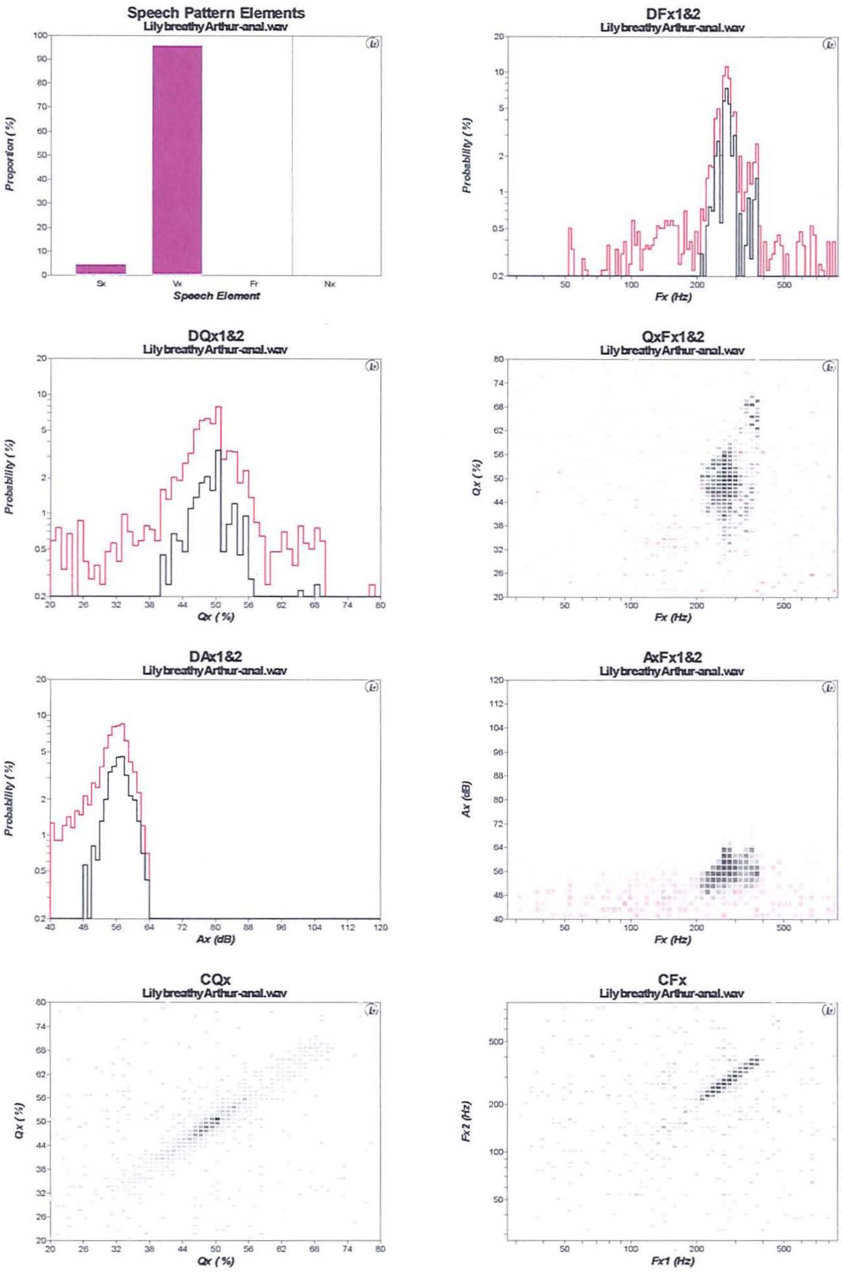
This measures the cycle to cycle variations in amplitude in a sustained vowel (Greene & Mathieson, 2001). It is an important element in voices perceived as hoarse (Baken, 1996).

4.5.3 Contact Quotient or CQ

Contact quotient is the measurement obtained from the electrolaryngograph. It produces a waveform which can give a measure of the degree and duration of vocal fold contact in each cycle (Gauffin & Sundberg, 1989). This is in general a measure of vocal efficiency. A faster closing rate of the vocal folds caused by the folds snapping together more quickly or with more force (indicated by a steeper rising slope to the waveform), will result in a louder perceived sound (Welch & White, 1993). As the folds separate, during the open phase some acoustic energy travels into the subglottic cavity, where it is effectively lost to the listener. This is known as subglottal damping (Howard, 2005). If the closure time in each vibratory phase is increased, this longer closed phase will result in less acoustic energy lost in this way and more efficient voicing (Howard et al., 1990). If, however, the closed phase is too long, it can be an indicator of pressed phonation (see 2.3.4). In normal speech, women have a higher percentage closed phase than men (Stathopoulos & Sapienza, 1997); men's vibratory pattern is characterised by medial surface bulging and greater contraction of the vocalis muscle than women (Titze, 1989). Trained choristers have been shown to have a CQ of 55.3%, similar to that of trained adult singers (56.2%) and significantly greater than that of both untrained children (37.38%) and adults (41.3%) (C. A. Barlow & Howard, 2002; Howard et al., 1990; Welch & White, 1993).

4.5.4 Examples of these measurements in analysis using Speech Studio

The three vocal behaviour examples shown in Figures 4.14 to 4.16 can be seen here in Speech Studio analysis, looking particularly at aspects of voice quality. Healthy vocal fold behaviour has a consistency of both frequency and amplitude from cycle to cycle. Unhealthy vocal fold behaviour has cycle by cycle irregularity; this is analysed by the laryngograph and illustrated in the graphs. Figure 4.21 shows an analysis of breathy voice. This particular sample gives some unexpected readings in the speech pattern element which may be due to wrongly placed electrodes. The separate graphs are explained on the following pages.



Graph	Samples	Mean	Mode	Median	Std. Dev.	Coherence	80% Range	90% Range	Irreg.
Speech Pattern Elements	6033								
DFx1&2 (1)	3332	264.14Hz C4	273.21Hz C4#	270.81Hz C4#	118.20Hz 0.53 Oct	39.02%	117.9, 373.6Hz 1.66 Oct	75.7, 487.8Hz 2.69 Oct	
DFx1&2 (2)	1300	271.72Hz C4#	273.21Hz C4#	274.13Hz C4#	37.73Hz 0.19 Oct	39.02%	243.3, 336.3Hz 0.47 Oct	231.8, 365.9Hz 0.66 Oct	
DQx1&2 (1)	2800	47.18 %	50.50 %	48.72 %	9.81 %	25.14%	35.3, 58.3 %	27.9, 65.9 %	
DQx1&2 (2)	704	48.46 %	50.50 %	49.29 %	6.07 %	25.14%	42.9, 55.5 %	40.8, 60.8 %	
QxFx1&2	2694					61.02%			
DAx1&2 (1)	2783	53.48dB	57.50dB	55.50dB	5.11dB	41.14%	46.6, 60.1dB	43.7, 61.3dB	
DAx1&2 (2)	1145	55.39dB	57.50dB	56.63dB	3.53dB	41.14%	52.3, 60.7dB	50.3, 61.7dB	
AxFx1&2	2712					60.62%			
CQx	3044								34.79%
CFx	3368								16.02%

Figure 4.21 Speech Studio analysis of breathy voice, child aged 10 years

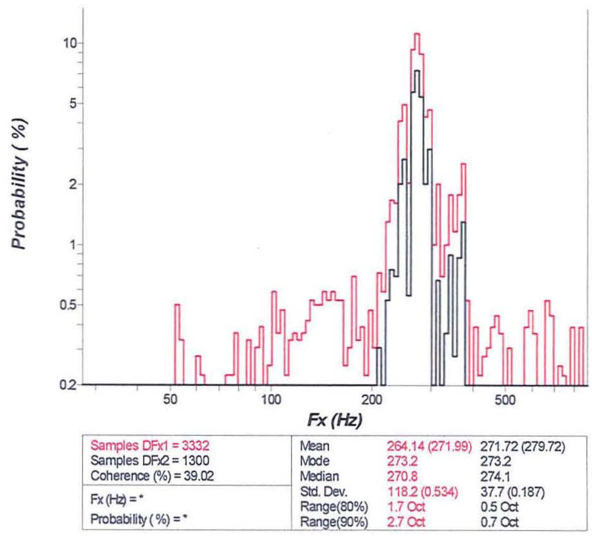


Figure 4.22 DFx1&2 for child breathy voice

The DFx1&2 in Figure 4.22 shows the distribution of the fundamental frequencies (x axis) in the voice. Those within the red histogram are all individual cycles: these are DFx1. Those within the black histogram represent individual cycles which have the same fundamental frequency as the cycle immediately following them: this is DFx2. This graph shows a high degree of irregularity; the coherence is only 39%. It also shows that there is an unusually high peak at one particular frequency, around 273Hz; this will be due to a rather monotonal delivery of the spoken text (this is on track 4.2 on the CD). There is another, separate peak at around 370Hz (F#4). This is a high pitch for speech and could be as a result of pushing the air through a narrowed glottal opening; the child in this example was using an unusually high subglottic pressure in order to maintain a breathy phonation in what was in fact a healthy larynx.

The DAx1&2 in Figure 4.23 shows a similar distribution, this time for the amplitude of each vocal fold vibratory cycle. The distribution of the amplitude (mean = 55dB) is generally low when compared with later samples recorded on the same occasion under the same conditions (see harsh voice Figure 4.26 – the mean amplitude is 80dB), showing how breathy voice use is generally weak and not able to be projected. There is also a noticeable level of irregularity, particularly in the cycles at lower amplitudes. The DQx1&2 in Figure 4.24 shows the irregularity in the degree of vocal fold closure from cycle to cycle. This example has a coherence of only 25%. More of the vocal fold closure is at less than 50% (to the left of the graph), this is due to the inefficiency of closure illustrated in the waveform in Figure 4.14.

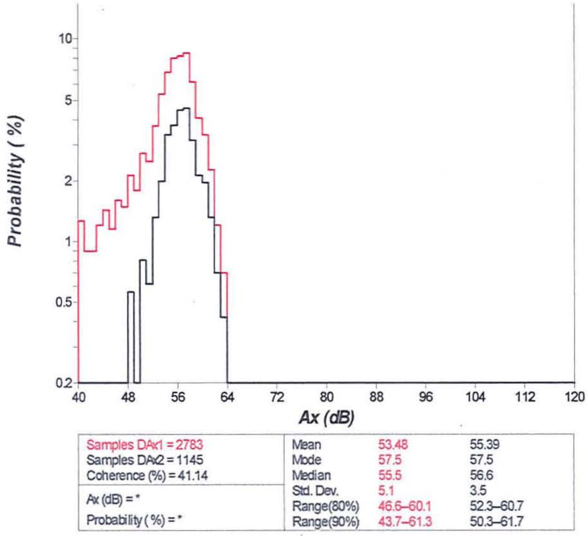


Figure 4.23 DAx1&2 for child breathy voice

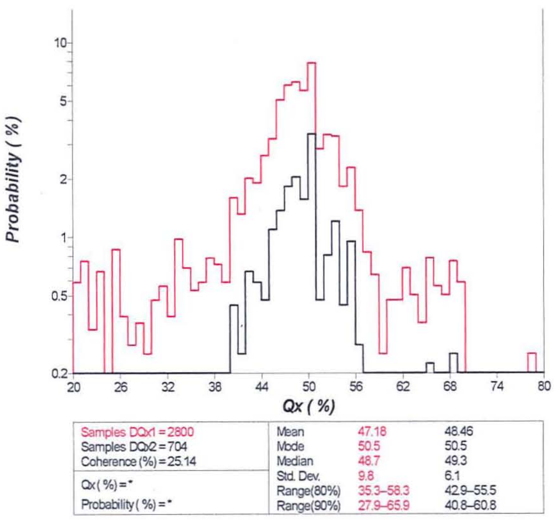
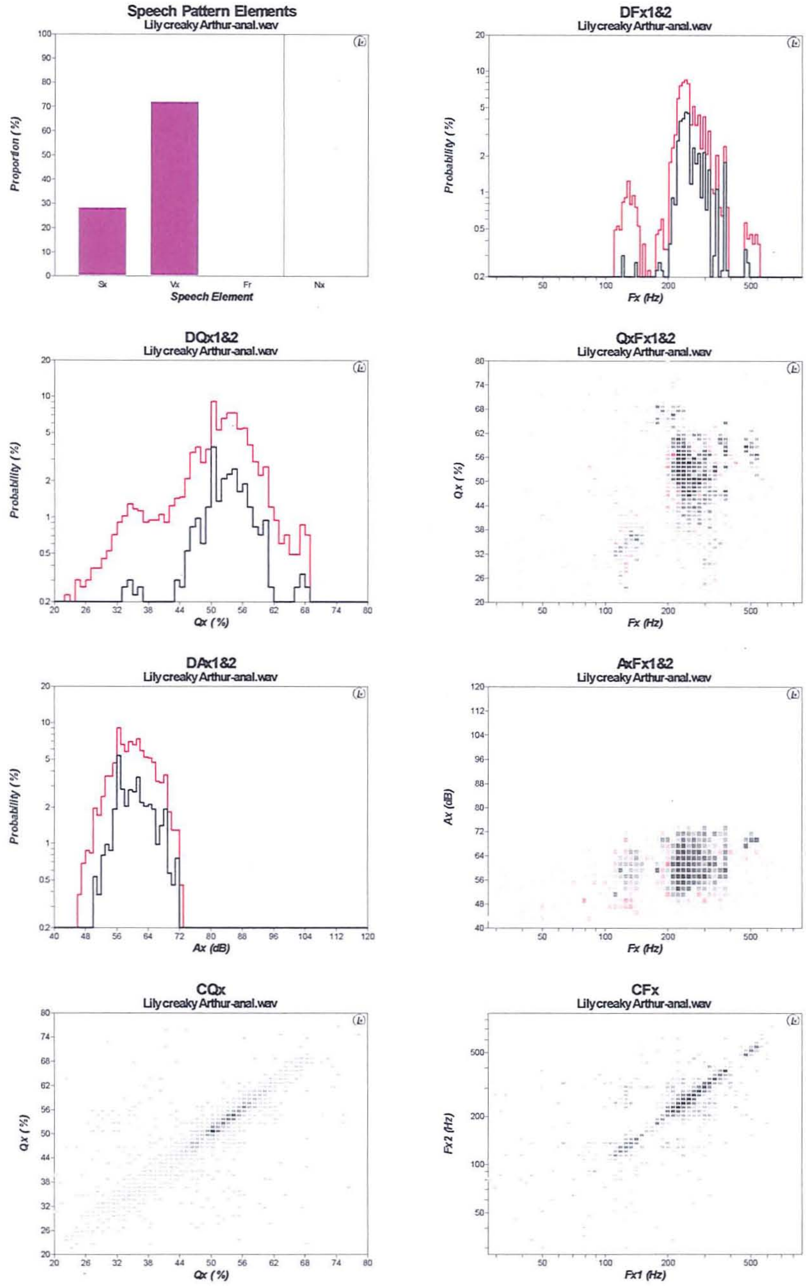


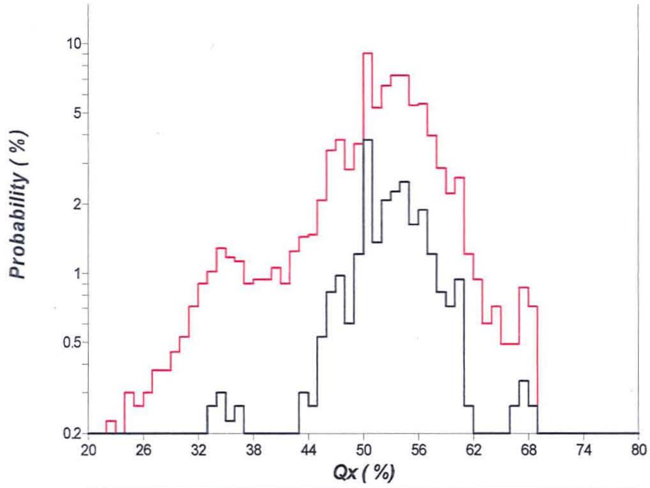
Figure 4.24 DQx1&2 for child breathy voice



Graph	Samples	Mean	Mode	Median	Std. Dev.	Coherence	80% Range	90% Range	Irreg.
Speech Patt2680 lements									
DFx1&2 (1)	2637	246.93Hz B3	243.40Hz B3	246.13Hz B3	76.70Hz 0.39 Oct	42.81%	144.9, 341.2Hz 1.24 Oct	123.3, 378.6Hz 1.62 Oct	
DFx1&2 (2)	1129	255.39Hz C4	243.40Hz B3	248.60Hz B3	62.68Hz 0.32 Oct	42.81%	214.0, 343.2Hz 0.68 Oct	167.0, 376.5Hz 1.17 Oct	
DQx1&2 (1)	2619	49.72 %	50.50 %	52.13 %	8.61 %	28.48%	37.5, 59.7 %	33.1, 62.5 %	
DQx1&2 (2)	746	51.28 %	50.50 %	52.89 %	7.11 %	28.48%	44.7, 60.0 %	36.5, 63.1 %	
QxFx1&2	2618					58.79%			
DAx1&2 (1)	2641	59.04dB	56.50dB	60.00dB	5.58dB	39.64%	53.1, 67.6dB	50.7, 69.0dB	
DAx1&2 (2)	1047	59.63dB	56.50dB	60.36dB	4.98dB	39.64%	55.0, 67.9dB	52.9, 69.0dB	
AxFx1&2	2635					58.44%			
CQx	2608								34.46%
CFx	2632								16.94%

Figure 4.25 Speech Studio analysis of creaky voice, child aged 10 years

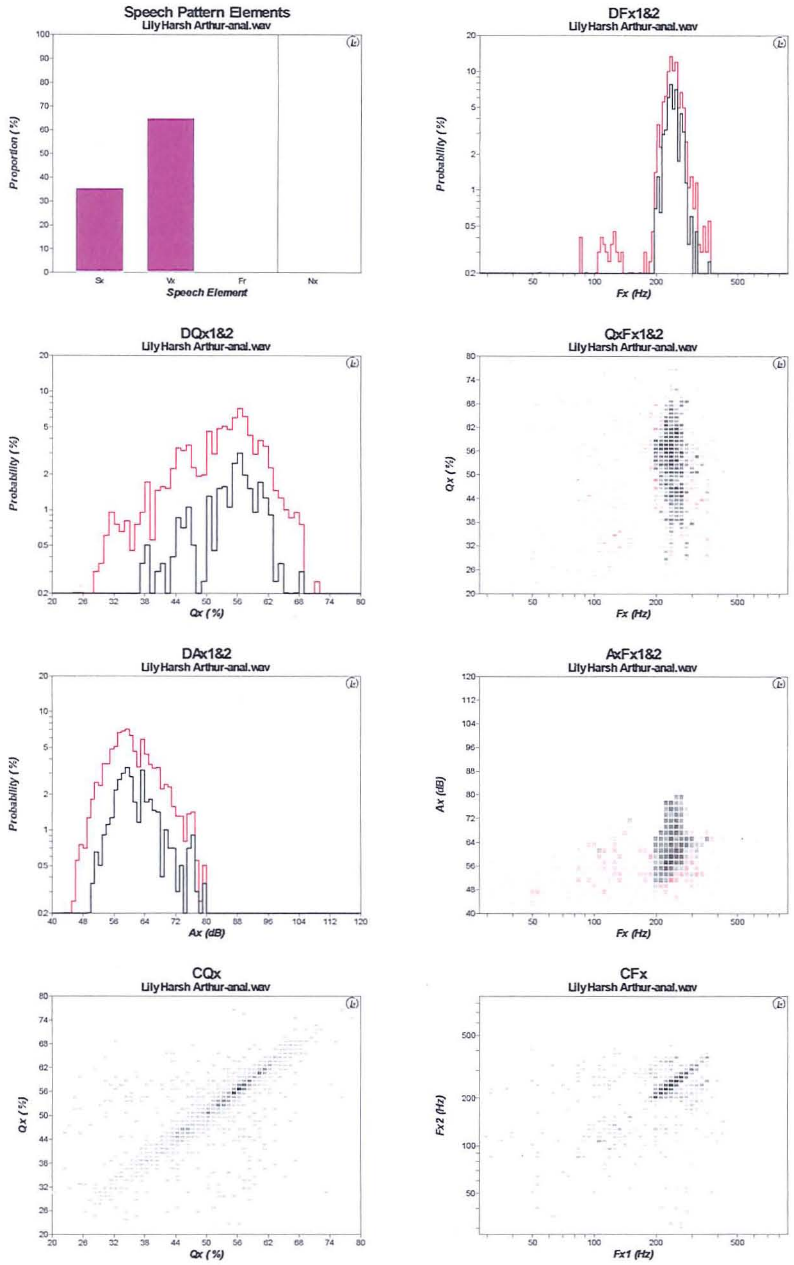
The collection of graphs in Figure 4.25 shows the element of voice behaviour in creaky speech. This differs from breathy speech in several areas: the overall amplitude is greater, the mean amplitude of the breathy voice is 53dB, of the creaky voice it is 59dB. The breathy voice has a greater spread of irregular vocal fold cycles at lower frequencies. The creaky voice has a lower coherence for vocal fold closure (28.5%), this is shown in Figure 4.25. In creaky voice there are a large number of irregular cycles throughout the closure distribution, but more so at the lower degrees of vocal fold closure.



Samples DQx1 = 2619	Mean	49.72	51.28
Samples DQx2 = 746	Mode	50.5	50.5
Coherence (%) = 28.48	Median	52.1	52.9
Qx (%) = *	Std. Dev.	8.6	7.1
Probability (%) = *	Range(80%)	37.5–59.7	44.7–60.0
	Range(90%)	33.1–62.5	36.5–63.1

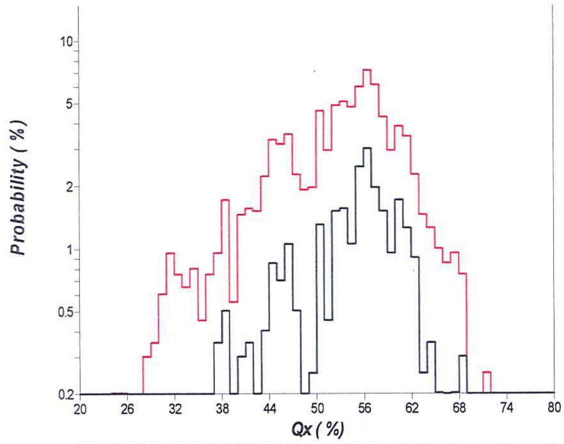
Figure 4.26 DQx1&2 for child creaky voice

Figure 4.27 shows the Speech Studio analysis of harsh voice in the ten-year-old child. This has a much higher degree of vocal fold closure, a mean of 53%. This corresponds with the closure shown in the laryngograph waveform, Figure 4.17. The vocal fold closure is also irregular from cycle to cycle (see Figure 4.28); not as much as in creaky voice (Figure 4.26), but more so than normal voice. The frequency has an element of jitter, shown in the isolated red peak in the lower frequency ranges in Figure 4.29.



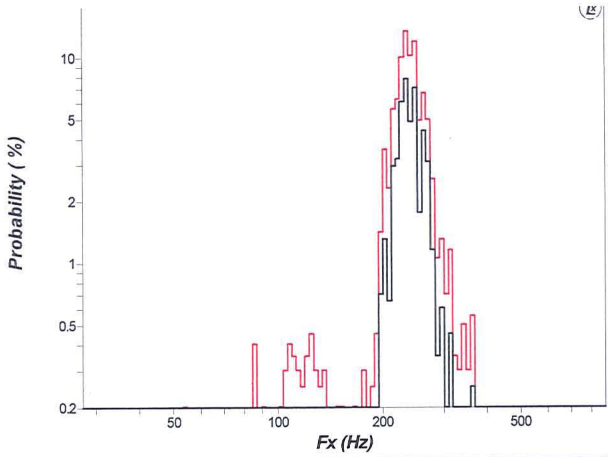
Graph	Samples	Mean	Mode	Median	Std. Dev.	Coherence	80% Range	90% Range	Irreg.
Speech Patt2012lements									
DFx1&2 (1)	1971	228.77Hz A3#	236.47Hz A3#	239.12Hz A3#	46.15Hz 0.26 Oct	47.89%	201.8, 276.0Hz 0.45 Oct	124.1, 297.8Hz 1.26 Oct	
DFx1&2 (2)	944	236.44Hz A3#	236.47Hz A3#	240.70Hz B3	25.99Hz 0.15 Oct	47.89%	217.3, 272.8Hz 0.33 Oct	207.5, 281.7Hz 0.44 Oct	
DQx1&2 (1)	1955	51.12 %	56.50 %	53.79 %	8.91 %	27.77%	40.0, 61.9 %	34.4, 64.6 %	
DQx1&2 (2)	543	53.13 %	56.50 %	55.68 %	7.24 %	27.77%	44.2, 61.8 %	40.0, 63.8 %	
QxFx1&2	1954					63.92%			
DAx1&2 (1)	1973	60.04dB	59.50dB	60.19dB	6.90dB	37.91%	52.7, 70.6dB	50.5, 73.9dB	
DAx1&2 (2)	748	61.19dB	59.50dB	60.91dB	6.33dB	37.91%	55.0, 71.3dB	53.1, 75.6dB	
AxFx1&2	1968					63.47%			
CQx	1939								36.69%
CFx	1965								16.05%

Figure 4.27 Aspects of voice quality in child harsh voice, aged 10 years



Samples DQx1 = 1955	Mean	51.12	53.13
Samples DQx2 = 543	Mode	56.5	56.5
Coherence (%) = 27.77	Median	53.8	55.7
Qx (%) = *	Std. Dev.	8.9	7.2
	Range(80%)	40.0–61.9	44.2–61.8
Probability (%) = *	Range(90%)	34.4–64.6	40.0–63.8

Figure 4.28 DQx1&2 of harsh voice, child aged 10 years



Samples DFx1 = 1971	Mean	228.77 (235.64)	236.44 (243.44)
Samples DFx2 = 944	Mode	236.5	236.5
Coherence (%) = 47.89	Median	239.1	240.7
Fx (Hz) = *	Std. Dev.	46.2 (0.265)	26.0 (0.150)
	Range(80%)	0.5 Oct	0.3 Oct
Probability (%) = *	Range(90%)	1.3 Oct	0.4 Oct

Figure 4.29 DFx1&2 of harsh voice, child aged 10 years

4.6 Summary

The numerous methods of assessment can make this type of investigation unnecessarily cumbersome. It must also be noted that, despite the undoubted sophistication of acoustic assessment methods available to the researcher, there is none as sophisticated as the human ear. Listeners' judgements are the standard by which measures of voice are evaluated (Kreiman et al., 1993). The challenge is to facilitate consistent quantification methods, enabling the listeners to provide reliable judgements. This challenge has been attempted in the following chapters where a series of pilot studies has led to a methodology enabling an overall quantitative conclusion to be reached.

Chapter 5

Methodology:

Research protocol and assessment rationale

5.1 Introduction

The main aims of the thesis are to explore the nature of boy choristers' singing development and vocal health in a professional performance context. In particular, there is a focus on understanding how vocal behaviour (speaking and singing) changes over time within a cathedral music culture that demands significant vocal loading (related to the potential effort and tissue stress required for professional standard singing; see 1.3.1). For the purposes of addressing the aims of the thesis, the design is multi-sited and multi-method in its approach. This includes the gathering of longitudinal data from choristers aged seven to thirteen years in a London cathedral where they were required daily to sing for religious services and in related rehearsals (see 5.2.2). Such performances require considerable vocal mastery of a professional music repertoire. In order to locate these cathedral chorister data in comparison with what might be regarded as usual vocal behaviour from boys of a similar age and school environment, comparative vocal data were collected from boys in similar educational environments in other locations in South East England.

5.1.1 Introduction to the methods of data gathering

One of the central challenges in the research design has been to generate insights into an appropriate method for the gathering of data that is both environmentally valid (in the sense of being related to everyday singing activities) and reliable (relatively consistent as indicative of the individual performer's voice) and which can be applied to develop an increased understanding of what counts as 'normal' vocal behaviours and possible vocal dysfunction for such choristers (see 1.3.1).

This study was multi-method in its structure, partly due to its exploratory nature. Children's voices have been assessed in previous research projects and there was a body of literature employed to aid the design of the research protocol for this study. However, the assessment in this manner of the voices of children who are trained and skilled singers was a new undertaking. Because of this, there was a certain amount of trial and error involved in the design of the methodology. This led from the initial use of the detailed VPA assessment method, through the use of the single-score EAIS method, and ending with the single-score VAS method.

5.1.2 The use of panels of judges to validate perceptual assessments of vocal health

The main data assessment for this study was based on perceptual judgements from one individual; the author. As outlined in the Introduction 1.1, the author had considerable experience and expertise in the teaching of singing to children of this age and level of professional musical performance. Nevertheless, this experience in itself was still subjective and was not in itself the product of any formal training in assessment of voices. In order to give more validity to these perceptual judgments, it was considered important to involve a panel of judges at each stage to enable consistency and reliability to be calculated and evaluated.

These judges were taken from various professional backgrounds: singing teaching, spoken voice teaching, voice research and clinical speech therapy. This was intended to represent the wide range of training and experience from professional practitioners involved in the assessment of children's voices in the UK.

5.2 Research methodology related to each research question

The following three sections (5.2.1 to 5.2.3) provide an overview of the research methodology in relation to each of the three research questions given in 1.5.

5.2.1 What is the vocal behaviour of boys who experience an intensive, performance-focused training?

Participants (and location)

The participants (n=34) were a cohort of choristers at a major London cathedral and aged eight to thirteen years.[2] These boys lived on site as boarders in the choir school. They had a demanding daily schedule of rehearsals and performances (see Chapter 1, Table 1.1) as well as the usual classroom curricula, and sporting and leisure activities of schoolboys of this age. The choir school was located in the centre of London. The choice of the participants and choir school was based on (a) the recognised workload of the choristers (established through informal contact and published schedules of daily services), (b) the recognition of the quality of the sung performance culture as an internationally known location of Anglican worship dating back nine centuries, as well as (c) established professional connections of the author as a professional performer and teacher. A letter was sent to the choir school inviting them to participate and a series of initial meetings was held to explain the purpose of the research. The researcher (and, on one occasion, with the supervisor) met with key management personnel, including the Headmaster of the school, the Director of Music in the school, the Director of Music in the cathedral and a senior cathedral authority. Once their agreement had been secured in principle, each chorister and his parents were approached in writing to seek their participation (see 5.5.6).

Data collection

Each of the participant boys' voices was recorded at six-monthly intervals over a three-year period. The recordings took place in one of the school classrooms that was well-known to the boys and relatively isolated geographically from the rest of the school. Recording sessions were at the end of the school day during the boys' private study time.

Research tools

The basic model for the selection of research tools was initially adapted from those used in a study of the female choristers at Wells Cathedral (Welch, 2003), as well as with reference to

[2] The total number of choristers in the school prior to the beginning of the fieldwork was 37, but one declined to participate and two others had parents who did not agree to their child's participation.

two other, related studies (Vickers, 1990; Welch & White, 1993). These previous approaches also included both speaking and singing tasks. Subsequently, the protocol was altered slightly as a result of initial piloting undertaken at the beginning of the first year. The protocol included a greater range of assessment criteria than those needed for this particular study.

The participants followed a specially designed vocal behaviour assessment protocol that embraced speaking and singing activities (see Appendix 2). These included the reading aloud of an established spoken age-appropriate text ('Arthur the Rat') commonly used in voice clinics, vocal exercises (scales, pitch glides and messa di voce[3]), plus the singing of the first verse of a hymn tune that had been identified as being well-known to the choristers.
The resultant vocal behaviour was recorded digitally prior to (a) perceptual and (b) acoustic analyses. Field notes were also taken by the author at each recording session.

Voice source data were collected in parallel to the acoustic data via an electrolaryngograph (Lx) for subsequent analysis. The Lx data represent the activity of the opening/closing mechanism of the vocal folds in running speech or singing (see 4.5; for recording equipment specifications see Appendix 4).

A simple questionnaire (supported by semi-structured interviews where necessary) was completed with the choristers, the musical director of the choir, their singing teacher, the school nurse and each boy's parents (see Appendix 5). This was designed to provide information about their overall physical and vocal health such as upper respiratory tract infections, either acute or chronic. It also provided information of the perceived singing ability of the chorister, both by the teaching staff, the chorister's peer group and the chorister himself. The participants completed a personality profile (Eysenck Junior Personality Test) which is described below in section 5.4.

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[3] Messa di voce is a vocal exercise sung on one vowel, starting quietly, evenly increasing to loud and then decreasing to quiet again. It demonstrates the ability to control the pitch of the note while changing the loudness.

Data analyses protocols

Following the precedents over choice of appropriate methods of determining vocal quality underlying sung products in the established literature (see Chapter 4), two kinds of analysis were undertaken: perceptual and acoustic. Perceptual analyses embraced:

(i) Perception of observed vocal behaviour against a range of parameters drawn from the literature on voice profiling – see 4.2 and 5.6;

(ii) Perception of vocal health from the connected speech samples from within the same overall data set (using two different rating scales: EAIS and VAS, see 4.2.4);

(iii) Perception of vocal health from the song recordings;

(iv) Validation and reliability assessments using panel ratings of initial author perceptions by expert judges of sub-sets of this data (i.e., related to i, ii and iii above). The subsets were examples selected by the author as representing a range of vocal health and singing skills. The judges' agreement was subsequently measured using a selection of statistical methods (see Chapter 6).

Subsequently, selected Lx analyses of perceptually salient vocal events in the data were inspected to see if there was any independent voice source evidence of variations in vocal fold waveforms that might explain variations in the perceptual data (see Chapter 7 for more detail). The interview and questionnaire data were used as supplementary and contextual information for the perceptual analyses of the audio (and checked against the author's field notes of each chorister recording session). The results of the personality profile were used to provide additional contextual information for the evaluations of vocal behaviour (see Personality types, 5.4).

Data processing

(i) The judges' ratings were collated and entered into the statistical analysis program SPSS for subsequent analyses. Principal component analyses and bivariate (Pearson) correlations were undertaken of all quantified parameters (i.e., demographic background information, quantised vocal behaviour ratings and personality scores) in order to establish the possibility of any significant and/or co-dependent variables[4].

(ii) One-way ANOVAs were applied to compare scores from the panel of judges, R^2 or Kendall's W was calculated for members of the panel of judges to establish inter-judge agreement (for definitions of these statistical terms, see Chapter 6).

(iii) and (iv) Additional comparisons of scores obtained from sub-groups of the original 36 voice profile parameters were undertaken in order to establish possible correlations and co-dependent groups.

5.2.2 How does such behaviour change over time?

In order to assess how male chorister singing changes over time, the overall chorister fieldwork included a longitudinal perspective (see 5.14).

Participants (and location)

The participants (n=11) were a sub-group of the 34 choristers (as specified in 5.2.1 above). They were selected in two groups: five who were new to the choir at the start of the research (known as Probationers) and six in school Year 6 (aged ten to eleven). Over three years of longitudinal assessments, regular voice measures of those who had begun as probationers were made to indicate any effects of development and training from their relatively untrained level at intake into the choir. In contrast, the regular voice assessments of the Year 6 boys were intended to log the maturation of the chorister voice over time, and its further development into adolescent voice change (noting that the average age of onset of adolescent voice change is in school Year 8, aged twelve to thirteen years – see 3.8.5). The two groups of participant choristers represent a spread of ages encompassing junior choristers from their first week in the choir at recording 1 (Research fieldwork Year 1) to the most senior choristers just before they left the choir at recording 6 (Research fieldwork Year 3).

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[4] As the distribution of scores was non-parametric both Pearson and Spearman correlations were undertaken. There was no significant difference between the outcomes for each test (see 6.1.1).

Data collection

The boys were recorded at six-monthly intervals over a period of three years, making six times in total, including the recordings made as part of the pilot study described in 5.2.1 above.

Research tools, data analyses protocols and data processing

The research tools were the same as those specified in 5.2.1 above for all the choristers because those involved in the longitudinal study were a subset of the original larger group. The collected data was subject to the same analyses processes using SPSS as detailed above, but additionally looking out for any time-sensitive behaviours as indicators of longitudinal development and (for the older group) possible adolescent voice change.

5.2.3 Is the nature and incidence of perceived vocal dysfunction different from what might be found in boys of a similar age and school environment?

In order to provide a perspective on whether the choristers were typical or untypical of boys of a similar age and background, other groups of participants were recruited to provide a comparative perspective.

Participants (and location)

There were four activity and environment based groupings of participants:

1 Choristers (boarders) from a major UK cathedral in London (i.e., the participants in the sections above 5.2.1, including the subset in 5.2.2);
2 Their non-chorister 'day pupil' peers in the same school;
3 Other choristers ('day pupils') who were from a provincial cathedral in South East England;
4 Groups of boys who boarded in two traditional (non-music specialist) preparatory schools in South East England.

The criteria for selecting these participants were as follows:

(i) Group 2 were boys from the same school as attended by the longitudinal chorister group. Consequently, the day-time social and classroom environment was the same as for their chorister peers; these day boys, however, were not involved in any of the cathedral musical activities and went home to their families at 3.30pm every day until arriving at school at 8.45am the next morning.

(ii) Group 3 were choristers at the cathedral local to the author's home town.

(iiii) It was not possible to have a comparison school which had boarding pupils and was also located in a city centre. All boarding schools for this age group in the UK tend to be in rural settings, except those that are specifically choral foundations (see Chapter 1). The boarding schools selected for comparison had boy pupils only and were not known particularly for their musical or choral expertise.

Data collection

The comparative data were collected at a single recording event for each of the groups identified as 2–4 above. Within each group, participants were recorded individually using the same digital acoustic procedure as applied to the London choristers. There was no Lx recording of these boys due to the limited availability of the specialised equipment. The recording took place in a classroom of their school during their private study time at the end of the formal taught period of the school day, i.e. at a comparative time and place.

Research tools, data analyses protocols

The participants completed a simplified version of the specially designed vocal behaviour protocol (see above) that embraced speaking and singing activities. This simplified version omitted the questionnaires for the boys, teachers and parents. It did not include recordings made with the laryngograph for practical reasons. As with the London choristers, the speaking and singing were digitally recorded to facilitate subsequent (a) perceptual and (b) acoustic analyses. The approaches for the perceptual analyses of vocal behaviour and their validation were identical across all groups (see 5.2.1 for details). Subsequent one-way ANOVA analyses were undertaken on the ratings obtained from each group in order to generate information on any significant differences between them.

5.3 Grouping of boys according to activity

The comparative groups specified in 5.2.3 (i.e., additional to those in the London cathedral main study – including its longitudinal strand) were chosen to provide comparative data from a similar population (i.e., in relation to participant sex, age, social stratum, educational context and environment). The criteria used in the selection of participants for comparative 'similarity' were: sex – boys educated in a single-sex school, age – boys educated at a school exclusively with Years 3 (aged seven to eight years) to 8 (aged —twelve to thirteen years), social strata and educational context – these boys were at fee-paying, independent schools.

In addition, there were several known factors that have been reported in the literature to influence the vocal health of children (see Chapter 3). Children at greater risk of vocal dysfunction are those who:

1. Spend a greater amount of time each day in large groups (Sederholm, 1996a);
2. Live in urban environments (Sederholm, 1996a);
3. Suffer from allergies and respiratory tract infections (Cornut & Venet, 1966);
4. Have a psychological profile showing a tendency to be perceived as 'less stable' and 'more extrovert' (Brandell, 1982);
5. Are boys (Sederholm, 1996a).

According to the information provided by those responsible for each group of participants and the available demographic data, the selected main focus chorister group was male, spent time each day in large groups and lived in an urban environment. Similarly, the non-chorister boarders lived in the same boarding school environment and were likely to be in large groups all day and evening (school classes of about 25, dormitories of four to six, and the boys' socialising in 'free time' tended to be in one large common room). The choir school selected was located in the centre of London, surrounded by busy roads; there was a noticeable level of background noise at all times against which the boys would need to raise the level of their habitual speaking voices. All these participants were boarders. Conversely, boys at day schools are likely to spend their non-school time in their family home, in relatively smaller rooms; often spending time alone in their bedrooms or in front of a computer or a television. These activities involve little or no voice use.

Category 3 (above) can be linked to environment: urban settings will have higher levels of pollution and rural settings will have a higher level of pollens. In this study, the location of each school was not considered with respect to the occurrence of particular allergens. Category 4 (above) has not been linked with any particular environmental factor and for the purposes of this study was assumed to be relatively evenly distributed across participants.

There was one other group of choristers selected. These were boys who rehearsed in a choir on most days but were not living in a boarding environment. The choir in which they sang was in a smaller, provincial cathedral, with arguably less performance stress on the choristers. The weekly performance and rehearsal schedule was shared with a girls' choir. These categories and the numbers of boys in each one are summarised in Table 5.1.

Table 5.1 The numbers of boy participants in this study and the dates of recordings

Group	Numbers of participants	Dates of recordings						
		Time A	Time B	Time C	Time D	Time E	Time F	Time A
London choristers	23	October 2003	May 2004					
	11	October 2003	May 2004	November 2004	April 2005	October 2005	July 2006	
London day-school	30						July 2006	
Provincial cathedral	20							October 2006
Boarding non-choristers A	11							October 2006
Boarding non-choristers B	29							October 2006

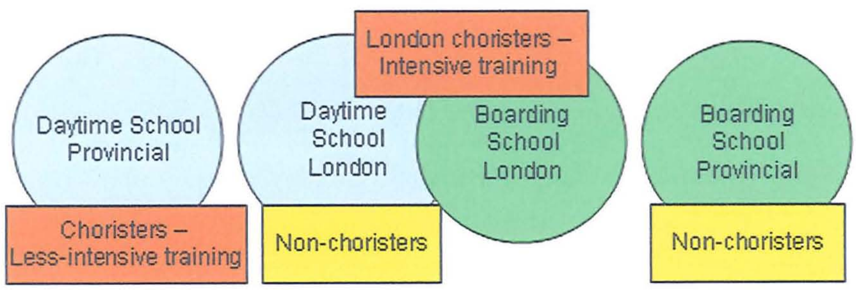

Figure 5.1 Groups of subjects showing school environment and vocal activity

Recording a significant number of boys was considered to be necessary in order to enable significant statistical analysis. In a pilot study by McAllister into six individual children's voices, there was no agreement between perceptual and acoustic assessment (McAllister et al., 1995). In a follow-up study with 50 children, although a high degree of scatter was seen in the distribution of perturbation measures, a significant correlation between perceptual and acoustic measures was demonstrated (McAllister et al., 1998). This current study used a total of 125 boys drawn from across the four activity groups.

5.4 Personality types (H. J. Eysenck & Eysenck)

It has been noted that personality type is a contributory factor in determining which boys may suffer from voice disorders (see 3.9.4). The idea of grouping individuals according to their temperament was used by the ancient Greeks (see the central sections of the chart Figure 5.2). Eysenck believed that these personality types are essentially genetically determined and are present in the individual at birth (Thomas, 1990). The Eysenk Junior Personality Test is a standardised set of questions with 'yes' or 'no' answers. These give indications of how the boy would respond in certain circumstances and how he may feel in various situations.

These answers can be analysed to give a score in each of four areas:

P = Psychoticism or tough-mindedness

N = Neuroticism or emotionality

E = Extroversion

L = Lie or desire to be liked: this gives an indication of whether the boy is answering the questions truly or whether he is giving the answers he believes are required.

According to Eysenck, the three types of personality (P, N, E) are designed to show no significant correlation with each other: it is just as possible to be a low-neurotic extrovert as a high-neurotic extrovert. The extrovert personality is associated with levels of arousal in the autonomic nervous system: introverts have higher levels of arousal and so seek situations with less nervous stimulation; extroverts have low levels of arousal and seek situations with more nervous stimulation. The neurotic personality scale is a measure of the emotionality and sensitivity of the individual.

The addition of the P scale adds a third dimension; high-scoring individuals will be more inclined to be aggressive, assertive, egocentric, unsympathetic, manipulative, achievement-oriented, dogmatic, masculine or tough-minded. A high score of P can be associated with a relatively high testosterone level.

There is some evidence to suggest that musicians have a tendency towards introversion. This has been demonstrated to be linked to personal resourcefulness and self-sufficiency, not timidity or shyness (Hallam, 1998). The introvert is believed to be able to create an internal and imaginative world of sound. They will also have more patience to persist with instrumental practice, as, according to Arousal Theory (Boyce & Ellis, 2005; Hallam, 1998), they will seek out solitary and predictable situations.

Most individuals have scores lying towards the centre of the scale. The score for E tends to lie, on average, between 17.5 and 19 (out of a possible 24) for boys of ages seven to thirteen, with a tendency to be slightly higher in the older boys. The score for N tends to lie, on average, between 10 and 10.5 for boys of ages 7 to 13.

The relationship between these three personality types can be combined to give an overall individual personality type. The balance between the scores for N and E can be summarised in this chart in Figure 5.2: a higher score for N indicated a leaning towards the Unstable area of the chart, a higher score for E indicated a leaning towards the Extroverted area of the chart. Children in Sweden with symptoms of chronic hoarseness tended to have higher than average scores in both neuroticism and extroversion (Sederholm et al., 1995) suggesting that children who are more extrovert and less emotionally stable will be more prone to voice disorders.

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Figure 5.2 The relationship between personality types from Eysenck (H. J. Eysenck & Eysenck)

The L test assesses whether the individual is giving answers which they feel they should give, rather than giving honest answers to the questions. It has been suggested that all scores over 8/20 in primary school children should be excluded from analysis (M. W. Eysenck, 2000). Scores in the L test are lower in children with higher intelligence; the correlation between the L scale and intelligence tests was demonstrated to be 0.36 to 0.25 in a previous study by the author of the tests. A total linear correlation would be a score of 1, a score of 0 shows no correlation at all, a score of 0.5 or above is considered to be a good correlation. These correlations show that there is some link but that it is not particularly strong. The L test scores are inversely related to age (see Figure 5.3)

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Figure 5.3: Age trends for the L test score (H. J. Eysenck & Eysenck)

<u>5.4.1 The use of these tests within the research cohort</u>

These tests were only carried out on the boarding choristers. This was due to the limitations of available time with the other boys. The tests were completed during the boys' private study time in the evening. They were only undertaken once: this was at the onset of the research schedule in the autumn of 2003.

5.5 Ethics and risk assessment

The modern idea of ethics in research was drawn up by the Nuremberg Military Tribunal in 1949, as a reaction to wartime experimental atrocities (Farrell, 2005). It became evident to the general population that not all research had been carried out with the welfare of the participants as a primary consideration. Therefore, it became necessary to legislate accordingly. Specific guidelines for research involving children were published in 1977 by the American Academy of Pediatrics [sic]. Since then, the question has been raised of the level at which children are able to engage as competent participants in research (Danby & Farrell, 2004).

There are three important questions to consider when involving children in research (Alderson & Morrow, 2004):

- Is the project worth doing?
- In whose interest are the research questions being asked?
- Can the investigators explain the project clearly enough so that any potential participant can give informed consent or refusal?

In this particular research project, the answers to these questions indicate that the children themselves will be the prime beneficiaries of the information obtained, and that they are fully capable of understanding their participation. The potential issues which were considered in relation to this project are detailed in the following sections.

5.5.1 The manner of data collection with regard to child protection

The recording sessions were conducted in a room within the school. This room had to have the door shut in order to minimise external noise pollution. The boys had to have the equipment physically fitted by an adult (Appendix 4, Picture 4.4). At the choir school there were three to four adults in the room for each session when there were between one and four boys present. At the comparison schools, the author was potentially alone with each boy although, in practice, there tended to be at least one other boy in the room. Although this potential for isolation raises concerns regarding child protection, all adults involved had up-to-date enhanced CRB (Criminal Records Bureau) clearance to work with children. All rooms used had a clear glass panel in the door so that the proceedings could be observed by a third party from outside the room at any time.

5.5.2 Photography and audio recordings

The use of any photographs or recordings in any publications or academic presentations had been agreed, in writing, by the parents of all individuals concerned.

5.5.3 Storage of sensitive information

All information of a potentially sensitive nature has been stored in coded form; no record exists linking names to data. All paper records are in a locked cabinet. This information includes:

- the identity of the schools involved;
- the identity of the boys involved;
- the information collected regarding medical history;
- the subjective evaluations of vocal skill given by the children's teachers;
- the boys' own opinions of their fellow-choristers;
- the information held on personality type;
- the subsequent evaluations of vocal health.

5.5.4 Impact on the timetable of the boys and schools concerned

The practicalities of setting up each visit resulted in some inconvenience for each school. The choir school has a particularly busy and demanding schedule with very little flexibility to allow for extra activities. It was necessary to negotiate the following:

- establishing a mutually convenient time;
- asking the school to set up a timetable for a number of boys to attend recording sessions;
- finding an available and suitable room for recordings;
- asking the boys to take time out from either their music practice or private academic study.

This relied upon the goodwill and cooperation of the schools involved, often primarily from the music and secretarial staff. The London choir school was subject to the greatest inconvenience in allowing this study to take place. They, however, stood to gain the most from any results, whatever the outcome, as the new information arising could have an important influence on their policies related to chorister activities and vocal health.

5.5.5 Possible consequences of research outcomes

This research had the potential to quantify the effects of intensive training to the possible detriment of the establishments concerned. There could have been a negative outcome, implying that intensive training could potentially compromise the vocal health of these boys. This would have had the potential for a reassessment of the very nature of this activity which has been a part of the established practice of the Christian religious community in this country for many hundreds of years.

This possibility was discussed with the assurance that the establishments concerned would be alerted if this could be the case. Incidentally, the staff in one London cathedral had been advised by their legal team that, under no circumstances were they to allow any research which would involve the choristers. They were concerned with the possible effects of adverse publicity on their future recruitment of boys. In contrast, a meeting was held with senior staff at the London choir school that agreed to participate (see opening to this chapter). They were willing to engage with the project and to meet to have a full briefing prior to the research commencing.

5.5.6 Written consent forms

A written assurance of anonymity was given to all participating schools and a written agreement was signed by each boy's parents (see Appendix 6). The boys themselves were not required to sign anything, although they were informed of the research and knew that they could withdraw at any time (and one did). In retrospect, it may have been better to include them as signatories in the process (Danby & Farrell, 2005). All participating families were provided with a full description of the research project (see Appendix 7) and a copy of the British Educational Research Association code of ethics (see Appendix 8). All potential participants who were initially approached were given the clear option either to participate or not to do so. Of the total of 37 possible chorister subjects, two sets of parents (both lawyers) and one boy declined. One further boy withdrew half-way through the project. All others were happy to take part.

5.5.7 Disabilities

None of the children taking part had any registered disabilities (Cuskelly, 2005). This was not because any had been excluded; it was merely because no children with such disabilities happened to be within the groups selected for study. Had any children with disabilities wanted to take part, this would not have presented any problems or barriers to the research team.

5.5.8 Anonymity of judges

All participating judges were guaranteed anonymity.

5.6 Perceptual voice profile analysis: author perception of the whole data set against a range of parameters drawn from the literature on voice profiling

The overall study used more than one evaluation system. The first analysis method was devised using GRBAS (see 4.4.2) as a basic model, augmenting this with Shewell's Voice Profile Analysis system (see 4.2.3). Shewell's system was based on initial work by Laver (1981) and was still in the formative stage at the time of this research. It was incorporated for use in this study after personal discussions and a one-day training session with Shewell. Shewell's method is used primarily to assess speech for both voice teaching and speech therapy. For this study it was adapted to take the voice qualities and attributes observed in the singing voice as well as the speaking voice into account. The assessment profile allows for evaluation of both vocal health or dysfunction, as well as vocal skill or artistry (see Appendix 9).

Each category or quality is given a score of 0, 1, 2 or 3. A score of 0 means that there is no evidence of that quality present in the recording of the voice, a score of 3 means that there is an unusually high degree of that quality. Some of the qualities are mutually exclusive, for example: the presence of nasality or de-nasality and whether the position of the larynx is raised or lowered. This method was used to assess all the recordings made over the three-year period (n=203).

5.6.1 Categories of voice use

These are the thirty-six parameters assessed in the complete Voice Profile Analysis. These are as follows:

Category: Phonation Type

Harshness: This is the degree of laryngeal constriction, audible as a hard tone, possibly with some cracking. Instrumental analysis would show vibratory inconsistencies in the acoustic waveform and levels of both jitter and shimmer (see 4.4).

Whisper: This is the amount of air leakage through the glottis, audible as a breathy quality. Inefficient glottal closure can be as a result of inefficient interarytenoid use, a relatively flaccid thyroarytenoid, vocal fold pathology (a cyst, polyp or nodules interfering with the vocal fold closure), vocal fold oedema or high subglottic pressure (see 2.2.3). Instrumental analysis would show a short closed phase on the laryngograph waveform. A spectrogram would show a wide band of low-level sound energy in the higher frequencies in addition to the voiced sound. A degree of breathiness is often considered to be normal in children's voices; perceptual judgments can evaluate a sound as not breathy when laryngoscopic examination reveals incomplete glottal closure (McAllister et al., 1994).

Creak: This is otherwise known as fry. It is the 'creaky door' quality demonstrated at low pitch phonation. It seems to be more common in children and may, therefore, be less of an indicator of vocal dysfunction (Sederholm et al., 1993). It can occur during speech or singing, often at the onset or offset of the sound; it can be also an indicator of a tired voice. The vocal folds are closely approximated and vocal fold vibration is aperiodic. At higher pitches, the fry quality is produced by the collision of the false vocal folds while the F_0 is produced by the true vocal folds, hence the diplophonic effect (the impression of two simultaneous sounding pitches). This collision of the false vocal folds can be caused by laryngeal constriction. This level of constriction will result in an irregular vibration pattern in both true and false vocal folds. If it is employed habitually it can lead to the formation of vocal nodules (Greene & Mathieson, 2001; Titze, 1994).

Modal-falsetto: This is when the voice flips between modal and falsetto use, it is less common in children, and is only evident in some of the adolescent voices in this group. It is a symptom of a relatively flaccid thyroarytenoid and overused posterior cricoarytenoid and lateral cricoarytenoid. A true falsetto voice quality may only available to children during and post-adolescence due to the later development of the vocal ligament (see 3.5.2).

Asthenia: This is weakness in the sound, audible as such despite obvious physical effort from the speaker. It may be a sign of vocal fold pathology or oedema.

Category: Velopharyngeal

Nasal: This quality is as a result of inefficient closure of the velopharyngeal port, or soft palate. It can often be an affected habitual pattern, rather than an issue concerning vocal health.

Denasal: This is due to a blockage in the nasal passage, either from swollen adenoids, swollen nasal mucosa or excess mucous caused as a result of a respiratory tract infection. The sound travelling through the nose on consonants such as 'm' or 'n' is reduced or stopped altogether. The word 'man' would sound like 'bad'.

Category: Excess Tension

Laryngeal constriction: This is also evident as *harshness* in Phonation Type and also as *audible inhalation* in Breathing. It was therefore discarded in the later analysis of results.

Pharyngeal constriction: This results in a 'squeezed' quality (similar to the voice of Kermit the frog in the Muppet Show, or the character Mr Bean). It is often erroneously employed by singers in an attempt to enhance the higher frequencies in order to project the sound (from the author's professional experience).

Supralaryngeal – general: This gives an indication of the overall level of tension in the supralaryngeal area, rather than a specifically located type (e.g. pharynx, tongue root, jaw). It is a useful indicator of a generally tense system overall.

Category: Larynx Position

Larynx raised: The resulting shortened vocal tract is evident in the sound as a shallow or younger sound with raised formants. It is indicative of overuse of the suprahyoid muscles, including the hyoglossus, stylohyoid, mylohyoid, geniohyoid, and digastric muscles. This can be a sign of vocal strain, ineffective postural support of the lower back/abdomen or misalignment of the cervical spine (Blake, 2003). This score is also shown by *F1 and F2 distribution – too high* and so was omitted from the final evaluation.

Larynx lowered: This is heard as a 'hooty' quality in the sound, often due to tongue root pressure on the top of the larynx (Chapman, 2006). It can be erroneously used by singers who wish to make a richer sound quality (enhanced lower frequencies). It is also represented by *F1 and F2 distribution – too low* and 'Backed tongue' and so was also omitted from the final evaluation.

Category: Jaw

Minimised jaw movement: This is a sign of tension in the biting muscles – masseter and temporalis, limiting the movement of the temperomandibular joint (Chapman, 2006). This will in turn inhibit the flexibility of the palatal muscles and tongue movement.

Category: Tongue

Lisp: This is an observation of general oromotor skills. It is not necessarily a vocal health issue (Chapman, 2006).

Backed: This is tongue root tension described in *Larynx lowered.*

Weak: This is a general description of under-developed tongue use. It can be an indicator of unnecessary tension elsewhere or over-use of the jaw as an articulator. It results in weak consonant articulation.

Category: Pitch Range

High mean: The spoken pitch was at a noticeably higher fundamental frequency than would be expected.

Low mean: The spoken pitch was at a lower fundamental frequency (normally evidence of the onset of adolescent voice change) than would be expected.

Wide range: This refers to the extended pitch range and so was only measured in the choristers.

Narrow range: This refers to the extended pitch range and so was only measured in the choristers.

Category: Pitch Control

The level of stability in pitch control was measured in the *messa di voce* test. This was only performed by choristers and was a measure of how they had learned to maintain a steady pitch with variable loudness.

Pitch stability: This demonstrated the degree of stability as a learned skill.
Pitch instability: This demonstrated the degree of instability, either as a lack of skill or as evidence of adolescent voice change.

Category: Loudness

This category was later discarded as it was not relevant enough to the study.
High mean: This indicates a voice that is generally too loud.
Low mean: This indicates a voice unable to use louder phonation.
Wide range: A voice with an unusually wide distribution of loudness.
Narrow range: A voice with an unusually small distribution of loudness.

Category: Breath Support

Pushed: This is an unnecessarily high subglottic pressure. It is as a result of either poor understanding of singing technique or it is employed to compensate for inefficient glottal closure.
Weak: This measures breath efficiency, generally in speech rather than singing.
Audible inhalation: Although this is in the Breathing category, it is evidence of laryngeal constriction.
Controlled flow: This is a measure of how effective the breathing is for sung phrase lengths. Unskilled singers will run out of air more quickly. This measure was added to the later analyses.

Category: Passaggio

The passaggio is the 'gear change" in the voice as phonation patterns alter (McAllister, Sederholm, & Sundberg, 2000). In the child voice the upper passaggio occurs at about D5. The lower passaggio is the transition from modal voice (chest) to thinner-fold phonation (head). In the child voice this occurs anywhere between D4 and G4. Management of the passaggio is an indicator of learned skill as well as vocal health.

There were four aspects of passaggio that were noted:

Upper passaggio obvious

Upper passaggio well-managed

Lower passaggio obvious

Lower Passaggio Well-managed

Category: F1 and F2 distribution

This category assesses the formant positions as would be observed on a spectrogram. It is an indicator of vocal use or technique. It was discarded from later assessments as these parameters are covered by other categories within the assessment. Two elements were originally noted:

Too high (shrill)

Too low (hooty)

5.6.2 Method of data processing of perceptual voice profile analysis: researcher perception of the whole data set

The process of data analysis went through several different versions. These are detailed below. The complete set of data obtained from the 36 parameters was analysed for co-dependent variables and inter-variable correlations using the statistical analysis program SPSS.

Combined groupings version 1

The scoring in the original VPA assessment gave values of 0 to 3 for 34 variables. Analysis of this scoring method using SPSS proved rather clumsy and unnecessarily detailed (see 6.2). It was considered an advantage to the process of data analysis to condense the scores into fewer variables with a scoring scale of 1 to 7.

These were:

1 Voice source – vocal fold behaviour

2 Voice source – laryngeal muscle behaviour

3 Voice modification – vocal tract behaviour

The method and reasoning for producing these figures is given in Appendix 10.

Combined groupings version 2

Another version of the groupings was tried. This combined the data into six parameters; the scores for each original perceptual parameter were added together to form the new version of the grouping (see Table 5.3).

The parameters from both versions of the grouping, from the left and the right columns in Table 5.2 were analysed for co-dependent groupings and inter-parameter correlation. The most relevant factors as identified by the statistical factor analysis were used in the final analyses of vocal behaviour, in particular for the longitudinal evaluation of vocal development within the chorister cohort.

Table 5.2 Perceptual parameter groupings version 2

Original perceptual parameter	Grouping version 2
Harshness Whisper Creak	Vocal fold contact inefficiency
High mean Low mean Narrow range Pitch instability	Pitch irregularity
Upper passaggio obvious Lower passaggio obvious	Passaggio instability
Breath support pushed Breath support weak	Breathing efficiency
Nasal Denasal	Soft palate control
Laryngeal constriction Pharyngeal constriction Supralaryngeal – general Larynx raised Larynx lowered Minimised jaw movement Lisp Backed Weak Audible inhalation	General level of tension in vocal tract

5.7 Panel ratings of a sub-set of this data

5.7.1 Data analysis using panel ratings

Of the 203 recorded examples, 10 samples were selected by the author as representing a range of vocal health and singing skill. The complete audio recorded protocol was presented to three judges. They were asked to assess the voices using the VPA method outlined in section 5.6.

Judge MM was a voice teacher and Speech and Language Therapist (SLT) with experience of using the Voice Profile Analysis method (Appendix 9) to assess vocal behaviour in a clinical setting. Judge MM rated the samples twice. Judge TR had experience of undertaking research into the vocal health of children and making perceptual assessments of their vocal behaviour and rated the samples once. Judge VC was a singing teacher with experience of teaching boy choristers. Judge VC rated the samples twice. The author rated the samples once.

5.7.2 Data processing of panel ratings

These were assessed for intra and inter-judge reliability using Spearman's rho. This was partly to evaluate how robust the analysis method may be, and also to establish the degree of agreement of the author (Judge JW) with the other judges. It was necessary to establish this in order to validate the results from JW of the remainder of the assessments (a total of 125 boys, 203 recordings). The scores from the assessments carried out by JW on the complete set of recordings were the ones used in the analysis of the results in section 6.2.

5.8 Author perception of vocal health from within the connected speech samples (using two different rating scales)

5.8.1 Rationale for introducing a single-score assessment

The assessment method using the voice profile form was designed to provide as much detail as possible. The reason for having so many categories for vocal behaviour was to give as accurate a picture as possible of the complexities of the boys' vocal production.

This in itself was not a flawed method of analysis. It did provide detail which could be useful for certain specific purposes. There were, however, various problems with this method. Firstly, analysis of the data using SPSS did not give enough significant results when the scoring ranges were so small; 0–3 meant that most scores were 0 or 1. This did not give enough variety for some correlations to be significant. Secondly, a possible inaccuracy arose when the data was condensed in order to be able to make broad comparisons. This effectively gave equal weighting to different qualities. This could have skewed the outcome, shifting the balance away from key voice qualities and giving too much importance to minor issues. An example of this is the allocation of equal emphasis to weak tongue use and pharyngeal constriction. The former is an articulatory deficit which may or may not affect the vocal production; it may or may not be a symptom of muscle imbalance in the overall articulatory mechanism. The latter is a symptom of a more problematic form of muscular tension which is far more likely to result in laryngeal dysfunction. The two do not have equal importance when assessing laryngeal dysfunction. In adding the two scores together the factors are assumed to have equal weighting and importance.

The eventual scorings in the three categories of vocal fold activity, laryngeal muscle behaviour and voice amplification were considered to not necessarily give a true representation of what could be heard in the voices in terms of basic vocal health and behaviour.

5.8.2 EAIS single-score rating of speaking voice

It was decided to give one score of overall vocal health to the speaking voice as used in the connected speech sample of 'Arthur the Rat'. This was about a twenty-second sample for each boy. The speaking voice will show disorder but will not reflect singing skill. The same was done for the sample of melody singing in order to assess vocal health, not learned vocal skill.

The vocal health was scored on an EAIS (equal appearing interval scale) from 1 to 7. A score of 1 suggested that the voice was flawlessly healthy, a score of 7 would have indicated complete voice loss, a total inability to phonate. This test was carried out by the author on all the recording samples.

It became evident (see 6.4) that the ratings obtained from the EAIS method did not give enough differential between the individual scores. The rating scale, 1 to 7, had to encompass all levels of vocal health which may have been perceived in the recording cohort. In actuality, the boys who had been recorded for this study were essentially 'normal', in other words, they were mostly healthy. The ratings given were nearly all between 2 and 4. This spread of scores allowed some observations to be made about overall trends and patterns between the groups (see 6.4.3); the data were not sufficiently specific to generate statistically significant differences. For this reason, the method of analysis was retried using a VAS rating system (see below).

5.8.3 VAS single-score rating of speaking voice

Connected speech was chosen from the variety of exercises recorded in the original protocol. In the example of connected speech (Arthur the Rat, Para 1 – Appendix 3), the habitual vocal behaviour of the individual would be most evident. Any evidence of vocal dysfunction would be audible to the trained expert listener.

Of the 199 available recordings, 17 were chosen at random to be repeated stimuli. The judge was provided with two CDs with 216 tracks in an order which had been randomised for each listener. Each CD lasted approximately 45 minutes; the listener was given an instruction sheet (Appendix 11). The VAS scale measured *phonational efficiency*. This term covered all aspects of vocal function and dysfunction and gave an overall impression of the health and behaviour of the voice. The listener was asked to listen to the recordings and rate each one for vocal efficiency by marking the rating line. A score at the right of the line suggested complete loss of phonation. A score at the left of the line suggested a totally healthy voice with optimally efficient phonation. The listeners were asked to be discerning regarding low levels of vocal inefficiency; breathiness, creak and harshness. A score on the far left of the line would suggest absolutely flawless phonation.

5.9 Author perception of vocal health from within the singing recordings

5.9.1 EAIS single-score rating of singing voice

The boys recorded for this study came from a variety of environments. Two of the groups were trained singers who sang daily as part of their school and cathedral activity. The other two groups had no specialist singing activities. Despite that fact, nearly all of the boys recorded were willing to sing for the recording. Some sang their own choice of repertoire, whilst others sang 'Happy Birthday', a familiar song for all UK schoolchildren. This enabled analysis of the health of their singing voices to be undertaken, even though only some of the boys were specialist singers. For this task, the melody alone was selected. The vocal health was scored on an EAIS (equal appearing interval scale) from 1 to 7. A score of 1 suggested that the voice was flawlessly healthy, a score of 7 would have indicated complete voice loss, a total inability to phonate.

5.10 Panel ratings of examples from 5.8 and 5.9 using the EAIS rating scale

This method of analysis used the same protocol as that described in section 5.8.2 and 5.9.1, but used a panel of judges instead of a single judge. From the total number of 203 recordings, a selection of 13 recordings was chosen: 5 singing and 8 speaking (with two of these repeated to assess intra-judge reliability), giving a total of 15 recordings. The examples were selected by the author as representing a range of vocal health and singing skill. These were assessed by a panel of 16 judges. These were a combination of speech therapists (7), singing teachers (6), voice teachers (2) and an ENT consultant. All of them had considerable experience of working with children's voices (they were all delegates attending a seminar on the subject of children's voices). They were given definitions of the scale terms. For the complete ratings form, see Appendix 12.

The vocal health was given one score from 1 to 7. The score assesses any audible breathiness, roughness or strain. It is assessing larynx function only (for example, nasality and articulation were ignored).

1 = totally healthy, clear phonation

2/3 = slight dysphonia (probably only noticeable to the voice professional)

4 = noticeable dysphonia

5 = sounds unwell, would not be encouraged to sing in this condition

6 = sounds extremely unwell

7 = voiceless

These results were analysed for inter and intra-judge reliability, with particular reference to the experience and profession of each judge.

5.11 Panel ratings of examples from 5.8 using VAS rating scale

This element of the study used a panel of raters (n=15) to assess the vocal health of a portion of connected speech from each boy recorded. The panel comprised experienced speech and language therapists who would find this task similar to those undertaken as part of their daily work in assessing vocal health. Some raters had particular experience of children's voices, others had relevant research experience. All of them had at least ten years of experience as a therapist working with voices.

The assessment protocol was the same as detailed in section 5.8.3. The total of 216 recordings was randomised for each listener. In order to assess the reliability of each judge, a calculation of R^2 was employed. R^2 is the square of the correlation coefficient for a plot showing the rating given the second time the stimulus occurred as a function of the rating given the first time it appeared, The scores from the judges who had a R^2 value of 0.3 and below were eliminated (a score of 0.5 is the probability equivalent of random chance). The mean score for the ten best judges was used for further calculations (see 5.15).

5.12 Spectral analyses of particular vocal products

The long term average spectrum (LTAS – see 4.4.3) of selected recordings was analysed. The graph was obtained using the program 'Wavesurfer' (http://www.speech.kth.se/wavesurfer/ last accessed November 2009). The selected recordings had particularly high or low scores in various individual voice qualities such as breathiness or harshness, and also in overall scores for perceived vocal dysphonia. The spectral peaks and dips were able to illustrate the perceived voice qualities.

5.13 Selected laryngographic (Lx) analyses of perceptually salient vocal events

Certain recordings were selected to illustrate examples of particularly high or low scores for overall vocal health. Other recordings were selected to illustrate examples of qualities such as breathiness or creak. The laryngograph signal gives a waveform. This was observed in the program 'Wasp' (http://www.phon.ucl.ac.uk/resource/sfs/wasp.htm last accessed November 2009) and the image captured using 'Snagit' (http://www.softwarecasa.com/snagit.html?gclid=CObzoKQboZ4CFUYA4wodBW-hlA last accessed November 2009).

5.14 Longitudinal analysis of choristers' vocal behaviour

5.14.1 A comparison of vocal behaviour between the London choristers in group 1 and the boys in group 2

The boys recorded in year one of the research were all of the choristers currently singing at the chosen London cathedral, a total of thirty-four boys (excluding two who were unwilling to participate in the research). Twelve of these boys (those new to the choir, known as probationers[n=6], and those currently in school year six [n=6]) were asked to continue in the longitudinal study to continue for a further two years. One of the probationers dropped out after recording number three, subsequently the subgroup comprised eleven boys. One of the senior boys left the school after recording number five, leaving five boys in this year group. The first SPSS analysis was a comparison between the remainder of the boys (group 2, n=22) recorded in the first year, and those initially selected for the longitudinal study (group 1, n=12). This analysis uses condensed voice categories 1, 2 and 3: Vocal fold behaviour, Laryngeal muscle behaviour and Voice amplification. These variables were considered for the boys in group 1 (recorded at time A and time B – see Table 5.1) and the boys in group 2 recorded at time A and time B.

5.14.2 Longitudinal analysis of selected vocal behaviours

It was established that the smaller sample of boys in group 1 were considered to have vocal behaviour which was representative of the larger group (2) (7.3.1). Their scores, taken from the Voice Profile scores obtained by Judge JW and then grouped (see Table 5.3), were analysed in Excel to show trends within the chorister group over time. These show the influence of the training and the possible results of vocal fatigue.

5.14.3 Longitudinal analysis of the Lx waveform

The Lx waveform gives information of the degree of vocal fold closure. This can be used to assess the efficiency of phonation (steeper closing slope, longer closed phase) and can show the changes in vocal fold closure patterns with the onset of adolescent voice change. The Lx waveform of the descending G major scale for one boy (boy H) was assessed on two occasions: unchanged (age twelve years and no months) and changing (thirteen years and ten months). Certain pitches on the scale were selected (G5, B4, E4 and G3) and the waveform investigated and compared between the two recordings.

5.15 A comparison of the vocal behaviour of the four different activity groups assessed for this study

For these analyses, the data obtained from the methods described in 5.8 and 5.9 were used. Excel-based analyses using bar graphs illustrated general trends and differences observable between the groups. This analysis made use of the ratings for both singing and speaking voice and enabled comparisons to be made between the four groups and the perceived vocal health of both singing and speaking activities.

SPSS analyses of one-way ANOVA were employed to assess any statistically significant differences in perceived vocal health between the four groups of boys. SPSS histograms were generated to illustrate trends and weightings across and between each group.

5.16 Summary

This study was multi-method in its structure. This was partly due to the exploratory nature of this work. Children's voices have been assessed in previous research projects and there was a body of literature employed to aid the design of the research protocol for this study. However, assessing trained and skilled children's voices in this manner was a new undertaking. Because of this, there was a certain amount of trial and error involved in the design of the methodology. This led from the initial use of the detailed VPA assessment method, through the use of the single-score EAIS method, and ending with the single-score VAS method.

Each system in turn generated data, analysis of which was integral to the design of the following assessment method. Each system was a significant part of the development of the overall methodology and all three methods generated data which was used in the data analysis described in chapters 6 and 7. At each stage, the perceptual assessments carried out by one individual (the Author) were evaluated against a sample of assessments carried out by a panel of expert judges.

Chapter 6

Results: statistical analyses of data

6.1 Introduction

This chapter primarily presents the results of statistical examination of the data produced from the perceptual assessments of vocal behaviour outlined in Chapter 5. The statistical analysis was undertaken mostly with the program SPSS and occasionally with Excel. Analysis of the earlier data illustrated patterns of vocal behaviour and general trends exhibited by the cohort as a whole. This analysis also clarified the relevance of the categories in the Voice Profile Analysis (VPA – see 5.6). As a result of this a revised VPA assessment form was generated (see Table 9.2).

Most of the significant statistical conclusions relating to the environment and activity of the subjects were as a result of analysis of the later methods of generating data. These methods produced single scores for overall perceived vocal health which enabled comparisons to be made between the boys' activity groups.

The results are presented in the same order as detailed in Chapter 5 – Methodology. This presents the analysis of the author-perceived evaluation before the peer analysis of a group of expert judges. All author-perceived evaluations were subsequently ratified by a panel of judges.

6.1.1 Bivariate correlation

Many of the statistical calculations are bivariate correlations. These compare two variables (for example, the degree of breathiness and harshness in a voice) for the strength of the relationship between them. The Pearson product-moment coefficient of correlation, r, is a measure falling between -1 and 1; r=1 indicates complete positive association, r=-1 indicates complete negative association. In order to establish that any association is more than just a chance happening, the calculation is done using a null hypothesis. If the hypothesis is that, for example, a high level of breathiness is *nearly always* associated with a high level of harshness, the correlation calculation sets out to show how far the evidence strays from an assumed hypothesis that breathiness is *never* linked with harshness. The correlation coefficient shows the association between two factors, from the assumption that there will be no association at all between them.

There are two figures given in the tables; the Pearson Correlation is a figure between -1 and 1. The significance is a figure between 1 and 0; it is testing the probability of the result being due to sampling error, or chance. It relates to the possibility of whether a similar result could be obtained with a different sample. The smaller the p-value, the smaller the probability of the observed correlation being due to chance; therefore it is more likely that there is a true relationship between 2 variables. If the significance level is tested at the 95% confidence level, accepting that in any measurement there may be 5% probability of error, a significant correlation will be a p value of less than 0.05. If the p value is less than 0.01, allowing for a 1% probability of error, the correlation between the two sets of results is considered to be very high. Significance is calculated according to the sample size and the distance of the correlation from 0.

The Pearson Correlation is a parametric analysis; it assumes that the distribution of the scores will fall under an inverted 'U' shape (parabolic curve). There are non-parametric analyses (for example, Spearman's rank correlation). When the results from these two analyses were compared, there was no noticeable difference observed, so it was decided to continue with Pearson correlation calculations. A Shapiro-Wilk normality test showed the results from the VAS vocal health assessment to have a significance of 0.000. This suggests that the scores are near to parametric or normal distribution.

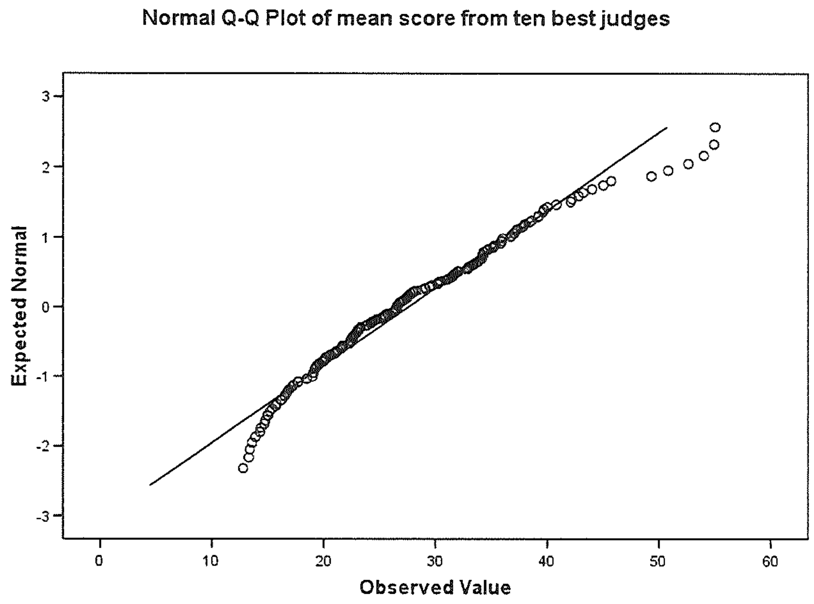


Figure 6.1 The distribution of scores from the VAS rating: observed values against the expected normal distribution

6.1.2 Factor analysis

This was used to establish groups from the many variables which were measured in the voice assessment. As a statistical tool it is used to reduce large numbers of variables to a smaller number of factors, to establish that multiple tests may measure for the same factor and to identify clusters of cases and/or outliers.

6.2 Perceptual analyses: author perception of the whole data set against a range of parameters drawn from the literature on voice profiling

The assessment method using the Voice Profile Assessment detailed in 5.6.1 produced ratings for up to 36 vocal behaviour parameters. Not all parameters were evaluated in all cases as some were only applicable to those boys who were receiving singing training. Some of the parameters had scores which showed correlation with others; other voice quality measurements appeared to stand alone in relation to others.

6.2.1 Bivariate correlations to show likely links between factors of phonation type measures

These relationships could demonstrate where vocal behaviour parameters correlated to the degree that they could be considered as mutually dependent. This could allow for a reduction in the number of parameters considered in the overall analysis. The vocal behaviours were assessed together in related groups.

Table 6.1 shows the relationship between the five phonatory measures. *Whisper* (breathiness) and *asthenia* (weakness) show a strong correlation ($r = .413$, $p<0.01$ where r = the Pearson correlation and p indicates the significance of this figure). *Creak* has a link with *modal-falsetto* instability. However, this is less significant ($r = .189$, $p<.035$). The other factors appear to be independent of each other.

Table 6.1 Correlations between aspects of phonatory vocal behaviour

		Harshness	Whisper	Creak	Modal-falsetto
whisper	Pearson Correlation	.125			
	Sig. (2-tailed)	.166			
creak	Pearson Correlation	-.048	-.107		
	Sig. (2-tailed)	.598	.234		
modal-falsetto	Pearson Correlation	-.090	-.080	.189(*)	
	Sig. (2-tailed)	.318	.375	.035	
asthenia	Pearson Correlation	.135	.413(**)	-.072	-.047
	Sig. (2-tailed)	.133	.000	.425	.606

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).
n = 125

The strong link between breathiness and asthenia justified one of these variables to be eliminated as an independent factor. There was less of a link between creak and modal-falsetto. The existence of modal-falsetto voicing in boys is very rare until they undergo adolescent voice change. At this stage there are other factors which provide evidence of this, such as the falling average fundamental frequency of the speaking voice. From these demonstrated correlations and known links, both *asthenia* and *modal-falsetto* were eliminated as factors for further independent analysis. Principal component analysis of these three remaining elements, illustrated in Table 6.2, showed that *creak* was negatively linked with the other factors and that there was a possible but not significant link between *harshness* and *whisper*.

Table 6.2 Component matrix showing the principal component of three phonatory factors

	Component
	1
harshness	.609
creak	-.556
whisper	.714

From these results it was decided to reduce the factors describing phonatory behaviour to these principal three factors: *harshness*, *whisper* and *creak*. The presence of one or more of these factors was an indicator of a degree of inefficient phonation, and all three factors were able to stand alone and independent. This prompted the decision to add the scores from any of these three factors to give an overall phonatory behaviour rating (*Vocal fold contact*; see 6.4.1).

6.2.2 Issues of muscular tension in the vocal tract

All factors relating to muscular tension in the vocal tract were assessed for bivariate correlation as shown in Table 6.3. The degree of *nasality* (tension in the muscles of the soft palate) had no links to any of the other factors and therefore could be considered as an independent factor. The degree of *tongue backing* had a link with the degree of *laryngeal lowering* ($r = .427$, $p<0.05$) and *minimised jaw movement* ($r = .311$, $p<0.05$) but none of the other factors were related to these. The degree of *general supralaryngeal tension* showed a strong correlation with the *degree of pharyngeal constriction* ($r = .309$, $p<0.01$), *laryngeal constriction* ($r = .544$, $p<0.01$) and *minimised jaw movement* ($r = .183$, $p<0.05$). The *degree of pharyngeal constriction* was linked to *laryngeal constriction* ($r = .423$, $p<0.05$), *general supralaryngeal tension* ($r = .309$, $p<0.01$), *minimised jaw movement* ($r = .341$, $p<0.01$) and *tongue backing* ($r = .475$, $p<0.01$). The *degree of minimised jaw movement* had strong links with *pharyngeal constriction* ($r = .341$, $p<0.01$), *laryngeal constriction* ($r = .508$, $p<0.05$) and *general supralaryngeal tension* ($r = .183$, $p<0.05$)).

Table 6.3 Correlations of factors relating to muscular tension in the vocal tract

		pharyngeal constriction	laryngeal constriction	general supra-laryngeal tension	laryngeal lowering	minimised jaw movement	tongue backing
nasality	Pearson Correlation	.054	-.266	.064	-.243	.072	-.086
	Sig. (2-tailed)	.547	.210	.481	.253	.427	.344
pharyngeal constriction	Pearson Correlation		.423(*)	.309(**)	.165	.341(**)	.475(**)
	Sig. (2-tailed)		.040	.000	.440	.000	.000
laryngeal constriction	Pearson Correlation			.544(**)	.350	.508(*)	.070
	Sig. (2-tailed)			.006	.094	.011	.747
general supra-laryngeal tension	Pearson Correlation				.159	.183(*)	.163
	Sig. (2-tailed)				.459	.041	.070
laryngeal lowering	Pearson Correlation					.000	.427(*)
	Sig. (2-tailed)					1.000	.038
minimised jaw movement	Pearson Correlation						.311(**)
	Sig. (2-tailed)						.000

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).
n=125

Table 6.4 Component matrix showing three factors relating to muscular tension in the vocal tract. Extraction Method: Principal Component Analysis; Rotation Method: Varimax with Kaiser Normalization; a Rotation converged in six iterations.

	Component		
	1	2	3
degree of nasality	-.008	-.046	.894
degree of pharyngeal constriction	.773	.298	.207
degree of laryngeal constriction	.714	.170	-.415
degree of general supra-laryngeal tension	.862	.012	-.009
degree of laryngeal lowering	.070	.822	-.360
degree of minimised jaw movement	.611	-.216	-.499
degree of tongue backing	.115	.827	.240

A principal component analysis of these factors indicated that they form three groups; these are shown in Table 6.4.

Group 1 –**Vocal tract constriction**

- Laryngeal constriction
- General supra-laryngeal tension
- Pharyngeal constriction
- Minimised jaw movement

Group 2 –**Tongue tension**

- Tongue backing
- Laryngeal lowering

Group 3 –**Velar**

- Nasality

Cronbach's alpha is a statistical coefficient of reliability. If the correlation between items is high, Cronbach's alpha is high. If the data is multi-dimensional (for example, having more than one common factor or grouping, such as the data in Table 6.4), then Cronbach's alpha will be lower. In Table 6.5, Cronbach's alpha is .560. Any score higher than this suggests that the group would have more consistency if this item were removed. The score given for nasality is higher than .560; the application of Cronbach's alpha suggests that degree of nasality should be eliminated from the group in order to give a stronger link between the remaining factors. On removing this, the degree of tongue backing also appears to stand alone from the group. On removing this, a single component emerges with the three measures of tension in the vocal tract having a strong group relationship – see Table 6.6.

Table 6.5 Levels of agreement, using Cronbach's alpha scores, of factors relating to muscular tension in the vocal tract

	Cronbach's Alpha if item deleted In this instance, Cronbach's Alpha is .560
pharyngeal constriction	.310
laryngeal constriction	.477
general supra-laryngeal tension	.351
tongue backing	.556
nasality	.681

	Cronbach's Alpha if item deleted In this instance, Cronbach's Alpha is .681
degree of pharyngeal constriction	.506
degree of laryngeal constriction	.595
degree of general supra-laryngeal tension	.534
degree of tongue backing	.751

Table 6.6 Component matrix showing single principal component of three factors relating to muscular tension in the vocal tract

	Component
	1
pharyngeal constriction	.800
laryngeal constriction	.795
general supra-laryngeal tension	.861

From these results it was decided to reduce the factors describing vocal tract muscular tension to these principal three groups: Vocal tract constriction, Tongue tension and Velar. The presence of one or more of these factors was an indicator of an element of inefficient phonation, and all three groups were able to stand alone and independent. This prompted the decision to add the scores from any of these three groups to give an overall vocal tract tension rating (Voice amplification; see 6.4.1).

6.2.3 Vocal behaviour relating to pitch and vocal range, choristers only

The measures relating to vocal skill were only assessed in the choristers. These are not necessarily aspects of vocal health. They are more likely to be illustrating the aspects of acquired vocal skills, as a result of the choral training of the boys.

The *degree of obvious lower passaggio* was a measure of how the boy managed the transition from speech quality (lower range) to his upper vocal range. An easy transition can be an indicator of vocal training; an awkward one can be an indicator of poor vocal health or adolescent voice change. Bivariate correlations of factors indicating a negative ability to control aspects of pitch showed some links between this factor and a general instability of pitch ($r = .269$, $p<0.05$) and an inability to manage the upper passaggio ($r = .329$, $p<0.05$). As these are all likely indicators of vocal training, these factors and the links can be assessed as relating to the *Supranormal* not the *Subnormal* (see 1.5.5).

Table 6.7 Correlations between factors relating to pitch management

		instability of pitch	obvious upper passaggio	obvious lower passaggio
narrrowness of pitch range	Pearson Correlation	.178	.263	-.247
	Sig. (2-tailed)	.199	.055	.071
instability of pitch	Pearson Correlation		.139	.269(*)
	Sig. (2-tailed)		.315	.049
obvious upper passaggio	Pearson Correlation			.329(*)
	Sig. (2-tailed)			.015

* Correlation is significant at the 0.05 level (2-tailed).
n=54

A more detailed table of bivariate correlations between all factors relating to pitch management for boarding choristers only can be seen in Appendix 13. This shows significant negative correlations between the mutually exclusive factors; for example: well-managed and obvious passaggio, narrow and wide pitch range. It does not show significant correlations between any other pitch management factors.

Principal component analysis suggests that these factors fall into four groups shown in Table 6.8. The factors with strong links are highlighted in orange; the link is between each variable and the component, not between the variables themselves. Group 1 seems to contain factors relating to vocal skill and training. This group could be called **Vocal Skill.** Group 2 suggests a link between a lower pitch mode to the voice and poor management of the upper passaggio. This is most likely to be relating to maturation of the voice and adolescent voice change. This group could be called **Voice Change**. Group 3 suggests that boys with a higher than average pitched voice may also have a corresponding small vocal range. This may be related to the relative youth of the boys concerned and can be called **Junior Voice 1**. Instability of pitch stands in a group alone. The correlation between this factor and the instability of the lower passaggio management demonstrated above does not link these factors in principal component analysis; in fact they have a negative relationship. There is a far stronger link in this component analysis between instability of voice pitch and a well-managed lower passaggio. This link would apply to younger boys who may conceivably have less well-managed pitch control; the smaller and thinner vocal folds would have a less obvious change from thick to thinner-fold phonation (lower passaggio – see 2.3.6). This group could be called **Junior Voice 2**. Factors relating to voice pitch management were later linked together in a group **Laryngeal Muscle Coordination**.

Some of the correlations in Table 6.8 show a significant negative relationship. These are highlighted in blue. These tend to be factors which are mutually exclusive. For example, pitch is ether stable or unstable; if there is a positive correlation with pitch stability, such as in component 1, there will be a high negative correlation with pitch instability. The same can be said for the height of pitch mean and depth of pitch mean in component 2.

Table 6.8 Component matrix showing the four principal components of factors relating to pitch management in the voice, all choristers (n=52)

	Component			
	Vocal Skill	Voice Change	Junior Voice 1	Junior Voice 2
narrowness of pitch range	-.316	.273	.721	-.269
height of pitch mean	.131	-.739	.252	-.131
depth of pitch mean	.203	.655	-.135	.137
width of pitch range	.425	-.021	.391	-.119
instability of pitch	-.584	-.251	.188	.599
stability of pitch	.643	.166	-.274	-.411
obvious upper passaggio	-.672	.491	-.081	-.104
well-managed upper passaggio	.682	-.261	-.172	.229
obvious lower passaggio	-.518	-.201	-.655	-.053
well-managed lower passaggio	.572	.368	.115	.552

6.2.4 Other bivariate correlations of related vocal behaviours

There were behavioural links observed between other factors. Table 6.9 shows a very strong link between the degree of *harshness* and the degree of *laryngeal constriction* ($r = .852$, $p<0.0001$).

Table 6.9 Correlation between *laryngeal constriction* and *harshness* (n=24)

		Harshness
laryngeal constriction	Pearson Correlation	.852(**)
	Sig. (2-tailed)	.000

** Correlation is significant at the 0.01 level (2-tailed).

It would have been feasible to eliminate *laryngeal constriction* from the factors as it had no independence as a factor. With relation to muscular tension in the vocal tract it had a strong correlation with *pharyngeal constriction* (see Table 6.3). With relation to phonatory behaviour it has a strong correlation with *degree of harshness*. As a factor standing alone it appeared to have no independent relevance to the voice assessment in this study.

A bivariate analysis of the relationship between the degree of *pushed breath support* (unnecessarily high sub-glottic air pressure) showed that there was a significant relationship between high sub-glottic air pressure and *harshness* (r = .198, p<0.05), but not *whisper* as shown in Table 6.10.

Table 6.10 Correlation between *degree of breath support pushed* and two phonation types (n=125)

		Harshness	Whisper
breath support pushed	Pearson Correlation	.198(*)	.005
	Sig. (2-tailed)	.026	.959

* Correlation is significant at the 0.05 level (2-tailed).

6.2.5 Correlations between vocal behaviours and age, choristers only

These show a significant relationship between age and the inability to manage the upper passaggio (r = .453, p<0.01). The older the boys were, the more obvious the upper passaggio became. There are no other significant links in this group of boys (none of whom is undergoing adolescent voice change in the recordings made at time A).

Table 6.11 Relationship between age and pitch management (n=34)

		narrowness of pitch range	instability of pitch	obvious upper passaggio	well-managed upper passaggio	obvious lower passaggio	well-managed lower passaggio
Age in months at time A	Pearson Correlation	.330	-.195	.453(**)	-.122	-.105	.301
	Sig. (2-tailed)	.057	.270	.007	.492	.556	.083

** Correlation is significant at the 0.01 level (2-tailed).

6.2.6 Relationship between age and personality L test score

According to Eysenck (H. J. Eysenck & Eysenck), the L test score (the probability that answers are given in order to please, rather than as an honest response) is inversely related to age (see Figure 5.3). A scatterplot (Figure 6.2) did not show any clear trend to illustrate this relationship; there is a Pearson correlation of r = .305 which suggests that the correlation between the two variables is not significant.

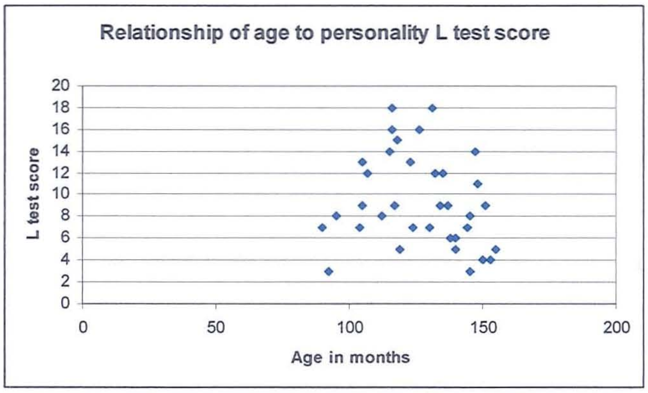


Fig 6.2 The relationship between age in months and score in personality L test

However, when the ages were banded into three groups, the relationship became more apparent. In Figure 6.3, there appears to be a cluster of scores at the upper end of the young age band, the cluster for the mid-range age band is at lower scores, and for the older boys, even lower. This fits with the findings of Eysenck (op. cit.). The ages were banded as follows: 1 = 90–27 months, 2 = 128–145 months, 3 = 146–166 months. At the time of the personality testing, none of the boys was older than 155 months. This explains the smaller numbers in age band 3 at this time.

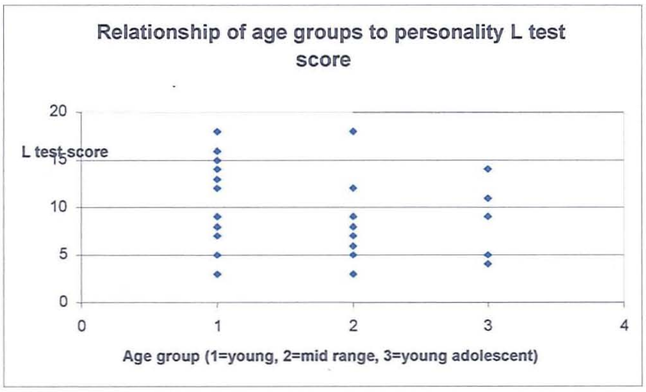


Figure 6.3 The relationship between age group and score in personality L test

Eysenck suggests that test results from children who score over a critical number in the L test should be omitted from any overall analysis. For later analyses (see Table 6.13) it was decided to remove boys from age group 1 with a score of 11 or above, from age group 2 with a score of 9 or above and from age group 3 with a score of 7 or above. Eysenck suggests removing all primary aged children with a score of over 10; the grouping into three age bands allowed for this removal to be adjusted according to age.

6.2.7 Correlation between personality type and perceived vocal health

There was no statistically significant correlation between any of the personality types and the perceived vocal health rating.

Table 6.12 Correlation between personality type and perceived vocal health – all boys

		Psychoticism	Extroversion	Neuroticism
Mean score from 10 best judges	Pearson Correlation	-.075	.104	-.249
	Sig. (2-tailed)	.682	.572	.170
	N	32	32	32

Table 6.13 Correlation between personality type and perceived vocal health – selected boys (low score on L test)

		Psychoticism	Extroversion	Neuroticism
Mean score from 10 best judges	Pearson Correlation	.385	.201	-.022
	Sig. (2-tailed)	.093	.395	.925
	N	20	20	20

However, when individual cases were looked at, the boy with the highest rating for perceived vocal dysphonia had a correspondingly high score for both the N(22) and E(19) tests, but not P(4). The boy with the next highest rating had a high score for the E(22) test but not N(7) or P(2). This is discussed further in Chapter 8 (8.3.3).

6.2.8 The establishment of sub-sets of variable groupings

The ratings representing the subsets *Vocal Fold Contact*, *Voice Modification* and *Laryngeal Muscle Coordination* as defined in 6.2.1 were established and used in further analysis (see Chapter 5 – Methodology).

6.3 Panel ratings of the data from 6.2

Ten complete recordings had been selected for evaluation by the panel of judges (see 5.7.1). The scores for the first five voice qualities (Harshness, Whisper, Creak, Modal/Falsetto and Asthenia) allocated by the judges were entered into SPSS and analysed for the degree of agreement between the judges. A Shapiro-Wilk test of normality showed that the scores did not have a normal distribution; the significance ratings for the six judges were 0.067, 0.152, 0.328, 0.002, 0.238 and 0.276. The correlation was tested using the non-parametric test, Spearman's rho. Judge 1 was the author JW, Judges 2 and 3 were the same person, Judge MM, who assessed the recordings on two occasions. Judges 4 and 6 were Judge VC, who likewise assessed the recordings on two occasions. The correlations were analysed to decide which of the duplicate judgments to choose and whether to eliminate any judges giving outlying responses; these are in Table 6.14. Judges giving responses which are significantly different for those given by the majority can be eliminated from the analysis. They are assumed to be unreliable judges.

Table 6.14 Relationships between the scores given by the panel of judges for ten recordings

		Judge 1	Judge 3	Judge 4	Judge 5	Judge 6
Judge2	Correlation Coefficient	.645(**)	.249	.405(**)	-.231	.495(**)
	Sig. (2-tailed)	.000	.081	.004	.107	.000
Judge3	Correlation Coefficient	.225		.548(**)	.295(*)	.227
	Sig. (2-tailed)	.115		.000	.038	.113
Judge4	Correlation Coefficient	.378(**)			-.038	.188
	Sig. (2-tailed)	.007			.795	.190
Judge5	Correlation Coefficient	-.261				.013
	Sig. (2-tailed)	.067				.928

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).
N=50

When choosing between the results of Judge 2 and Judge 3 (both Judge MM), the scores for Judge 2 had more significant correlation with the other judges; although, interestingly, not with the scores for Judge 3. When choosing between the results of Judge 4 and Judge 6 (both Judge VC), the scores for Judge 4 had more significant correlation with the other judges; although, interestingly, not with the scores for Judge 6. This suggests that neither judge was particularly consistent in their assessments. The scores for Judges 2 and 4 were selected. Judge 5 had little significant correlation with any of the other judges; the only slight significance was with the results of Judge 3, who was not selected.

When comparing Judge 1 (JW) with the other two selected judges, the final correlation between the scores for Judges 1 and 2 (MM) ($r = .645$, $p<0.01$), and 1 and 4 (VC) ($r = .378$, $p<0.01$) were significant. This means that the scores and assessments made by Judge 1 are generally in line with those of the other judges, and that the scores from JW can be used for statistical analysis.

6.4 Author perception of vocal health from within the connected speech and singing samples using EAIS rating scale

The vocal health was scored on an EAIS (equal appearing interval scale) from 1 to 7. A score of 1 suggested that the voice was flawlessly healthy, a score of 7 would have indicated complete voice loss, a total inability to phonate. This was a judgment of laryngeal health, the criteria were primarily relating to the phonatory activity of the vocal folds. Other aspects of habitual articulatory behaviour or levels of vocal skill were not applied. This test was carried out by the author on all the recording samples.

6.4.1 Health of the speaking voice

Table 6.15 Correlation between single EAIS rating and three sub-sets of vocal behaviour aspects (n=124)

		Laryngeal muscle coordination	Voice modification	Vocal fold contact
Laryngeal muscle coordination	Pearson Correlation			
	Sig. (2-tailed)			
Voice amplification	Pearson Correlation	.193(*)		
	Sig. (2-tailed)	.032		
Vocal fold contact	Pearson Correlation	.097	.272(**)	
	Sig. (2-tailed)	.284	.002	
Health of speaking voice	Pearson Correlation	.166	.073	.490(**)
	Sig. (2-tailed)	.066	.420	.000

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

As this was a judgment of the health of vocal fold activity, it was not surprising that there was a moderate correlation between the single score for *health of the speaking voice* and that of *vocal fold contact* (r = .490, p<0.01). The rating for *vocal fold contact* also has a significant correlation with the rating for *voice amplification* (r = .272, p<0.01), and *voice modification* has a less significant correlation with *laryngeal muscle coordination* (r = .193, p<0.05). This can be seen in Table 6.15.

A comparison of the scores from the four activity groups gives us some information about similarities and differences between these groups. Table 6.16 shows a crosstabulation of the scores for each activity group.

Table 6.16 Health of speaking voice at time A / Type of vocal loading crosstabulation

		Type of vocal loading				Total
		Boarding choristers	Non-boarding Non-choristers	Non-boarding Choristers	Non-chorister boarders	
Health of speaking voice at time A	no dysfunction	1	0	0	0	1
	2.00	10	9	4	10	33
	3.00	13	12	11	14	50
	4.00	7	7	5	14	33
	5.00	3	2	0	2	7
Total		34	30	20	40	124

The chi-square test is one of association, not difference. If all four groups were identical: chi-square would be 1, as this could not have happened by chance. As the figure approaches 0, the confidence of association is reduced A chi-square test of these ratings shows that there is a significance of 0.776 (x^2 (12) = 8.115, p = .776). This figure suggests that the pattern of distribution of the ratings across the four groups is fairly similar.

When the four groups were taken separately and compared with the other three groups combined, the chi-square significance altered. This can be seen in Table 6.17. The non-boarding non-choristers seemed to have the closest similarity to the other groups combined; the boarding choristers appeared to have scores which were significantly different from the rest of the boys.

Table 6.17 The chi-square and t-test significances of the scores for health of the speaking voice for each of the activity groups

Activity group	Boarding choristers	Non-boarding choristers	Boarding non-choristers	Non-boarding non-choristers
x^2 in relation to the other three groups combined	.365	.520	.635	.948
t-test	p = .605	p =.798	p =.373	p =.832

6.4.2 Health of the singing voice

Correlations between the ratings for speaking and singing showed a significant link between the two aspects of voice use ($r = .608$, $p<0.05$); see Table 6.18.

Table 6.18 Correlation of EAIS ratings for singing and speaking voice for all the boys (n=112)

		Health of singing voice at time A
Health of speaking voice at time A	Pearson Correlation	.608(**)
	Sig. (2-tailed)	.000

** Correlation is significant at the 0.01 level (2-tailed).

Further analysis of the ratings for singing health showed some differences when the boys' activity groups were taken into account.

Table 6.19 Correlation of *vocal fold contact* with speaking and singing voice ratings; boarding choristers only (n=34)

		Health of singing voice	Health of speaking voice
Vocal fold contact	Pearson Correlation	.364(*)	.257
	Sig. (2-tailed)	.038	.149

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

In the boarding choristers cohort, vocal fold contact appeared to have a more significant correlation with the health of the singing voice than with the health of the speaking voice (see Table 6.19). The reverse appears to be the case for the non-boarding choristers (see Table 6.20).

Table 6.20 Correlation of *vocal fold contact* with speaking and singing voice ratings; non-boarding

		Health of singing voice	Health of speaking voice
Vocal fold contact	Pearson Correlation	-.096	.624(**)
	Sig. (2-tailed)	.688	.003

** Correlation is significant at the 0.01 level (2-tailed).

In the non-chorister cohort (see Tables 6.21 and 6.22), the vocal fold contact had a significant correlation with both the health of the speaking voice (boarding: r = .674, p<0.01, non-boarding: r = .555, p<0.05) and singing voice (boarding: r = .608, p<0.01, non-boarding: r = .574, p<0.05).

Table 6.21 Correlation of *vocal fold contact* with speaking and singing voice ratings; boarding non-choristers only (n=40)

		Health of singing voice	Health of speaking voice
Vocal fold contact	Pearson Correlation	.608(**)	.674(**)
	Sig. (2-tailed)	.000	.000

** Correlation is significant at the 0.01 level (2-tailed)

Table 6.22 Correlation of *vocal fold contact* with speaking and singing voice ratings; non-boarding non-choristers only (n = 30 for speaking, 18 for singing)

		Health of singing voice	Health of speaking voice
Vocal fold contact	Pearson Correlation	.574(*)	.555(**)
	Sig. (2-tailed)	.013	.001
	N	18	30

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

A comparison of the scores from the four activity groups gives us some information about similarities and differences between the health of the singing voice for these groups. Table 6.23 shows a crosstabulation of the scores for each activity group.

Table 6.23 Health of singing voice at time A / Type of vocal loading crosstabulation

		Type of vocal loading				
		Boarding choristers	Non-boarding non-choristers	Non-boarding choristers	Non-chorister boarders	Total
Health of singing voice at time A	no dysfunction	2	0	0	0	2
	2.00	19	4	4	7	34
	3.00	10	9	12	17	48
	4.00	1	5	3	13	22
	5.00	1	0	1	3	5
	6.00	1	0	0	0	1
Total		34	18	20	40	112

A chi-square test of these ratings shows that there is a significance of .008 (x^2 (15) = 31.317, p = .008). This figure suggests that the pattern of distribution of the ratings for health could have happened by chance and there is no significant association across the four groups.

When the four groups were taken separately and compared with the other three groups combined, the chi-square significance altered. This can be seen in Table 6.24. The non-boarding non-choristers and the non-boarding choristers seemed to have the closest similarity to the other groups combined. The boarding choristers appeared to have scores which were significantly unrelated to the rest of the boys (chi-square = .000). The boarding non-choristers appeared to have scores which were significantly unrelated to the rest of the boys (chi-square = .041). Looking at the graph in Figure 6.8, the difference would be that the singing voices of the boarding choristers are more healthy than the other groups and that the singing voices of the boarding non-choristers are less healthy than the other groups.

Table 6.24 The chi-square and t-test significances of the scores for health of the singing voice for each of the activity groups

Activity group	Boarding choristers	Non-boarding choristers	Boarding non-choristers	Non-boarding non-choristers
x^2 in relation to the other three groups combined	.000	.629	.041	.703
t-test	p =.000	p =.681	p =.004	p =.679

6.4.3 Excel-based analysis of the EAIS scores

Speaking voice

An initial analysis of the results from the test described in 6.2, using bar graphs created in Excel, showed some discernible trends in vocal behaviour between the four activity groups. These are all tentative observations of trends which appear to be evident in the graphs. Further analysis of the significance of these comparisons is in 6.4.4.

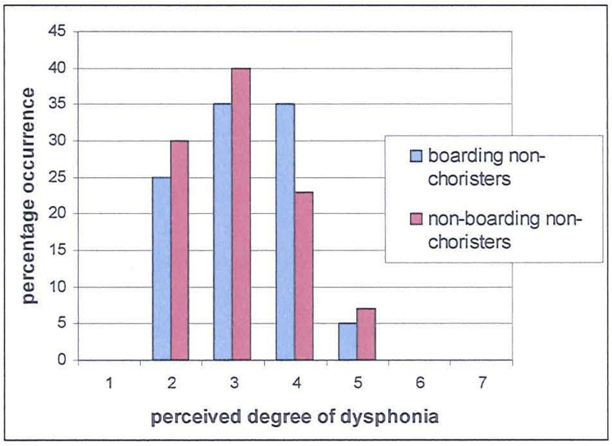


Figure 6.4 Non-choristers; a comparison between the perceived dysphonia of boys who are boarding and non-boarding

Figure 6.4 shows the perceived vocal health of non-chorister boys. The x-axis is the degree of perceived dysphonia with 1 being clear and 7 being voiceless. The y-axis shows the percentage of the whole sample. This chart showed that boarders had a higher incidence of perceived dysphonia at level 4 and a lower incidence of perceived dysphonia levels 2 and 3 than non-boarders. This suggested that the boarding environment may have caused a higher level of voice disorder. This agreed with the current literature (Casper, Abramson, & Forman-Franco, 1981; Sederholm, 1996a) referring to the increased likelihood of voice disorder in children who spend a large part of each day in noisy environments.

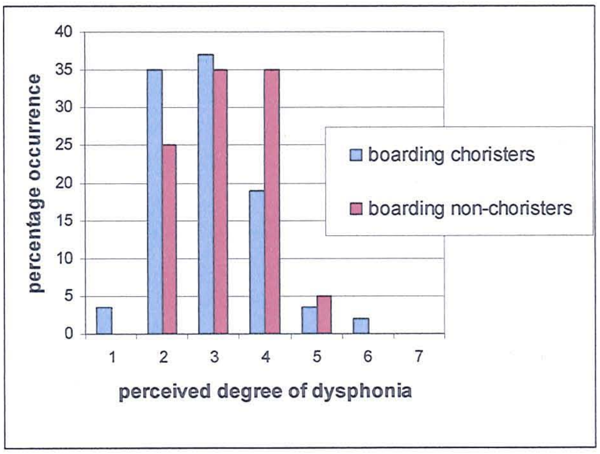


Figure 6.5 Boarders; a comparison between the perceived dysphonia of boys who are choristers and non-choristers

Figure 6.5 shows that the choristers have a lower incidence of perceived dysphonia in level 4 and a higher incidence in levels 2 and 3. This would suggest that, although they have been exposed to an environment encouraging a greater vocal loading, they have learned vocal behaviours to reduce their level of dysphonia within this environment.

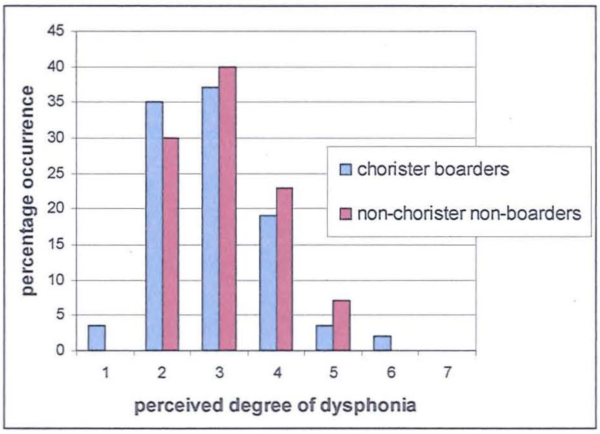


Figure 6.6 Boys attending the London choir school; a comparison between the perceived dysphonia of boys who are boarding choristers and non-boarding, non-choristers

The vocal activities and loading of the two groups in Figure 6.6 had the most different activities and environmental influences of the four groups assessed in this study. Despite this, the two curves implied by the chart are more similar than any of the other comparisons (see also Figures 6.16 and 6.19).

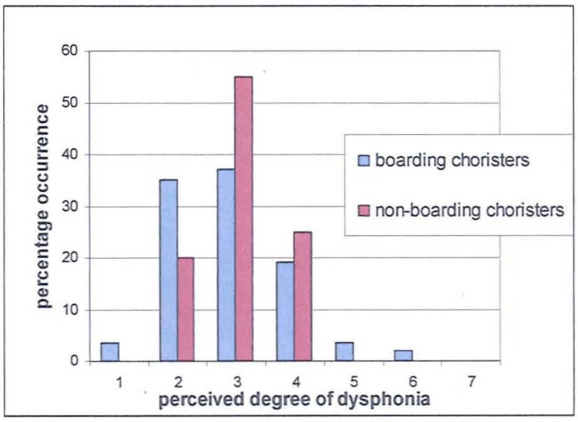


Fig 6.7 Choristers: a comparison between the perceived dysphonia of boys who are boarders and non-boarders

Figure 6.7 shows that the non-boarding boys appeared to have a higher incidence of voice disorder although we would have expected their levels of vocal loading, according to the parameters we have been using in this study, to be lower (see 8.5.2). A small number of the choristers have a particularly high level of dysphonia; two score 5 and one scores 6. These high scores may reflect the effect of an acute respiratory tract infection, or they may signify a more severe level of vocal fatigue. This may be evidence of a small number of the boys suffering the adverse effects of intensive training. However, from background examination of all the details of the individual cases, these high scores appear to be related to normally occurring viral infections.

Singing Voice

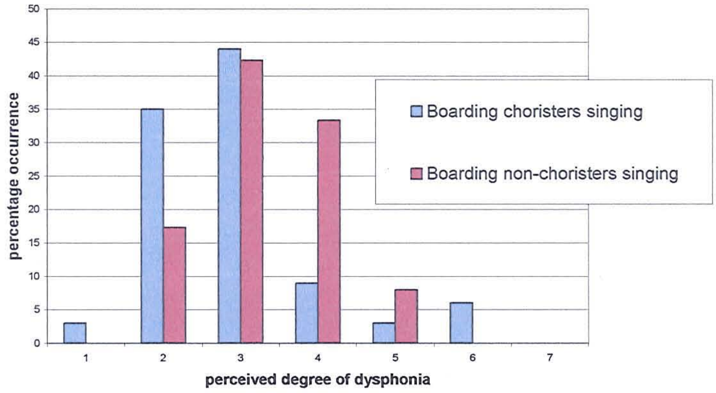


Figure 6.8 Boarders: choristers and non-choristers

Figure 6.8 shows a comparison between the perceived vocal dysphonia of boarding choristers and non-choristers in their singing voices. The choristers had the additional vocal loading of the singing activities each day, but their level of perceived dysphonia in singing was lower than the non-choristers. As a comparison with the equivalent chart for the speaking voice (Figure 6.5), the non-choristers showed even higher levels of dysphonia than they did in their speaking voices, whereas the choristers had generally healthier singing voices than speaking ones. This is possibly due partly to the fact that the choristers had been trained to use their singing voices and so found the task easier to perform. There is a direct comparison of the speaking and singing behaviours of the boarding choristers in Figure 6.10.

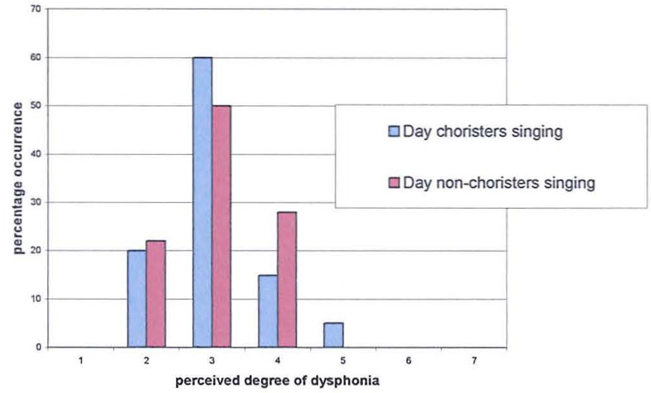


Figure 6.9 Non-boarders: a comparison between the perceived dysphonia of the singing voices of boys who are choristers and non-choristers

The non-choristers showed higher levels of perceived dysphonia in their singing voices. This is a similar comparison to that in Figure 6.8.

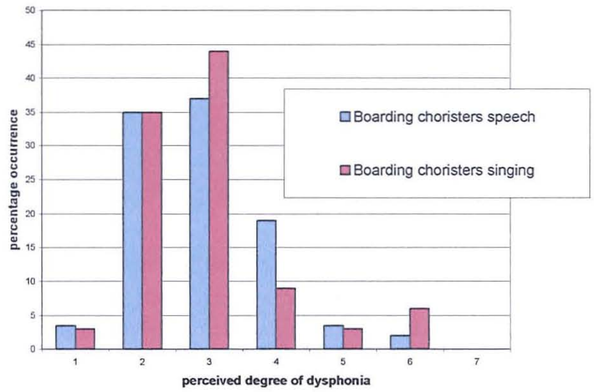


Figure 6.10 Boarding choristers: a comparison between the perceived dysphonia of speaking and singing voices of boys who are boarding choristers

The boarding choristers show a slightly higher level of dysphonia in their speaking voices, except at more severe levels of voice loss when speech is possible but singing is not. The day choristers in Figure 6.11 show a similar tendency.

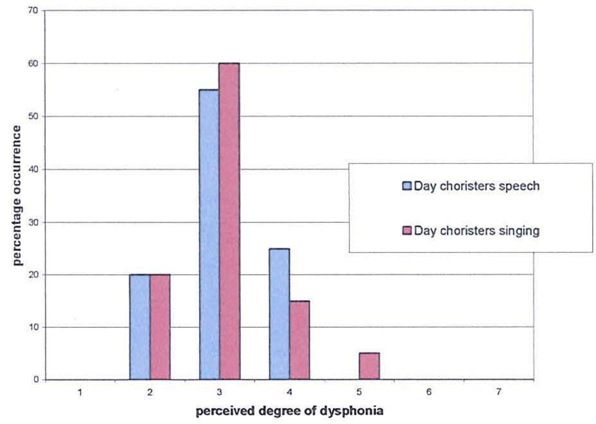


Figure 6.11 Non-boarding choristers: a comparison between the perceived dysphonia of speaking and singing voices of boys who are non-boarding choristers

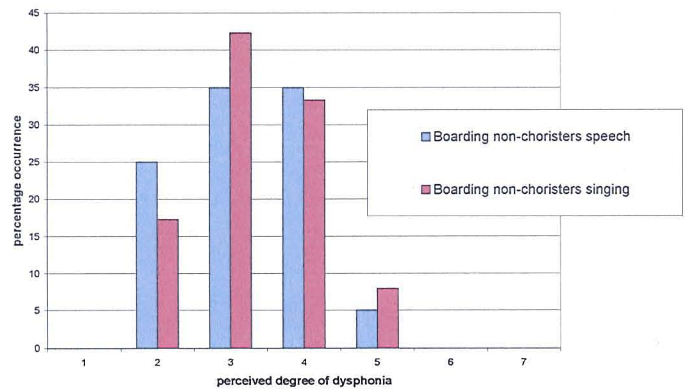


Figure 6.12 Boarding non-choristers: a comparison between the perceived dysphonia of speaking and singing voices of boys who are boarding non-choristers

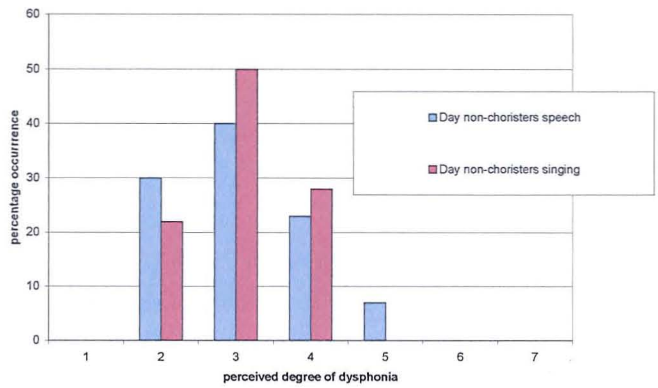


Figure 6.13 Non-boarding non-choristers: a comparison between the perceived dysphonia of speaking and singing voices of boys who are non-boarding non-choristers

Figures 6.12 and 6.13 show comparisons between speaking and singing vocal behaviours in non-choristers, both boarding and non-boarding. The charts show similar trends, that the singing voice is slightly less comfortable than the speaking voice in boys who are not undergoing formal singing training.

6.4.4 SPSS Analysis of these results

Table 6.25 Analysis of significant differences in ratings for perceived degree of dysphonia in the speaking voices of four different activity groups

Dependent variable: Health of speaking voice
LSD

(I) Type of vocal loading	(J) Type of vocal loading	Mean difference (I–J)	Std. error	Sig.	95% Confidence interval	
					Lower bound	Upper bound
boarding choristers	non-boarding non-choristers	-.037	.224	.868	-.481	.407
	non-boarding choristers	-.021	.252	.935	-.520	.479
	boarding non-choristers	-.171	.209	.416	-.584	.243
non-boarding non-choristers	non-boarding choristers	.0167	.258	.949	-.495	.528
	boarding non-choristers	-.133	.216	.539	-.562	.295
non-boarding choristers	boarding non-choristers	-.150	.245	.542	-.636	.336

Although trends are observable in the Excel graphs (section 6.4.3), Table 6.25 shows that this analysis did not reveal any of these differences to have statistical significance; in the ANOVA test $F(3,120) = .271, p=.846$ illustrated this conclusion. This lack of significant statistical evidence is most likely because the scoring system did not give enough detail. The rating scale, 1 to 7, had to encompass all levels of vocal health which may have been perceived in the recording cohort. In actuality, the boys recorded were essentially 'normal'; in other words, they were mostly healthy. As a result of this, the ratings given were nearly all between 2 and 4. This spread of scores allowed some observations to be made about overall trends and patterns between the groups (see 6.4.3); the data were not sufficiently specific to generate statistically significant differences. For this reason the VAS rating system was used (see 5.8.3).

6.5 Panel rating of the data described in 6.4

The panel was a group of 17 voice professionals attending a seminar in London on the subject of child voice. They were self-selecting and their skills represented a cross-section of training and experience. The stimuli were a selection of 13 samples from the recordings, chosen for their range of voice qualities and behaviour. They included both sung and spoken samples and two of the samples were repeated making a total of 15 stimuli (see 5.10).

Where some data were missing, for example when the judge had missed an example, the mean score of the other judges was inserted. With only two repeated stimuli it was not possible to calculate a coefficient of determination, or a value of R^2. The value of R^2 is a percentage; this figure is the percentage of the variation along the y-axis which can be explained by the variation along the x-axis. The higher the value of R^2, the closer the relationship between the two sets of variables (or, in this case, two sets of scores) and therefore the more reliable the judge. This calculation was used in analysis of data in section 6.6.

Table 6.26 shows the ratings given by the judges, Table 6.27 shows the sum of the discrepancies between the two repeated stimuli in each case. It could be argued that a discrepancy of three or more was enough to consider that judge to be excluded from the final analysis of results; these scores are coloured red in the table.

Table 6.26 Judge ratings for vocal efficiency for 15 stimuli

Rater		Stimulus														
Judge case	Judge activity	S1a	**S2a**	S3a	**S4a**	S5a	S6a	S7a	S8a	**S9a**	**S10a**	S11a	S12a	S13a	S14a	S15a
1	1	2	2	1	1	2	5	4	2	4	2	2	2	3	2	2
2	1	2	3	2	4	1	6	3	4	1	1	2	4	2	4	4
3	2	2	2	2	2	1	5	2	1	2	4	1	2	4	2	2
4	2	2	2	2	2	1	5	4	2	2	1	1	2	3	3	2
5	2	1	2	1	3	1	6	3	2	2	2	1	2	2	4	1
6	2	2	2	4	3	1	4	2	1	4	4	2	2	2	2	3
7	2	1	1	2	2	1	4	2	2	2	2	1	1	3	3	1
8	2	2	3	2	2	3	5	3	2	1	2	1	2	2	4	3
9	3	2.5	2.5	1	2.5	2.5	6	4	1	2.5	2.5	1	2.5	2.5	2.5	2.5
10	3	2	2	2	1	1	5	2.5	1	2.5	2.5	1	1	4	2.5	2.5
11	3	5	4	4	3	1	6	4	3	4	2.5	1	2	2	4	2
12	3	1	2.5	1	1	1	5	4	2.5	4	2.5	1	1	4	4	2.5
13	3	3	2	2	3	1	6	3	2	3	2	1	2	2	3	3
14	4	1	3	2	2	1	6	5	4	3	4.5	2	4	4	5	4
15	4	1	2	4	2	1	5.5	2	2	1	4	1	4	4	2	1
16	5	3	2	3	1	1	5	3	1	1	1	1	3	4	2	2
Best 11 judges	mean	2.23	2.32	1.91	2.14	1.32	5.18	3.23	1.91	2.27	2.36	1.09	2.14	2.77	3.36	2.27
17/JW	3	2	3	3	4	2	5	3	3	3	5	2	2	3	3	3

Table 6.27 The sum of discrepancies between repeated stimuli taken from table 6.26

Rater class	Judge activity	1	1	2	2	2	2	2	2	3	3	3	3	3	4	4	5	JW/ 3
Stimulus	**S2a**	2	3	2	2	2	2	1	3	2.5	2	4	2.5	2	3	2	2	3
	S9a	4	1	2	2	2	4	2	1	2.5	2.5	4	4	3	3	1	1	3
	S10a	2	1	4	1	2	4	2	2	2.5	2.5	2.5	2.5	2	4.5	4	1	5
	S4a	1	4	2	2	3	3	2	2	2.5	1	3	1	3	2	2	1	4
Summed discrepancies		**3**	**5**	**2**	**1**	**1**	**3**	**1**	**2**	**0**	**2**	**0.5**	**3**	**2**	**2.5**	**3**	**1**	**1**

Table 6.28 The average discrepancy between judges of different professions

Judge activity	1	2	3	4
average discrepancy	4	1.66	1.42	2.75
discrepancy removing outliers		1.33	1.0	2.5

Judge activity:
1 = SLT, 2 = experienced SLT, 3 = singing teacher, 4 = voice teacher, 5 = ENT consultant

Table 6.28 shows the reliability of judges according to their profession or training. The ENT consultant was omitted as there was only one in the sample. The most reliable listeners were the singing teachers and the experienced speech therapists. The inexperienced speech therapists and the voice teachers did not perform as consistently.

Table 6.29 The correlation between the scores given by the best eleven judges and judge JW

		Best 11 judges
JudgeJW	Pearson Correlation	0.617(*)
	Sig. (2-tailed)	0.014
	N	15

* Correlation is significant at the 0.05 level (2-tailed).

Table 6.29 shows that judge JW gave scorings which were compatible with the other judges. This gives sufficient validity to the author perception scores analysed in 6.4.

6.6 Author perception and panel rating of vocal health from within the connected speech and singing samples using VAS rating scale

The 17 repeated and randomised stimuli gave an opportunity for intra-judge reliability to be calculated. The results of the reliability of the judges are in Appendix 15. These show a large variation in the intra-judge reliability. Judge 15 was the most reliable with an R^2 of 0.84. Judge 13 was the least reliable with an R^2 of 0.01. The ten most reliable judges were selected and a mean value of their scores was used to calculate the analyses. There were no individual voices which produced particularly inconsistent results from the judges; all cases were considered in the analysis.

6.7 The VAS ratings in context; comparisons with the data from other rating scales

6.7.1 Correlation between the scores from the ten best judges in the VAS rating and the previous rating scales

The figures in Table 6.30 show the VAS rating scale to be consistent with the previous methods of rating; there is a particularly strong correlation with the EAIS rating for health of speaking voice. This suggests that they are compatible measures. The VAS however, gives ratings which are more detailed for SPSS analysis.

Table 6.30 Correlations between single VAS rating and three other measures of vocal behaviour (n=110)

		Vocal fold contact	Health of singing voice	Health of speaking voice
Mean score from ten best judges	Pearson Correlation	.373(**)	.532(**)	.640(**)
	Sig. (2-tailed)	.000	.000	.000

** Correlation is significant at the 0.01 level (2-tailed).

6.8 An analysis of the relationship between the VAS data obtained from each of the four activity groups

Comparative analysis of the four activity groups shows significant statistical differences between the ratings of the different groups of choristers, see Table 6.31. This was not possible using the EAIS ratings (see 6.4). This fact confirmed the suitability of the VAS rating scale as the most appropriate for this data analysis.

There was a noticeable difference between the perceived vocal health of boarding choristers (m = 27.01)[5] and boarding non-choristers (m = 33.56). An independent samples t-test

[5] In this case, 'm' is the mean score from the ten best judges in the VAS rating detailed in 5.8.3.

showed this to be significant (t (69)[6] = -.655, p= .001). This suggests that the chorister factor is significant for ratings of vocal health; boys who are training as choristers can be seen to have more healthy voices than those who do not.

There is a noticeable difference between the boarding non-choristers (m = 33.56) and the non-boarding non-choristers (m = 26.60). An independent samples t-test showed this to be significant (t (65) = -6.97, p = .002). This suggests that the boarding factor is significant for ratings of vocal health; boys who are boarders have less healthy voices than those who are day-pupils.

There are still differences (although not statistically significant) between all of the groups except the boarding choristers and the non-boarding non-choristers. This is also shown in the distribution graphs, Figures 6.13 and 6.16.

Table 6.31 Comparisons of perceived levels of dysphonia between the four different activity groups; dependent variable: mean score for ten best judges

(I) Type of vocal loading	(J) Type of vocal loading	Mean difference (I–J)	Std. error	Sig.	95% Confidence interval	
					Lower bound	Upper bound
boarding choristers	non-boarding non-choristers	.413	2.102	.845	-3.751	4.577
	non-boarding choristers	-2.596	2.315	.265	-7.182	1.991
	boarding non-choristers	-6.555(*)	1.938	.001	-10.393	-2.717
non-boarding non-choristers	non-boarding choristers	-3.009	2.378	.208	-7.719	1.702
	boarding non-choristers	-6.968(*)	2.012	.001	-10.953	-2.982
non-boarding choristers	boarding non-choristers	-3.959	2.234	.079	-8.384	.466

* The mean difference is significant at the 0.05 level.

6 In this instance 69 is the number of degrees of freedom

6.8.1 Analysis of the ratings for all ten judges individually

The Analysis of Variance (ANOVA) for the best ten judges and the four groups compares the mean scores from each judge for each group. It shows that the judges (except Judge 9) perceive the groups to be different. This is seen in the significance score in the final column of Table 6.31 (the complete tables for these tests are in Appendix 14): these are all lower than 0.05, except for Judge 9. In all the other judges there was a significant difference in the mean rating for the different groups of boys.

Table 6.32 ANOVA significance scores for the ten judges in all four groups

	Sig.
Judge1	.000
Judge2	.001
Judge4	.000
Judge6	.000
Judge8	.001
Judge9	.298
Judge10	.000
Judge11	.028
Judge14	.019
Judge15	.000

In order to establish the information behind these significances, in other words, which groups are more different than others, the groups were then assessed in pairs with a t-test. This test compares the mean scores from each judge for pairs of groups in order to evaluate the significance of this difference.

Table 6.32 shows the mean scores of perceived vocal dysfunction for each judge for the four different boys' activity groups. These show that, in general, the scores for the boarding choristers (BC) and the non-boarding non-choristers (NBNC) are lower then those of the other two groups, and that the scores for the boarding non-choristers (BNC) are generally the highest (except for Judge 14). This can be seen more clearly in the chart, Figure 6.14. Some judges score generally higher than others; Judge 6 scores highly, Judges 8 and 14 also score higher than the other judges. Judges 4 and 9 are lower with their mean scores for perceived vocal dysfunction across all the groups. Despite these differences, it can be seen that the distribution of scores between the four groups is consistent between all the judges. Group BNC has the highest scores in nearly every judge; group BC has the lowest score in nearly every case.

Table 6.33 Mean scores of perceived vocal dysfunction for each judge for the four different boys' activity groups

Judge number	BC mean	NBNC mean	NBC mean	BNC mean
Judge 1	20.9340	24.1290	26.2381	31.9250
Judge 2	19.6604	17.4194	25.4286	29.2250
Judge 4	15.3962	16.5806	18.6190	22.0500
Judge 6	37.8491	38.1290	41.3810	51.0250
Judge 8	29.9623	33.9677	36.7143	39.7750
Judge 9	16.9057	18.8065	16.8095	18.6000
Judge 10	22.5849	28.8065	26.1905	35.3250
Judge 11	26.9245	28.4516	28.9524	35.3250
Judge 14	38.6038	38.6452	46.4762	44.6750
Judge 15	19.7547	21.1613	26.6190	29.3750

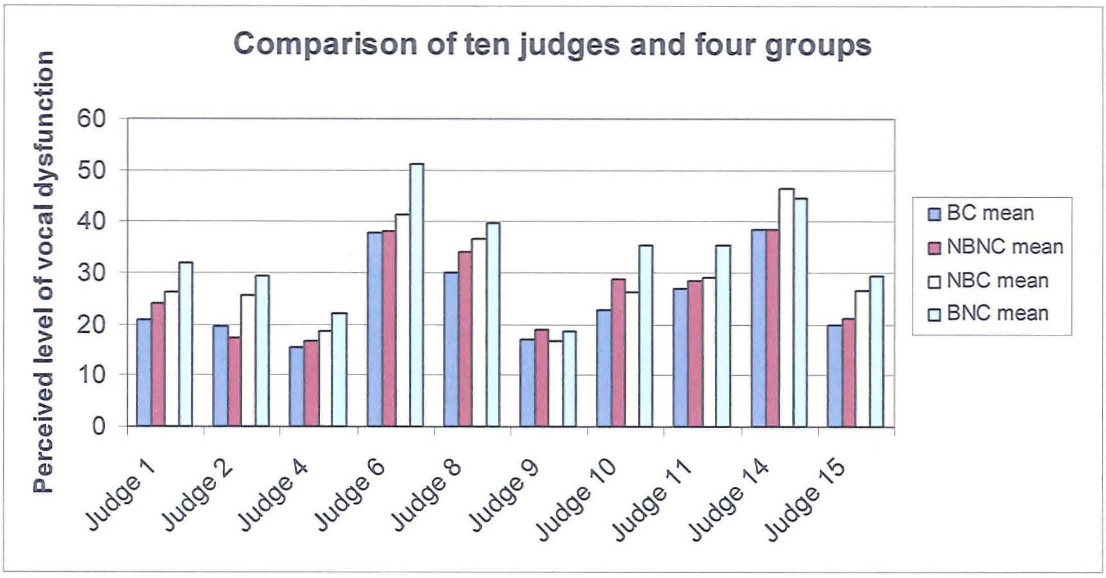


Figure 6.14 Mean scores of perceived vocal dysfunction for each judge for the four different boys' activity groups

Table 6.34 the t-test significance (2-tailed) of the comparison of mean scores of perceived vocal dysfunction for each pair of groups, Tukey HSD multiple comparisons*

Judge number	BC vs NBNC 1.2	BC vs NBC 1.3	NBNC vs NBC 2.3	BC vs BNC 1.4	NBNC vs BNC 2.4	NBC vs BNC 3.4
Judge 1	.571	.262	.927	.000	.039	.306
Judge2	.862	.315	.184	.002	.003	.747
Judge4	.903	.386	.830	.000	.038	.438
Judge6	1.000	.804	.896	.000	.007	.131
Judge8	.470	.160	.890	.001	.279	.835
Judge9	.457	1.000	.680	.474	.999	.720
Judge10	.046	.564	.856	.000	.092	.020
Judge11	.959	.941	.999	.014	.221	.390
Judge14	1.000	.081	.186	.083	.261	.962
Judge15	.942	.087	.386	.000	.026	.834
Average of ten judges	0.721	0.460	0.683	0.057	0.197	0.538

*Dark grey cells indicate significant differences

Table 6.33 shows the t-test significance ratings for each group compared with each other group. It can be seen that there are a greater number of significant differences between the comparisons involving the group BNC and each of the other groups. This would suggest that this group is significantly different from the others for each of the judges.

6.8.2 Distribution of the ratings for the four activity groups

Figure 6.15 shows the box plots for the perceived vocal dysfunction of each activity group. There is a greater spread of scores for the non-chorister non-boarders. There is one outlier from the non-boarding non-chorister group; he has a particularly high score for perceived vocal dysfunction, he may have been suffering from an acute respiratory tract infection on the day of recording. This is itself is a totally normal occasional occurrence in every child. It was not possible to separate the cases of perceived dysphonia as a result of illness, from that as a result of poor habitual voice use. It was assumed that respiratory tract infections would be occurring to some degree in all of the groups of boys.

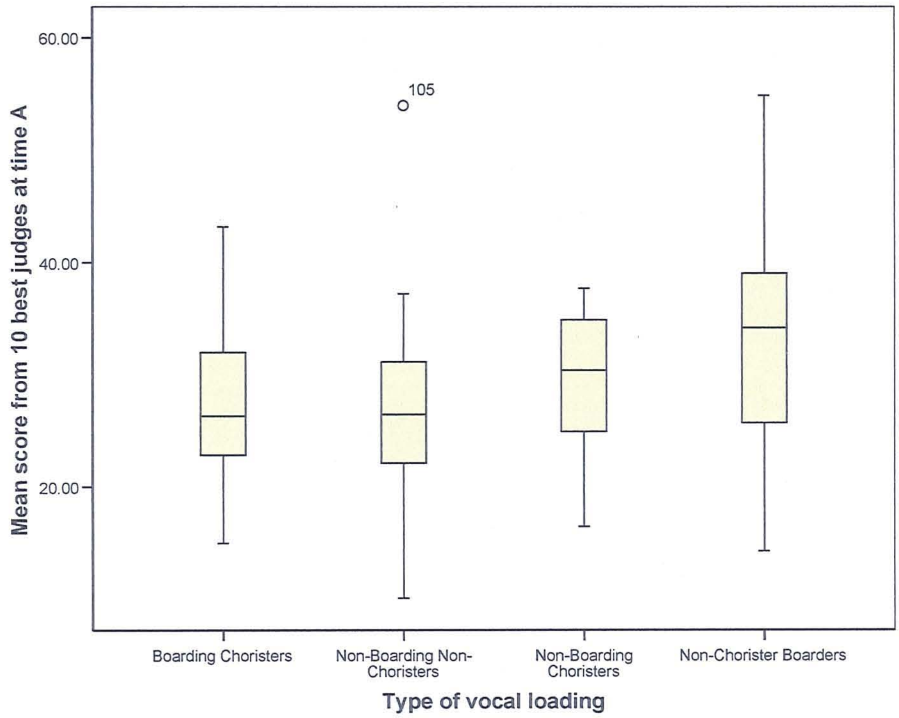


Figure 6.15 The median ratings (50th percentile) and standard deviation for the four different activity groups.

The histograms, Figures 6.16 to 6.19 show the distribution of the ratings of the four activity groups. This illustrates not only the level of perceived vocal dysfunction, but also the weighting of the various levels of this dysfunction.

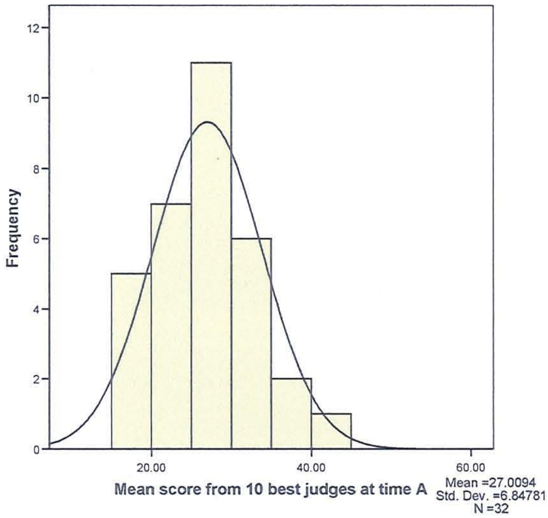


Figure 6.16 Distribution of ratings for the boarding choristers at time A

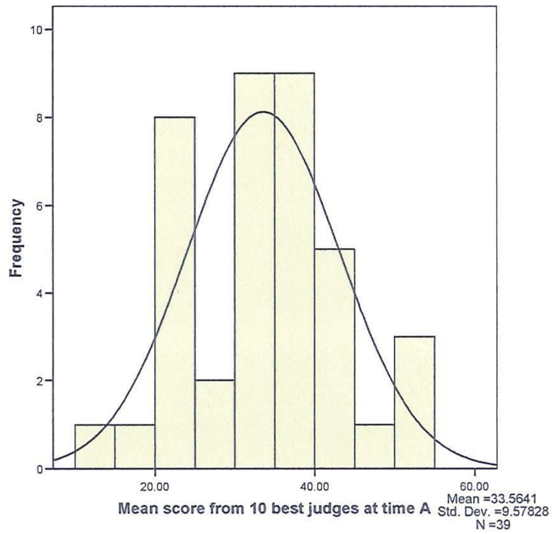


Figure 6.17 Distribution of ratings for the boarding non-choristers

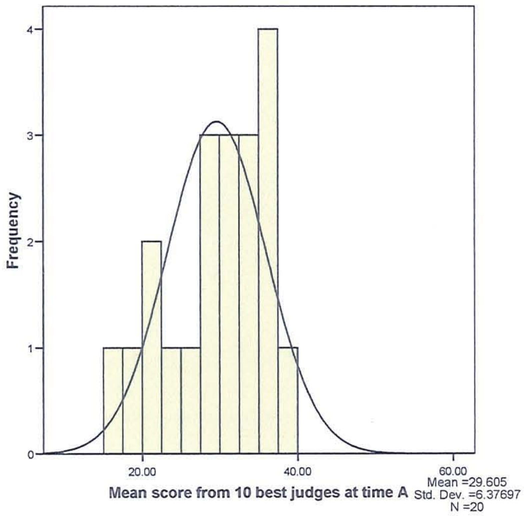


Figure 6.18 Distribution of ratings for the non-boarding choristers

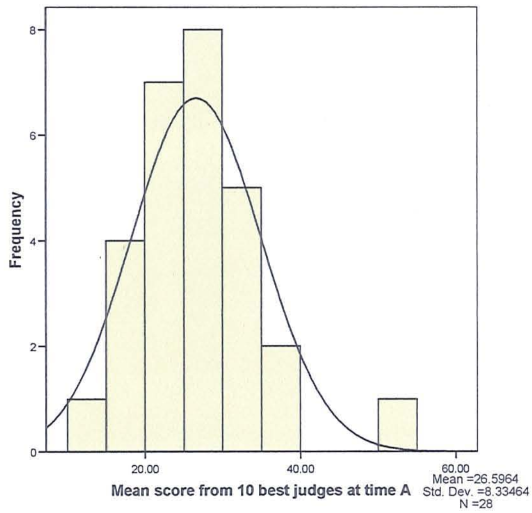


Figure 6.19 Distribution of ratings for the non-boarding non-choristers

The results were similar to those obtained from the EAIS ratings, analysed using Excel and described in 6.4.3. Firstly, one may expect that the boarding school environment causes greater vocal loading. This appeared to be the case when comparing those boys who are not choristers. Although similar environmental factors have been reported in the literature (Sederholm et al., 1995), the boarding school environment had not previously been considered in isolation. Considering that the choristers not only boarded but also sang for many hours a week, resulting in an even greater vocal loading, we may have expected to have seen an even higher incidence of perceived vocal dysfunction. However, their underlying vocal health appeared to be significantly better than that of the non-choristers.

Looking at the distribution of the scores, one can observe that the choristers in fact have a higher incidence of low-level disorders. This suggests that they were indeed vocally fatigued, but that their vocal health tended not to degenerate beyond a certain level. The choristers who did not board (those in a provincial cathedral) had a surprisingly high level of perceived vocal disorder (see 5.4).

One final observation was that there was a striking similarity between the boys who are both boarders and choristers, and the boys who are neither boarders nor choristers. These two groups had very different activities, but happen to go to the same school between 8.45 and 3.30, Monday to Friday. Perhaps the influence of peer group on voice use is more powerful than either that of activity or voice education.

6.9 Summary

This chapter shows the results from the various methods of voice analysis used in this study. The detailed analysis method (VPA) used initially gave a thorough insight into the vocal behaviour of each individual boy. The data generated 385 variables for 125 boys. This is a comprehensive, but cumbersome database. The single-score EAIS method generated some interesting observations, but did not allow any statistically significant comparisons to be made. The single-score VAS method resulted in data which could be analysed more thoroughly and resulted in some significant findings relating to the vocal behaviour of boys in different school environments and activities.

The data from the VPA method enabled not only a detailed assessment of the vocal behaviour of each boy, but also engendered a more appropriate initial analysis form for future use. The data from the EAIS method and the VAS method provided evidence of patterns of vocal health between the activity groups; the boarding choristers emerged as the group with the healthiest voice use, the boarding non-choristers as the group with the least healthy voices.

Chapter 7

Results 2: acoustic, voice source and longitudinal analyses

7.1 Introduction

The perceptual analysis, outlined in Chapter 6, gives a detailed account of the voice qualities known to be evident in healthy and unhealthy voices. Acoustic and voice source analysis, both spectral and laryngographic, can be used to quantify and, to an extent, ratify these perceptual evaluations. There have been two main methods used. The first is spectral; in particular, observing the features observable in the long-term average spectrum. The second method is to analyse the results of laryngographic data.

7.2 Spectral analyses of particular vocal products

The long-term average spectrum (LTAS) is described in 4.4.3. In this, one can observe the nature of the fundamental frequency, the distribution of the upper frequencies, and the overall intensity of the signal. It was important to calibrate the sound pressure level (see SPL, 4.3) of each recording. The SPL was measured at the microphone for each recording (see Appendix 5.1). The reading for this was then used to evaluate the equivalent amplitude level on the acoustic waveform. The difference between the two was used to calculate the relative intensity of each recording, and to make adjustments to the figures for amplitude at all frequencies. All LTAS plots are calculated to absolute dB SPL values.

The LTAS graphs are shown with both a linear and a logarithmic frequency scale. The logarithmic scale represents our aural perception more closely and provides more detail regarding the lower frequencies. The upper frequencies (1000 to 10000Hz) show other timbral factors of the voice. These upper frequencies are more clearly observed in the linear frequency scale. The creaky, breathy and harsh voice examples were selected as samples which had been given a high score for these particular qualities on the VPA, but not high scores in other voice qualities. Within each category of voice quality there will be individual variations in both the spectral and the laryngographic evidence. All the samples selected were considered to be a fair representation of the voice qualities. It is also worth noting that these samples were selected to illustrate the individual voice qualities: creaky, breathy and harsh, discrete from one another. In most cases, however, these voice qualities occurred in various combinations.

7.2.1 Creaky voice

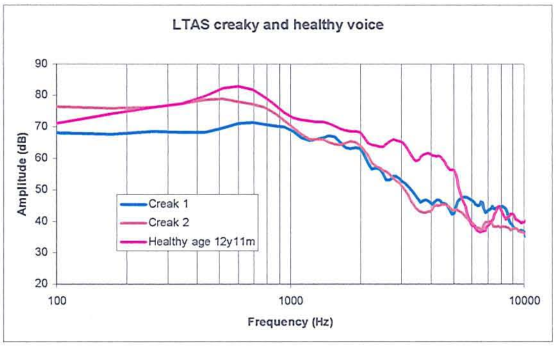


Figure 7.1 LTAS of two examples of creaky voice and one example of healthy voice (pink line), using a logarithmic frequency scale

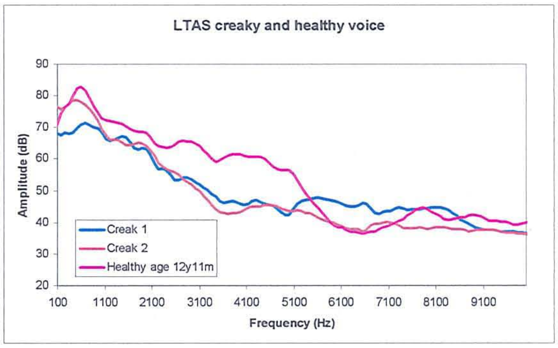


Figure 7.2 LTAS of two examples of creaky voice and one example of healthy voice (pink line), using a linear frequency scale

Figures 7.1 and 7.2 show the LTAS for two examples of creaky voice, alongside one example of healthy voice. The creaky voices have a lower intensity from 100 to 5000Hz; above this the intensity rises. This shows a level of higher frequency noise in the signal, possibly generated by 'noise' from air escaping through a constricted larynx. Figure 7.3 shows a wideband spectrogram of a selection of the text. Clear horizontal lines show that the upper frequencies generated are harmonic: they are related to the fundamental frequency of the sound. If they are not clearly delineated, they may be due to noise, either breathiness, fricative consonants or irregular vibrations of the vocal folds. In this it can be seen that on the word 'whenever' the horizontal bands are less clear than they are on the word 'mind'.

This is a particularly creaky example from the whole speech passage (it can be heard on track 7.1 on the CD). The upper frequencies (4000–5500Hz) on the creaky word are stronger, suggesting that these are due to noise or irregular vibrations.

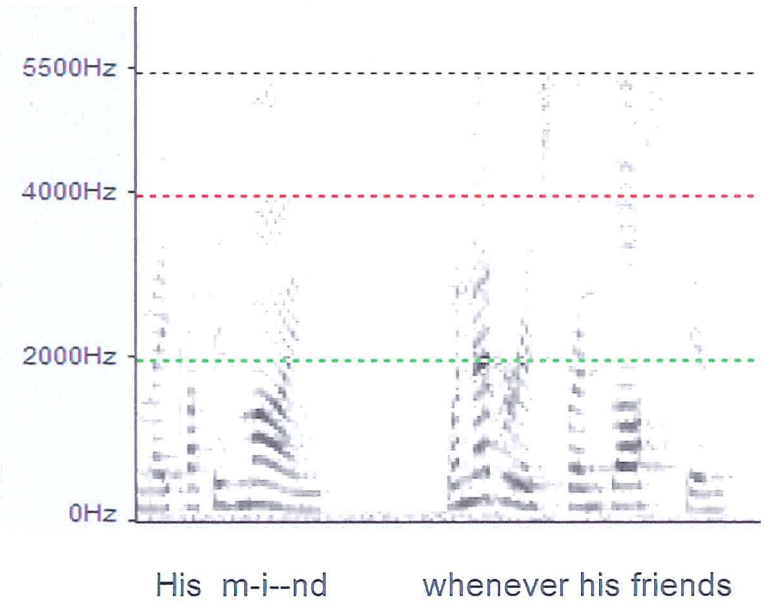


Figure 7.3 A wideband spectrogram of part of 'Arthur the Rat' to show creaky voice on the word 'whenever'

7.2.2 Breathy voice

Figures 7.4 and 7.5 show examples of breathy voice in a LTAS. They show a characteristic rise in intensity of the upper frequencies (above 10000Hz) created by 'noise' as air rushes through the glottis. The orange line is a particularly weak intensity; it is at least 10dB lower than the healthy voice signal. This difference makes the breathy voice half as loud as the normal one (Howard & Angus, 1996, second edition 2001). This boy is unable to project his voice effectively due to the inefficiency of the breathy phonation. This can be heard on track 7.2 on the CD.

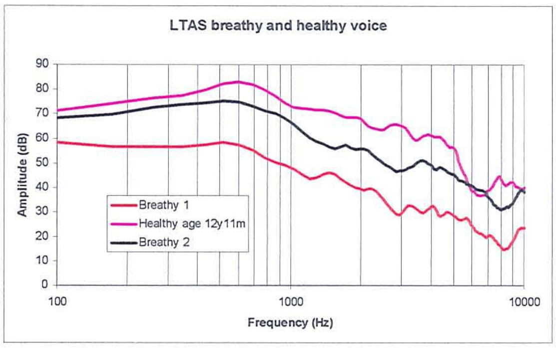


Figure 7.4 LTAS of two examples of breathy voice and one example of healthy voice, using a logarithmic frequency scale

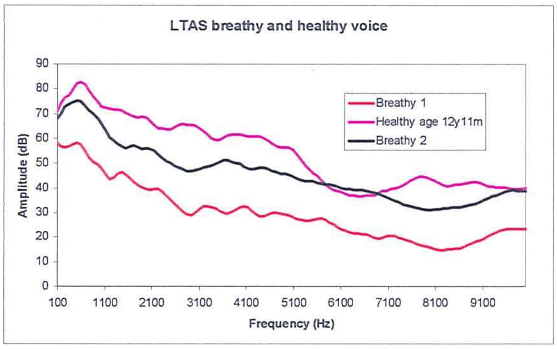


Figure 7.5 LTAS of two examples of breathy voice and one example of healthy voice, using a linear frequency scale

7.2.3 Harsh voice

Figures 7.6 and 7.7 show the LTAS of a harsh voice. This has a similar spectral profile to the healthy voice, but it is at a significantly lower amplitude; this voice quality is less efficient at projecting (track 7.3 on the CD).

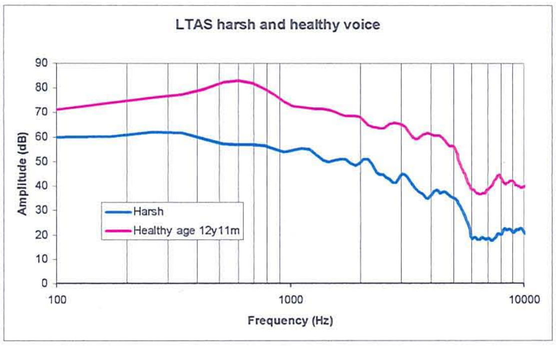


Figure 7.6 LTAS of an example of harsh voice and an example of healthy voice (pink line), using a logarithmic frequency scale

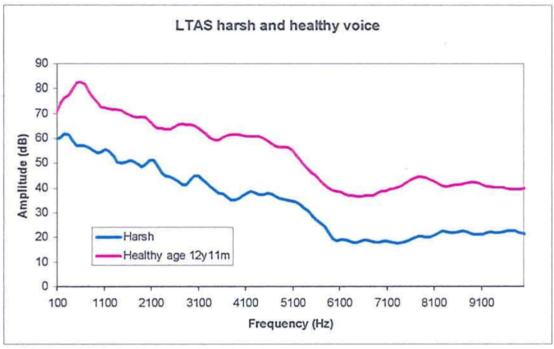


Figure 7.7 LTAS of an example of harsh voice and an example of healthy voice (pink line), using a linear frequency scale

7.2.4 Vocal health and the onset of adolescent voice change

Figures 7.8 and 7.9 show the spectral signal from one boy with eleven months between the recordings (tracks 7.4 and 7.5 on the CD). The boy in question had a normal healthy voice in both recordings. In the second recording he was entering into adolescent voice change: his larynx had been growing rapidly and the muscular coordination was potentially compromised as a result of this. The issue for observation here is whether this voice appears to have some of the attributes of an unhealthy voice or inefficient voice use purely as a result of the rapid growth and not as a result of vocal fatigue.

The average fundamental frequency is not easy to see on the LTAS; as it tends to move around it typically produces a smoothed peak. In the pink line, there is a peak at about 600Hz. This is normal in a healthy voice. This peak is not as evident in the orange line: this voice will not sound as clear to the ear. There is further analysis of this in 7.3.4.

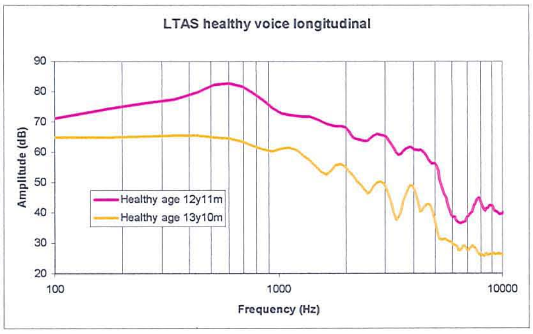


Figure 7.8 LTAS of a boy aged 12 years 11 months and later aged 13 years 10 months, frequency scale is logarithmic

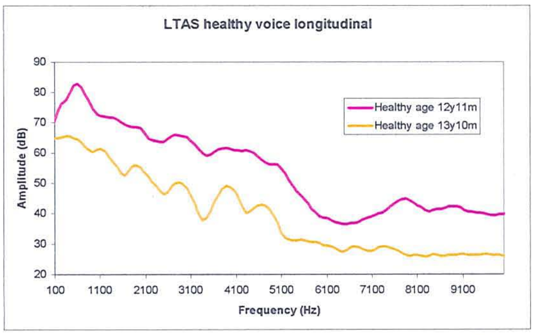


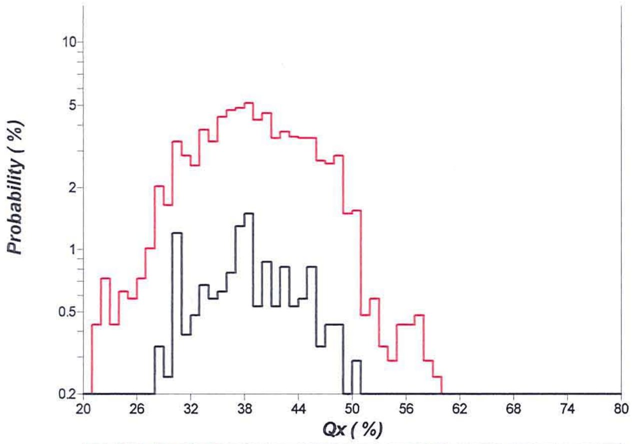
Figure 7.9 LTAS of a boy aged 12 years 11 months and later aged 13 years 10 months, frequency scale is linear

7.3 Selected Lx analyses of perceptually salient vocal events

The samples selected for Lx analysis were the same as those selected for LTAS analysis, allowing a direct comparison of the two sets of results. In each case the sample is compared with the equivalent in a voice which has been perceived as healthy. It should be noted that these graphs will show slight irregularities. This suggests that even a perceptually healthy voice may still have aspects of phonation which are less healthy. The overall vocal health score for the 'healthy' voice was 12.8 (12.8mm on a VAS scale of up to 100mm): this was one of the lowest scores given; there were none of 0. This implies that the panel of experts were unwilling to rate any voice as having absolutely healthy phonation. The absolute dB levels given in the Ax (amplitude) analysis (for example: Figures 7.12 and 7.13) cannot be compared between samples as these were not calibrated using the SPL measurements taken for each recording. They were calibrated for the LTAS analyses.

7.3.1 Creaky voice

The sample of creaky voice illustrated in Figure 7.10 shows a noticeable difference between the red and the black plots. This means that the cycle by cycle degree of closure is irregular; in this case the coherence is 17.4%. The sample of a relatively healthy voice in Figure 7.11 has a greater agreement between the red and the black plots; in this case the coherence is 37.8%. The coherence is the degree of agreement between the two plots.



Samples DQx1 = 1767	Mean	38.34	37.75
Samples DQx2 = 307	Mode	38.5	38.5
Coherence (%) = 17.37	Median	38.9	38.4
	Std. Dev.	7.7	6.2
Qx (%) = *	Range(80%)	30.1–48.6	30.5–46.9
Probability (%) = *	Range(90%)	27.7–51.2	29.7–48.6

Figure 7.10 DQx1&2 of creaky voice

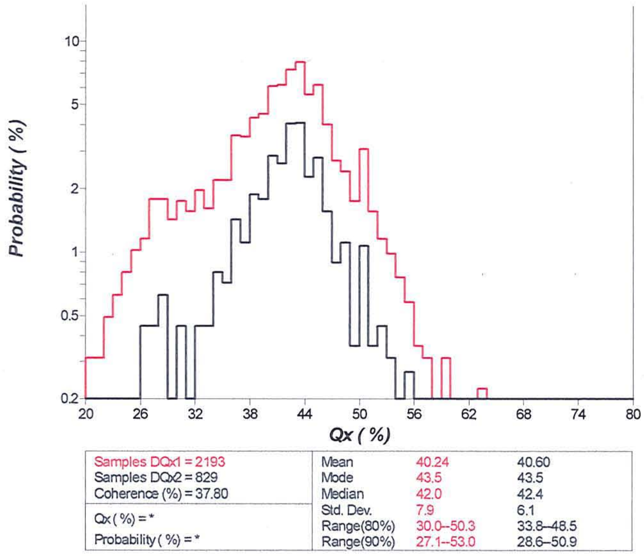
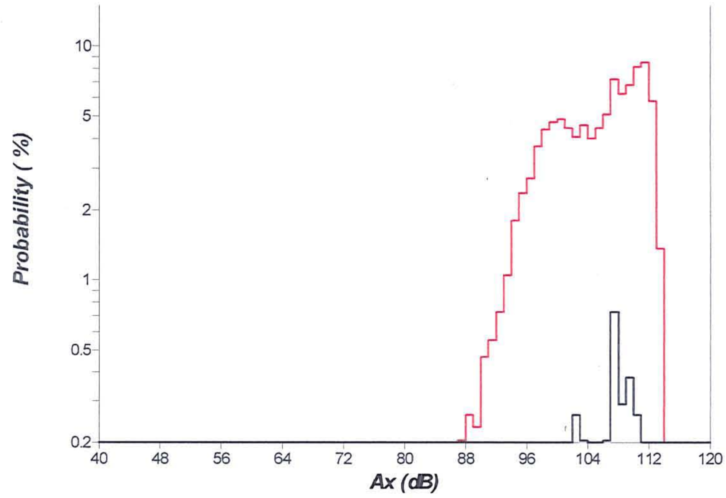


Figure 7.11 DQx1&2 of healthy voice

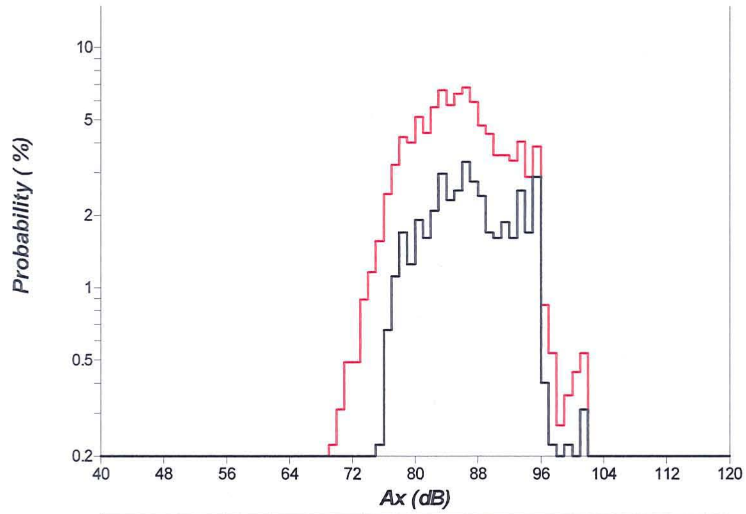
7.3.2 Breathy voice

The sample of breathy voice illustrated in Figure 7.12 shows a noticeable difference between the red and the black plots. This means that the cycle by cycle degree of amplitude is extremely irregular (shimmer); in this case the coherence is 3.2%. The large part of the red plot not covered by the black plot is probably caused by portions of vocal fold closure which are not efficient enough to generate a true vibration which would have an element of regular periodicity. The sample of a relatively healthy voice in Figure 7.13 has a greater agreement between the red and the black plots; in this case the coherence is 42.8%.



Samples DAx1 = 3421	Mean	103.79	105.18
Samples DAx2 = 111	Mode	111.5	107.5
Coherence (%) = 3.24	Median	105.9	107.3
Ax (dB) = *	Std. Dev.	5.9	3.8
	Range(80%)	96.7–111.7	100.8–110.4
Probability (%) = *	Range(90%)	94.6–112.4	99.3–111.1

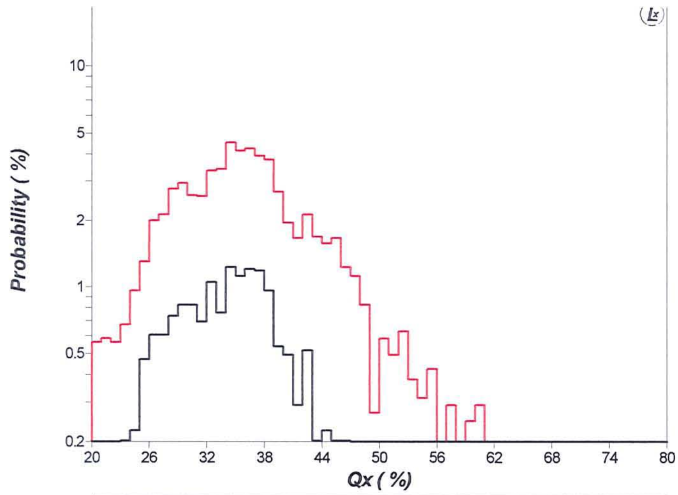
Figure 7.12 DAx1&2 of breathy voice



Samples DAx1 = 2234	Mean	84.57	86.10
Samples DAx2 = 956	Mode	86.5	86.5
Coherence (%) = 42.79	Median	85.5	86.8
Ax (dB) = *	Std. Dev.	6.2	5.8
	Range(80%)	77.7–94.0	79.2–95.1
Probability (%) = *	Range(90%)	75.8–95.5	77.9–95.8

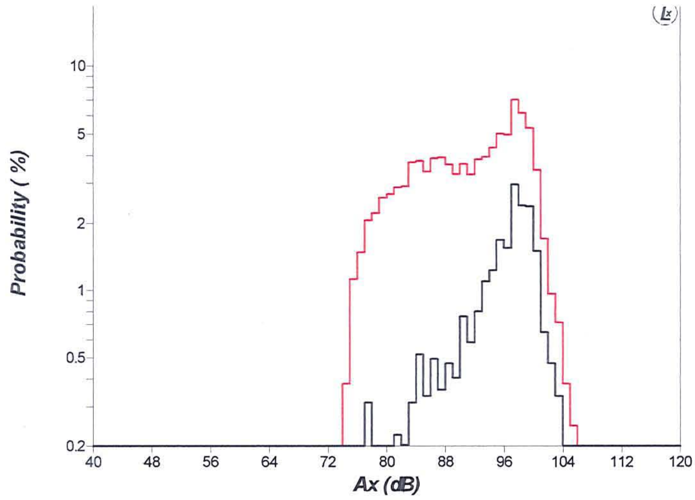
Figure 7.13 DAx1&2 of healthy voice

7.3.3 Harsh Voice



Samples DQx1 = 3113	Mean	36.26	33.63
Samples DQx2 = 727	Mode	34.5	34.5
Coherence (%) = 23.35	Median	35.9	34.6
Qx (%) = *	Std. Dev.	9.4	6.4
	Range(80%)	27.2–48.0	26.7–42.5
Probability (%) = *	Range(90%)	25.1–55.0	25.1–45.7

Figure 7.14 DQx1&2 for harsh voice



Samples DAx1 = 4444	Mean	89.71	93.70
Samples DAx2 = 1042	Mode	97.5	97.5
Coherence (%) = 23.45	Median	91.6	96.7
Ax(dB) = *	Std. Dev.	7.4	6.4
	Range(80%)	80.0–99.6	84.8–100.7
Probability (%) = *	Range(90%)	77.9–100.8	80.9–102.1

Figure 7.15 DAx1&2 for harsh voice

Figures 7.14 and 7.15 show the regularity of vocal fold closure and amplitude for harsh voice. In each case, there is a low coherence between Dx1 and Dx2. In the closure it is 23% (37% in the healthy voice), in amplitude it is 23% (42% in the healthy voice). It is possible that one would expect a higher mean degree of closure in the harsh voice; this may have been prevented by the irregularity of the cycle by cycle closure pattern.

7.3.4 Vocal health and the onset of adolescent voice change

The example here is of a boy with a low score, suggesting that he had a relatively healthy voice. This was 12.8 at the age of twelve years and eleven months. Less than one year later, he was entering adolescent voice change and his vocal health score was 20.6. This raises the question of whether the effects of the growth and change to his larynx were resulting in instabilities which are in fact 'normal' and healthy for changing voices, and to what degree these voice elements may be perceived as unhealthy by listeners. A detailed analysis of the laryngographic waveform can be found in 7.4.4. Figures 7.16 and 7.17 show the DFx1&2 of the boy on the two occasions. These show a healthy agreement between the red and the black plots in each case (a coherence of 55% in Figure 7.16 and 67% in Figure 7.17). The difference between the two is the range of the fundamental frequency; in the first plot the mean F_0 is 241Hz (B3), in the second plot the mean F_0 is 161Hz (E3).

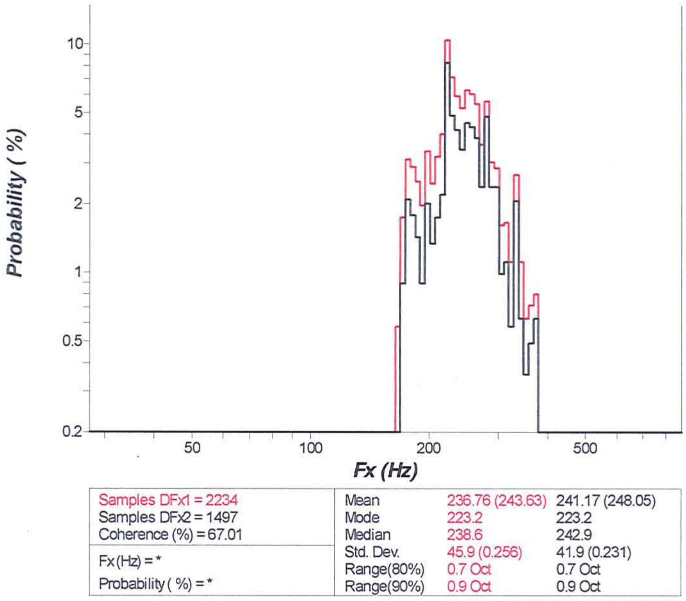


Figure 7.16 DFx1&2 of healthy voice, boy aged 12 years11 months

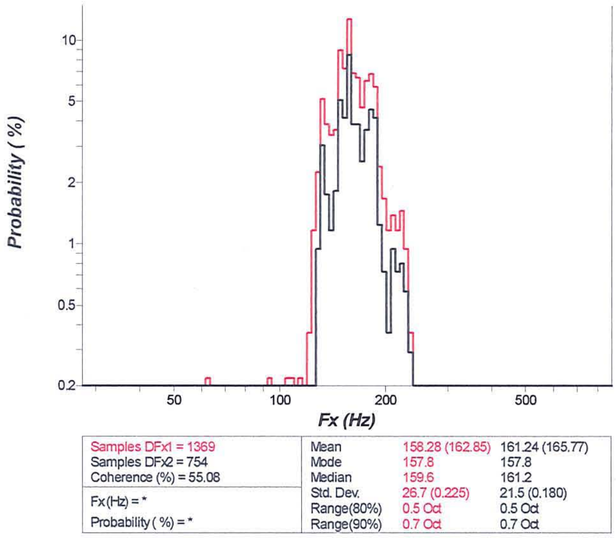


Figure 7.17 DFx1&2 of healthy voice, boy aged 13 years10 months

The emerging irregularities in the voice can be seen in the closure and amplitude of the voice. In the older voice, the closure is generally higher per cycle, but there is a greater cycle by cycle variation. This is evident in the comparison between figures 7.18 and 7.19. The degree of coherence in Figure 7.18 is 37.8%; in Figure 7.19 it is 34.1%. In the comparison of the two illustrations of amplitude, it can be seen that Figure 7.21 has a more noticeable difference between the black and the red plots. The coherence for Figure 7.20 is 42.8%, for

Figure 7.21 it is 19.2%. In the later recording, the boy has a considerably lower mean amplitude, reduced from 77dB down to 66dB. This reduction in power and projection in the voice may be due to the reduced coordination of the laryngeal muscles during rapid growth (see 3.8.4). It is also shown in further analysis (see Figure 7.39) that the rate of closure is faster in the younger voice, giving a greater amplitude to the signal.

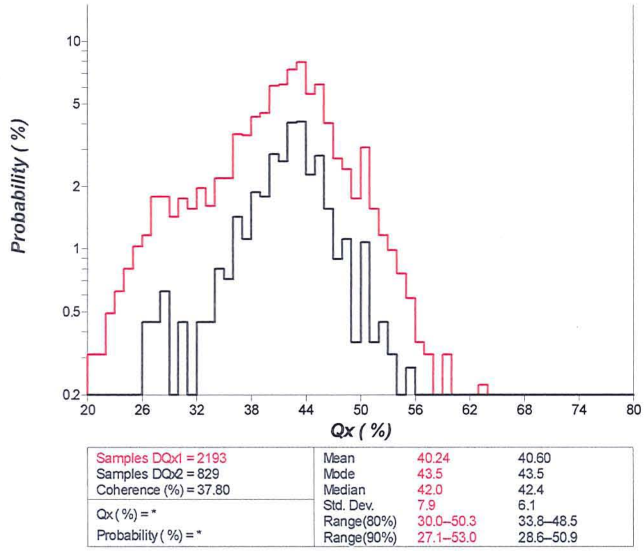


Figure 7.18 DQx1&2 of boy aged 12 years 11 months

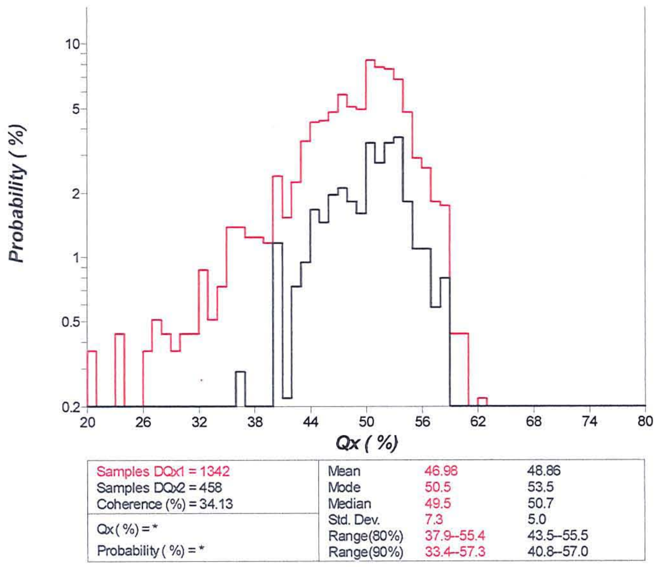
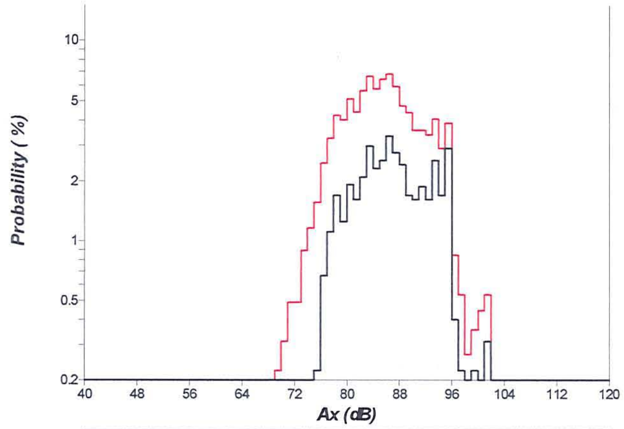
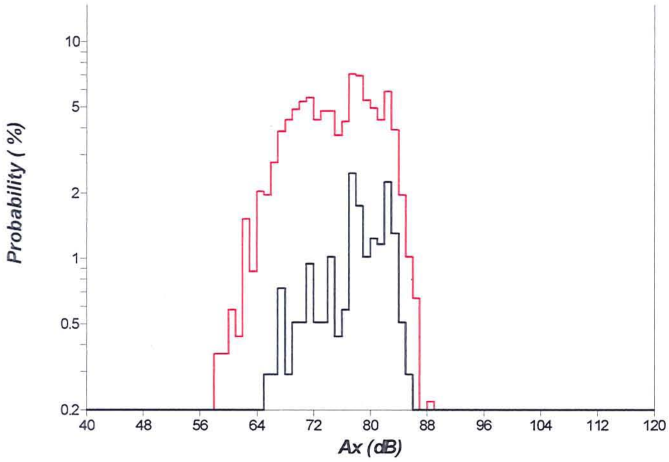


Figure 7.19 DQx1&2 of boy aged 13 years 10 months



Samples DAx1 = 2234	Mean	84.57	86.10
Samples DAx2 = 956	Mode	86.5	86.5
Coherence (%) = 42.79	Median	85.5	86.8
Ax(dB) = *	Std. Dev.	6.2	5.8
	Range(80%)	77.7–94.0	79.2–95.1
Probability (%) = *	Range(90%)	75.8–95.5	77.9–95.8

Figure 7.20 DAx1&2 of boy aged 12 years 11 months



Samples DAx1 = 1370	Mean	73.85	76.27
Samples DAx2 = 263	Mode	77.5	77.5
Coherence (%) = 19.20	Median	75.3	78.1
Ax(dB) = *	Std. Dev.	6.2	5.5
	Range(80%)	66.6–82.7	69.0–83.3
Probability (%) = *	Range(90%)	64.4–83.8	67.1–84.1

Figure 7.21 DAx1&2 of boy aged 13 years 10 months

Figures 7.18 and 7.19 compare the regularity of vocal fold closure on these two occasions; Figures 7.20 and 7.21 compare the regularity of amplitude at vocal fold level. Each of these comparisons shows a marked increase in irregular vocal fold behaviour as the boy is in adolescent voice change. The evidence points to irregular behaviour: the cause is unlikely to be ill health, or even vocal fatigue, it is merely lack of muscular coordination in the rapidly growing system. This potential ambiguity in this type of assessment is discussed later in 9.4.2.

7.4 Longitudinal analysis of the data

7.4.1 A comparison of vocal behaviour between the boys in group 1 and the boys in group 2

The boys recorded in year one of the research were all of the choristers currently singing at the chosen London cathedral, a total of thirty-four boys (excluding two who were unwilling to participate in the research). Twelve of these boys (those new to the choir, known as probationers, and those currently in school year six) were asked to continue in the longitudinal study for a further two years (group 1, n=12). The first SPSS analysis was a comparison between the remainder of the boys (group 2, n=22) recorded in the first year, and those selected for the longitudinal study. This analysis uses condensed voice categories 1, 2 and 3: Vocal fold behaviour, Laryngeal muscle behaviour and Voice amplification. These variables were considered for the boys in the longitudinal group (recorded at time A and time B) and the remaining boys recorded at time A and time B.

Table 7.1 A comparison of overall vocal behaviour at time A and time B (six -month difference) between group 1 (longitudinal sample, n=12) and group 2 (remaining boys, n=22) * means are statistically different at $p. < .05$

Voice category	Mean (SD) for group 1 at time A	Mean (SD) for group 2 at time A	Mean (SD) for group 1 at time B	Mean (SD) for group 2 at time B
Vocal fold behaviour	2.6*(1.07)	3.13*(1.15)	3.0*(1.10)	3.10*(1.30)
Laryngeal muscle behaviour	2.5*(0.91)	2.88*(0.99)	2.75*(1.27)	2.76*(1.06)
Voice amplification	3.73*(1.27)	3.53*(1.19)	3.85*(1.40)	3.16*(1.32)

The boys in the longitudinal group were demonstrated not to be significantly different from those boys in the remaining group. Any results of further study of this smaller group can be considered to be representative of the larger group of choristers.

7.4.2 Longitudinal analysis of selected vocal behaviours

These assessments used selected vocal attributes and behaviours grouped from the initial voice profile analysis (see Table 5.3). These scores were analysed in Excel to show trends within the chorister group over time. These show the influence of the training and the possible results of vocal fatigue. The vertical axis shows the degree of inefficiency or the perceived vocal dysfunction.

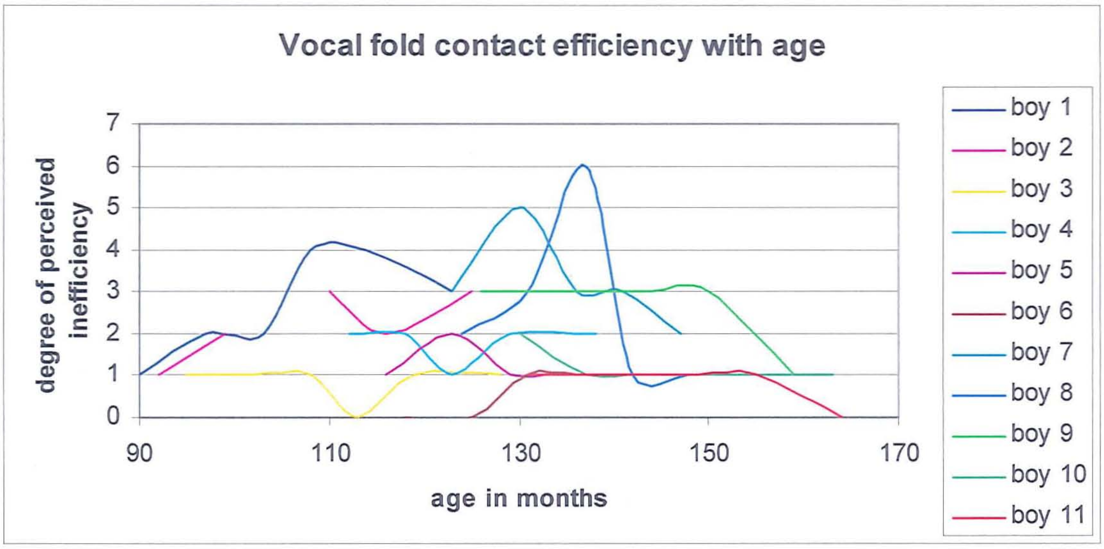


Figure 7.22 Line graphs showing the 'degree of inefficiency' of vocal fold closure of 11 boys over a three-year period from the ages of 8 to 13

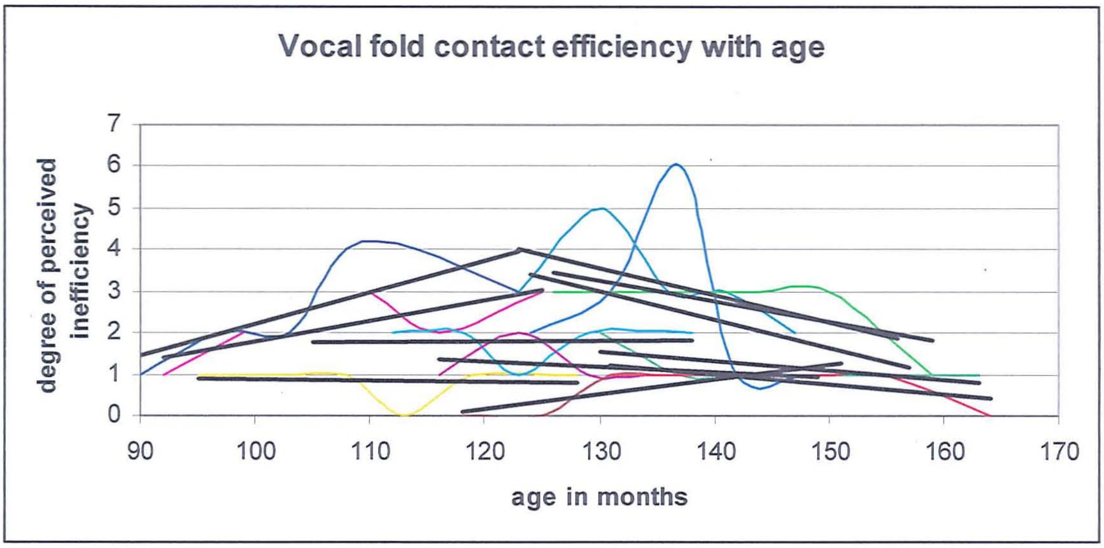


Figure 7.23 Line graphs showing the 'degree of inefficiency' of vocal fold closure of boys over a three-year period from the ages of 8 to 13 with a trend line inserted for each boy

Vocal fold contact – This is a measure of efficiency of vocal fold contact, which can be related directly to efficiency of phonation. This seems to begin well in the younger choristers with relatively low scores for inefficiency, get less efficient in the middle of the age-span as the scores increase slightly, and ends well with the scores rising again. This is shown in the trend lines which generally rise between the ages of 10 and 11 years and then fall again. A hypothesis for this could be that the voice becomes tired as the vocal loading and responsibility increases with age. As the boy reaches the age of 12 or 13, the larynx has grown to accommodate a stronger musculature, resulting in increased stamina. The singing technique of the boy also improves to accommodate this, resulting in an increase in efficiency in the latter years. An additional factor may be that with the onset of adolescent voice change, the boy is often required to retire from singing the treble line in the choir; this will result in a decrease of vocal loading.

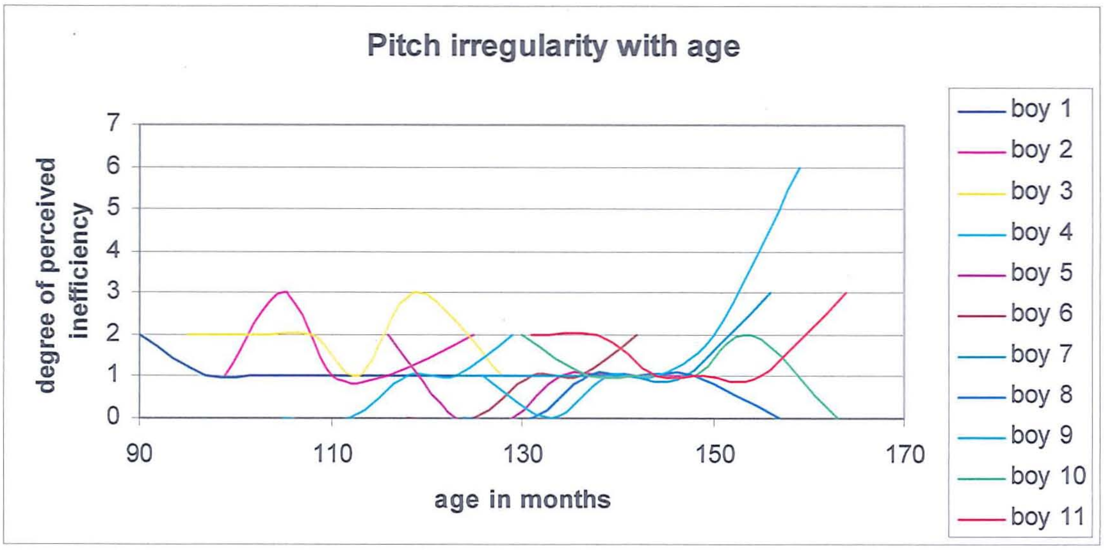


Figure 7.24 Line graph showing the degree of irregularity of pitching in boys over a three-year period from the ages of 8 to 13

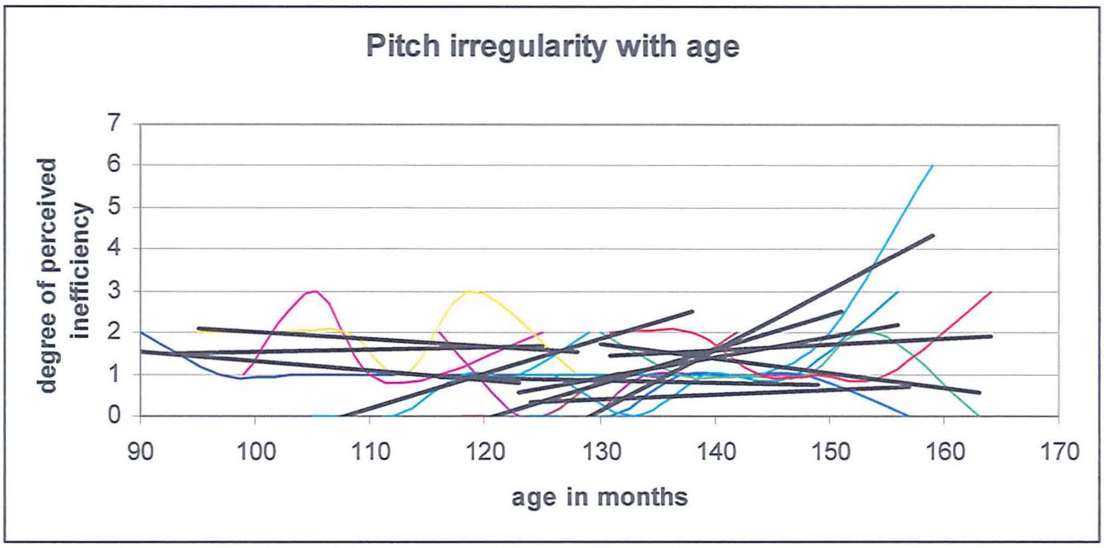


Figure 7.25 Line graph showing the degree of irregularity of pitching in boys over a three-year period from the ages of 8 to 13 with a trend line inserted for each boy

Pitch irregularities – These drop slightly in the early years, up to the age of 11. Irregularity increases significantly with the onset of adolescent voice change illustrated in the ages 150 to 170 months, where the scores range from 3 to 6. Despite the fact that these boys have had singing training for up to five years prior to voice change, where pitch accuracy is considered to be a necessary skill, these scores show how difficult they find pitch regulation as the larynx begins the rapid growth of adolescent voice change.

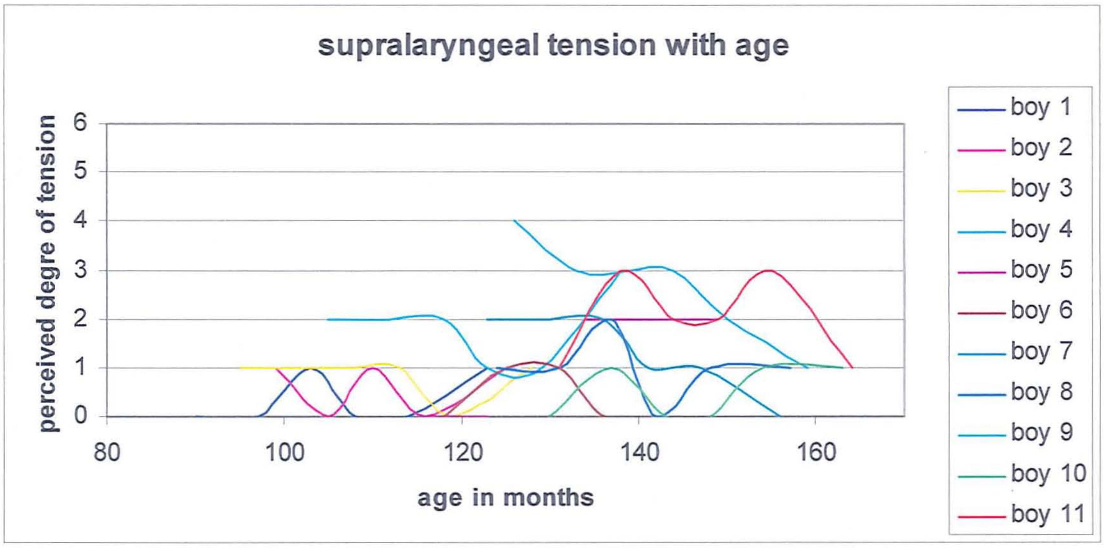


Figure 7.26 Line graph showing the degree of supralaryngeal tension in boys over a three-year period from the ages of 8 to 13

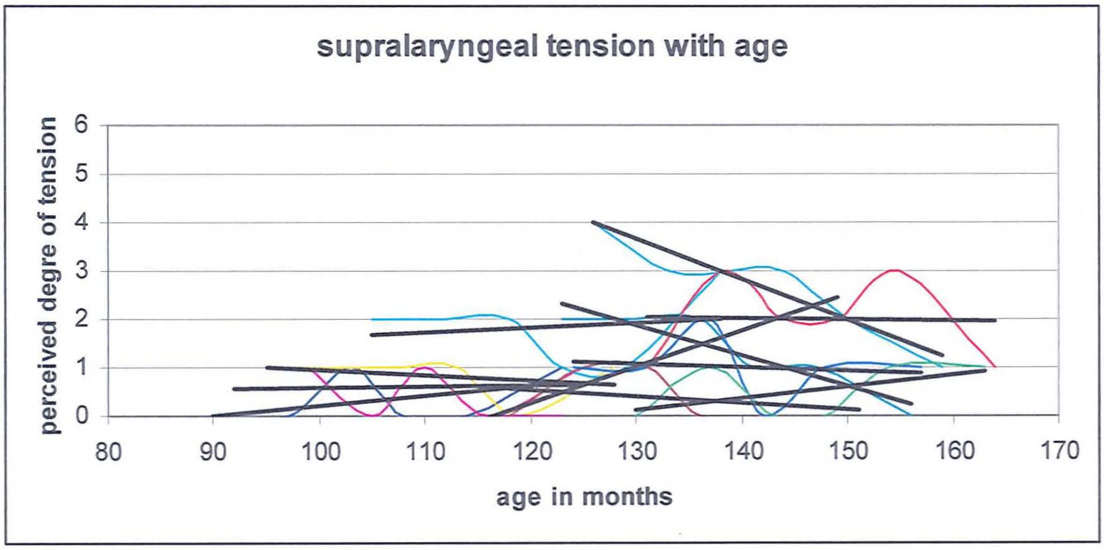


Figure 7.27 Line graph showing the degree of supralaryngeal tension in boys over a three-year period from the ages of 8 to 13 with a trend line inserted for each boy

Supralaryngeal tension –This appears to be variable. The younger boys show a general increase of supralaryngeal tension up to the age of 11. Some of the older boys show an increase, some show a decrease. The increase could be due to the increased levels of expectation of the senior choristers. They are required to demonstrate a leadership role, bearing more responsibility. This increase in cognitive anxiety is likely to result in a greater degree of overall tension in the vocal performance system (see 3.9.5). They also have a greater number of hours of voice use over the year than the younger boys. Those boys showing a decrease in supralaryngeal tension in the later months may be those who have stopped singing in the choir as a result of adolescent voice change.

7.4.3 Longitudinal analysis of overall vocal health

The chorister recordings have mostly been made in the early evening, after a day of vocal activity. This may result in a greater level of temporary vocal fatigue. One set of recordings (April 2005, recording 4), were made on the first day of the school term, after a two-week holiday from singing activities. Figure 7.28 shows the mean vocal health scores of the eleven boys in the longitudinal cohort on the six different recording times. There appears to be a noticeably lower score for time 4; the scores for the other times are surprisingly similar (within 1.35 in a scoring range from 0 to 100). This could suggest that the boys' voices are rested after the two-week break. The boys were never recorded at a particularly busy performing time, because the recording session itself would have put an unnecessary burden on their time. The other five recording times were during the run of the school term and could be counted as 'normal' or 'average' vocal loading for the boys. It is only possible to surmise that the level of perceived vocal dysfunction would rise during a period of increased vocal loading as it has dropped after a period of decreased vocal loading.

A repeated measures ANOVA test and a Friedman test showed that this difference was not, however, statistically significant.

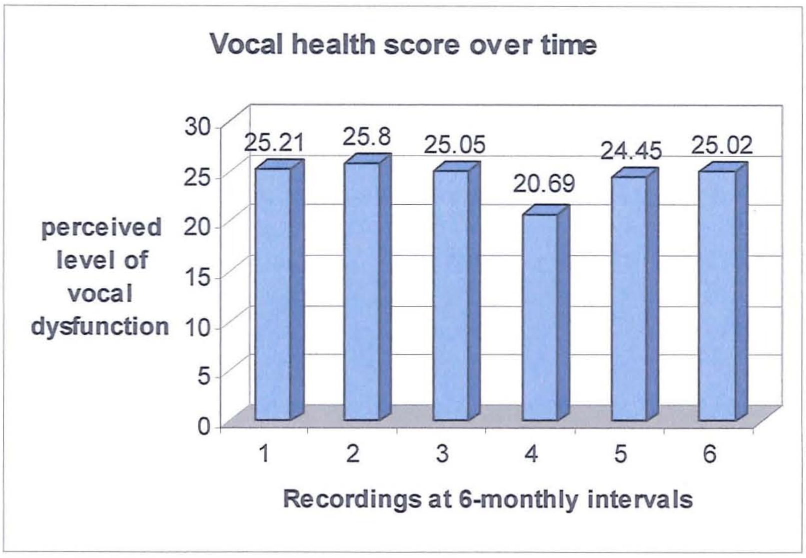


Figure 7.28 The mean perceived level of vocal dysfunction on six occasions

7.4.4 Longitudinal analysis of the Lx waveform

The Lx waveform gives information of the degree of vocal fold closure. This can be used to assess the efficiency of phonation (steeper closing slope, longer closed phase) and can show the changes in vocal fold closure patterns with the onset of adolescent voice change.

Lx waveform of an unchanged voice

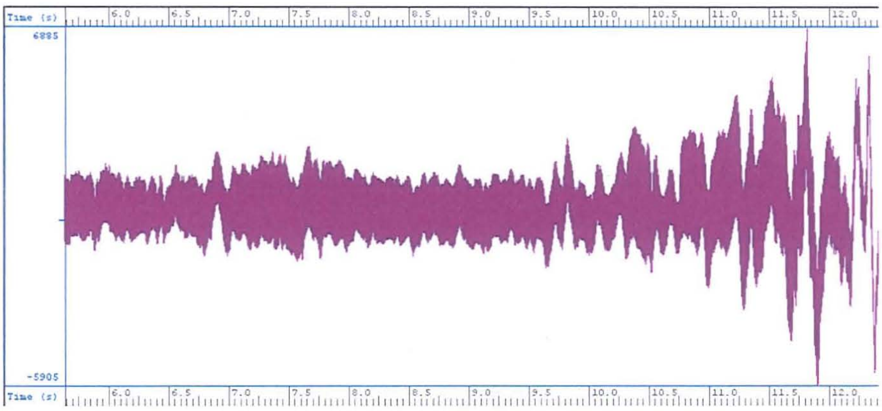


Figure 7.29 The Lx waveform of boy H aged 12 years, 0 months, singing a descending slide from G5 to G3

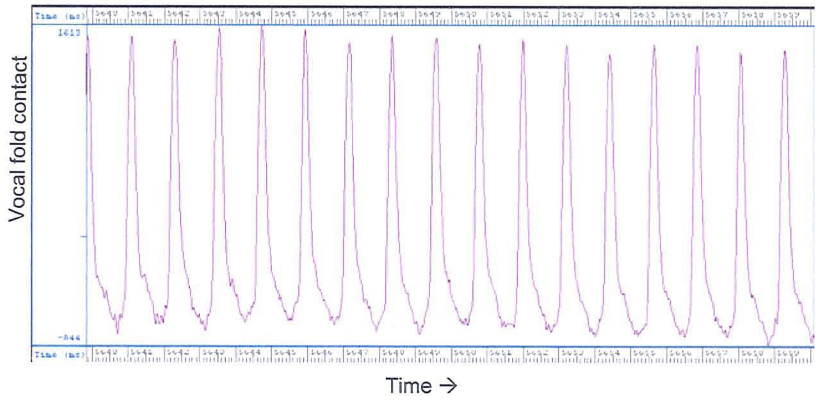


Figure 7.30 Selected portion of the Lx waveform of boy H aged 12 years, 0 months, singing G5 from a descending slide from G5 to G3

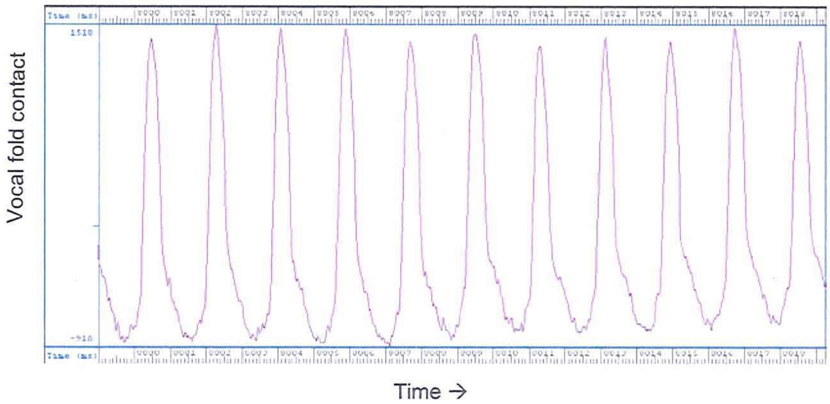


Figure 7.31 Selected portion of the Lx waveform of boy H aged 12 years, 0 months, from a descending slide from G5 to G3

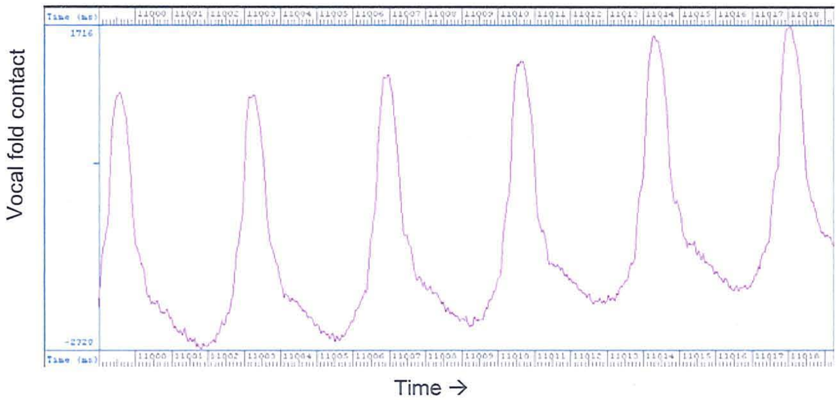


Figure 7.32 Selected portion of the Lx waveform of boy H aged 12 years, 0 months, from a descending slide from G5 to G3

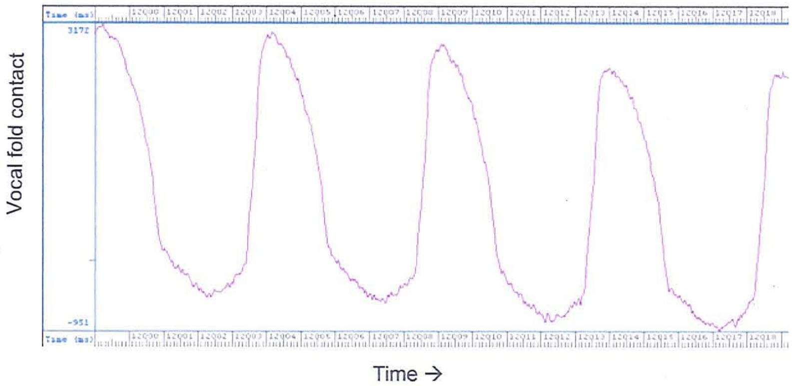


Figure 7.33 Selected portion of the Lx waveform of boy H aged 12 years, 0 months, singing G3 from a descending slide from G5 to G3

Figures 7.30 to 7.33 show the vocal fold closure pattern over a two-octave pitch range in an unchanged voice. Each window showing a selected portion of the waveform is of 20ms duration; there are fewer cycles at the lower pitches as the frequency is lower. This boy shows a fairly consistent pattern of closure over the pitch range. Figure 7.34 shows the whole two-octave pitch range; pitches where the larynx is functioning with a degree of instability are seen as disturbances to the overall pattern of the waveform. These are the passaggio points between vocal registers (see 2.3.6). This slide is track 7.6 on the CD.

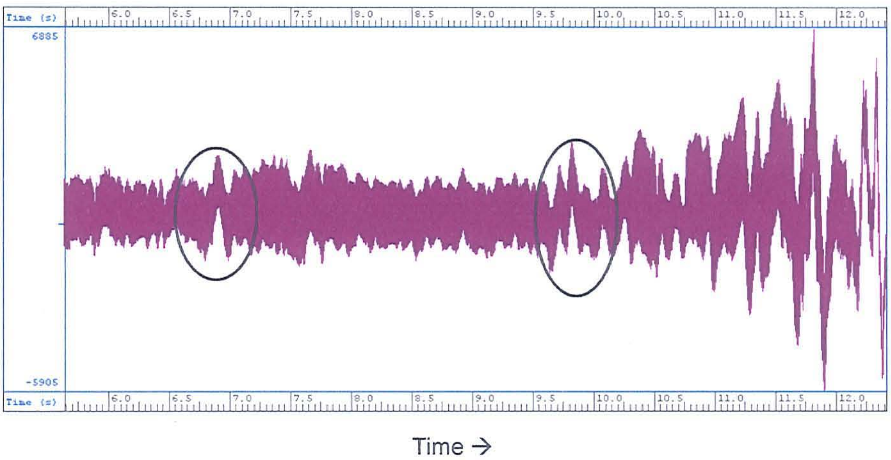


Figure 7.34 The laryngographic waveform of a two-octave slide showing the two passaggio points marked

Lx waveform of a voice in the early stages of voice change

The next set of figures show the Lx waveform of the same boy twenty-two months later. At this time his voice was in stage lll of voice change (see 3.8.5).

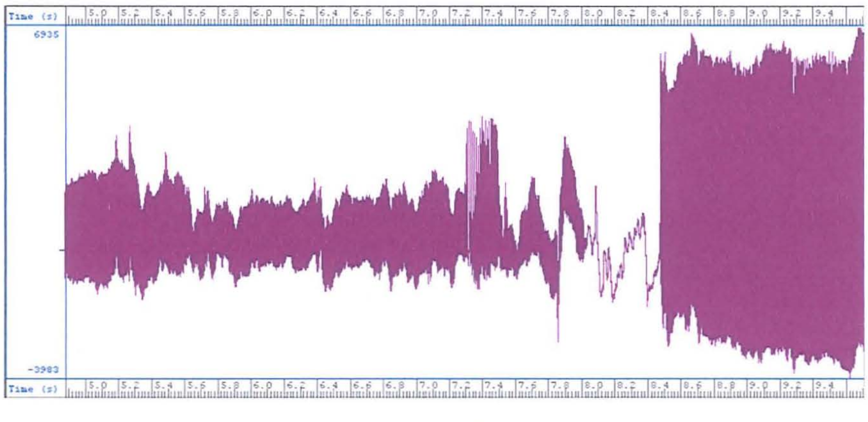


Figure 7.35 The Lx waveform of boy H aged 13 years 10 months, singing a descending slide from G5 to G3

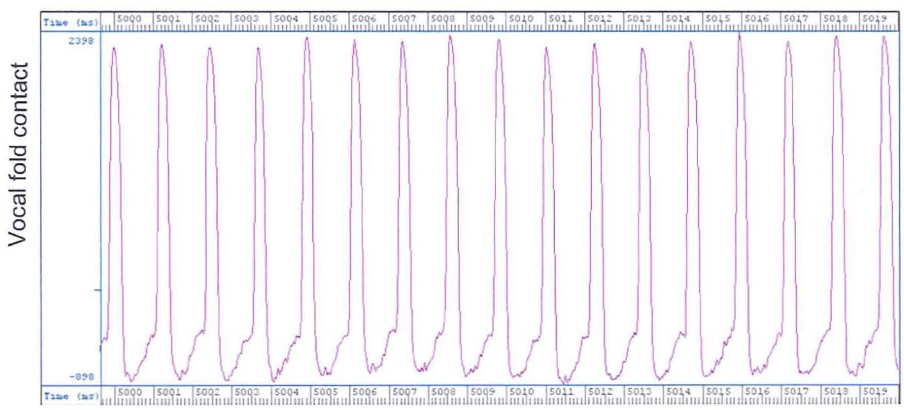


Figure 7.36 Selected portion of the Lx waveform of boy H aged 13 years 10 months, singing G5 from a descending slide from G5 to G3

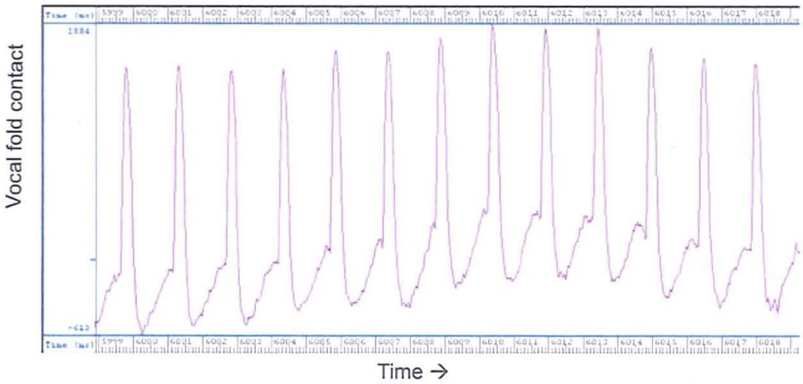


Figure 7.37 Selected portions of the Lx waveform of boy H aged 13 years 10 months, from a descending slide from G5 to G3

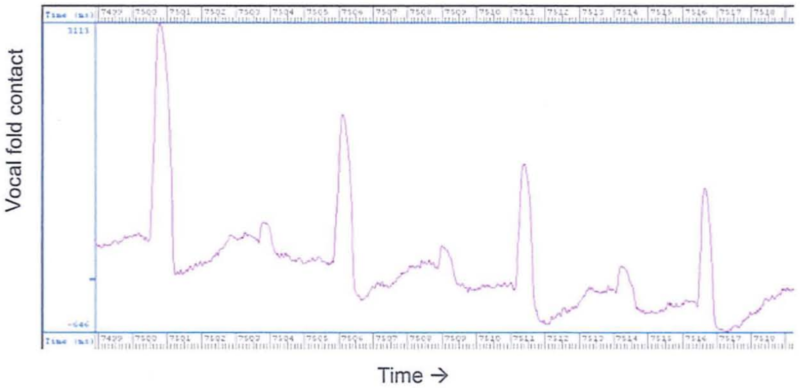


Figure 7.38 Selected portions of the Lx waveform of boy H aged 13 years 10 months, from a descending slide from G5 to G3

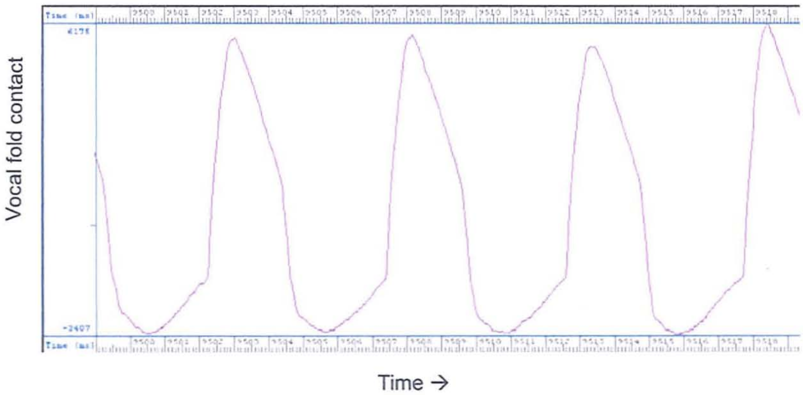


Figure 7.39 Selected portion of the Lx waveform of boy H aged 13 years 10 months, singing G3 from a descending slide from G5 to G3

This slide is on track 7.7 on the CD. These Figures (7.36 to 7.39) show a noticeable difference in vocal fold contact patterns over the two-octave pitch range. At the lower pitch (G3) the closed phase is longer and the opening slope has a 'knee'. This is typical for thick-fold phonation of the adult voice; the 'peel apart' of the lower edges of the vocal folds is at a slower rate than the mid to upper edges (this is less evident in waveform A of Figure 7.40, but it is generally observed in lower pitch phonation of the adult both male and female).

The second-lowest pitch (the second graph from Figure 7.37) shows extreme instability in the waveform. There appear to be two peaks, one strong and one weak. This is caused by an irregular vibratory pattern leading to weakness in alternate vocal fold collisions. Aurally, this is heard as diplophonia, or two pitches sounding simultaneously. The stronger collisions are heard as a pitch an octave lower than that of the combined collisions; these two pitches are heard at the same time giving rise to the phenomenon of diplophonia. This irregularity occurs at the main register transition point between thick-fold (speech quality) and thin-fold (upper range).

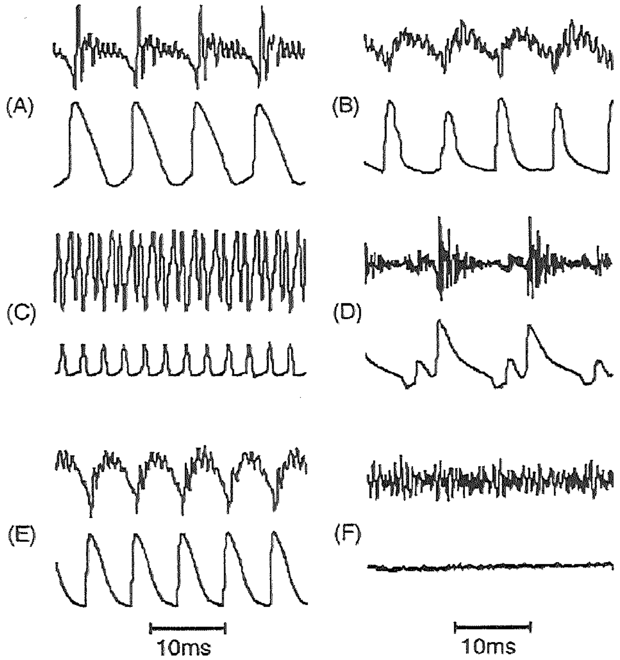


Figure 7.40 Speech pressure (upper) and electrolaryngograph (lower) waveforms for the vowel of 'spa' spoken by an adult male using: (A) modal voice; (B) breathy voice; (C) falsetto voice; (D) creaky voice; (E) harsh voice; and (F) whispered voice (Tom Harris et al., 1998)

The upper pitches in the recordings of boy H at stage lll of voice change are surprisingly close to those of the same boy when unchanged. The waveform is not that of falsetto singing, which would typically be a sinusoidal pattern (see waveform C in Figure 7.40). It appears to be closer to the phonation used by children and adult females at this pitch. It is possible that, as the larynx grows, the boy retains the ability to sing with the soprano sound. Although this has not been longitudinally assessed in boys undergoing voice change, it is known that trained male alto singers use a similar phonation, rather than the pure falsetto used by untrained adult male singers in their upper range.

Analysis of the rate of vocal fold closure over time

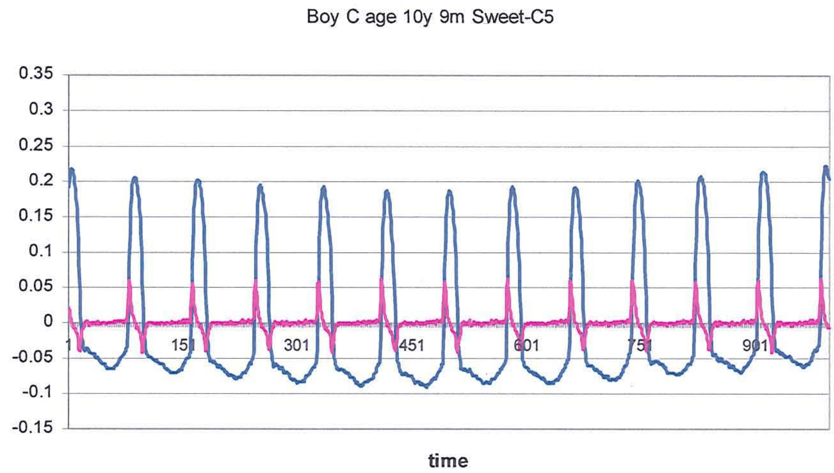


Figure 7.41 Efficiency of vocal fold closure in boy C at C5, aged 10 years 9 months

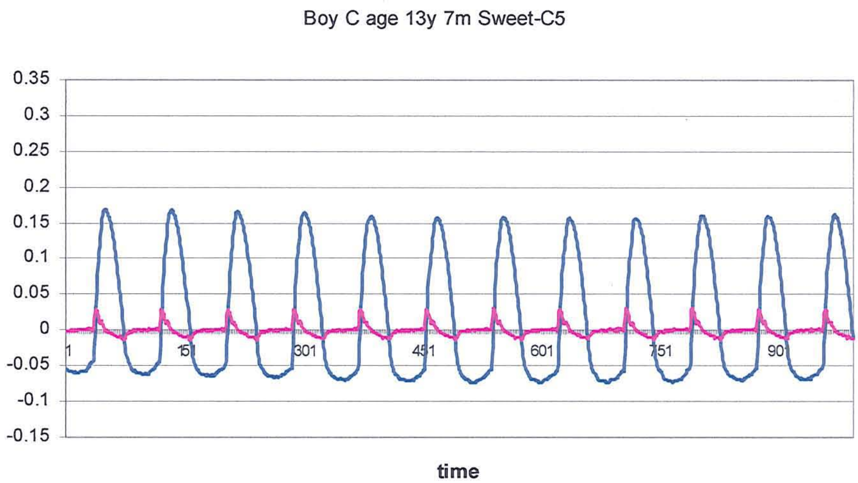


Figure 7.42 Efficiency of vocal fold closure in boy C at C5, aged 13 years 7 months

Figures 7.41 and 7.42 show the Lx waveform of the upper pitch range of another boy, Boy C. The superimposed line in pink shows the steepness of the rising part of the curve; this indicates the rate of closure of the vocal folds. The earlier recording, Figure 7.41, shows a more rapid vocal fold closure. This not only produces a stronger excitation impulse but also boosts the higher frequency spectral component in the region of 5,000 Hz (D. Howard & Murphy, 2008). This can be seen in the LTAS in Figures 7.43 and 7.44. The earlier recording (track 7.8 on the CD) with the more rapid closing phase of the vocal folds has a boost of frequencies in the upper range (4000–5000Hz) which is not seen on the later recording. The voice use of the boy when older was perceived to be more constricted (track 7.9 on the CD), evidence of this can be seen by the longer closed phase on Figure 7.42, but is less acoustically efficient (see also 7.3.4).

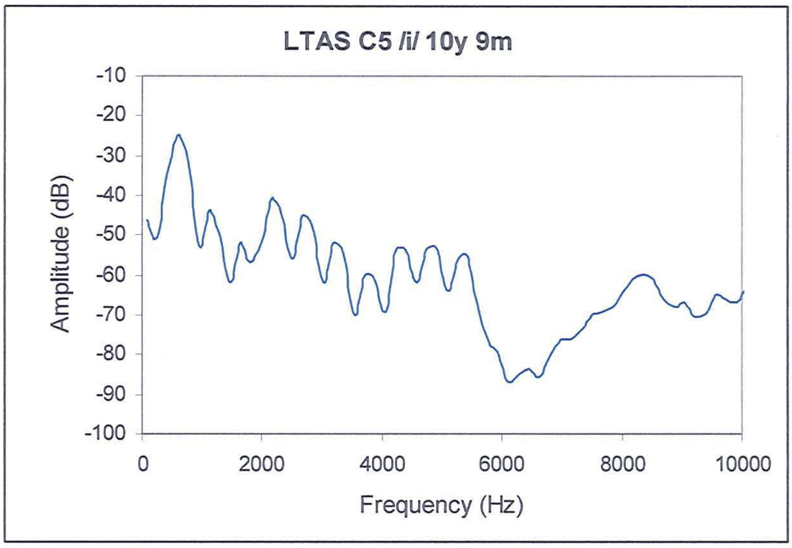


Figure 7.43 LTAS of [i] vowel on C5, Boy C aged 10 years 9 months

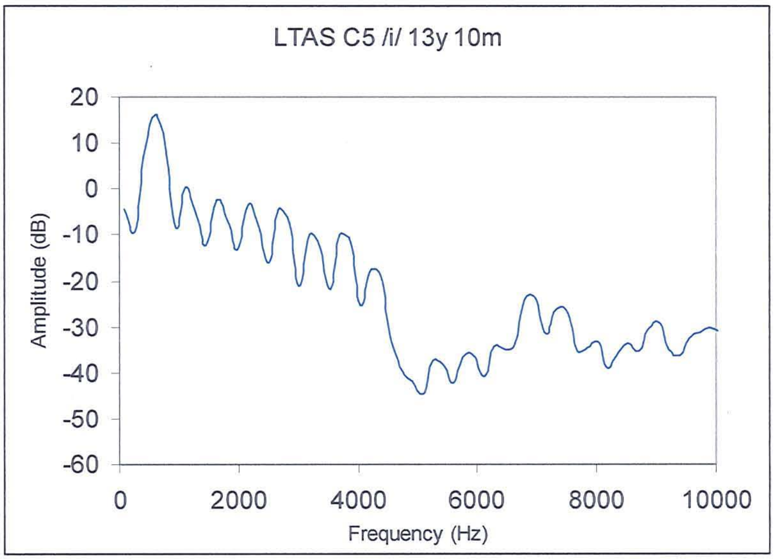


Figure 7.44 LTAS of [i] vowel on C5, Boy C aged 13 years 10 months

7.5 Summary of results of acoustic, voice source and longitudinal analysis

A total of 112 recordings of choristers was made with the laryngograph in addition to the acoustic recording. A selection of these recordings was chosen to represent the three primary vocal qualities which are known to be indicators of voice fatigue or dysfunction: whisper (breathiness), creak and harshness (see Table 6.2). The recordings selected had a high score for each of these qualities alone. This means that the acoustic analysis would be less likely to have cross-contamination from other factors of phonatory behaviour. It should be noted, however, that voices exhibiting isolated voice qualities are rare; most of the voices assessed were observed to have these voice qualities combined in individually varying quantities.

The observation of the elements seen in the LTAS was unsurprising. Creaky voice had evidence of irregular vocal fold vibration; creaky, breathy and harsh voice showed a reduced ability for loud phonation. The analysis of the laryngographic waveform gave more detailed results. These showed evidence of irregularity in the vocal fold vibrations in all cases. Breathy voice showed a significant proportion of the vocal fold collisions to have inefficient closure (97%). Creaky voice had a marked irregularity in the degree of vocal fold closure with a small figure for coherence (17%). Harsh voice showed irregularity in the cycle by cycle amplitude measurement with a coherence of 23%.

The observations of vocal fold behaviour with the onset of adolescent voice change were more surprising. The voice attributes were similar to those of fatigued or dysfunctional voices. Adolescent voices are medically normal and healthy; the inefficiencies of phonation will be as a result of reduced muscular coordination following a period of unusually rapid growth. The changes to lower pitch phonation were noticeable as the vocal folds became longer and thicker. The changes to upper pitch phonation were not as great as could have been expected; the habits of phonation in these pitches seemed to persist despite structural developments and alterations. The differences were in the efficiency of vocal fold closure and the acoustic signal generated in the upper frequencies as a result of this.

The longitudinal analyses of vocal behaviour showed trends within the chorister cohort in aspects of vocal fold contact efficiency (incorporating all three indicators of fatigue or dysfunction), pitch regularity and supralaryngeal tension. Both vocal fold contact inefficiency and pitch regularity tended to peak at around 10–11 years. Supralaryngeal tension tended to increase gradually, although the individual variation was significant.

A longitudinal look at the time of recording related to vocal activity immediately prior to this showed a noticeable improvement in vocal health at the end of a two-week holiday.

The analysis in these cases was qualitative. The observations helped to confirm the perceptual judgments of vocal behaviour described in Chapter 6.

Chapter 8

Jake: a case study of the vocal development of one chorister over three years

8.1 Introduction

This is a more detailed examination of the data on the voice of one individual participant, obtained from the methodology outlined in 5.6 to 5.14. He was recorded on six occasions, over a period of three years, with a follow-up interview two years after the last recording. His age at each recording was: 10 years 4 months, 10 years 11 months, 11 years 5 months, 12 years 4 months, 12 years 10 months and 13 years 1 month with a follow-up at age 15 years 4 months.

Jake was a normal, healthy boy. He achieved well academically, eventually gaining a place at a prestigious independent school, and musically, gaining Associated Board Grade 6 on the cello, Grade 4 on the piano and Grade 8 singing by the time that he had completed his preparatory schooling (age 13). These achievements were considered to be average for the cohort of choristers at his school. He was good-natured and eager to please. He had settled into boarding school life well and had plenty of friends.

This particular boy was selected as he was the only one of the choristers who underwent any medical procedures related to his voice during the period of this study. This chapter describes his progress through vocal problems including chronic tonsillitis, diagnosis of a vocal fold cyst, the resulting surgery, his subsequent recovery and, finally, the effect of adolescent voice change on his speaking and singing.

8.2 Interview material

All the boys participating in the study were interviewed at each time of recording. The structure of the interview is in Appendix 5.3. The interview was designed to ask similar questions to those asked of the parents and teachers of the boys, but with answers from the boys' personal perspective.

8.2.1 The boys' perception of their vocal health

When asked about their general health, such as how many times they had missed cathedral singing as a result of illness, for example, they were always in agreement with the teachers and school nurse. This was one fact of which they were very aware and recalled with accuracy. Most of the boys did not like to miss out on singing, as they were sometimes teased by the other boys. They mostly felt a sense of purpose and duty towards the music of the cathedral and enjoyed their personal contribution to this.

If a boy had 'time off' for illness, there was the question of what may be an appropriate replacement activity. If they were not to participate in the rehearsal and performance time in the cathedral, they were often left in school to amuse themselves. This suited some individuals some of the time, but in the main, they preferred to be 'one of the pack'.

Some of the boys, however, tried to feign illness from time to time in order to have time to themselves, or simply to have some individual attention. As is often the case with attention-seeking behaviour, the falsification of illness was often not at a deliberate or conscious level for the boy. This took some skilled diagnosis and understanding from the teachers to unravel often very complicated emotional situations. Sometimes illness coincided with a weekend, and this could mean that the boy was allowed to go home to his parents. The author noted more than one case where voice problems developed alongside family problems (often a breakdown of the parents' relationship and the subsequent parental separation). This perceived dysphonia in the boy could have been as a result of generally increased emotional strain leading to muscular strain, leading to muscle tension dysphonia or psychological voice disorder (see 3.9.2). It also could have been a sub-conscious desire to be at home. In more than one case, parents waited until their son was 'settled' in a boarding environment before separating. The boy could interpret this situation as 'his fault'; in his view the separation had occurred after he had left the family; therefore if he returned, the family rift could heal.

These cases were not investigated at a deeper level and so these possible causal factors were not clearly evidenced. However, a deep-seated desire to be at home could lead to voice disorders if the boy subconsciously perceived singing activities as the prime factor removing him from home.

8.2.2 The boys' perception of others' singing; personal values

One question asked of the participants was: 'Of the other boys in the choir, name three whose singing you most admire, and say why'. The answers given to this question by the boys gave some interesting and perhaps unexpected insight into the vocal qualities which they valued amongst their peers. There was a total of 112 interviews given over the three-year period. The answers are summarized on Table 8.1.

Table 8.1 Singing qualities valued by chorister peers

Quality cited by interviewee	Number of times mentioned from 288 responses
"sings well/good voice/clear/musical"	88
"good leader"	63
"strong/powerful voice"	48
"good soloist"	34
"reliable/always gets everything right/steady/responsible"	23
"high voice"	18
"amazing/good sight-reader"	8
"works hard"	6
"helps people"	5
"good diction"	3
"sets an example on behaviour" "won a cup" "he's head chorister"	2
"good at adapting" "amazing" "very good at music" "ignores mistakes around him" "has developed his own style of singing" "doesn't leave work to the other boys" "understands what he's singing" "can't hear his passaggio" "same quality on different vowels" "gets others out of trouble" "keeps everybody calm" "blends well with choir" "Mr X always says 'well done'" "keeps his voice healthy" "listens to everything Mr X says" "keeps his body free" "well-prepared" "doesn't work too much on the sound" "knows a lot about singing"	1

The most highly regarded quality was that of being a good singer. This was mentioned 88 times. It included such qualifiers as: "sings well", "good voice", "clear voice", "musical singer". The next most common quality cited was that of being a "good leader". This was mentioned 63 times. After this came "strong or powerful voice", 48 times mentioned; and "good soloist", 34 occasions. Then was "reliable, accurate, responsible" with 23 citings; and "high voice", or "good high notes", 18 occasions. Some qualities were mentioned a few times: "good sight-reader" – 8, "works hard" – 6, "helps people" – 5, "good diction" – 3.

The qualities fell into two broad categories; those relating to vocal prowess, and those relating to reliability and leadership. Vocal skills and ability were mentioned a total of 207 times; leadership skills were mentioned 81 times, 28% of the responses.

8.2.3 Jake's perception of the other choristers' singing

Initially, Jake valued features to do with the quality of the singing from his peers. As he progressed through the choir and took on a more senior position, his priorities shifted to encompass issues of reliability and leadership. He himself was rated by the other choristers and by his teachers as primarily providing good leadership rather than exceptional singing.

8.2.4 Jake's perception of his own singing

On the whole, the boys were fair and accurate at rating their own singing compared to the rest of the group. Although their ratings related to those of their teachers, on the whole the boys were more confident of their own abilities. None of them rated themselves as less than average. Jake himself noticed an improvement in his singing after two years in the choir; "It sounds nicer than it used to be". When he was having difficulties with his singing, he gave a fair assessment of his own abilities.

8.3 The first year

Jake's personality test showed him to be emotionally stable, with scores of P0, E23, N14 and L4 (see 5.4). These would suggest that he was keen to be liked and an extrovert and yet laid-back and sensitive. This is a personality profile of a boy very unlikely to develop a voice disorder (see 3.9.4). The personality profile was made at the start of the fieldwork, in the autumn of 2003 when Jake was aged 10 years and 4 months. There was only one observation from the background information given by his parents; he had been slow to develop speech, which had not really come until he was aged 4 to 5 years. There was no explanation given by his parents for this, such as whether it was a hearing, articulatory or cognitive problem. They stated that it had not been followed up as he had "got there in the end". His speech and use of language was completely normal by the age of 10 so there was no reason to suspect that this delayed development could have had a lasting effect on his voice use.

The first three recordings of Jake were made in October 2003, May 2004 and November 2004.

8.3.1 October 2003

In this recording session, there was some tension observed in the jaw and tongue. His voice was more constricted in singing than in speech. His singing teacher reported "a lot of jaw and tongue tension". The Director of Music for the cathedral stated that he had a "lovely voice". In general, his singing ability was rated as 'average' by both Jake himself and by his teachers. He was healthy and according to the school nurse, he had had "hardly any days off singing". The recording of his speaking voice at this time is track 8.1 on the CD, and his singing voice is on track 8.2. The VPA[7] assessment of his voice was Harshness 1, Whisper 1 and Breathiness 1 (where a score of 0 is clear and a score of 3 is severe). The EAIS score for speech health and singing health were both 4 (where 1 is clear and 7 is severe) and the VAS score was 29.5 (where 0 is clear and 100 is severe).

These scores and observations suggest that Jake's voice use showed a low level of disorder, but had no significant problems. He was intelligent, musical and eager to please so he may have been pushing himself to perform against an underlying dysfunction.

8.3.2 May 2004

Jake's voice continued to show underlying levels of dysfunction. He was clearing his throat a lot during the recording, a sign of accumulated mucus (possibly due to oedema – see 3.9.3) or a general level of discomfort in the larynx. Tension was observed in his vocal production. His score on the VPA was Harshness 1, Whisper 2, Creak 2 and Asthenia 1. His EAIS scores were still both 4 and the VAS score was 26.5. Some of these scores show an increase in vocal dysfunction, others show the same or a slight decrease. His singing teacher and Director of Music both referred to him as "rather tense". He appeared to have greater vocal problems, but had probably learned skills to overcome these more effectively. He had had

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[7] VPA or Voice Profile Analysis – see 5.6 EAIS or Equal Appearing Interval Scale – see 5.8.2
VAS or Visual Analogue Scale – see 5.8.3

no reported days off from singing as a result of illness or vocal fatigue. His confidence and belief in himself had also increased; his teachers still rated him as 'average', whereas he considered his singing to be 'good'. He stated that his voice was "stronger, with less jaw tension, generally good". The recordings of him at this time are on tracks 8.3 and 8.4.

8.3.3 November 2004

By the autumn of that year, Jake's vocal health had deteriorated considerably. He had suffered from chronic poor health all term and was waiting for a referral to the Ear, Nose and Throat Clinic for examination. His VPA scores still gave him Harshness 1, Whisper 2, Creak 2 and Asthenia 1. His EAIS scores were 5 for speech and 6 for singing, and the VAS score was 40. These show a considerable increase in voice disorder. The speech recorded at this time is on track 8.5. His singing ability was still rated as 'average' by both Jake and his teachers but his pitch range was considerably reduced.

8.4 Surgery and vocal health recovery

8.4.1 April 2005

Jake underwent a tonsillectomy and removal of left vocal fold cyst in March 2005. The recordings made in April 2005 showed a remarkable vocal recovery. His VPA score was Harshness 1 and the others were all 0. His EAIS score was 3 for both speaking and singing, his VAS score was 16.5; this is extremely low and indicates a very healthy voice. There was still some tension in his singing; this was probably a residual habitual use rather than as a result of voice disorder. His ratings had returned to 'good' from Jake himself and 'average' from his teachers. The recordings of his speaking and singing at this time are on tracks 8.6 and 8.7.

8.4.2 October 2005

By October 2005, Jake had reached the age of 12 years and 4 months; he was beginning to show signs of adolescent voice change. His speaking F_0 had remained at A3 for the previous two years; by October 2005 it had dropped a tone to G3. He still had healthy voice use: his scores were Harshness 1, both speaking and singing were scores of 3 on the EAIS, and 14.8

on the VAS. His speaking and singing recordings at this time are on tracks 8.8 and 8.9. In his singing he continued to show habits of tension. His singing teacher gave him an ability rating of 'poor': she was frustrated with his persistent levels of tension, despite his vocal quality being healthy. She suggested that his high levels of tension were as a result of his increased responsibility within the choir. She described him as "one of the most reliable and robust choristers, despite his singing not being one of the best". In his role within the choir, he performed rather better with ability ratings of 'good' by both the Musical Director and by Jake himself.

At this time the recording team was intrigued by his sudden and spectacular return to vocal health and asked him what had happened. Jake gave his version of the story (track 8.10). His chronic ill-health reported in the recording made in November 2004 was eventually diagnosed as tonsillitis. The surgeon, when filming the larynx to examine the vocal tract, happened to see a cyst on the left vocal fold (Figure 8.1 shows a cyst on a child's larynx for illustration purposes). Jake reported this as a nodule in the interview. However, nodules cannot develop unilaterally, as they are caused by aggressive vocal fold collisions: they always develop bilaterally on each vocal fold. A cyst can develop as a result of several causes (see 3.9.1); for example, haemorrhage of the vocal fold mucosa, or scarring from trauma such as an inhaled foreign body. They are generally not as a result of voice use and often remain unnoticed. The cyst was removed at the same time as the tonsils, in March 2004. Within six weeks, Jake's voice had made not only a full recovery, but appeared to be significantly better than it had been at any time during his career as a chorister (as perceived by Jake and observed by the Author). Jake also sang a popular song he enjoyed listening to (track 8.11). This was sung at a significantly lower pitch than his choir repertoire. At first it was thought that he was using a different voice quality for pop singing; on further investigation it was shown that the original artist recorded the song at the same pitch. Jake had absolute pitch (the ability to recognise and reproduce any given pitch from memory) and was instinctively copying the recording artist at the original pitch.

IMAGES REDACTED DUE TO THIRD PARTY RIGHTS OR OTHER LEGAL ISSUES

Figure 8.1 Example of a left vocal fold cyst on a juvenile larynx (from Mr B Hartley, consultant ENT surgeon, Great Ormond Street Hospital, 2007)

The residual tension Jake continued to use in his singing voice may have been purely habitual. As a result of the cyst, perhaps he had spent the first three years of his chorister career trying to achieve efficient vocal fold closure despite the presence of a lesion on one vocal fold. In order to do this, he would have to use some increased lateral adductory pressure, resulting in a level of harshness throughout his singing. It is most likely that even when the cyst was removed, these compensatory habits remained.

8.5 Adolescent voice change

8.5.1 March 2006

On this date an extra, un-assessed recording was made to record the progress of the older boys though adolescent voice change. Jake's speaking voice can be heard on track 8.12: his F_0 has dropped to F3, making his stage of development to be somewhere between Cooksey's voice stages II and III (see 3.8.5). By this stage, he had recently stopped singing in the soprano line within the choir. As the alto, tenor and bass parts are sung by professional adult male singers, this meant that he was no longer singing in the cathedral choir. He was certainly still capable of singing notes within the soprano range, although he was reluctant to do so; this is shown in track 8.13. His singing and speaking voices appeared to be rather constricted and pushed down in pitch. It was as if he was pushing down in order to try to sound further developed that he actually was. Track 8.14 is a recording of Jake singing in a lower, more comfortable pitch range.

8.5.2 July 2006

This was the final recording for assessment of the boys. By this time Jake had not sung in the choir for five months. His speaking voice (track 8.15) showed a F_0 of E3, a comfortable Cooksey stage lll with a developing tenor range (track 8.16). The pitch glide in track 8.17 shows that he still has access to high pitches, but he is reluctant or uncomfortable with using these. His voice remains relatively healthy (VPA of Harshness 1, EAIS of 2 for speech and 3 for singing) but his VAS score has risen slightly from 14.8 to 23. This was the mean score given by the panel of judges. It is possible that they could have been perceiving the onset of voice change as unhealthy voice use. The difference between the two appears to be difficult to evaluate (see 10.8.2).

8.6 Graphic illustration of the data

These graphs show the general trend of Jake's vocal health over three years. It is possible to observe the deterioration of his vocal health, heading to a peak of ill-health at the time of the third recording. There is a sudden return to a more healthy voice after his surgery.

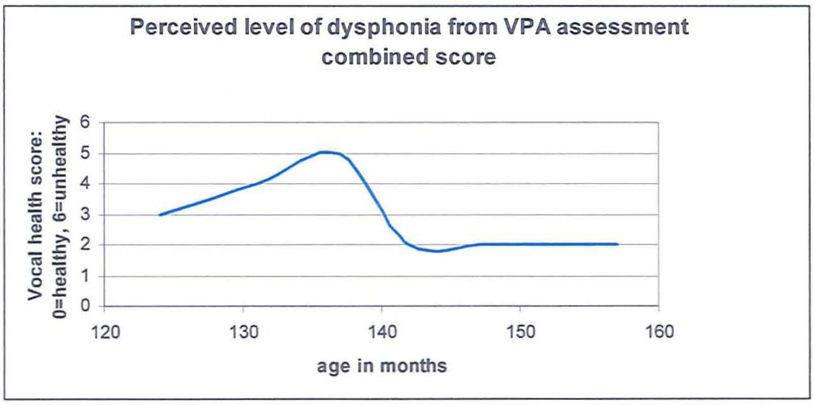


Figure 8.2 Perceived vocal health combined score from the VPA assessment

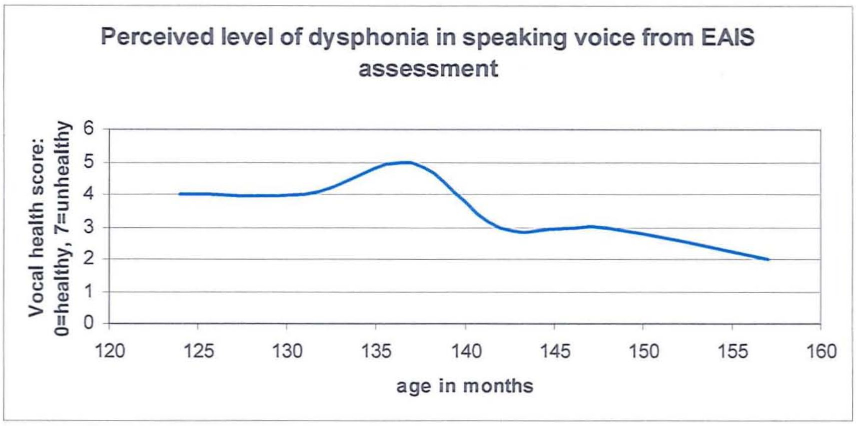


Figure 8.3 Perceived vocal health of the speaking voice from the EAIS assessment

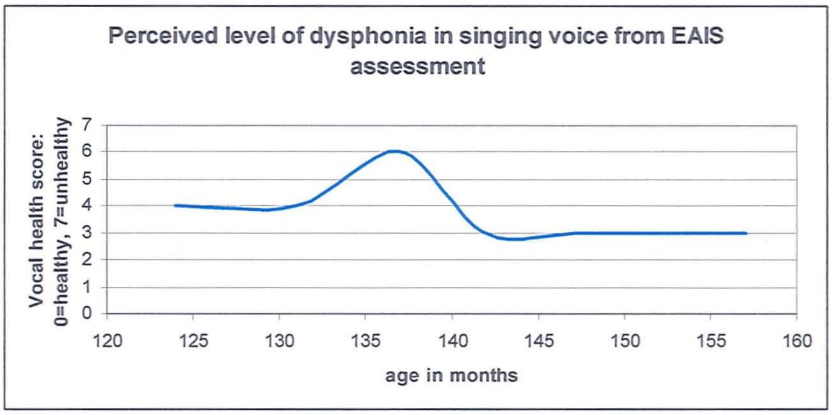


Figure 8.4 Perceived vocal health of the singing voice from the EAIS assessment

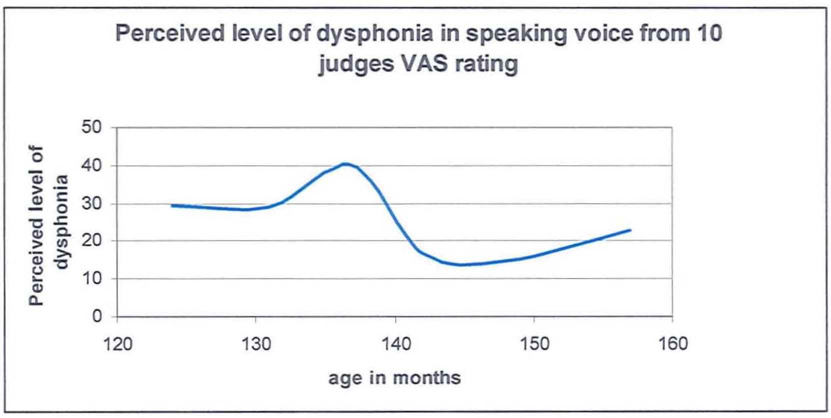


Figure 8.5 Perceived vocal health of the speaking voice from the mean score given by the ten best judges in the VAS rating

8.6.1 Graphic illustration of the onset of adolescent voice change

The final recording shows a slight improvement in vocal health of the speaking voice in figure 8.3 and a slight deterioration of his speaking voice seen in the figure 8.5. This was the time of the noticeable onset of adolescent voice change (see Figure 8.6). The average fundamental frequency (F0) of Jake's speaking voice appears to rise slightly as a result of his operation and then fall with the onset of adolescent voice change. The rise may be as a result of an increased overall pitch range. This can be seen in the DFx1&2 plot on Figures 8.13 and 8.14. The pitch range is greater with more spread into the upper pitches (seen as covering a greater range of frequencies on the x-axis) in the second illustration; this is likely to be as a result of the ease of phonation throughout the pitch range resulting from the cyst removal. The pitch range demonstrated in Figure 8.14 is closer to a 'normal' pitch range for a boy of that age.

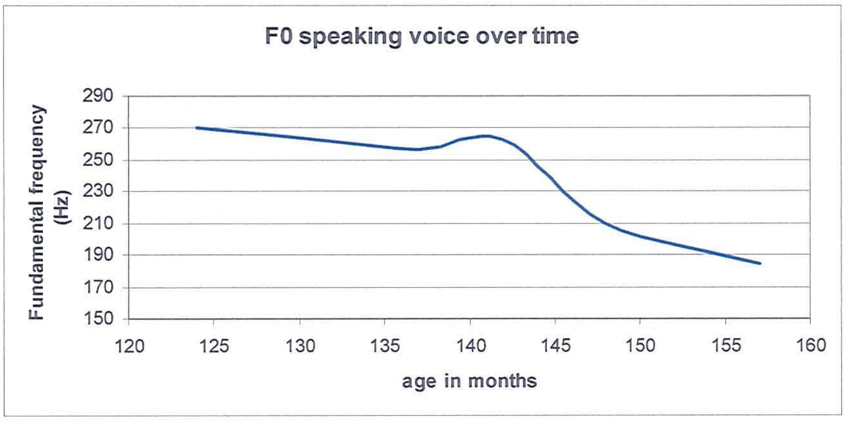


Figure 8.6 Changes in average fundamental frequency (F_0) of Jake's voice during the early stages of adolescence

The score in Figure 8.3 was the EAIS score allocated by judge JW, a listener with extensive experience of boys' voices in this stage of voice change. The score in the VAS ratings was the mean score for ten judges, all of whom were considered to be consistent and reliable in their judgements, but some of whom had less experience than others in the voice qualities exhibited in this particular stage of voice change. The perceptual instability and roughness of the voice in Cooksey Stage 3 (see 3.8.5) may have been interpreted as unhealthy phonation (see 8.5.2). This discrepancy is illustrated in Figure 8.7.

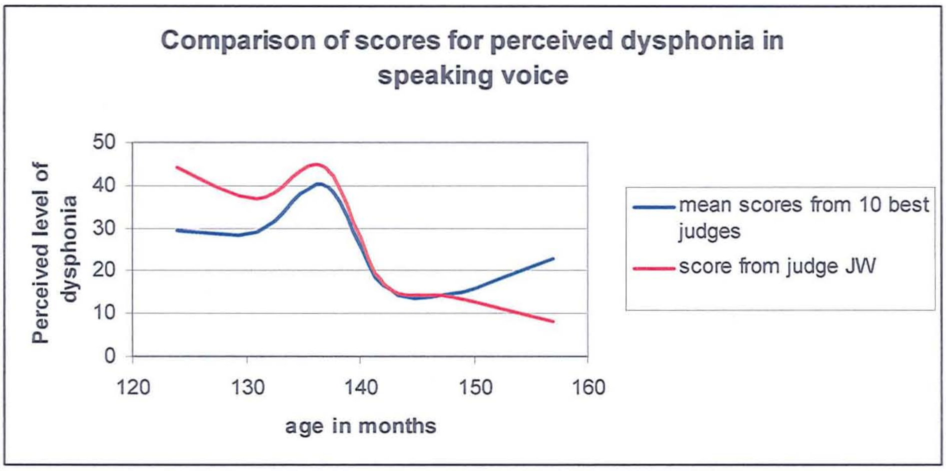


Figure 8.7 Comparison of VAS scores given by judge JW and the mean of ten judges

JW was not a particularly high scorer as seen in the comparison of mean scores given overall. JW gave an overall mean score of 22.65, the remaining nine judges gave a mean score of 26.47. In practical terms, on a 10cm line, this was a difference of less than 4mm. There is, however, a noticeable difference in the score given by JW and the other judges when Jake was first developing his voice problems (JW scored higher) and when he was entering voice change (JW scored lower). This discrepancy during voice change suggests a possible overlap in the perception of a slightly unhealthy voice and that of a boy entering voice change. JW allocated a score of 8, the other nine judges gave a mean score of 23. This is a difference of 15mm on the VAS scale.

8.7 Acoustic analysis of the data

8.7.1 Long-term Average Spectrum (LTAS) of Jake's singing voice over time

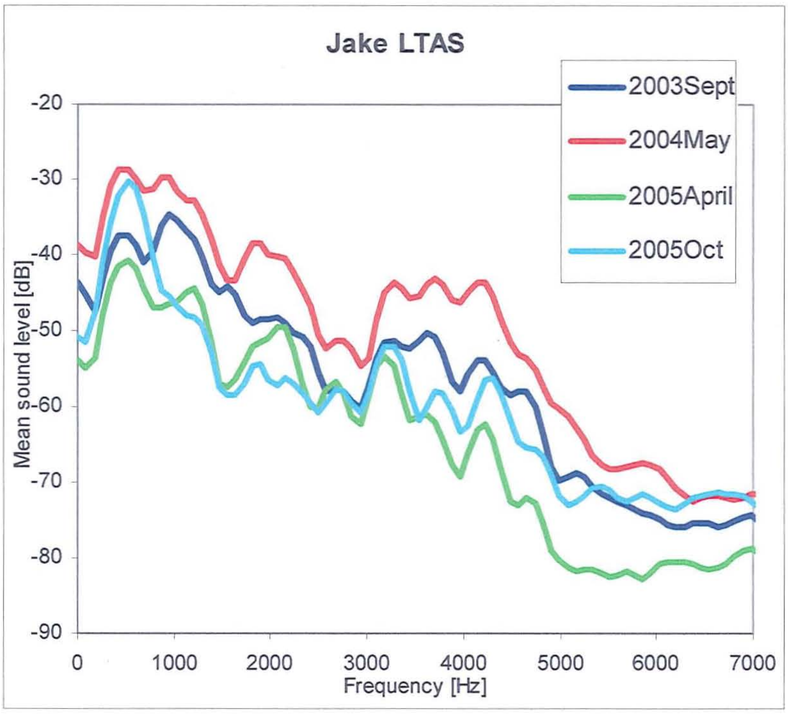


Figure 8.8 LTAS for singing (melody) on four occasions

The LTAS shown in Figure 8.8 show the spectra for Jake's melody singing on four occasions. These have been calibrated to absolute dB SPL. The second recording in May 2004 shows him singing more loudly than any of the others. This could have been due to a number of reasons. For example, over the three-year period he was developing his singing technique which would include work on power and projection. If this were the reason, then one would have expected his singing to continue to get louder. It was conceivable that he was in fact pushing and straining somewhat, possibly due to the vocal fold cyst (undetected at the time of recording). The distribution of the resonance frequencies is similar in the first two recordings, and again similar in the last two recordings. In the first two, not only was his voice younger but he was possibly struggling with the vocal fold cyst as well as this. There are also other factors which may have contributed to his general vocal loudness, such as temporary fatigue or his overall mood. There is no recording of his singing voice from November 2004: at the time of the recording his voice was not in good enough health for him to be singing in the cathedral services and he was therefore unwilling to sing under any circumstances at the time.

In the LTAS of Jake's speaking voice, there is more evidence of changes to his vocal production as a result of the cyst removal.

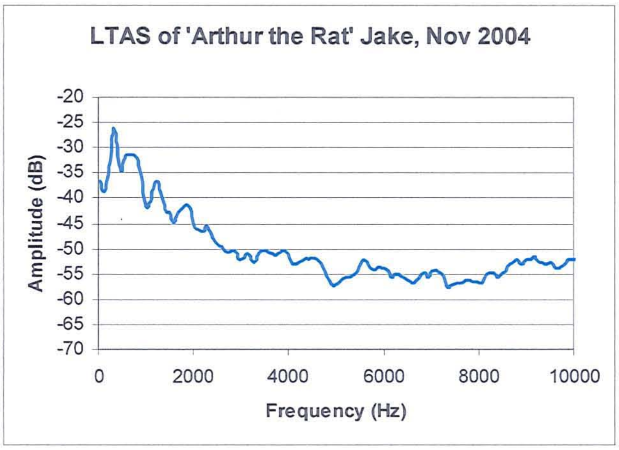


Figure 8.9 LTAS of speech, pre-operation

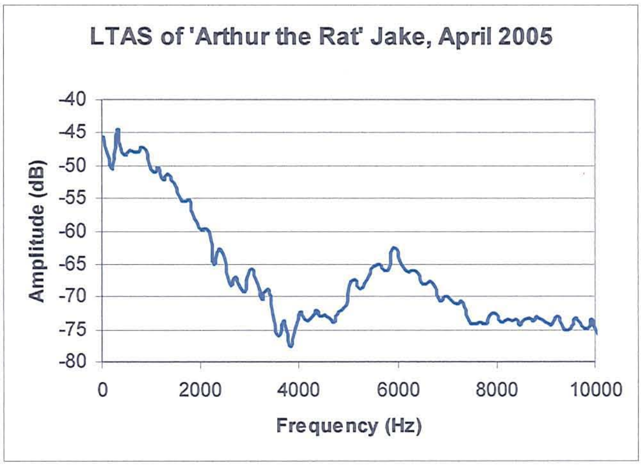


Figure 8.10 LTAS of speech post-operation

In the first graph, in Figure 8.9, after the initial peaks in the spectral energy, there is a gradual fall-off of spectral energy; this is associated with the LTAS trace of breathy voice or insufficient vocal fold closure (see Figure 4.7). In the second graph, in Figure 8.10, there is a noticeable peak of energy at around 6000Hz. This is more normal in efficient voicing. It can be a result of the more rapid closure of the vocal folds generating a 'ringing' peak in the acoustic signal.

8.7.2 Laryngographic (Lx) analysis of Jake's speaking voice over time

The laryngographic data has fewer clues to the possible effects of the vocal fold cyst in Jake's speaking voice. Although the judges were in agreement with their assessments that his voice was less healthy before the removal of the cyst, there is little evidence in the laryngographic data. The Lx waveform for the pre-op recording (November 2004) is very similar to the waveform for the post-op recording (April 2005). An example of this is shown in Figure 8.11.

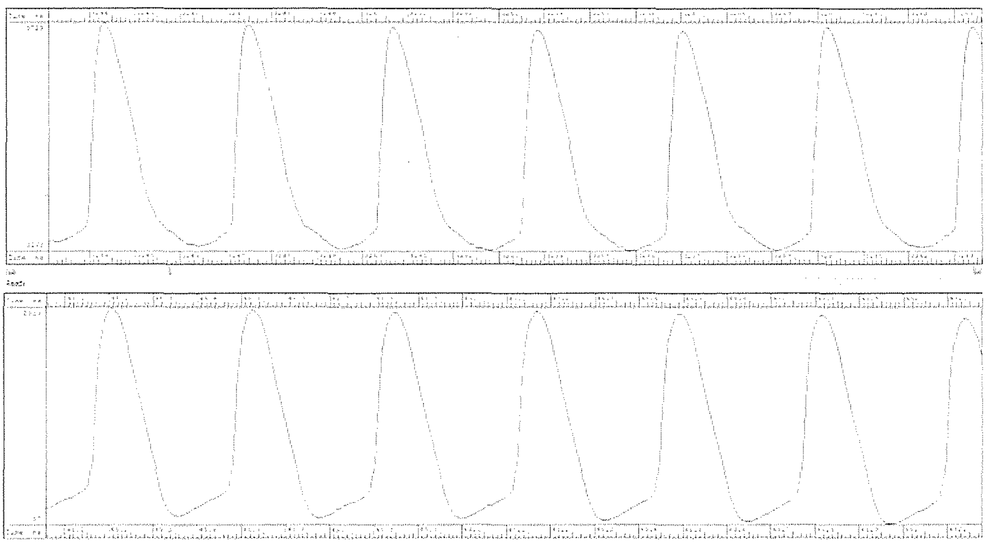
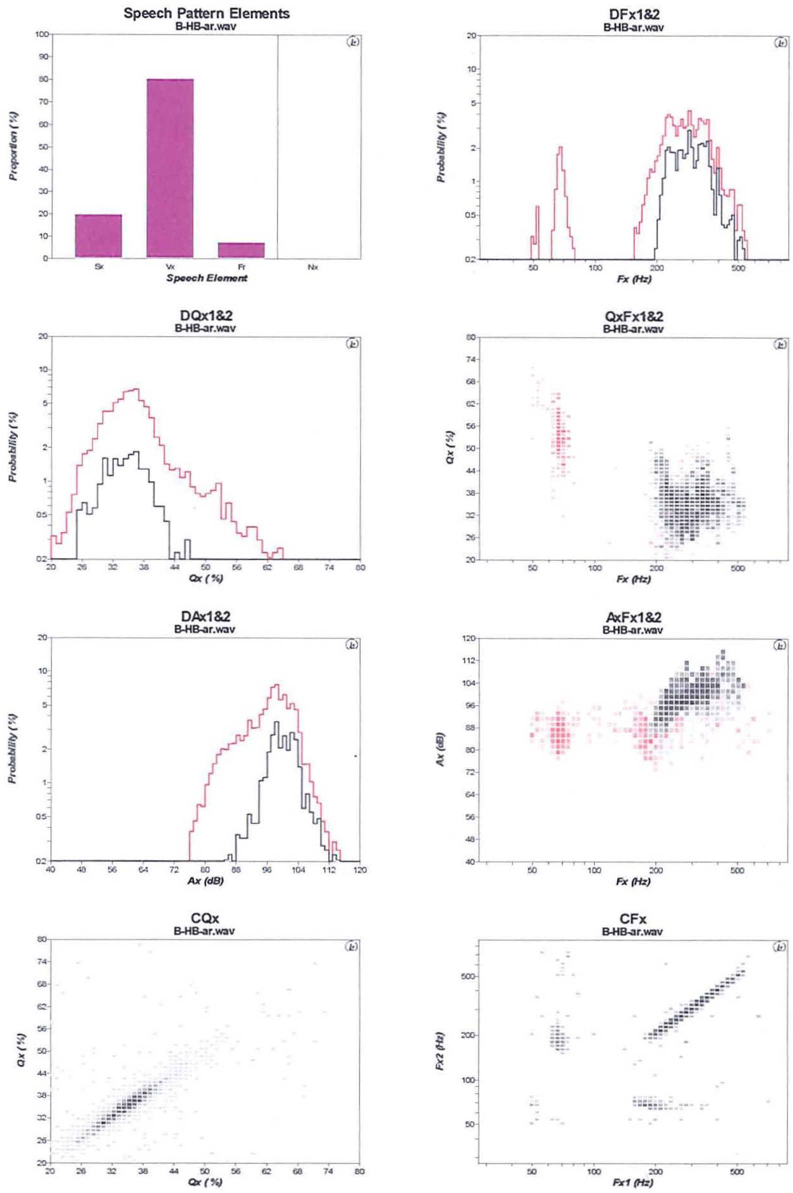


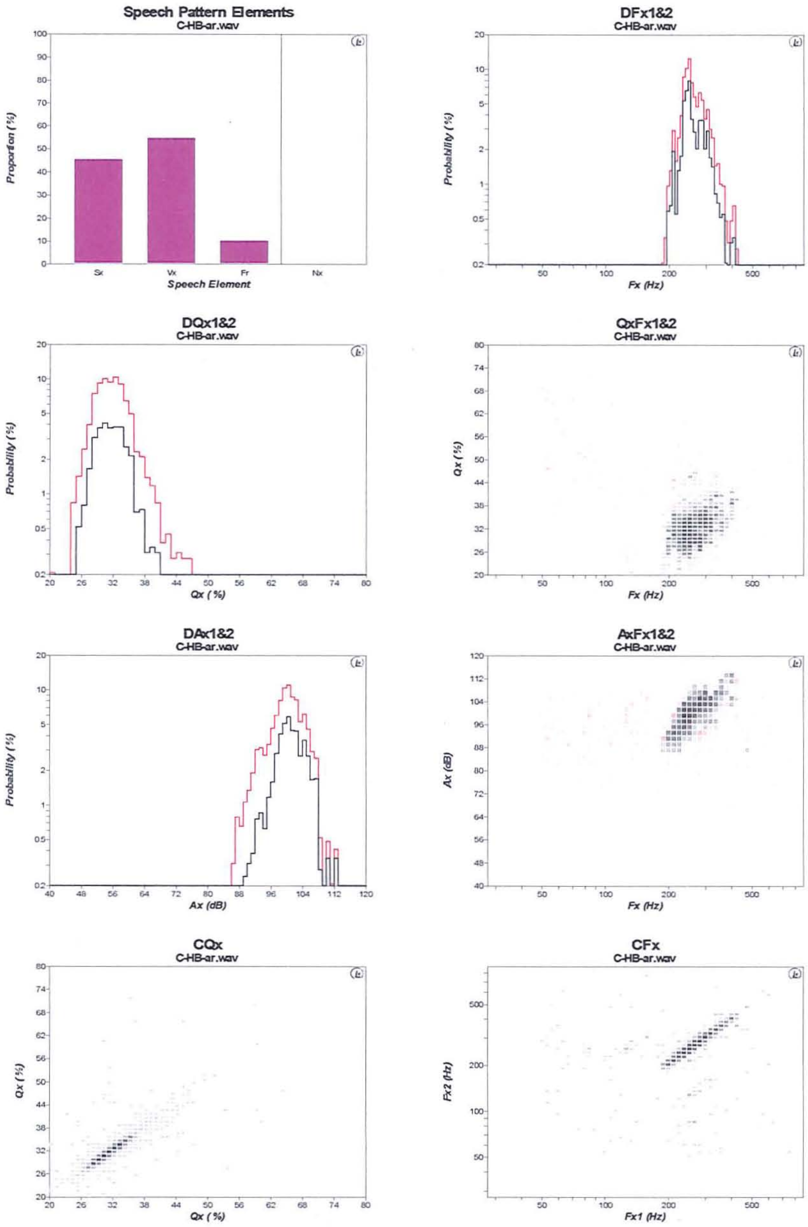
Figure 8.11 A comparison of the Lx waveform for pre-op speaking (upper) and post-op speaking (lower)

Figures 8.12 to 8.14 are the Speech Studio analyses of Jake's speaking voice (connected speech from 'Arthur the Rat'). There is evidence of fundamental frequency irregularity in the top right-hand graph in Figure 8.12, observed as a noticeable part of the graph occurring as a pair of red peaks in the lower frequencies, 50–100Hz. This would be generated by occasional isolated vocal fold collisions as a result of moments of diplophonia (see Figure 4.17). Figure 8.13 still has evidence of irregularity: the DFx1&2 graph shows a narrower pitch range and more of a peak to the distribution. On comparing this with the same plot n Figure 8.14, the distribution of the frequencies after the cyst removal has a more even spread. The QxFx1&2 graph in Figure 8.13 shows an upward slope to the lower edge of the graph. As the frequency rises, the degree of vocal fold closure also rises. In Figure 8.14, the distribution is more even, showing a more regular pattern of vocal fold closure over the full range of frequencies. This appears to back up the assessment of the judges, that the voice after the cyst removal was functioning in a more healthy manner.



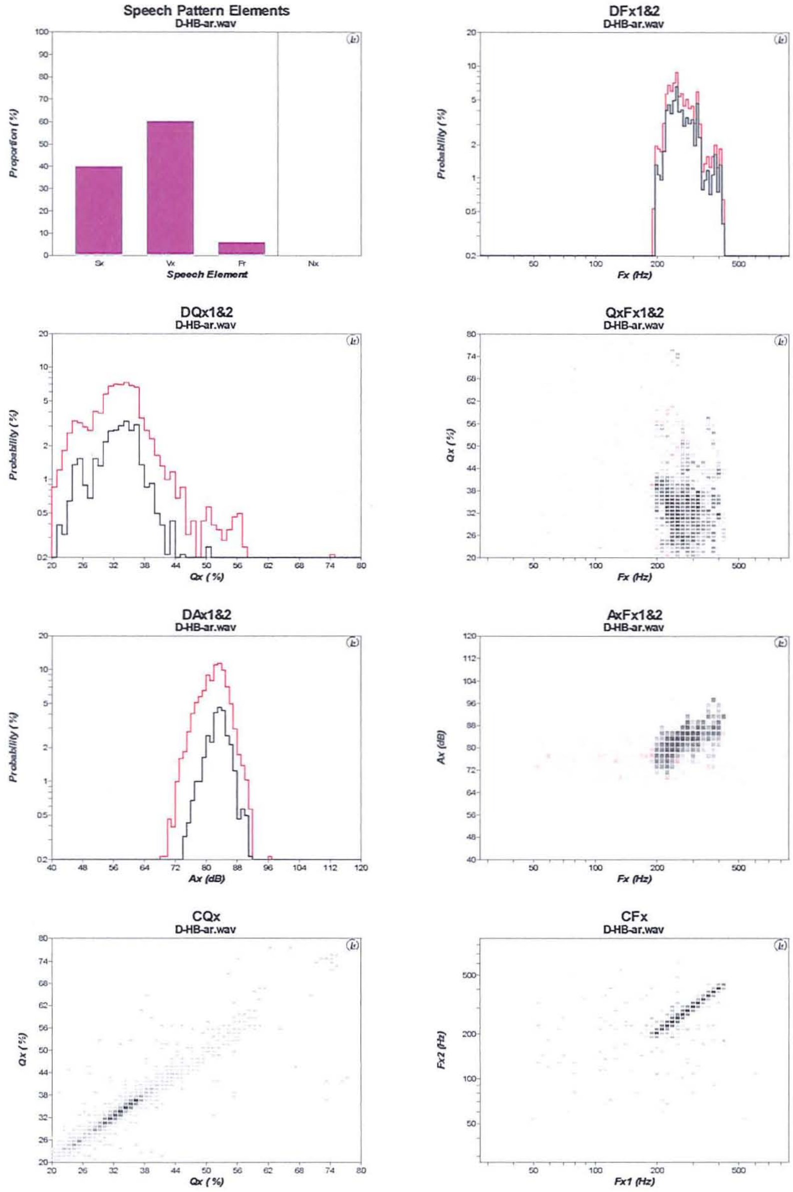
Graph	Samples	Mean	Mode	Median	Std. Dev.	Coherence	80% Range	90% Range	Irreg.
Speech Patt	5236 lements								
DFx1&2 (1)	4339	262.71Hz C4	289.45Hz D4	268.10Hz C4	106.54Hz 0.49 Oct	43.93%	80.0, 396.5Hz 2.31 Oct	67.4, 454.0Hz 2.75 Oct	
DFx1&2 (2)	1906	297.11Hz D4	289.45Hz D4	293.66Hz D4	69.48Hz 0.30 Oct	43.93%	225.5, 400.8Hz 0.83 Oct	216.8, 449.8Hz 1.05 Oct	
DQx1&2 (1)	3753	36.18 %	36.50 %	35.74 %	8.37 %	23.71%	28.6, 48.7 %	26.4, 54.5 %	
DQx1&2 (2)	890	33.69 %	36.50 %	34.70 %	5.03 %	23.71%	28.2, 41.0 %	26.4, 42.9 %	
QxFx1&2	3752					63.89%			
DAx1&2 (1)	4354	94.77dB	98.50dB	97.14dB	7.42dB	31.24%	84.9, 103.9dB	82.1, 106.3dB	
DAx1&2 (2)	1360	98.65dB	98.50dB	99.81dB	5.65dB	31.24%	92.9, 106.2dB	89.1, 108.8dB	
AxFx1&2	4339					55.96%			
CQx	3741								32.74%
CFx	4330								22.90%

Figure 8.12 Speech Studio analysis of the Lx data for the spoken passage ‘Arthur the Rat’, May 2004



Graph	Samples	Mean	Mode	Median	Std. Dev.	Coherence	80% Range	90% Range	Irreg.
Speech Patt3821 lements									
DFx1&2 (1)	2888	256.04Hz C4	250.53Hz B3	255.57Hz C4	52.12Hz 0.27 Oct	54.47%	217.9, 321.3Hz 0.56 Oct	203.2, 347.8Hz 0.78 Oct	
DFx1&2 (2)	1573	259.46Hz C4	250.53Hz B3	254.77Hz B3	38.66Hz 0.20 Oct	54.47%	227.5, 318.5Hz 0.49 Oct	211.9, 341.4Hz 0.69 Oct	
DQx1&2 (1)	2519	31.27 %	32.50 %	31.80 %	4.55 %	37.51%	27.8, 36.9 %	26.6, 39.5 %	
DQx1&2 (2)	945	30.85 %	30.50 %	31.63 %	3.26 %	37.51%	28.1, 35.7 %	27.1, 37.4 %	
QxFx1&2	2519					72.33%			
DAx1&2 (1)	2889	98.66dB	100.50dB	100.13dB	4.95dB	46.49%	93.0, 105.4dB	90.9, 106.8dB	
DAx1&2 (2)	1343	99.94dB	100.50dB	100.85dB	4.08dB	46.49%	96.0, 105.9dB	93.4, 107.3dB	
AxFx1&2	2888					69.25%			
CQx	2518								18.00%
CFx	2888								6.52%

Figure 8.13 Speech Studio analysis of the Lx data for the spoken passage 'Arthur the Rat', November 2004



Graph	Samples	Mean	Mode	Median	Std. Dev.	Coherence	80% Range	90% Range	Irreg.
Speech Patt3290 lements									
DFx1&2 (1)	2810	263.40Hz C4	250.53Hz B3	259.84Hz C4	56.04Hz 0.28 Oct	67.65%	217.0, 351.1Hz 0.69 Oct	202.5, 385.9Hz 0.93 Oct	
DFx1&2 (2)	1901	268.01Hz C4	250.53Hz B3	263.11Hz C4	49.06Hz 0.24 Oct	67.65%	222.5, 351.7Hz 0.66 Oct	213.3, 385.6Hz 0.85 Oct	
DQx1&2 (1)	2675	32.87 %	34.50 %	33.20 %	7.85 %	36.15%	24.9, 42.1 %	23.3, 49.5 %	
DQx1&2 (2)	967	32.14 %	34.50 %	33.24 %	6.02 %	36.15%	25.4, 39.1 %	24.1, 42.1 %	
QxFx1&2	2674					80.85%			
DAx1&2 (1)	2813	80.88dB	83.50dB	82.27dB	4.24dB	31.21%	76.3, 86.7dB	74.6, 88.4dB	
DAx1&2 (2)	878	82.13dB	83.50dB	83.29dB	3.65dB	31.21%	78.4, 87.2dB	76.8, 89.1dB	
AxFx1&2	2810					78.68%			
CQx	2672								21.44%
CFx	2811								4.88%

Figure 8.14 Speech Studio analysis of the Lx data for the spoken passage 'Arthur the Rat', April 2005

When comparing the laryngographic analysis of the voice from May 2004 to April 2005, there are also noticeable differences in in speech elements. At the time when Jake's score for perceived dysphonia was at its highest, November 2004, he was using far shorter voiced elements, relative to the unvoiced, such as consonants. This can be seen as the differential between the first column and the second column in each of Figures 8.15 to 8.17. The middle recording, scoring the highest for perceived level of dysphonia from all ten judges, has a noticeably reduced proportion of voiced elements (Vx) and an increased proportion of unvoiced (Sx).

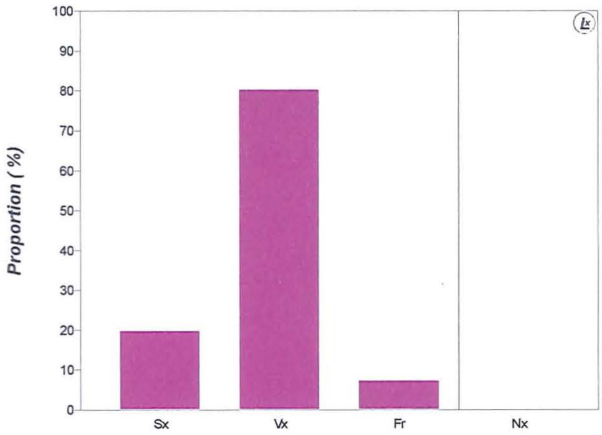


Figure 8.15 Speech Elements May 2004

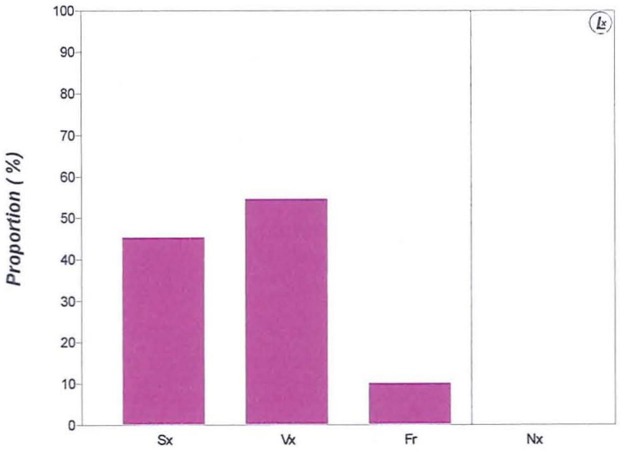


Figure 8.16 Speech Elements November 2004

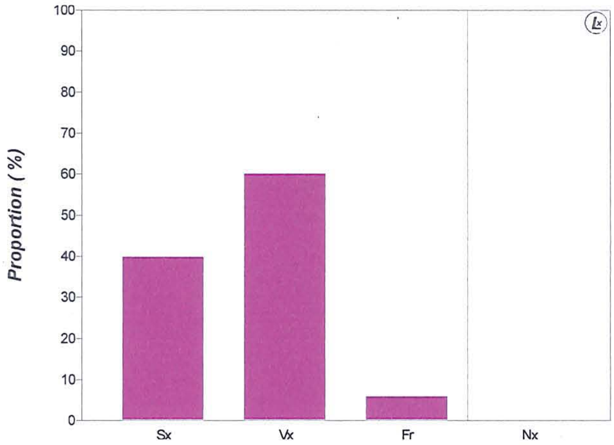


Figure 8.17 Speech Elements April 2005

8.8 Follow-up interview September 2008

Jake was interviewed at home more than two years after he had left the cathedral choir. During this time he had not been singing; he had focused his musical attention on his instrumental playing, at which he was becoming increasingly successful. The interview material from Jake gives insight into his own interpretation of his career as a chorister with some happy memories and a few regrets.

Jake's home background appeared to be completely normal and balanced, if a little chaotic. Both parents were professional musicians and so were aware of the demands of the performer's lifestyle. The author made one visit to his house on the occasion of the interview in 2008. On knocking, the front door could not be opened. After some pushing and shoving, the accumulated debris from the day before was pushed aside to allow enough room to squeeze through the doorway. During the visit Jake's mother had to rush to the shops with his younger sister as she had lost one of her new shoes and was due to start school in one hour. Jake, by now a somewhat monosyllabic teenager, was interviewed at length and was more than happy to try out some singing, having not done so for two years.

When asked how he remembered his voice in the period of illness leading up to his operation he said it had been:

> "…groggy, it's just stuffy, it didn't come out, not very good, basically. It was quite frustrating because, like, I was off singing, like, a lot, and um, they were doing good music and so, I had to sit out." (Track 8.18)

As a result of the operation, his voice felt:

> "…a lot easier, definitely, to sing and the actual sound was probably clearer and it felt a lot better to sing" (Track 8.19)

One of the main reasons for seeking out a follow-up interview was to ask him why he had stopped singing in the choir. In the early part of his chorister career, he had always been so eager to please; in fact, this had often led to him employing a singing technique with a great deal of strain and constriction, in order to achieve a strong sound. Considering how easy he felt his singing to be after the operation, it would have seemed that he would have wanted to use this voice to its full, for as long as he was able. During the recording in October 2005 it was evident that Jake's voice was starting to undergo the early stages of adolescent voice change. He was, however, still able to sing comfortably with his upper pitch range and could have continued to do so until the end of the academic year, and the end of his time as a chorister. He demonstrated this, somewhat reluctantly, in the recordings made in March and July 2006. It was apparent that he had exaggerated the symptoms of voice change in order to excuse himself from the choir.

When asked what had happened; why such an enthusiastic chorister had chosen to take this route, his response was an honest self-examination.

> "Well, all my friends were, like, when evensong was on, they got to stay in the common room and play pool and watch TV. You got more time, a lot more free time because you could do your homework then and then when everyone else was doing their homework you didn't have to do it really, and if you get everything done early and have the evening, basically. And the biggest thing was, um, that you were allowed to go home on Fridays, so you could spend the weekend at home which was appealing – yeh? But I probably should have just stayed there and stayed on because it would have been a lot better, and, yeh, I kind of feel, uh, a bit regretful. I regret the decision that, yeh, at the time, it was, I thought it was the right thing to do. So I

> knew, I'd sort of done everything that you would do if you were head chorister and so, I thought, there wasn't much more like, it could offer, really. I don't know, something probably just went, clicked in my head or something, dunno, something just went wrong, or I changed or something, I dunno." (track 8.20)

He then tried to sing again, having not done so for two years. A nascent tenor voice emerged, with all the musicality from his chorister training (track 8.21). He then said that he would resume singing and give it another try.

8.9 Summary

There appear to have been three distinct phases in Jake's chorister career. In phase one (up until the summer of 2005) he was generally healthy, but with some vocal tension probably due to his eagerness to do well. The cyst was not obviously evident in the sound, although low levels of disorder were present throughout. In stage two, in 2005, he was falling into chronic ill-health due to tonsillitis (and possibly the cyst), not necessarily as a result of voice use. He then underwent surgery to remove both his tonsils and the vocal fold cyst. He made a total and spectacular recovery, resulting in a singing voice that was perceived to be easier and clearer than he had ever had before. The final stage of Jake's time as a chorister saw him entering adolescence. This not only involved physical developments to his singing voice, but also introduced emotional and social changes. There were situations in which he found himself choosing to socialise with his friends instead of participating in the choir, despite having been such an enthusiastic member when younger.

Chapter 9

Discussion of results

9.1 Introduction

This study was not only multi-method and multi-site, it was also multi-disciplinary. As primarily an educational study, it drew heavily on information from anatomy and physiology of the voice; this was dependent on information from medical and clinical settings. It relied on assessment methods from the fields of both acoustics and statistics. It was influenced by information from psychology and music, and was deeply embedded in a specific cultural and historic environment.

As such, it may appear to be generalist in its baseline level of assessment and analysis. This is an essential factor in an exploratory study of this type: it will enable further studies to probe the subject in greater depth and with more attention to detail. This chapter will summarise the findings from the data analyses, discuss matters arising and suggest further areas for study.

9.2 Use and development of assessment methods

9.2.1 Perceptual assessment methods

The assessment methods used in this study seemed to fall into several groups. The first was a means of assessing the overall health and behaviour of each voice. This was generally a perception of vocal health, primarily at the level of phonation. This method enabled broad comparisons to be made, analysing the possible links between school environment, choral activity, age and personality type on the basic vocal health of each boy. The most effective method evolved for this task emerged as the single-score VAS rating (see 5.8.3). Single-score assessment methods have been used in several published research projects on the health of children's voices (McAllister et al., 1998; Sederholm, 1995, 1996a, 1996b; Sederholm et al., 1995; Sederholm et al., 1993).

The second was a means of analysing vocal behaviour in much more detail. This enabled more specific longitudinal analyses of the vocal behaviour of individual boys. The most effective method that evolved for this task was the use of combined groupings version 2 (see 5.6.2), arising from the VPA rating system (see 5.6). This method is in current clinical usage, but has not yet been considered, it its finished format, in any published research.

The third was the use of acoustic measurements, primarily the LTAS and the Lx waveform. This enabled the perceptual analyses to be checked against other analysis methods, and it facilitated detailed measures of glottal closure patterns. Acoustic analysis of this sort is very common in published voice research, and has been used in research on children's voices (McAllister et al., 2000; McAllister et al., 1994; McAllister et al., 1998; Pedersen, Møller, Krabbe, Bennett, & Svenstrup, 1990; Rammage & Sakeld, 1994).

9.2.2 Spectral analysis of voice

For this analysis, the method used was observation of the spectral section of the Long-term Average Spectrum (LTAS) (Sargeant & Welch, 2008; P. J. White, 2000). This graph gives an appropriate visual representation of the sound perceived by the ear for a given period of time. It is possible to note the strength of the fundamental frequency, and the relative excitation in the upper frequencies. This provides evidence contributing to our evaluation of vocal quality and implied efficiency (in terms of acoustic output). This output is enhanced by rapid and complete vocal fold closure with each cycle, and by the resonant properties of the vocal tract. These contribute to any 'ringing' quality in the voice (Howard & Williams, 2009). From the LTAS it was possible to infer aspects of vocal health in terms of vocal quality and implied efficiency.

The LTAS of voices with specific elements of phonatory behaviour was observed. Those with perceived creaky voices showed higher levels of 'noise' in the upper frequencies generated by air escaping through the glottis. Noise was represented by an increase in the spectral energy in the upper frequencies not related to the harmonic spectral energy. Breathy voice also showed higher levels of 'noise' in the upper frequencies for the same reason as the creaky voice; the breathy voice was also considerably weaker perceptually than the healthy voice. Harsh voice had a similar profile to healthy voice, but was noticeably weaker in amplitude, as measured by a comparison of the calibrated sound pressure level reading for each recording.

These observations were all entirely consistent with the research literature on voice assessment using LTAS. Not all two hundred recordings had LTAS analysis. The recordings used had been specifically selected; they were examples of voices which had been given a particularly high perceptual rating on, for instance, breathiness, and a relatively low rating for the other main phonatory behaviours. Recordings of voices which had been given a particularly healthy score were also selected as comparison examples. The evidence for the existence of the perceived phonatory behaviours was confirmed in each case by the evidence in the LTAS.

9.2.3 Electrolaryngographic voice source analysis

The analysis of the laryngographic (Lx) data provided complementary information to that of the LTAS assessment. All voice perturbation measurements tend to vary with both pitch and loudness (Pabon et al., 2000). There are problems associated with these measurements as they can be affected by the recording equipment, sampling frequency and method of F_0 extraction (Karnell, Scherer, & Fischer, 1991). Voice source analysis has been shown to be a relatively robust method of vocal assessment (Howard et al., 1990).

The Lx data was analysed both as observation of the Lx waveform, and also using Speech Studio. The irregularities observed in the chosen examples of phonatory behaviour were all consistent with the existing literature on adult voice assessment (Abberton et al., 1989). Creaky voice showed significant irregularity in the cycle by cycle vocal fold closure. Breathy voice showed a notable irregularity in cycle by cycle amplitude measurement (shimmer). Harsh voice showed irregularity in both shimmer and vocal fold closure.

9.3 Findings concerning research question 1: what is the vocal behaviour of boys who experience an intensive, performance-focused training?

9.3.1 Measures of phonatory behaviour

The five parameters derived from Shewell's VPA system (see 5.6) were able to be reduced as a result of correlation and principal component analysis (see 6.2.1). *Whisper* and *asthenia* were observed to be mutually dependent. This appears logical, as whisper reduces the glottal efficiency and, therefore, reduces the ability to project the sound. It would be possible to have an asthenic voice without whisper, but this was not observed in any of the cases assessed in this research.

Creak and *whisper* appeared to be mutually exclusive. Again this fits current understanding of phonatory behaviour: *creak* involves a specific type of vocal fold, and sometimes false vocal fold collision, *whisper* involves very little direct vocal fold contact. For *creak* and *whisper* to happen simultaneously, the phonation would be extremely dysphonic. Although possible, it was unlikely that this level of dysphonia would be found in a cohort of 'normal' boys.

On comparing the various measures of phonatory behaviour used, the results from all of them had a strong correlation with each other; the vocal fold contact derived from the combined ratings in the VPA system, the single-score EAIS rating and the single-score VAS rating had significant correlations with each other. These results are shown in Table 9.1. The strongest correlation was between the EAIS rating for speaking voice and the VAS rating. These were essentially rating the same aspect of voice use from the same perspective, the only difference was the type of rating scale used.

Table 9.1 Correlation between the outcomes of the three main methods of perceptual analysis

		Health of speaking voice	Health of singing voice	Vocal fold score
Mean score from 10 best judges	Pearson Correlation	.640(**)	.532(**)	.377(**)
	Sig. (2-tailed)	.000	.000	.000
	N	119	108	119
Health of speaking voice	Pearson Correlation		.608(**)	.480(**)
	Sig. (2-tailed)		.000	.000
	N		112	124
Health of singing voice	Pearson Correlation			.378(**)
	Sig. (2-tailed)			.000
	N			112

** Correlation is significant at the 0.01 level (2-tailed).

These correlations show that any of these measures is robust enough to be used in analysis; there is a significant relationship between all of them as measures of vocal health.

9.3.2 Measures of muscular tension in the vocal tract

Principal component analyses of these ratings suggested that these measures seemed to fall into three specific groups (see 6.2.2).

- Group 1: **Vocal Tract Constriction** *(Laryngeal constriction, General supra-laryngeal tension, Pharyngeal constriction and Minimised jaw movement)*

  These are all muscles which are involved principally with swallowing (Greene & Mathieson, 2001). It is likely that they will act together as a group unless specific isolatory behaviour has been learned by the individual.

- Group 2: **Tongue Tension** *(Tongue backing* and *Laryngeal lowering)*

  The tongue root has its insertion on the hyoid bone, the top of the larynx (Netter, 1997). The backing of the tongue will have a direct affect on the height of the larynx.

- Group 3: **Velar** *(Nasality)*

  This aspect of muscular tension stands alone from the other factors.

There was a strong link between the degree of *harshness* and the degree of *laryngeal constriction.* This relationship is also acknowledged in voice pedagogy (Chapman, 2006), but has not yet been documented in child voice pedagogy.

A significant link was shown between high subglottic air pressure (*pushed breath*) and *harshness,* but not *whisper.* This may indicate that in boys' voices, breathy phonation is not as a result of over-working the breath supply, but is possibly more likely to be as a result of vocal fold oedema.

9.3.3 Measures of vocal skill and maturity

There were also links and groupings relating to vocal skill and development over time. These are described in 6.2.3. The results of the factor analysis on all of the categories of voice skill and development suggested that these could be summarised by the categories **Vocal Skill, Junior Voice** and **Voice Change**. The group **Vocal Skill** deals with all issues to do with pitch control and pitch range. These are skills observed to develop in the boys' voices over time (see 7.3.2). **Junior Voice** illustrates aspects of vocal behaviour evident in the younger voices and will give an idea of vocal maturity. **Voice Change** covers vocal behaviours which emerge as the boy enters adolescent voice change. The scorings on these sub-categories would give an indication of any onset in voice change, and the degree to which this may have progressed.

9.3.4 A revised Voice Profile Assessment form

As a result of these observations, a revised version of the VPA form for use with children and, in particular, trained child singers, is proposed. This is illustrated in Figure 9.1. It may appear that certain important sub-categories have been omitted, such as *Laryngeal Constriction* or categories referring to *Loudness* or *Breath Management.* However, the results of the factor analysis in Chapter 6 has shown these categories are likely to be covered by other, co-dependent categories, or to be not as significant in the assessment of young singers' voice use as those categories that are included.

Voice Profile Assessment in Singing

Context	Type of measure	Category	Normal/ Neutral	Sub-categories perceived as *'non-normal'* features	1	2	3	4	5	Comments (e.g. singing *vs* speech)
Observations in performance ☐	Measures of muscular tension in the vocal tract	Phonation Type		Harshness						
				Whisper						
				Creak						
Observations in rehearsal ☐		Velo-pharyngeal		Nasal						
				Denasal						
		Excess tension		Pharyngeal constriction						
				Jaw – minimised range						
Observations in special test ☐		Tongue		Lisp						
				Backed						
Observations from recording of special test ☐	Measures of vocal skill and maturity	Vocal skill		Pitch stability						
				Wide range						
		Junior voice		High pitch mean						
				Narrow pitch range						
				Easy passaggio management						
		Voice change		Modal-falsetto in speech						
				Pitch instability						
				Low pitch mean						
				Upper passaggio obvious						
				Lower passaggio obvious						
Other comments										
Health										
Self rating of voice										
Vocal ability/progress in choir										

Figure 9.1 Revised Voice Profile Assessment form for use with children and especially trained child singers

The revised form gives a more extended scoring range for the perceived degrees of each category; these range from 0 to 5, rather than from 0 to 3. If these scorings are to be used in statistical analyses, a greater range of scores will enable a higher change of significant statistical agreement or disagreement (Pallant, 2007).

The author suggests that, based on the fieldwork experiences, this revised form is simple and easy to use; it does, however, contain all of the important vocal categories and sub-categories with which to make a full and detailed analysis of the vocal behaviour of a child.

9.3.5 Influence of personality type on voice use

The analysis of the L test scores was in agreement with the findings of Eysenck (1964), in that the scores were inversely related to the age of the individual. The relationship between the other personality factors and voice use were not directly conclusive. This is most likely because specific personality types are only contributory factors to the whole picture. When individual cases were looked at, the boy with the highest rating for perceived vocal dysphonia had a correspondingly high score for Neuroticism (22), an average score for Extroverion (19) and an unusually low score for Psychoticism (4). Most individuals have scores lying towards the centre of the scale. The score for E tends to lie, on average, between 17.5 and 19 (out of a possible 24) for boys of ages seven to thirteen, with a tendency to be slightly higher in the older boys. The score for N tends to lie, on average, between 10 and 10.5 for boys of ages 7 to 13. In the case of this boy, the high score for Extroversion and the low score for Psychoticism may indicate that he has some inbalance in his personality traits. This is a possible contributory factor to voice disorder (Brandell, 1982; Glassell, 1972). The boy with the next highest rating had a high score for the E(22) test, but not N(7) or P(2). In this case also, the boy has one unusually high scoring trait and two unusually low scoring traits. A link between high scores for N and E has been shown in dysphonic children's voices (Sederholm, 1996a). It could be said that these high scores had a contributory influence on the perceived dysphonia in the voices of these boys. It does not necessarily follow that *all* boys with high scores in these personality types will develop dysphonic voices. High (or low) scores in these personality aspects can have positive or negative outcomes for the individual.

These observations have several functions. They confirm that certain aspects of vocal behaviour which have been documented in literature relating to the adult voice can also be applied to the boy's voice (Baker, 2003; Butcher, Elias, & Raven, 1993; Greene & Mathieson, 2001). They also confirm that information relating to children's voices in general can also be applied specifically to the highly skilled child voice user.

The results of this study also provide information on vocal health assessment methods for this number of individuals. It would appear that for the purposes of detailed overview, whether or not statistical analysis is required, a single-score VAS rating gives the most useful data.

9.3.6 Inter and intra-judge reliability ratings

Judge reliability is a measure of consistency. Inter-judge reliability is a measure of the consistency of ratings given between judges, intra-judge reliability is a measure of the consistency of ratings given by one judge. The way in which intra-judge reliability has been measured in this study is using the test re-test design. In this, a selection of the recorded samples was chosen to be repeated. These repeated stimuli were randomly distributed among the other stimuli. The listener had no idea where these may be, nor even that there were repeated stimuli. The score given to the first hearing (test) was compared with the score given to the second hearing (re-test).

All three of the inter- and intra-judge tests produced acceptable results. The perceptual judgments were somewhat inconsistent, despite the expertise and experience of the individual judges selected.

The first inter-judge reliability test (reported in 6.3) shows that the scoring of vocal health from each of the judges was consistent with those of Judge JW. These were illustrated in Table 6.14. The agreement is not particularly strong, and the judges who repeated the tests were not necessarily in agreement with themselves. The two judges whose experience had been from a pedagogical background were in agreement with each other and with the Author, JW. The remaining judge was not in agreement with any of the other judges: she was much younger, had come from a research background and may not have had the same level of practical experience in analysing children's voices as the other three judges. The main purpose for obtaining scores from a panel of assessors was given in 5.1.2. The validation from the first inter-judge reliability test assessing ten boys gave credence to the assessment scores given for all the remaining boys, judged only by the author, Judge JW. These scores were subsequently used for a whole range of statistical tests described in Chapter 6, with the resulting revised assessment protocol illustrated in Table 9.2. That is, there was intra-judge consistency in the assessments by JW and, in general, these accorded with two of the three judges involved (i.e., three of the four judges demonstrated a general agreement).

The second judge reliability test (reported in 6.5) was both inter-judge and intra-judge. The discrepancy between test and re-test was evaluated and the five most unreliable judges were eliminated from the comparisons. The inter-judge reliability was then calculated and the correlation between the best eleven judges and Judge JW was $r = .617$, $p<.014$. This was significant enough to suggest that the assessments of Judge JW in the EAIS ratings were reliable for the remaining assessments of the one hundred-and-eighty recordings which had not been selected for the four judges.

As an offshoot of these intra-judge reliability tests, it was observed that those judges who were also singing teachers were the most consistent with their scorings, followed closely by those who were experienced speech and language therapists (i.e., of more than five years' experience).

The third judge reliability test used the results from the panel of judges for the VAS rating (reported in 6.6). As there were seventeen re-test stimuli, it was possible to calculate the value of R^2. This is a more reliable test of intra-judge reliability and ranged from the most reliable with an R^2 of 0.84 to the least reliable with an R^2 of 0.01. The average reliability in the literature reported tends to hover around 0.30 (Fiske, 1994); the average reliability of all the judges in this exercise was 0.33. This test suggested that Judge JW was the most consistent with her scorings.

When comparing the ten best judges who participated in the VAS ratings, we can see in Table 9.2 an agreement between them. Kendall's W is .293 and Chi-Square is 463.504.

Table 9.2 Inter-judge agreement in VAS ratings

	Mean Rank		N	198
Judge 1	4.84		Kendall's W(a)	.293
Judge 2	4.07		Chi-Square	463.504
Judge 3	3.26		Df	8
Judge 4	3.22		Asymp. Sig.	.000
Judge 6	7.59			
Judge 8	6.63			
Judge 10	5.30			
Judge 11	5.71			
Judge 15	4.38			

a = Kendall's Coefficient of Concordance

9.4 Findings concerning research question 2: how does such behaviour change over time?

The behaviour of the main group of chorister voices was evaluated over the three-year period of the research project. This gave some insight into the progress of the boys' vocal health and behaviour, both individually and as a general trend of the cohort. The boys chosen for this assessment fell into two age groups: the first were the younger boys new into the choir, the second were the boys in school year 6 (aged ten to eleven years) who were assessed until they left the choir at the end of year 8. The age of the younger group at the end of the study was the same as the age of the older group had been at the outset; this enabled an overall pattern of changes for the entire duration of a chorister career to be modelled.

9.4.1 Longitudinal analysis of selected vocal behaviours – Vocal fold contact, supralaryngeal tension and pitching accuracy

With vocal fold contact, the efficiency was measured by a combination of selected vocal attributes and behaviours grouped from the initial voice profile analysis. This incorporated evaluations of harshness, whisper and creak in the voice. The vocal fold inefficiency score dropped in the middle of the age span (ages ten to eleven) as the scores increased slightly, and ended with the scores falling again. This trend is also observed in the measures of supralaryngeal tension. The general levels of muscular strain are greatest for the boys in the middle of the chorister age span. A hypothesis for this could be that the voice becomes tired as the vocal loading and responsibility increases with age. However, as the boy reaches the age of twelve or thirteen, the larynx has grown to accommodate a stronger musculature, resulting in increased stamina. The singing technique of the boy also improves to accommodate this, resulting in an increase in efficiency in the latter years. An additional factor may be that with the onset of adolescent voice change, the boy is often required to retire from singing the treble line in the choir; this will result in a decrease of vocal loading. As these choristers continued to perform successfully it may be that the slight changes that were observed related to maturation and pre-adolescent voice change in the ongoing growth of the voice source and surrounding structures (Titze, 1994).

In the measures of pitching accuracy, the scores seem to show a general improvement over time as the boys became more skilled; this dropped off markedly with the onset of voice change. The rapid growth of the larynx would result in these skills becoming less easy to manage (Malina et al., 2004).

These results are not surprising. They do, however, suggest that the methods of data collection and measurement were robust enough to demonstrate these somewhat expected results. Nearly all of the results confirmed the expectations whch may be present arising from knowledge of the existing literature on children's voices.

9.4.2 Longitudinal analysis of overall vocal health

The results illustrated in Figure 6.13 suggest that there is a relationship between the amount of vocal rest and the score for perceived vocal dysphonia. When the boys were recorded at the end of a two-week break, their mean score for perceived vocal dysphonia was noticeably lower. The voice rest which the boys would have had during the holiday time was not complete rest; they would still be using their voice for everyday family activities. The prime differences would be that not only were they not using their voices for singing several hours each day, but that they were also not living with the high noise levels of a boarding school environment. This data pattern supports the notion that relative voice rest is beneficial for vocal health (Davies, 2004).

Another observation concerning vocal health over time is that relating to the onset of adolescent voice change. It was observed in several instances that the voices of boys exhibited aspects of phonatory behaviour associated with less healthy voices as they entered the period of adolescent voice change. It must be assumed that adolescent growth and development is normally a healthy process. Any changes to phonation as a direct result of this likewise have to be considered as healthy phonatory patterns. This raises the question of how the quality of voices in this particular developmental stage should be assessed.

9.4.3 Vocal health and adolescent voice change

The comparisons of Speech Studio analysis of a healthy voice before and during voice change showed some notable differences. Fundamental frequency analysis showed the expected drop in the average F_0 of the speaking voice (Figures 7.16 and 7.17). It also showed a reduction in the pitch range of the speaking voice (as reported by Cooksey, 2000). This could be a social habit – teenagers can be known for their rather monotonal speech delivery (from the personal experience of the author as a teacher of teenage children) – or it could be a result of a less than comfortable adjustment of the pitching mechanism within the larynx as a result of the rapid growth of muscles and cartilages. The amplitude analysis (Figures 7.20 and 7.21) showed a drop in loudness of the voice as well as an increase in irregularity. The vocal fold closure analysis (Figures 7.18 and 7.19) showed a rise in the mean percentage closure, probably as a result of the thickening of the vocal folds enabling a longer closure per cycle. It also showed an increase in closure irregularity.

The potential for misinterpretation during voice change of normal growth for ill-health was evident in the longitudinal analysis of the vocal health scores for the case study, Jake, in Chapter 8 (Figure 8.7). The majority of the judges (all of whom had demonstrated relative consistency in their judgements) perceived the onset of adolescent voice change in Jake's voice as a rise in the perceived level of dysphonia; the aspects of phonatory behaviour would all indicate this to be the case. The only judge hearing this as a more healthy voice was Judge JW. This discrepancy could be due to the fact that this judge had had considerable experience of working with the voices of with teenage boys and had therefore developed an expectation for hearing these phonatory qualities as normal aspects of the voice use of the teenage boy.

All of these aspects of phonatory behaviour, frequency, amplitude and vocal fold closure, are dependent on muscular coordination. As a result of rapid laryngeal growth, the normal pattern of coordination of the intrinsic laryngeal musculature will be compromised in the adolescent boy. The question raised by these observations is that of appropriate assessment of boys at this stage of development. It would appear that the perception of what is healthy or normal needs to be adjusted among voice therapists and pedagogues.

9.4.4 Longitudinal analysis of the Lx waveform

The comparisons of the Lx waveform before and during adolescent voice change did not necessarily show any evidence of the emergence of a falsetto phonation in the upper pitch range at this stage of development. Cooksey states, however, that in Stage lll of voice change, falsetto phonation is evident in the upper pitch range (Cooksey, 2000). It is possible that the technical skills exemplified by the boys at this stage of their chorister careers enable them to undergo the transition with greater continuity. This may give some insight into the way in which professional male altos use a type of hybrid phonation (Tom Harris et al., 1998), using both falsetto and the thin-fold which tends to be associated with the upper pitch range of children and adult females (Doscher, 1994). This is presumably a learned skill, assuming that the individual has some physical aptitude for this thin-fold phonation. Due to the relatively small number of highly-trained choristers assessed in this study, there were only four who were undergoing voice change during the research period. The Lx waveform for each of these four boys was analysed and the same pattern of upper voice phonation was observed. This may not necessarily be the case in all trained choristers, and is unlikely to be the case in less experienced singers.

These findings could inform the practice of singing teachers and choir trainers. The current advice to boys during voice change tends to be to sing in the lowest comfortable pitch range for the duration of this time. These results may suggest that it is possible to maintain a singing voice with a high tessitura, at least for some of the time, during the early stages of voice change, and that the generally given advice may not necessarily apply to skilled boy choristers. This is integral to an ongoing debate between advocates of Cooksey's advice and that of Phillips and Leck. They represent two schools of thought regarding the stages of voice change for males. The first, or "limited range" school believes that boys' voices change predictably, lowering gradually according to a rather prescribed pattern. Irvin Cooper was the originator of this theory (the "Cambiata" concept); two of his students continue to advocate this approach: Don Collins (founder of Cambiata Press) and John Cooksey (the "Eclectic" theory). Cooksey (1992) expands upon Cooper's work and now includes five stages for the male pubertal voice during change. The second, or "extended range" school believes that boys' voices can change slowly or quickly and may not be limited to a midvoice comfort range of an octave or less during puberty. Frederick Swanson was the originator of this school and contemporary advocates include Henry Leck (2009) and Kenneth Phillips (2004). The Cooksey system of five stages may be a useful guide for less experienced teachers and singers. It is relatively simple to grasp, and it is unlikely to be misinterpreted. The 'extended range' school may be more applicable to experienced boy singers, who may have a larger accessible pitch range. This would need further research before it could be assumed to be sound pedagogical recommendation.

It is also interesting when cultural and historical perspectives are considered. There are a number of early recordings of boy singers using their upper (soprano) pitch range with a high level of vocal artistry and skill (Beet, 1998). Some of these boys were mid- or post-puberty: this can be heard on the one or two rare spoken interviews with them. Track 9.1 on the CD had a short spoken passage from Robin Lough in 1960, at the age of 14. This gives his average speaking F_0 at about 160Hz (E3/Eb3) which places him at Cooksey Stage lll of voice change – mid-way through (Cooksey, 2000). He is then recorded singing soprano. There is also a recording of him made two years later (Track 9.2), when he must have been a fully-fledged young baritone, also at this time singing soprano. It is possible that some boys are able to retain their soprano voices whilst their larynx is growing in power and stamina, especially if these early phases happen relatively fast. The boys on these recordings were reported to have stopped singing when their voices 'broke' (often at the age of 17 or 18). As this event came some time after they had undergone adolescent voice change (probably at the age of 14 or 15), it is only possible to conjecture what may have precipitated this 'breaking' and what was happening physically. It is conceivable that the reported 'breaking' was a sudden inability of the laryngeal structures to sustain this thin-fold phonation as the larynx became less pliable in early adulthood. At the time of writing, maintaining the practice of singing in the soprano range after the onset of voice change is not generally popular amongst boys. There is no evidence to suggest whether or not this could be potentially harmful physically in terms of vocal habits persisting into adult singing.

9.5 Findings concerning research question 3: is the nature and incidence of perceived vocal dysfunction different in choristers from what might be found in boys of a similar age and school environment?

9.5.1 The boarding school

The graphs produced using Excel, shown in 6.4.3, show clearly discernible trends across the four activity groups. Firstly, the data reported in Figure 6.5, suggested that the boarding environment may have contributed to a higher level of voice disorder. This finding agreed with the current literature (Casper et al., 1981; Sederholm, 1996a) referring to the increased likelihood of voice disorder in children who spend a large part of each day in noisy surroundings. Anecdotally, anyone who has been into a school dining room, for example, will have observed that the level of background noise in the school environment is particularly high during mealtimes and playtimes. Individuals trying to make their voices heard above this noise will be using more vocal effort, higher intensity and a greater force of vocal fold collision. All of these factors are contributory to the development of vocal disorders. For children attending a day school, their environment changes when they leave school at the end of the day (normally between 3.30 and 4.30pm). They are more likely to go to homes which are quieter than school. In a boarding school, individuals may be in noisy environments for a much greater part of the day. These data in Figure 6.5 show a higher incidence of vocal dysphonia in the non-chorister boys attending boarding school, and suggest the possible effect of this environment on the level of perceived voice disorder.

9.5.2 The chorister activity within this environment

Choristers are known to have a higher vocal loading than non-choristers (see 1.3.1). Boys in a boarding environment have been observed to have a higher incidence of perceived dysphonia (see 8.5.1). The comparison illustrated in Figure 6.8 suggests that, despite these two factors, choristers in a boarding school have a lower incidence of perceived dysphonia than their non-chorister counterparts. This suggests either that they have developed a strategy (likely other-than-conscious) for preserving their vocal health and/or their regular singing activities strengthen the vocal mechanism sufficiently to withstand better the acoustic demands of the boarding environment. (For further elaboration of this, see 9.5.7 below)

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9.5.3 The potential influence of peer-group

Figures 6.13 and 6.16 indicate the relationship between the perceived degree of dysphonia of the two groups of boys attending the London choir school. These boys have different living environments (boarding and home) and different activities (chorister and non-chorister). Despite this, the two curves implied by the chart are more similar than for any of the other comparison groups. A hypothesis for this is that the social environment (i.e., everyday school activities, 8.45am to 3.30pm) of the boys was the most powerful influence of all, and that they adapted, like a chameleon, to mirror the voice use most dominant in the group, regardless of other influences (Wiltermuth & Heath, 2009).

9.5.4 Non-boarding choristers

Figure 6.7 shows that the non-boarding choristers have a significantly higher level of perceived dysphonia than their boarding school counterparts. This was consistent with the author's observation while recording them. Following discussion between the author and both their singing teacher and choral director, some possible reasons for this were suggested.

1 The London boys could have been more rigorously selected for chorister places. This has since been discounted as a result of the evidence shown in Table 9.3.

2 The provincial boys were from families in a very wealthy area who have a tendency to encourage their children to participate in very many activities. The boarding choristers had a set timetable with limited activities; most importantly, they were always in bed early on the night before a demanding singing day. It was suggested by a member of staff at the school, that some of the non-boarders may have had more chaotic home lives, packed full of other activities and often with late nights. Personal communication from their singing teacher suggested that they were often extremely tired as a result of their other activities.

3 The choir trainer for the boys from the provincial cathedral choir had a speaking voice with a noticeable degree of pharyngeal constriction. They could have been subconsciously mirroring this.

A further study may indicate that if boys are to experience an intensive chorister training, they are better provided-for in a boarding environment as this will give a complete weekly schedule appropriate to their vocal requirements.

9.5.5 Singing voice observations

In general, the choristers (both boarding and non-boarding) showed lower levels of perceived dysphonia in their singing voices than in their speaking voices; non-choristers (both boarding and non-boarding) showed the reverse. When the choristers are using their voices for singing, they are likely to be using their learned vocal technique; this will enable them to overcome any low-level dysfunction in their voice. When they are speaking, however, they are less likely to be considering their voice use to such an extent. Despite the intense nature of their singing activity, both in terms of hours and anxiety levels, they are applying learned vocal technique throughout, hopefully minimising any vocal strain as a result. The speaking voice uses the thicker, lower edges of the vocal folds (see Chapter 2). These may become oedematous with excessive use, giving the speaking voice a rough or breathy quality. The singing voice, however, is using the thinner, upper edges of the vocal folds and so can phonate with no evidence of the vocal fold oedema on the lower edges of the vocal folds caused primarily by speech. When they are using their speaking voices, they tend not to employ the technical strategies learned for their singing voice production and may be more likely to tire. The boarding choristers had a significant link between the level of perceived dysphonia in their vocal fold contact and their speaking voice health, but not between the level of perceived dysphonia in their vocal fold contact and their singing voice health (Table 6.17).

The non-choristers do not have the technical experience to apply to either their speaking or singing voices. As they are more likely to be less vocally comfortable when singing, the non-choristers appear to have higher ratings for perceived dysphonia in their singing voices than in their speaking voices.

9.5.6 Statistical differences between the perceived dysphonia of the four activity groups

There was a significant difference between the perceived vocal health of boarding choristers and boarding non-choristers (Table 6.31). This suggests that the chorister factor is significant for ratings of vocal health. The position of Cathedral Organist and Director of Music was subject to a new appointment one-third of the way through this longitudinal study. This fact probably rules out the possibility for the data to be significantly influenced in the long-term by the training methods of one individual, although there may be a dominant culture in cathedral music that transcends the individual, given that the adults are often likely to be ex-choristers.

There was a significant statistical difference between the boarding non-choristers and the non-boarding non-choristers, which suggests that the boarding factor is significant for ratings of vocal health, as observed by the increase in the incidence of perceived vocal dysphonia in the boarders.

There are still differences (although not statistically significant) between all of the groups except the boarding choristers and the non-boarding non-choristers. This is also shown in the distribution graph, Figure 6.13. This phenomenon is also discussed in 8.5.3.

9.5.7 Distributions of the ratings for perceived dysphonia across the four activity groups

The histograms in 6.11.1 show the weighting of the ratings, not just the overall mean for each group. From this, it can be observed that the boarding choristers have a higher incidence of low level disorder, and a lower incidence of high level disorder.

The boys in the choir are all selected following auditions for places; there are several criteria to be satisfied. Each boy is required to sit academic tests to demonstrate that he has an above-average reading age. He is asked to sing a prepared song and to play pieces on any instrument which he is studying. He is given some musicianship tests, and he is observed in social interaction with other boys. It is generally considered of more value that the boy demonstrates exceptional musical potential rather than showing a high level of training at the time of audition. The criteria for singing ability are accurate intonation (within reason) and ease through the vocal range required for singing choral soprano parts. Any particular required timbral quality is assumed to develop with training and experience. It is possible that the choristers in the London cathedral had healthier voices from the outset of their training. It is equally possible that there was no difference between the baseline vocal health of the boys in any of the activity groups. This could be difficult to quantify; the boys who present for audition tend to all be reasonably good singers, the ones who are unsuccessful tend to be so due to other factors (musicianship, social behaviour or reading skills).

In this instance it was possible to assess the baseline vocal health of the London choristers before any training, as the first set of recordings were made in the first week of term. The boys new to the choir at this time (probationers) would not have been influenced by their training or by the increased vocal loading of the boarding chorister schedule. A statistical ANOVA test was made to compare the means of the vocal health scores from the London probationers with the equivalent age of boys from both the non-boarding non-chorister environment, and the boys from the non-boarding chorister environment. There were no equivalent-aged boys from the boarding non-chorister environment.

Table 9.3 ANOVA comparison of probationer choristers with equivalent aged boys in other environments

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	9.605	15	.640	.768	.690
Within Groups	2.500	3	.833		
Total	12.105	18			

The ANOVA analysis in Table 9.3 shows a significance of .690. For the probationer group to have a significantly healthier voice use than the other boys, this figure would need to be less than .05. From this it can be assumed that the boys selected as choristers in the London cathedral do not have healthier or unhealthier voices than their non-selected peers. Any subsequent significant difference in vocal health is likely to be as a result of experience and learned behaviour.

This suggests either that they have learned strategies to prevent their voices from reaching a critical level of dysphonia and/or that the singing activities condition the vocal system to be more robust. One could hypothesise the reasons for this. As their singing teacher in the past, the author would like to think that it was as a result of education, persistent and regular reminders, but it is more likely that the boys will only modify their behaviour if there is a tangible pay-off for them. It would only take a few occasions on which they have missed an opportunity as a result of over-use of their voice for them to learn to self-regulate. This of course applies to all of their voice use, especially in sport and social contexts. Furthermore, the collective singing voice of the choristers as a group is presumably 'healthy', so it is likely that any one individual would have their own individual sound and underlying vocal behaviour shaped by the collective, i.e., there is convergence within the group towards sounds that are more healthy and, as part of a virtuous circle, such healthy sounds tend to condition the voices to sustain this type of production.

From informal discussions with the boys, it is evident that they are consciously aware of their voice use in the choral environment and make adjustments accordingly. A senior boy may give a strong lead at the start of a musical phrase in order to give confidence to the younger boys; he may then ease off vocally once the phrase is underway. In sport and social contexts it is much less likely that the boys will be consciously regulating their voice use. Listening to them in the playground would suggest that they are free and uninhibited with their voice use. The evidence from the distribution of ratings would suggest, however, that caution is being exercised at some level, conscious or subconscious, at all times. A similar caution can be observed when one is watching young pianists and string players from a specialist music school when they are playing football. It is a much less tactile game as a result of their self-regulatory care.

9.6 Summary of discussion

This research has covered many issues of singing and vocal health of boys, both choristers and non-choristers. It has explored and engendered at least two effective methods of voice assessment. These have been tested for inter-judge agreement; acoustic and voice source analysis has confirmed the results of the assessment methods in all phonatory behaviours.

These assessment methods have enabled comparisons to be made between four different groups of boys, all with some common link of environment or activity, and with salient differences. It has been observed that boarding choristers, training at the highest level of professional achievement, have surprisingly good vocal health.

The results of the statistical assessments have also provided insight into the behaviour of boys' voices during the early stages of adolescent voice change. This has raised two important issues. The first is the question of boys' singing during this time: should they continue singing as sopranos, altos, or move to the lower voices, tenor or bass. The second question concerns the identification of poor vocal health in the developing voice, and how this may be confused with the normal, healthy effects of rapid laryngeal growth. These two questions have been discussed, but are not yet answered.

Chapter 10

Conclusion

10.1 Introduction

This study set out to investigate the vocal health and development of intensively trained boy choristers. This was in the context of a relative paucity of scientific research on the singing voices of healthy or 'normal' children and no published research, at the time, in the field of acoustics and psychoacoustics relating to the vocal health or behaviour of children trained in choral singing to a professional level.

10.1.1 Main aims of the research

In order to address the questions, it was necessary to establish the most appropriate tool for measuring attributes of healthy vocal behaviour in children. There was no such assessment specifically designed to assess children who are trained professional voice users and so it was necessary to review and possibly adapt current assessment protocols. Therefore, the design of the assessment method embraced perceptual and acoustic measures in current usage in clinical settings. These were combined and adapted in order to give a relatively rounded and relevant way to evaluate the voice use of the boys in question. The choristers concerned were rehearsing and performing at a professional level for up to twenty-four hours a week, as well as fulfilling the normal daily school curriculum. A professional full-time adult opera chorister will have a weekly contract for thirty hours of rehearsal and performance; this suggests that the boy chorister workload could be considered to be vocally demanding. The aims of this research were to investigate the impact of the choristers' intensive schedule of rehearsal and performing in relation to current vocal health and future development. In order to assess this, comparison groups were selected and assessed using similar methods.

This study set out to investigate answers to these three questions:

- What is the vocal behaviour of boys who experience an intensive, performance-focused training?
- How does such behaviour change over time?
- Is the nature and incidence of vocal dysfunction (self-perceived and/or quantifiable by others in some way) different from what might be found in boys of a similar age and school environment?

10.2 The boy chorister in British cathedrals – history and contemporary practice

The cultural background from both the history of the chorister in British cathedrals and the current cultural comparison with European choristers enabled the context for the 21st-century chorister to be established. It was necessary to place the practice of training boys at such an intense level against a background of long-term history and shorter-term cultural traditions and expectations. Boys have been singing in the daily worship of British cathedrals for hundreds of years; it is likely that they will continue to do so. In the light of recent research into the occupational health of professional adult musicians and into the dance and sport training of children, it was considered crucial to offer a similarly focused investigation into the health and welfare of child singers.

10.3 The anatomy and physiology of the human voice and child and adolescent voice development

These two sections gave a summary of information on and research into the structure and function of the vocal mechanism. This facilitated a far more detailed understanding of the nature of voice use in the child and young adolescent. Without this, it would not have been possible to understand the physiological aspects of the assessment methods and their application. An appreciation of more severe vocal malfunctions, as encountered in voice clinics, enabled the more subtle variations and malfunctions of the 'normal' voice to be evaluated. No voice use is totally and completely healthy, in the sense of absolutely perfect functioning; vocal health is on a spectrum of performance, although most people have functioning vocal behaviour towards the healthier end of this spectrum. Similarly, no person has perfect posture: most people have posture which, although it may be generally healthy, is still somewhere on the spectrum of dysfunctional use. This research and the methods of assessment have attempted to quantify a way in which to position the choristers' voice use on this spectrum of health and function.

10.4 Measurement of voice: perceptual and acoustic and methodology: research protocol and assessment rationale

These chapters looked into the methods currently used to measure voice. These fall into two main categories. Firstly perceptual, this is essentially a subjective measurement: this is generally made by a voice expert, someone with extensive professional training and experience. The second category is acoustic, which covers a range of relatively objective measures, designed to illustrate vocal characteristics with the aid of spectral and electroglottographic data (although the emergent data is subject to interpretation, often in the light of related perceptual information). A survey of these methods led to the various methodological approaches used in the course of this research.

10.5 Results: statistical, acoustic, individual and longitudinal

10.5.1 Statistical processing and comparison between groups

The results of statistical analysis of the data helped to bring together many existing assessment methods in order to find a suitable format for measuring the vocal health and behaviour of essentially healthy children's voices. The data generated was detailed and perhaps unnecessarily cumbersome, at least initially, because of the need to include as many possible aspects as might be necessary for a complete picture to emerge. It was, however, used to evaluate particular aspects of voice use, both of the group, and of individuals over time. The results from the detailed Voice Profile Assessment (VPA) method (see 4.2.3) were investigated using factor analysis in order to establish correlations and groupings. This descriptive system of voice quality analysis is a comprehensive and detailed method of voice assessment. The results of the factor analysis could effectively lead to the distillation of the detail on the VPA form to a more concise but still efficacious analysis of child voice. The resulting form (Chapter 9) was not used for this research, but it is suggested that it could be used for further evaluation of children's voices, especially those of trained boy choristers.

The results from the EAIS and the VAS ratings gave clearer parameters for comparison between the groupings. The boarding non-choristers had a significantly higher incidence of vocal dysfunction than any of the other groups. This would suggest that (a) the boarding school environment can contribute to less healthy voice use, but (b) that singing may help to mitigate the effects of this boarding environment on the choristers.

When the boarding choristers were compared with the other three groups, as a group they had the healthiest voice use. This was despite the increased vocal loading of both boarding and singing. It suggests that they are either athletically conditioned to support these activities, and/or that they are self-regulating their voice use at all times in order to maintain a healthy vocal system.

The potential influence of peer-group on voice use was suggested (8.5.3). The non-boarding non-choristers had the closest voice use profile to the boarding choristers. Despite the significant difference in activities, these boys shared the same classroom and social environment during the daytime. Perhaps peer-group is more influential than activity.

The non-boarding choristers were noted to have unexpectedly high perceived vocal dysfunction. Various reasons concerning lifestyle and scheduling were suggested which might explain this.

The results of the tests for personality type confirmed Eysenck's links between age and performance in the L test. They also showed that the boys with the highest score for perceived vocal dysfunction also had unusually high scores in either extroversion or neuroticism. This has been shown to be the case in previous research on Swedish non-choristers. It is now known to be applicable to UK singing boys as well.

Comparisons were made between vocal health in speech and singing. In very general terms, choristers with unhealthy speaking voices had healthier singing voices. Non-choristers with unhealthy speaking voices had unhealthier singing voices. It was suggested that the choristers employ technical strategies in their singing voices to overcome the effects of vocal fatigue. They do not need to do this in their speaking voices and so these recordings showed the true extent of their vocal fatigue.

10.5.2 Acoustic and voice source analysis

The observations of long-term average spectrum (LTAS) and of the electrolaryngographic (Lx) data described in Chapter 7 were primarily to confirm the observations made in the perceptual analysis. LTAS can illustrate evidence of, for example, efficient vocal projection (strong spectral peaks in upper frequencies) or inefficient or breathy voice production (non-harmonic 'noise' in the upper frequencies) Lx analysis enabled more detailed observation of vocal fold contact behaviour, illustrating efficient voicing as opposed to, for example, breathy (short contact phase) or harsh (long contact phase). The quantitative methodology of laboratory assessment was used in order to give credence to the qualitative evaluations made in the field. In all cases which were assessed in this manner, this was substantiated.

10.5.3 Individual behaviour

The progress of the chorister Jake was detailed through three years of singing and a follow-up interview two years after this. He was an intelligent, musical boy. He was eager to please and yet easy-going. His attributes suggested that he should have been a model chorister. His story progressed through low-level vocal dysfunction to chronic tonsillitis and several months of poor vocal health. He then made a healthy recovery from vocal fold surgery and not long after this slowly began the process of adolescent voice change. It was evident that his enthusiasm for singing soon became overtaken by a desire to socialise with his peers and to have more time at home with his family. His story ended on a positive note with some honest self-reflection and a renewed enthusiasm for singing, this time as a tenor.

10.5.4 Longitudinal observations

The observations over time showed a variety of vocal behaviour and development. Unsurprisingly, the vocal skills such as pitch stability improved over time, and then fell with the onset of adolescent voice change. Measures of vocal fatigue rose to a peak during the middle years of the chorister activity and fell off towards the end. This could suggest that the physical conditioning and maturity of the boys lags behind their vocal and musical demands.

The vocal health scores of the choristers over time showed a surprising consistency in the recordings made during the school term. There was, however, a relative increase in the score for vocal health in the recordings made on the first day of the school term, although this did not reach statistical significance, it was noteworthy that judges tended to agree on the relative health of these vocal products. Two weeks' rest from singing and school was likely to have made an important contribution to any required vocal health recovery.

The analysis of voices before and during the onset of adolescent voice change suggested that these voices were perceived as becoming less healthy. This raised the question of what might be an appropriate measure of vocal health for boys in this stage of development, and, also, how this knowledge may be integrated into the training of voice health professionals and singing teachers who may work with boys of this age.

The longitudinal analysis of the Lx waveform gave unexpected results. As far as is known, at the time of this research, there had been no systematic longitudinal Lx analysis of boys' voices as they are entering adolescent voice change. Based on Cooksey's information (2000) on the stages of voice change, it was expected that evidence of falsetto phonation would emerge as they entered the mid-point (Stage lll) of change. This appeared not to be the case with trained professional boy singers: the boys continued to sing with efficient vocal fold closure in the upper ranges. The waveform for falsetto phonation is noticeably different; it resembles a sinusoidal shape rather than the longer contact phase evident in the Lx of these boys. The waveform had more similarities with that of an adult female or an adult trained countertenor. It is suggested that the training these boys received as children enabled them to shift into a hybrid form of phonation, seamlessly bridging the gap between child and adult. This finding had important implications for the training of boys during voice change. When they are actually capable of singing both parts, should they sing soprano or baritone?

10.6 Retrospective alterations to and improvements on the methodology

The methodology for the data collection was based on previous studies of a similar nature. It was also fairly limited by the availability of the subjects and ethical considerations of working with children. It would have been possible to make small improvements to this but probably nothing significant.

If it had been possible to examine the larynxes of the children using an endoscopic video camera, a great deal more information may have been obtained, although singing with a camera inside is not a comfortable or usual activity. At the time, this was considered to be too invasive and unethical on a group of healthy children; the possibility was not considered further.

10.6.1 The VPA assessment method

The methods of data analysis were able to be simplified in the light of use and analyses. The use of the original VPA gave rise to a very detailed database of information of the vocal behaviour of each boy. The revised VPA form (Table 9.2) would be a more efficient guide for voice assessment of children in future research.

10.6.2 Rating scales

The scores from voice assessment did not fall into a normal distribution curve in terms of the ways that the assessment scales are customarily constructed for clinical use. These children were 'normal' and so were generally on the healthier end of the scale. Considering this weighting, all the scores were more limited in their distribution. The data analysis program SPSS gives best results with not only a larger cohort, but also a greater distribution of scores. The three-point scale proved least effective, the seven-point scale slightly more effective and the VAS rating (giving scores between 0 and 100) was the most useful.

10.7 Suggestions for further research

10.7.1 Further research using the data already collected

Physical measurements of the boys were taken: height, weight and neck circumference. From these, taking into account any thickening of the neck with fatty tissue, if should be possible to calculate the approximate size of the larynx. It would be interesting to compare this data with the average speaking F_0 for each boy to see if there was a direct relationship between the two.

The *messa di voce* test was repeated using different vowels. This exercise requires pitch to be controlled with a varying loudness. It would be possible to assess which vowel was the easiest on which to perform this exercise. This would relate to vocal tract configuration, articulatory patterns and the relationship of tongue position to laryngeal facility.

The laryngograph signal from children is often unstable. The larynx sits high in the vocal tract, just under the jaw (see 3.6). As the pitch of the voice alters, the juvenile larynx may have a considerable up or down excursion. This makes the positioning of the electrodes crucial and sometimes results in a poor signal. In the first recording session (October 2003) there was an occasion where a younger boy was unfamiliar with the chosen hymn tune. In order to help him learn it, the author sang the melody with him. It was noted that the laryngograph signal (and therefore the laryngeal height) was considerably more stable when the boy was singing with another person. This is environmentally consistent with the day-to-day activity of a chorister; solo singing is only an occasional activity for them. In the second set of recordings (May 2004), the boys were recorded in groups of four. This enabled the laryngographic signal to be recorded in both solo and group singing. The comparison between the two situations was never assessed because of time constraints. This could be carried out as a future project.

10.7.2 Further work arising from the results of this research

There was an assumption that boarding schools have a higher level of background noise over a 24hr period. This would increase the vocal loading and increase the probability of vocal dysfunction. This increase was indeed the case when the boarders and non-boarders from the non-chorister groups were compared (see Figures 6.3 and 6.13). A further study to assess the sound pressure level of background noise for the boys during their waking hours would confirm the validity of this assumption.

In the longitudinal analysis of the chorister Jake (see 8.5), he began the process of adolescent voice change between the 4th and 6th recordings. The discrepancy between the score given by JW (the judge with most experience of working with boys' voices during adolescent voice change) and the mean vocal health score given by the remaining nine judges was noticeable (see 8.6.1). The results of electroglottographic analysis, which would be considered to give a more objective measurement of vocal health also suggested evidence of unhealthy or inefficient voice use. Further research could investigate the perceptual evaluation of boys' voices during voice change, and quantify the effect of rapid growth as opposed to any other symptom of poor vocal health.

There was no comparison in this study between the vocal health of professional child singers and professional adult singers. From the personal experience of the author, some singers working in a professional opera chorus can continue working with an apparently high level of vocal dysphonia, especially those who are regular smokers. This situation remains, partly because employment laws protect the employee from dismissal on the grounds of ill-health, especially if it could be seen as dysphonia related to occupational voice use or over-use. The prevalence of voice disorder among professional singers has not been formally assessed but would be an area for further study.

10.7.3 Implications for voice professionals

The issues arising from this research have implications for all professionals who have direct dealings with boy choristers and their singing. These include choir directors and singing teachers, as well as members of the medical profession.

The further implications extend to vocal health professionals in terms of assessment methods of both young boys and boys in early adolescence.

10.8 Original contributions to research on children's voices

This study set out to investigate answers to these questions:

- What is the vocal behaviour of boys who experience an intensive, performance-focused training?
- How does such behaviour change over time?
- Is the nature and incidence of vocal dysfunction (self-perceived and/or quantifiable by others in some way) different from what might be found in boys of a similar age and school environment?

Some of the answers from the study are:

- Intensively trained boy choristers, despite high levels of vocal loading, have healthier voices than their non-chorister counterparts. Choristers probably employ self-regulatory caution with their voice use at all times in order to ensure that they do not exceed certain levels of vocal fatigue. They may also athletically condition their voices to cope with the high vocal loading.

- When measuring detailed voice use of the individual, the Voice Profile Assessment form is the most appropriate; a revised version of this has been suggested in the light of statistical analysis of the data.

- When measuring broad comparisons between groups of this sort, the VAS is most appropriate as the resulting data has sufficient specificity for analysis using SPSS.

- Periodic vocal rest (holidays from intensive vocal activity) is beneficial for the vocal health of choristers.

- When entering voice change, trained boy singers do not use falsetto phonation in the upper pitch ranges; they use a form of phonation more commonly observed in adult male countertenor and adult female singers – this has implications for voice training during this period of development.

- When entering voice change, boys may exhibit attributes of less healthy phonation as a consequence of the rapid growth of the larynx, and not as a result of unhealthy voice use. This has implications for voice assessment practices of voice health professionals and singing teachers.

The challenges of undertaking this research have been essentially due to the nature of human fallibility. The ratings given by the panels of expert judges were surprisingly inconsistent, the assessments made using technological equipment did not always give the expected results. This issue was further compounded by the fact that the voices under examination were complex systems, affected by emotions and environmental factors way beyond the control of any one individual researcher. Despite these difficulties, the results can be seen to have relevancy both for children's voice education and for future research in the area.

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Appendix 1

The history of the chorister in British cathedrals

Although this research concerns the activities of a particular cultural and historical cohort within the Christian community in the UK, it is fundamentally concerned with vocal health from a clinical perspective and voice assessment methods from both clinical and pedagogical aspects. These are primarily scientific and educational subjects and are not dependent on a thorough historical investigation of the *raison d'être* of the professional boy chorister. This section is therefore not integral to the academic discourse of the thesis, but is included for the general interest of the reader who may be unfamiliar with the cultural context of boy choristers in UK cathedrals. It is a basic historical summary of the role of singing boys in the tradition of Christian worship in the UK and Europe, largely drawn from Mould, A. (2007). *The English Chorister.* London: Hambledon Continuum.

Anglo-Saxons

Children have sung in the daily worship of cathedrals, abbeys and collegiate churches for fourteen hundred years. This heritage itself arose from the Jewish practice of training Levite boys to sing psalms. In Canterbury from the start of the 7th Century, Augustine included boys from the age of seven in the Episcopal *familia.* These boys were essentially in training for the clergy, but they would sing in the daily worship. In 680, Bede tells of a choral workshop at Wearmouth, where an expert musician gave instruction to the cantors in the "theory and practice of singing". Incidentally, for the first few hundred years of Christianity in Britain, girls sang in nunneries. The re-introduction of girls into singing in modern cathedral foundations from the 1990s was controversial at the time but can be seen to have ancient roots.

The fate of singing in the daily liturgy has been subject to much upheaval with invasions, reformation, civil war and neglect. In 789 the first Danes arrived in the east of England; by the last quarter of the ninth century, monasticism had been almost eliminated from Anglo-Saxon England. Religious music was reintroduced from Europe following the period of rule of King Alfred and King Edgar. There are records of the musical and academic education of children in monasteries and nunneries from this time. Child oblation would have been considered the highest honour for a family. From the 12th Century, the practice of child oblation was dropped and boys were educated in secular cathedrals and collegiate churches where they were not bound for monastic life.

The Middle Ages

From the fourteenth century, boys were educated in cathedrals to prepare them for entry into grammar schools. Between 1350 and 1550 there was a great flowering of church music with a huge expansion of the number of churches and chapels in which choristers could be heard. Monasteries reintroduced boys into their singing as lay-members. Adult (male) singers in the choirs were employed primarily for their musical skills and were increasingly lay clerks and not clergy. Collegiate churches were established at Eton; Winchester; New College, Magdalen and Christ Church (known as Cardinal College when it was founded), Oxford; and King's College, Cambridge. The music itself was notated and complex; polyphony for five parts or more can be seen in the Old Hall Manuscript and in the Eton Choirbook. Little music survives from this period as much was destroyed during the following reformation of religious practice in England.

We know that by the close of the 15th Century there were approaching two hundred professional liturgical choirs with boys in England. Some accounts suggest that choristers could be quite unruly; in Southwell in 1503 the choristers' vestments were 'disgracefully torn' and the boys themselves were known to 'rave and swear'. A document from Wells before 1460 gives a clear set of rules for the daily schedule of the choristers. On rising, they said Mattins whilst dressing, making their beds, tidying their lockers and washing their hands. They should then go to the school 'peacefully and quietly, and sit down there without making a noise, and await the arrival and presence of the Master or Under-master'. After working on plainsong and pricksong they had breakfast before Prime. At 11am Dinner was taken and lessons continued through the afternoon until Evensong. After Evensong and supper the boys went out to play; this time was normally restricted to thirty minutes and extended on feast days. They were instructed that there should not be 'any swearing, fighting, quarrelling, or any vestige of raillery'.

The Tudors

During the reformation in the 1530s, many monastic foundations were re-founded as secular cathedrals. In the final years of Henry VIII's reign, composers such as Tallis, Sheppard and Tye produced some of their finest music for cathedral choirs. The introduction of Cranmer's Prayer book in 1549 meant that services were to be said or sung in English. This was followed by a return to Latin under the reign of the catholic Queen Mary in 1553 to be turned about once more by the protestant Queen Elizabeth in 1559. She encouraged music and singing as part of worship.

There are numerous accounts of lay clerks and organists in the late 16th and early 17th century as drunkards, gamblers, blasphemers and fornicators. There is a record from 1592 of the organist of Salisbury Cathedral, John Farrant, leaving evensong during the reading and attempting to murder the Dean in the deanery. When the Dean managed to escape, Farrant returned to sing the Anthem in evensong. There were, however, centres of excellence such as the Chapel Royal, and the sacred music of composers Purcell, Byrd, Mundy, Morley, Weelkes, Gibbons and Tomkins whose works are still central to cathedral music today.

A sideline of some of the choristers in places such as Westminster, St Paul's and the Chapel Royal, was participating in dramatic performances. Some of these were at court and others were in public theatres. In the 1570s the choristers of St Paul's Cathedral had their own raised stage with seating for about a hundred people.

Georgians and Victorians

With the Restoration of the monarchy in 1660 following Cromwell, the destiny of cathedral music and the boy chorister went into slow decline. Between 1700 and 1850 secular music in England flourished. Opera was popular, music societies were common as were choral societies. Church music was, however, almost wholly neglected by the most able composers of the time. Chorister numbers dwindled, the boys suffered neglect and maltreatment in much the same way as other children employed in the mines and factories.

Reform of the choristers' welfare was initiated by Maria Hackett in 1811 and continued by her until the 1870s. She was an educated lady with some financial means, enabling her to devote her life to improving the welfare of choristers. This was in a small way resembling the work of Elizabeth Fry in the prisons and Florence Nightingale in nursing. Her concern was with the boys' welfare, not with the standard of music-making. She visited cathedral foundations and wrote about what she found. There was a steady improvement in the attitude both to child welfare and to musical standards during the nineteenth century. Choristers returned to designated choir school lodgings and began to receive a broad and structured education. From the 1870s the idea of giving holidays to the choristers was introduced (until this time, they had sung every day of the year). By the middle of the century chorister numbers had begun to rise in many foundations.

At St Paul's Cathedral, major changes were made at the time of the appointment of John Stainer as organist in 1872. A report of a Sunday evensong in 1871 stated that 'at no time did there appear to be more than an irregular confused hum of children's voices, trying to sing something of which the majority seemed incapable'. Stainer supervised the building of a designated choir school premises in 1875 and increased the chorister numbers from twelve to forty. The choral sound was apparently transformed.

For further reading please see:

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Appendix 2 Recording protocol

1 Measurements were taken of height, weight and neck circumference. This was to enable a future calculation of the size of the larynx. Larynx size is related to general skeletal proportions and can be calculated from the neck circumference. This calculation needs to take into account the amount of fat in the neck measurement, which can be calculated as a body-mass-index from the weight and height of the boy. Larynx size may be related to average speaking F_0. Analysis of these data was, however, not included in the study forming the subject matter for this thesis.

The laryngograph and microphone were fitted onto the boy.

The recording levels were checked with the boy speaking the date, time and his name.

The sound pressure level (SPL) was measured with a SPL meter held as close as possible to the microphone. The boy was then asked to give a vocal sound on an open vowel with a varying loudness. The peak SPL reading was recorded. The peak of the acoustic signal was then calibrated with the peak of the SPL reading to standardise the results. Any variation of the SPL on a recording would be known to be as a result of vocal use, not because of a recording environmental artefact. This enabled direct comparisons to be made between different boys, and the same boy on different occasions, for assessment of the LTAS, for example.

The boy was asked to *count backwards from 20 to 1*. This is a useful way in which to establish the average speaking F_0. The boy's attention is taken with the task and he is unlikely to make alterations to his speaking voice due either to self-consciousness or any attempt to excel at the task. Between numbers 12 and 5 the comfortable F_0 will have been reached. From 20 to 13 it can be raised (due to raised Ps at the start of vocalization and excitement at the novelty of the task) from 5 to 0 it can be lowered (boredom and running out of energy) [JW field observation]. It has also been observed that the F_0 during continuous running speech is at the lower end of the overall pitch range (Pedersen, Møller, Krabbe, Munk, & Bennett, 1985). To be more specific this is usually four to five semitones above the lowest comfortable singing note (Cooksey, 2000).

Repeat this counting task at different loudness levels. This can be used to establish the relationship between dB and F_0. Increased subglottic air pressure can also cause a higher frequency of vibration (Gramming, Sundberg, Ternstrom, Leanderson, & Perkins, 1988). It is therefore important to represent F_0 as 'normal loudness'.

Text reading of the first paragraph of Arthur the Rat (see Appendix 5.1A). This is a standardised text used by speech therapists. From this one can establish the LTAS of the spoken voice as well as using specific sections of the recording for further analysis of voice quality. Connected speech tends to give a more accurate reading of voice use and enables greater consistency of ratings between listeners (Bele, 2005).

'Messa di Voce'. This is an Italian term from bel canto singing training: the exercise requires the singer to be able to maintain a constant pitch and voice quality whilst varying the loudness of the note. The individual, on a given pitch and vowel, begins as quietly as possible, crescendos to as loud as possible and then decrescendos to as quiet as possible, on one breath, whilst remaining on the same pitch. The pitches given were a D4 and D5 (D4 is one tone above middle C, D5 is an octave above this). These will provide different vocal challenges for the boy; D4 is within speech range, D5 is in extended singing range. This was repeated on all five vowels on two of the recording sessions to see if there were any vowels on which pitch control was easier.

Pitch glide from G4 to as high a pitch as possible, then to as low as possible then returning to G4. This will provide information of the total pitch range as well as the ease of negotiation of the passaggios or register breaks (see 2.3.6).

Two-octave scale from G3 to G5 and back to G3, with a breath in the middle if necessary. This gives another measure of the passaggios and of the range of vocal qualities within the structured singing range of the boy. On two recording occasions this exercise was repeated at two additional different loudness levels. This identified whether varying loudness levels brought about any changes in the ease of negotiation over the extended singing range.

Singing an unaccompanied melody (see Appendix 5.1A). This particular hymn tune was selected as the boys were all familiar with the melody, it has a relatively small range and no awkward pitch leaps.

IMAGES REDACTED DUE TO THIRD PARTY RIGHTS OR OTHER LEGAL ISSUES

Appendix 4 Recording equipment

IMAGES REDACTED DUE TO THIRD PARTY RIGHTS OR OTHER LEGAL ISSUES

The Senheisser MKH-20 omnidirectional Microphone was fixed at a constant distance from the mouth by means of a head-mounted boom (see picture 3.3)

IMAGES REDACTED DUE TO THIRD PARTY RIGHTS OR OTHER LEGAL ISSUES

Picture 3.3: Microphone fitted to a head-mounted boom, maintaining a constant distance from the mouth.

IMAGES REDACTED DUE TO THIRD PARTY RIGHTS OR OTHER LEGAL ISSUES

Picture 3.4: The complete recording set-up

Appendix 5 – Interview Structure

Eynsenck Questionnaire (once only)

Medical history from parents (once only)

(based on Andrews, 2002)

- Has he ever been intubated or on a respirator?

  The newborn infant larynx is extremely vulnerable & tiny, emergency intubation can result in scarring of the vocal folds, stenosis or dislocation of the arytenoid cartilages
- Has he any history of allergies?
- Do any other members of the family?
- Was he a 'sicky' baby?

  Reflux can cause irritation around the larynx
- Has he ever seen an ENT consultant or speech therapist?
- Has he ever had problems with his hearing (glue ear etc.)?
- Any other comments?

Questions for school nurse (once only)

- Did the year 1 audiology tests show any abnormalities?
- Is there a history of voice problems, allergies, athsma?
- How happy is the boy as a boarder?
  1. extremely happy
  2. generally happy
  3. variable
  4. generally unhappy
  5. extremely unhappy
- Any other comments?

Questions for school nurse (each visit)

- Has he had more that the usual number of coughs/ colds/ sore throat since our last visit?
- Has he seen an ENT consultant or a Respiratory Consultant?
- Is he on any medication relevant to this study (inhalers etc.)?
- Any other comments?

Questions for Director of Music and Singing Teacher

(two separate questionnaires with the same questions on each)

Since the last visit, has his singing

- Significantly deteriorated
- Become more variable
- Remained the same
- Improved a little
- Improved significantly

Compared with the general standard at the cathedral, is his singing

- poor
- average
- good

Does his singing alter when he moves from the rehearsal room to the cathedral?

Any other comments?

<u>Questions for boy – to be followed up by interview (each visit)</u>

How do you feel that your voice is today?

- Very good
- Generally good
- Average
- Not good
- Bad

Is this better or worse that usual?

How has your voice changed since last year?

- stronger/weaker
- range increased/decreased
- describe any change in the quality of the sound

How much have you been 'off singing' recently?

- frequently
- occasionally
- hardly ever

5 Who do you think are the best three singers in the choir, in order? Why?

Appendix 6 Parental Consent Form

This agreement is between Jenevora Williams of Parkers Lodge, Rectory Place, Portsmouth Road, Guildford GU2 5DG

and *Parents' names and address*

Parent Copy/Copy for return

I agree for my son *name* to participate in the pilot study on profiling vocal behaviour, for the academic year 2003–4.

I agree for medical information held by the school that is relevant to the study to be made available in confidence to the researcher.

Signed .... Date ....

This study has the full approval of the University of London and the Dean and Chapter of St Paul's Cathedral.

British Educational Research Association ethical guidelines will be followed (a copy of these is available in the School Office). All data will be anonymous; no individual will be identified.

If at any stage I should wish to terminate this agreement I shall write to you and send a copy to the school. The Dean and Chapter and school reserve the right to terminate the arrangement between Jenevora Williams and any pupil and his parents should the school consider it in that pupil's best interest.

Appendix 7 Information given to parents

A study of the effects of intensive training on the vocal behaviour, health and development of boy choristers

- As a singing teacher of cathedral choristers for the last fourteen years, my intention is to gain information that will be a positive help to all those involved in chorister training.

- Having worked within the cathedral school environment, I understand the time constraints on choristers and so I have designed an assessment protocol to minimise the impact on their time and on the school.

Time Scale

Pilot Study: a cross-sectional survey of St Paul's Cathedral Choristers of all ages in order to establish a robust assessment protocol. September 2003 to July 2004

Longitudinal study: a three-year survey of choristers from more than one cathedral, using the entire probationer intake (age 7/8 years) and the current year 6 (aged 10/11 years). September 2004 to July 2007

The practical impact on the choristers

- Six-monthly assessments comprising:
- Sound recording for acoustic analysis
- This will take 10–15 minutes per chorister and includes speaking and singing. This system is non-invasive and has already been used for collecting data for some years in many other cathedrals across the UK.
- Questions for the boys about their own perceptions of their voice use

- There would be approximately six standardised questions such as "how do you feel your voice has changed since we last heard it?".
- Information from the singing teacher and the choirmaster; a few notes on the progress of each boy.
- Health report from the school nurse to include any excessive occurrence of coughs/colds, relevant personal events (problems at home, bullying etc), details of any ENT referrals. All medical information will be given only with parental consent and will remain strictly confidential.

This would give us a longitudinal picture of each boy: his state of vocal health, any external factors that may have influenced this and his own perception of the situation.

More detailed information on the project

Introduction

The education of cathedral and major chapel choristers has altered significantly in the last 20 years. They have always had the challenge of giving performances of a professional standard on a daily basis, but there is now an increased workload and the possibilities of increased performance-related stress related to the following factors:

- The average age of the onset of adolescent male voice mutation is becoming lower (from 14 years in the 1940s to nearer 12 years now). This can have a significant impact on the top two years of choristers and requires detailed understanding of this process by choral trainers for effective management.
- Choristers are now also expected to keep abreast of their non-chorister peers in their academic education.
- There are now more 'high profile' events, such as live television broadcasts.
- It can be argued that greater access to recorded choral music has led the listening public to expect a higher overall standard from live performances. Also, recorded

performances may be more likely to be taken as 'benchmarks', by choir directors, of an acceptable performance standard.

Chorister training is currently the subject of some discussion. The opinions expressed range from those who believe that the experience is of enormous benefit to those who are concerned that the boys may compromise their current vocal health and future development. There is, however, no empirical evidence against which we can measure individual cases.

Proposed Study

The purpose of the proposed study is to establish a method of assessing the basic functioning of the male chorister voice that will enable an overall profile of vocal behaviour, health and development to be constructed. This is to be derived from acoustic and interview profile data.

The proposed study is focused particularly on boys who have a rigorous and sustained schedule of rehearsal and performance, in the more prestigious cathedral choirs. Ethical guidelines for research will be strictly followed: no boy will be included without the full consent of both the chorister and his parents, complete confidentiality is assured and the published results will preserve the anonymity of the individuals and choirs concerned.

The project will draw on the expertise of a Europe-wide interdisciplinary network of researchers who are engaged in different aspects of voice assessment, education and care. Some clinical data is already available in medical centres in Germany that have long-term associations with the Leipzig Thomanerchor and the Dresden Kreuzchor. A visit has already been made to these two centres; interviews and recordings have enabled the preparation of a report to compare and contrast the boys' choir tradition in Britain and Germany. This clinical data will be supplemented with other individual case study data from London hospitals that have voice clinics with links to the focus choral institutions.
Information from the German research centres has also established links between clinical data and acoustic data that can be collected non-invasively in a non-clinical setting, i.e. acoustic recordings that can be collected in the cathedral/choir school setting. The protocol for the acoustic data collection derives from that established under an existing Arts and

Humanities Research Board (AHRB) funded study of choristers at Wells Cathedral (conducted by Professors Welch and Howard – see team members below). This acoustic data will be supplemented by interview data to build a composite picture of chorister voice behaviour.

The results and outcome

It is intended that this study will provide detailed information on the functioning and development of boys' voices undergoing intensive singing training. The information obtained will enable us to understand better the effects of such training and performance on underlying vocal behaviour and vocal health and to establish parameters for these. This will form the basis for a system enabling comprehensive and objective vocal assessment to be made from simple acoustic measurements. The findings will have implications for singing teachers and choral directors in relation to particular methods of vocal education and rehearsal.

Core Team

Jenevora Williams (Principal Researcher), Singing Teacher
Graham Welch (Supervisor), Professor of Music Education, Institute of Education University of London, UK; Co-ordinator, European Child and Adolescent Voice Network

Advisory Team from European Child and Adolescent Voice Network

Johann Sundberg (Co-Supervisor), Professor of Music Acoustics, Royal Institute of Technology, Stockholm, Sweden. Visiting Professor, Institute of Education University of London.
David Howard (Adviser), Professor of Electronic Engineering, Head of the Music Technology Research Group, Department of Electronics, University of York
Friedemann Pabst (Adviser), Professor Dr. Med., Krankenhaus Dresden-Friedrichstadt HNO-Klinik, Dresden; Conservatory of Music "Carl Maria von Weber", Laboratory for Voice Research, Dresden, Germany
Michael Fuchs (Adviser), Dr. Michael Fuchs, Specialist in Otorhinolaryngology, University of Leipzig (Department of Otorhinolaryngology, Section Phoniatrics/Paedaudiology)

Appendix 8 BERA Code of Ethics

INSTITUTE OF
EDUCATION
UNIVERSITY OF LONDON

DOCTORAL SCHOOL INFORMATION SHEET

The British Educational Research Association: Code of Ethics

The British Educational Research Association believes that all educational research should be conducted within an ethic of respect for persons, respect for knowledge, respect for democratic values and for the quality of educational research.

RESPONSIBILITY TO THE RESEARCH PROFESSION

Educational researchers should aim to:

1. Avoid fabrication, falsification, or misinterpretation of evidence, data, findings, or conclusions;

2. Report their findings to all relevant stakeholders and so refrain from keeping secret or selectively communicating their findings.

3. Report research conceptions, procedures, results, and analyses accurately and in sufficient detail to allow other researchers to understand and interpret them;

4. Decline to review the work of others when strong conflicts of interest are involved or when such requests cannot be conscientiously fulfilled on time. Materials sent for review should be read in their entirety and considered carefully, with evaluative comments justified with explicit reasons;

5. Conduct their professional lives in such a way that they do not jeopardise future research, the public standing of the field, or the publication of results.

RESPONSIBILITY TO PARTICIPANTS

1. Participants in a research study have the right to be informed about the aims, purposes and likely publication of findings involved in the research and of potential consequences for participants, and to give their informed consent before participating in research.

2. Care should be taken when interviewing children and students up to school leaving age; permission should be obtained from the school, and if they so suggest, the parents.

3. Honesty and openness should characterise the relationship between researchers, participants and institutional representatives.

4. Participants have the right to withdraw from a study at any time.

5. Researchers have a responsibility to be mindful of cultural, religious, gendered, and other significant differences within the research population in the planning, conducting and reporting of their research.

RESPONSIBILITY TO THE PUBLIC

1. Educational researchers should communicate their findings and the practical significance of their research, in clear, straightforward, and appropriate language to relevant research populations, institutional representatives, and other stakeholders.

2. Informants and participants have a right to remain anonymous. This right should be respected when no clear understanding to the contrary has been reached. Researchers are responsible for taking appropriate precautions to protect the confidentiality of both participants and data. However, participants should also be made aware that in certain situations anonymity cannot be achieved.

RELATIONSHIP WITH FUNDING AGENCIES

1. The data and results of a research study belong to the researchers who designed and conducted the study unless alternative contractual arrangements have been made with respect to either the data or the results or both.

2. Educational researchers should remain free to interpret and publish their findings without censorship or approval from individuals or organisations including sponsors, funding agencies, participants, colleagues, supervisors, or administrators. This understanding should be conveyed to participants as part of the responsibility to secure informed consent. This does not mean however that researchers should not take every care to ensure that agreements on publication are reached.

3. Educational researchers should not agree to conduct research that conflicts with academic freedom, nor should they agree to undue or questionable influence by government or other funding agencies. Examples of such improper influence include endeavours to interfere with the conduct of research, the analysis of findings, or the reporting of interpretations. Researchers should report to the British Educational Research Association, attempts by sponsors or funding agencies to use any questionable influence, so that the British Educational Research Association may respond publicly as an association on behalf of its members thereby protecting any individual or contract.

4. The aims and sponsorship of research should be made explicit by the researcher. Sponsors or funders have the right to have disclaimers included in the research reports to differentiate their sponsorship from the contents of the research.

5. Educational research should fulfil their responsibilities to agencies funding research, which are entitled to an account of the use of their funds, and to a report of the procedures, findings, and implications of the funded research.

6. The host institution should appoint staff in the light of its routine practices and according to its normal criteria. The funding agency may have an advisory role in this respect, but should not have control over appointments.

7. Sponsored research projects should have an advisory group consisting of representatives from those groups and agencies which have a legitimate interest in the area of inquiry. This advisory group should facilitate access of the researcher(s) to sources of data, other specialists in the field and the wider educational community.

8. The funding agency should respect the right of the researcher(s) to keep his or her sources of data confidential.

9. The funding agency should respect the right of the researcher(s) over the conduct of the research, or threatened termination of contract, the terms of the dispute and/or grounds for termination should be made explicit by the funding agency or researcher and be open to scrutiny by the advisory group. If either party feels that ground for termination are unreasonable then there should be recourse to arbitration by a body or individual acceptable to both parties.

PUBLICATION

1. Researcher(s) have a duty to report both to the funding agency and to the wider public, including the educational practitioners and other interested parties. The right to publish, including educational practitioners and other interested parties. The right to publish is therefore entailed by this duty to report.

Researchers conducting sponsored research should retain the right to publish the findings under their own names. The right to publish is essential to the long-term viability of any research activity, to the credibility of the researcher (and of the funding agency in seeking to use research findings) and in the interests of an open society. The methodological principle of maximising the dissemination of information to all interested parties is an integral part of research strategy aimed at testing on a continuous basis the relevance, accuracy and comprehensiveness of findings as they emerge within the process of inquiry.

2. The conditions under which the right to publish might be legitimately restricted are:

   - general legislation (e.g. in the area of libel or race relations);
   - undertakings given to participants concerning confidentiality and generally not to cause unnecessary harm to those affected by the research findings;
   - failure to report findings in a manner consistent with the values of inquiry i.e. to report findings honestly, accurately, comprehensively, in context, and without undue sensationalisation;

3. Publications should indicate whether or not they are subject to reporting restrictions.

4. The researcher(s) should have the right, as a last resort and following discussions with the funding agency and advisory group, to publicly dissociate themselves from misleadingly selectively accounts of the research.

5. Funding bodies should not be allowed to exercise restrictions on publications by default, e.g. by failing to answer requests for permission to publish, or by undue delay.

6. Resources need to be made available for dissemination and publication and should be built in to funding.

7. In the event of a dispute over publication the researcher should seek recourse first to the advisory group and secondly to an independent arbitration body or individual.

INTELLECTUAL OWNERSHIP

Authorship should be determined on the basis of the following guidelines: all those, regardless of status, who have made a substantive and/or creative contribution to the generation of an intellectual product are entitled to be listed as authors of that product. First authorship and order of authorship should be the consequence of relative leadership and creative contribution. Examples of creative contributions are: writing first drafts or substantial portions; significant rewriting or substantive editing; contribution generative ideas or basic conceptual schema or analytic categories; collecting data which requires significant interpretation or judgement; and interpreting data.

RELATIONSHIP WITH HOST INSTITUTION

1. Institutions should both develop their own codes of practice which govern ethical principles and establish appropriate standards of academic freedom, including the freedom to disseminate research findings. While such codes should be observed within all research, including non-contract research, they are particularly important in respect of contract research. Such codes should be honoured by institutions and research in the negotiation of contractual arrangements put forward by funding agencies, and in the carrying out of these obligations once they have been agreed.

2. While academic staff should not engage in contract research without agreement by the institution, the latter should not be allowed to compel academic staff to engage in particular contract research.

3. It is assumed that contracts will in all cases be interpreted reasonably and with regard to due process. However, should a legitimate disagreement arise between the funding agency and the researchers engaged on it, then the researchers' institutions should give the researchers full and loyal support in resolving this disagreement.

Appendix 9 VPA form - Voice Profile Assessment in Singing

Contexts	Categories	Normal/ Neutral	Sub-categories Perceived as *'non-normal'* features	1	2	3	Comments (e.g. singing *vs* speech)
Observations in performance ☐	Phonation Type		Harshness				
			Whisper				
			Creak				
			Modal → Falsetto				
			Asthenia				
	Velo-pharyngeal		Nasal				
Observations in rehearsal ☐			Denasal				
	Excess tension		Pharyngeal constriction				
			Laryngeal constriction				
			Supralaryngeal - general				
	Larynx position		Raised				
			Lowered				
Observations in special test ☐	Jaw		Minimised range				
	Tongue		Lisp				
			Backed				
	Pitch range		High mean				
			Low mean				
			Wide range				
Observations from recording of special test ☐			Narrow range				
	Pitch control		Pitch instability				
			Pitch stability				
	Loudness		High mean				
			Low mean				
			Wide range				
			Narrow range				
	Breath support		Pushed				
			Weak				
			Audible inhalation				
	Passaggio		Upper obvious				
			Upper well-managed				
			Lower obvious				
			Lower well-managed				
	Frequency ratio		Too high (shrill)				
			Too low (hooty)				

Other comments
Health
Lx / LTAS
Self-rating of singing voice by Chorister
Vocal ability/progress in choir

Appendix 10 Groupings of factors for reduced parameters in VPA

Categories	Normal/ Neutral	Sub-categories Perceived as *'non-normal'* features	1	2	3	Comments
Phonation Type		Harshness				Red boxes show degrees of abnormality in voice source/vocal fold contact
		Whisper				0 1 2 3
		Creak				✓ ✓✓ ✓ ✓✓ ✓ ✓✓
		Modal → Falsetto				
		Asthenia				1 2 3 4 5 6 7
Velo-pharyngeal		Nasal				Green boxes show degrees of abnormality in voice amplification/supraglottal
		Denasal				
Excess tension		Pharyngeal constriction				Dark Blue boxes show degrees of abnormality in Voice amplification/subglottal
		Supralaryngeal - general				
Jaw		Minimised range				Add all scores in green and dark blue boxes. Score x 2/3 + 1
Tongue		Lisp				
		Backed				
		Weak				
Pitch range		High mean				
		Low mean				
		Wide range				
		Narrow range				Pink boxes show degrees of abnormality in voice source/laryngeal muscle coordination
Pitch control		Pitch instability				Add all scores found in pink boxes.
		Pitch stability				Score x 3/5 + 1
Breath support		Pushed				
		Weak				
		Audible inhalation				
		Controlled flow				Pale Blue boxes show degrees of musical performance/learned vocal skill
Passaggio		Upper obvious				Add all scores in pale blue boxes
		Upper well-managed				
		Lower obvious				
		Lower well-managed				

Score sub-categories: Vocal fold behaviour, Laryngeal muscle behaviour, Voice amplification

Scores must range from 1 to 7 in each sub-category

Scores in vocal fold behaviour are measured using only the three most relevant categories: harshness, whisper and creak. Scores given in these categories will indicate the nature of vocal fold closure and vibration. This is a good indicator of vocal health. Scores of 1 are considered fairly normal, scores of 2 in any category are slightly abnormal and a score of 3 in any category is severe. It is considered that a high score in one category is of greater severity than several low scores, hence the scaling of 1 to 7 as indicated.

Scores in laryngeal muscle behaviour ranged from 0 to 10. To bring these into scale the score was divided by 10, multiplied by 6 and added to 1.

Scores in voice amplification ranged from 0 to 9. To bring these into scale the score was divided by 9, multiplied by 6 and added to 1.

Degrees of musical skill are to be assessed at a later date. The current study is focussed on vocal health, normal to sub-normal.

Illness scores: 1 = healthy, 2 = healthy but with underlying problem (eg asthma), 3,4 = slight illness, 5-7 = too ill to sing

Voice change 1-6 - 1=unchanged, 2-6=Cooksey +1

Appendix 11 Vocal Health Evaluation Sheet

The two CDs each have 108 recordings of boys reading the first few lines of 'Arthur the Rat'. The boys come from a variety of backgrounds: some are choristers and some are not. Each sample lasts for about 20 seconds and there is a short gap between each one. I suggest that you have a break of at least 10 minutes between listening to the two CDs.

The CDs can be played on either a CD player or a computer. If you are listening on a computer, can I ask you to use headphones or speakers which will give a clear sound quality? The samples are not individually tracked; if you need to stop during the listening evaluation, you will need to use the pause button to begin again at the right place.

The sound levels vary, you may need to have the volume control handy. The recording quality is also variable, some have hum, some have background noise. I am very sorry about this but I felt that is was valuable to include all the recordings.

Please listen to the recordings and rate each one for vocal efficiency by marking the rating line. A score at the right of the line suggests complete loss of phonation. A score at the left of the line suggests a totally healthy voice with optimally efficient phonation. As these are 'normal' boys, nearly all of the recordings will be somewhere to the left or centre of the line. Please can you try to be discerning regarding low levels of vocal inefficiency; breathiness, creak and harshness. A score on the far left of the line suggests absolutely flawless phonation.

Please trust your first impressions, it should not be necessary to go back and re-do any of the scores.

CDA Boy Number	Phonational efficiency	
	extremely good	extremely poor
1	I_______________________________________	I
...		
216	I_______________________________________	I

Please give a brief summary of your training in perceptual evaluation of voice quality e.g. GRBAS, Voice Profile Analysis

Appendix 12 Assessment of vocal health 05.10.07

Boys aged 9 to 13, speaking and singing examples

Your details

<u>Profession:</u> (you may tick more than one box)

Singing teacher ☐

SLT ☐

Voice Teacher ☐

Other (please specify)______________________________ ☐

<u>Length of experience working in this profession</u> (the one in which you have been for the longest, if you have ticked more than one profession)

0 – 4 yrs ☐ 5 – 9 yrs ☐ More than 10 yrs ☐

<u>Rating scale</u>

The vocal health is given one score from 1 to 7
The score assesses any audible breathiness, roughness or strain.
It is assessing larynx function only (ie. ignore nasality, articulation)

1	= totally healthy, clear phonation
2/3	= slight dysphonia (probably only noticeable to the voice professional)
4	= noticeable dysphonia
5	= sounds unwell, would not be encouraged to sing in this condition
6	= sounds extremely unwell
7	= voiceless

<u>Recorded examples</u> – each recording is played once, some examples may be repeats

Boy	Score	Boy	Score	Boy	Score
1		6		11	
2		7		12	
3		8		13	
4		9		14	
5		10		15	

Appendix 13 Table showing bivariate correlations between all factors relating to pitch management, boarding choristers only, n=34

		degree of depth of pitch mean	degree of width of pitch range	degree of narrowness of pitch range	degree of instability of pitch	degree of stability of pitch	degree of obvious upper passaggio	degree of well-managed upper passaggio	degree of obvious lower passaggio	degree of well-managed lower passaggio
degree of height of pitch mean	Pearson Correlation	-.090	.070	-.070	.059	-.084	-.340(*)	.116	-.196	-.201
	Sig. (2-tailed)	.614	.693	.694	.740	.638	.049	.513	.268	.254
degree of width of pitch range	Pearson Correlation	-.044								
	Sig. (2-tailed)	.807								
degree of narrowness of pitch range	Pearson Correlation	-.076	.302							
	Sig. (2-tailed)	.671	.083							
degree of instability of pitch	Pearson Correlation	.141	-.180	.131						
	Sig. (2-tailed)	.426	.307	.462						
degree of stability of pitch	Pearson Correlation	-.125	.201	-.115	-.516(**)					
	Sig. (2-tailed)	.483	.254	.516	.002					
degree of obvious upper passaggio	Pearson Correlation	.029	-.100	.237	.121	-.321				
	Sig. (2-tailed)	.870	.572	.176	.497	.064				
degree of well-managed upper passaggio	Pearson Correlation	-.097	-.139	-.242	-.247	.321	-.541(**)			
	Sig. (2-tailed)	.585	.432	.167	.159	.065	.001			
degree of obvious lower passaggio	Pearson Correlation	.247	-.109	-.398(*)	.187	-.091	.218	-.149		
	Sig. (2-tailed)	.159	.539	.020	.290	.609	.216	.399		
degree of well-managed lower passaggio	Pearson Correlation	-.068	-.098	-.063	-.082	.249	-.009	.119	-.412(*)	
	Sig. (2-tailed)	.702	.583	.724	.644	.156	.961	.503	.016	

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Appendix 14 ANOVA and T-Test for ten judges and four boys' activity groups

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Judge1	Between Groups	3605.055	3	1201.685	8.165	.000
	Within Groups	28552.606	194	147.178		
	Total	32157.662	197			
Judge2	Between Groups	3561.313	3	1187.104	6.038	.001
	Within Groups	38139.440	194	196.595		
	Total	41700.753	197			
Judge4	Between Groups	1339.054	3	446.351	6.209	.000
	Within Groups	13945.759	194	71.885		
	Total	15284.813	197			
Judge6	Between Groups	5330.014	3	1776.671	6.618	.000
	Within Groups	52082.996	194	268.469		
	Total	57413.010	197			
Judge8	Between Groups	3116.513	3	1038.838	5.678	.001
	Within Groups	35496.078	194	182.969		
	Total	38612.591	197			
Judge9	Between Groups	148.519	3	49.506	1.236	.298
	Within Groups	7772.733	194	40.066		
	Total	7921.253	197			
Judge10	Between Groups	4906.867	3	1635.622	12.119	.000
	Within Groups	26182.588	194	134.962		
	Total	31089.455	197			
Judge11	Between Groups	2065.063	3	688.354	3.093	.028
	Within Groups	43178.801	194	222.571		
	Total	45243.864	197			
Judge14	Between Groups	1929.193	3	643.064	3.400	.019
	Within Groups	36690.468	194	189.126		
	Total	38619.662	197			
Judge15	Between Groups	3097.109	3	1032.370	7.002	.000
	Within Groups	28602.144	194	147.434		
	Total	31699.253	197			

Group Statistics

	1=BC, 2=NBNC, 3=NBC, 4=BNC	N	Mean	Std. Deviation	Std. Error Mean
Judge1	1.00	106	20.9340	11.15968	1.08392
	2.00	31	24.1290	9.98580	1.79350
Judge2	1.00	106	19.6604	12.20218	1.18518
	2.00	31	17.4194	12.33362	2.21518
Judge4	1.00	106	15.3962	7.58153	.73638
	2.00	31	16.5806	10.91719	1.96078
Judge6	1.00	106	37.8491	16.88380	1.63990
	2.00	31	38.1290	15.90753	2.85708
Judge8	1.00	106	29.9623	12.97391	1.26014
	2.00	31	33.9677	12.60287	2.26354
Judge9	1.00	106	16.9057	6.50059	.63139
	2.00	31	18.8065	5.81618	1.04462
Judge10	1.00	106	22.5849	10.66447	1.03582
	2.00	31	28.8065	13.17174	2.36571
Judge11	1.00	106	26.9245	14.75689	1.43332
	2.00	31	28.4516	15.14780	2.72063
Judge14	1.00	106	38.6038	12.47373	1.21156
	2.00	31	38.6452	13.12897	2.35803
Judge15	1.00	106	19.7547	11.78927	1.14508
	2.00	31	21.1613	11.71067	2.10330

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Judge 1	Equal variances assumed	.074	.786	-1.434	135	.154	-3.19507	2.22762	-7.60061	1.21047
	Equal variances not assumed			-1.525	53.864	.133	-3.19507	2.09560	-7.39674	1.00660
Judge 2	Equal variances assumed	.201	.655	.897	135	.371	2.24102	2.49751	-2.69828	7.18032
	Equal variances not assumed			.892	48.498	.377	2.24102	2.51231	-2.80897	7.29102
Judge 4	Equal variances assumed	4.570	.034	-.687	135	.493	-1.18442	1.72283	-4.59164	2.22280
	Equal variances not assumed			-.565	38.839	.575	-1.18442	2.09450	-5.42151	3.05267
Judge 6	Equal variances assumed	.432	.512	-.082	135	.935	-.27998	3.40415	-7.01234	6.45239
	Equal variances not assumed			-.085	51.428	.933	-.27998	3.29426	-6.89214	6.33219
Judge 8	Equal variances assumed	.675	.413	-1.522	135	.130	-4.00548	2.63245	-9.21165	1.20069
	Equal variances not assumed			-1.546	50.102	.128	-4.00548	2.59067	-9.20873	1.19777
Judge 9	Equal variances assumed	2.286	.133	-1.465	135	.145	-1.90079	1.29758	-4.46700	.66542
	Equal variances not assumed			-1.557	53.870	.125	-1.90079	1.22061	-4.34810	.54651
Judge 10	Equal variances assumed	2.134	.146	-2.704	135	.008	-6.22155	2.30117	-10.77255	-1.67054
	Equal variances not assumed			-2.409	42.163	.020	-6.22155	2.58254	-11.43274	-1.01036
Judge 11	Equal variances assumed	.246	.621	-.504	135	.615	-1.52708	3.03107	-7.52161	4.46744
	Equal variances not assumed			-.497	47.910	.622	-1.52708	3.07509	-7.71027	4.65611
Judge 14	Equal variances assumed	.013	.908	-.016	135	.987	-.04139	2.57730	-5.13849	5.05571
	Equal variances not assumed			-.016	46.994	.988	-.04139	2.65107	-5.37467	5.29190
Judge 15	Equal variances assumed	.302	.583	-.585	135	.559	-1.40657	2.40365	-6.16025	3.34711
	Equal variances not assumed			-.587	49.184	.560	-1.40657	2.39480	-6.21865	3.40550

Group Statistics

	1=BC, 2=NBNC, 3=NBC, 4=BNC	N	Mean	Std. Deviation	Std. Error Mean
Judge1	1.00	106	20.9340	11.15968	1.08392
	3.00	21	26.2381	9.24611	2.01767
Judge2	1.00	106	19.6604	12.20218	1.18518
	3.00	21	25.4286	13.85125	3.02259
Judge4	1.00	106	15.3962	7.58153	.73638
	3.00	21	18.6190	5.82646	1.27144
Judge6	1.00	106	37.8491	16.88380	1.63990
	3.00	21	41.3810	18.48642	4.03407
Judge8	1.00	106	29.9623	12.97391	1.26014
	3.00	21	36.7143	13.38336	2.92049
Judge9	1.00	106	16.9057	6.50059	.63139
	3.00	21	16.8095	6.33734	1.38292
Judge10	1.00	106	22.5849	10.66447	1.03582
	3.00	21	26.1905	10.69869	2.33464
Judge11	1.00	106	26.9245	14.75689	1.43332
	3.00	21	28.9524	12.48790	2.72508
Judge14	1.00	106	38.6038	12.47373	1.21156
	3.00	21	46.4762	13.81890	3.01553
Judge15	1.00	106	19.7547	11.78927	1.14508
	3.00	21	26.6190	10.51416	2.29438

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Judge 1	Equal variances assumed	1.047	.308	-2.042	125	.043	-5.30413	2.59785	-10.44561	-.16266
	Equal variances not assumed			-2.316	32.691	.027	-5.30413	2.29039	-9.96563	-.64264
Judge 2	Equal variances assumed	.894	.346	-1.935	125	.055	-5.76819	2.98111	-11.66817	.13179
	Equal variances not assumed			-1.777	26.503	.087	-5.76819	3.24665	-12.43561	.89922
Judge 4	Equal variances assumed	1.198	.276	-1.841	125	.068	-3.22282	1.75059	-6.68746	.24182
	Equal variances not assumed			-2.193	34.920	.035	-3.22282	1.46929	-6.20588	-.23976
Judge 6	Equal variances assumed	1.362	.245	-.862	125	.390	-3.53190	4.09648	-11.63933	4.57554
	Equal variances not assumed			-.811	27.016	.424	-3.53190	4.35465	-12.46665	5.40286
Judge 8	Equal variances assumed	.008	.931	-2.168	125	.032	-6.75202	3.11477	-12.91654	-.58750
	Equal variances not assumed			-2.123	27.956	.043	-6.75202	3.18075	-13.26797	-.23608
Judge 9	Equal variances assumed	.217	.642	.062	125	.951	.09614	1.54654	-2.96466	3.15694
	Equal variances not assumed			.063	28.967	.950	.09614	1.52024	-3.01326	3.20553
Judge 10	Equal variances assumed	.028	.868	-1.415	125	.160	-3.60557	2.54860	-8.64957	1.43842
	Equal variances not assumed			-1.412	28.439	.169	-3.60557	2.55411	-8.83380	1.62266
Judge 11	Equal variances assumed	1.432	.234	-.589	125	.557	-2.02785	3.44382	-8.84360	4.78789
	Equal variances not assumed			-.659	32.128	.515	-2.02785	3.07904	-8.29867	4.24296
Judge 14	Equal variances assumed	.429	.514	-2.595	125	.011	-7.87242	3.03314	-13.87538	-1.86945
	Equal variances not assumed			-2.422	26.845	.022	-7.87242	3.24981	-14.54229	-1.20254
Judge 15	Equal variances assumed	.049	.824	-2.479	125	.015	-6.86433	2.76948	-12.34547	-1.38319
	Equal variances not assumed			-2.677	30.840	.012	-6.86433	2.56425	-12.09525	-1.63341

Group Statistics

	1=BC, 2=NBNC, 3=NBC, 4=BNC	N	Mean	Std. Deviation	Std. Error Mean
Judge1	1.00	106	20.9340	11.15968	1.08392
	4.00	40	31.9250	16.62156	2.62810
Judge2	1.00	106	19.6604	12.20218	1.18518
	4.00	40	29.2250	19.01752	3.00693
Judge4	1.00	106	15.3962	7.58153	.73638
	4.00	40	22.0500	9.68199	1.53086
Judge6	1.00	106	37.8491	16.88380	1.63990
	4.00	40	51.0250	14.07396	2.22529
Judge8	1.00	106	29.9623	12.97391	1.26014
	4.00	40	39.7750	15.58679	2.46449
Judge9	1.00	106	16.9057	6.50059	.63139
	4.00	40	18.6000	6.23801	.98632
Judge10	1.00	106	22.5849	10.66447	1.03582
	4.00	40	35.3250	13.15273	2.07963
Judge11	1.00	106	26.9245	14.75689	1.43332
	4.00	40	35.3250	16.25973	2.57089
Judge14	1.00	106	38.6038	12.47373	1.21156
	4.00	40	44.6750	17.06907	2.69886
Judge15	1.00	106	19.7547	11.78927	1.14508
	4.00	40	29.3750	14.03601	2.21929

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Judge 1	Equal variances assumed	12.203	.001	-4.602	144	.000	-10.99104	2.38819	-15.71147	-6.27061
	Equal variances not assumed			-3.866	52.829	.000	-10.99104	2.84285	-16.69350	-5.28857
Judge 2	Equal variances assumed	8.998	.003	-3.587	144	.000	-9.56462	2.66670	-14.83555	-4.29370
	Equal variances not assumed			-2.959	51.596	.005	-9.56462	3.23207	-16.05146	-3.07778
Judge 4	Equal variances assumed	5.915	.016	-4.371	144	.000	-6.65377	1.52231	-9.66273	-3.64482
	Equal variances not assumed			-3.917	57.983	.000	-6.65377	1.69876	-10.05423	-3.25331
Judge 6	Equal variances assumed	2.259	.135	-4.391	144	.000	-13.17594	3.00077	-19.10719	-7.24470
	Equal variances not assumed			-4.767	83.694	.000	-13.17594	2.76427	-18.67329	-7.67860
Judge 8	Equal variances assumed	1.161	.283	-3.851	144	.000	-9.81274	2.54793	-14.84891	-4.77656
	Equal variances not assumed			-3.545	60.522	.001	-9.81274	2.76797	-15.34851	-4.27696
Judge 9	Equal variances assumed	.892	.346	-1.420	144	.158	-1.69434	1.19328	-4.05294	.66426
	Equal variances not assumed			-1.447	72.962	.152	-1.69434	1.17110	-4.02836	.63968
Judge 10	Equal variances assumed	1.665	.199	-6.027	144	.000	-12.74009	2.11397	-16.91852	-8.56167
	Equal variances not assumed			-5.484	59.393	.000	-12.74009	2.32331	-17.38839	-8.09180
Judge 11	Equal variances assumed	.293	.589	-2.982	144	.003	-8.40047	2.81660	-13.96770	-2.83325
	Equal variances not assumed			-2.854	64.691	.006	-8.40047	2.94344	-14.27947	-2.52147
Judge 14	Equal variances assumed	11.510	.001	-2.359	144	.020	-6.07123	2.57367	-11.15828	-.98417
	Equal variances not assumed			-2.052	55.466	.045	-6.07123	2.95833	-11.99873	-.14373
Judge 15	Equal variances assumed	2.452	.120	-4.168	144	.000	-9.62028	2.30803	-14.18227	-5.05830
	Equal variances not assumed			-3.852	60.925	.000	-9.62028	2.49729	-14.61404	-4.62653

Group Statistics

	1=BC, 2=NBNC, 3=NBC, 4=BNC	N	Mean	Std. Deviation	Std. Error Mean
Judge1	2.00	31	24.1290	9.98580	1.79350
	3.00	21	26.2381	9.24611	2.01767
Judge2	2.00	31	17.4194	12.33362	2.21518
	3.00	21	25.4286	13.85125	3.02259
Judge4	2.00	31	16.5806	10.91719	1.96078
	3.00	21	18.6190	5.82646	1.27144
Judge6	2.00	31	38.1290	15.90753	2.85708
	3.00	21	41.3810	18.48642	4.03407
Judge8	2.00	31	33.9677	12.60287	2.26354
	3.00	21	36.7143	13.38336	2.92049
Judge9	2.00	31	18.8065	5.81618	1.04462
	3.00	21	16.8095	6.33734	1.38292
Judge10	2.00	31	28.8065	13.17174	2.36571
	3.00	21	26.1905	10.69869	2.33464
Judge11	2.00	31	28.4516	15.14780	2.72063
	3.00	21	28.9524	12.48790	2.72508
Judge14	2.00	31	38.6452	13.12897	2.35803
	3.00	21	46.4762	13.81890	3.01553
Judge15	2.00	31	21.1613	11.71067	2.10330
	3.00	21	26.6190	10.51416	2.29438

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Judge 1	Equal variances assumed	.737	.395	-.770	50	.445	-2.10906	2.74053	-7.61358	3.39546
	Equal variances not assumed			-.781	45.256	.439	-2.10906	2.69956	-7.54541	3.32728
Judge 2	Equal variances assumed	1.080	.304	-2.186	50	.034	-8.00922	3.66339	-15.36736	-.65107
	Equal variances not assumed			-2.137	39.632	.039	-8.00922	3.74741	-15.58521	-.43322
Judge 4	Equal variances assumed	4.583	.037	-.782	50	.438	-2.03840	2.60706	-7.27483	3.19803
	Equal variances not assumed			-.872	47.844	.387	-2.03840	2.33693	-6.73751	2.66070
Judge 6	Equal variances assumed	2.489	.121	-.677	50	.501	-3.25192	4.80071	-12.89444	6.39059
	Equal variances not assumed			-.658	38.618	.515	-3.25192	4.94334	-13.25392	6.75008
Judge 8	Equal variances assumed	.229	.635	-.752	50	.456	-2.74654	3.65172	-10.08125	4.58816
	Equal variances not assumed			-.743	41.308	.461	-2.74654	3.69498	-10.20702	4.71393
Judge 9	Equal variances assumed	.454	.504	1.172	50	.247	1.99693	1.70425	-1.42615	5.42001
	Equal variances not assumed			1.152	40.536	.256	1.99693	1.73312	-1.50439	5.49825
Judge 10	Equal variances assumed	1.146	.290	.756	50	.453	2.61598	3.46007	-4.33379	9.56574
	Equal variances not assumed			.787	48.247	.435	2.61598	3.32373	-4.06594	9.29790
Judge 11	Equal variances assumed	.321	.573	-.125	50	.901	-.50077	3.99745	-8.52989	7.52835
	Equal variances not assumed			-.130	47.968	.897	-.50077	3.85070	-8.24325	7.24171
Judge 14	Equal variances assumed	.189	.666	-2.066	50	.044	-7.83103	3.78978	-15.44303	-.21903
	Equal variances not assumed			-2.046	41.574	.047	-7.83103	3.82802	-15.55864	-.10342
Judge 15	Equal variances assumed	.054	.817	-1.717	50	.092	-5.45776	3.17879	-11.84254	.92702
	Equal variances not assumed			-1.753	46.056	.086	-5.45776	3.11256	-11.72281	.80730

Group Statistics

	1=BC, 2=NBNC, 3=NBC, 4=BNC	N	Mean	Std. Deviation	Std. Error Mean
Judge1	2.00	31	24.1290	9.98580	1.79350
	4.00	40	31.9250	16.62156	2.62810
Judge2	2.00	31	17.4194	12.33362	2.21518
	4.00	40	29.2250	19.01752	3.00693
Judge4	2.00	31	16.5806	10.91719	1.96078
	4.00	40	22.0500	9.68199	1.53086
Judge6	2.00	31	38.1290	15.90753	2.85708
	4.00	40	51.0250	14.07396	2.22529
Judge8	2.00	31	33.9677	12.60287	2.26354
	4.00	40	39.7750	15.58679	2.46449
Judge9	2.00	31	18.8065	5.81618	1.04462
	4.00	40	18.6000	6.23801	.98632
Judge10	2.00	31	28.8065	13.17174	2.36571
	4.00	40	35.3250	13.15273	2.07963
Judge11	2.00	31	28.4516	15.14780	2.72063
	4.00	40	35.3250	16.25973	2.57089
Judge14	2.00	31	38.6452	13.12897	2.35803
	4.00	40	44.6750	17.06907	2.69886
Judge15	2.00	31	21.1613	11.71067	2.10330
	4.00	40	29.3750	14.03601	2.21929

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Judge 1	Equal variances assumed	8.051	.006	-2.307	69	.024	-7.79597	3.37988	-14.53865	-1.05328
	Equal variances not assumed			-2.450	65.357	.017	-7.79597	3.18175	-14.14971	-1.44222
Judge 2	Equal variances assumed	4.853	.031	-2.999	69	.004	-11.80565	3.93594	-19.65764	-3.95365
	Equal variances not assumed			-3.161	67.119	.002	-11.80565	3.73479	-19.26008	-4.35121
Judge 4	Equal variances assumed	.008	.927	-2.233	69	.029	-5.46935	2.44966	-10.35630	-.58241
	Equal variances not assumed			-2.199	60.444	.032	-5.46935	2.48761	-10.44456	-.49415
Judge 6	Equal variances assumed	.390	.534	-3.617	69	.001	-12.89597	3.56511	-20.00817	-5.78377
	Equal variances not assumed			-3.561	60.353	.001	-12.89597	3.62144	-20.13904	-5.65289
Judge 8	Equal variances assumed	1.648	.203	-1.689	69	.096	-5.80726	3.43754	-12.66497	1.05045
	Equal variances not assumed			-1.735	68.854	.087	-5.80726	3.34624	-12.48308	.86856
Judge 9	Equal variances assumed	.258	.613	.142	69	.887	.20645	1.44965	-2.68552	3.09842
	Equal variances not assumed			.144	66.610	.886	.20645	1.43668	-2.66148	3.07438
Judge 10	Equal variances assumed	.028	.868	-2.070	69	.042	-6.51855	3.14925	-12.80113	-.23597
	Equal variances not assumed			-2.069	64.604	.043	-6.51855	3.14983	-12.80993	-.22716
Judge 11	Equal variances assumed	.559	.457	-1.820	69	.073	-6.87339	3.77736	-14.40901	.66223
	Equal variances not assumed			-1.836	66.630	.071	-6.87339	3.74316	-14.34554	.59876
Judge 14	Equal variances assumed	5.418	.023	-1.628	69	.108	-6.02984	3.70409	-13.41929	1.35961
	Equal variances not assumed			-1.682	68.999	.097	-6.02984	3.58387	-13.17947	1.11980
Judge 15	Equal variances assumed	2.469	.121	-2.625	69	.011	-8.21371	3.12889	-14.45567	-1.97175
	Equal variances not assumed			-2.686	68.588	.009	-8.21371	3.05763	-14.31417	-2.11325

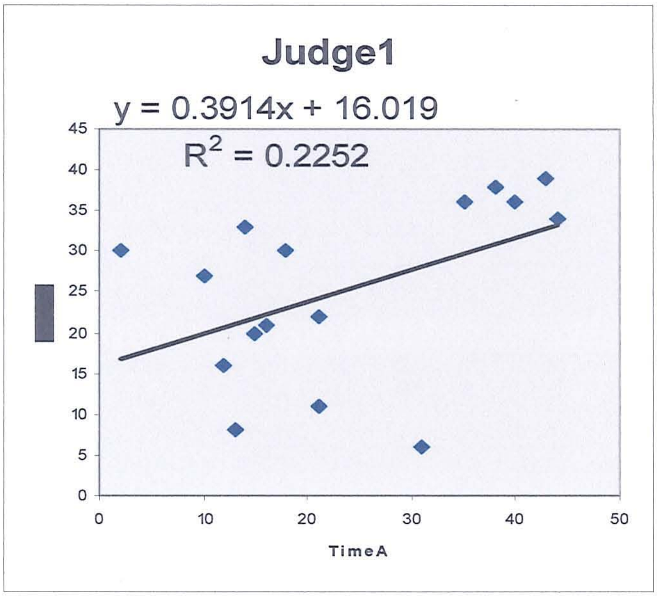
Group Statistics

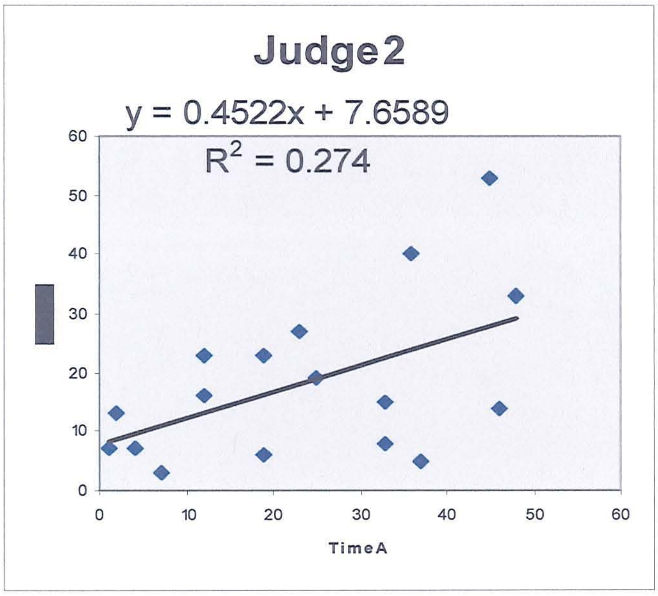
	1=BC, 2=NBNC, 3=NBC, 4=BNC	N	Mean	Std. Deviation	Std. Error Mean
Judge1	3.00	21	26.2381	9.24611	2.01767
	4.00	40	31.9250	16.62156	2.62810
Judge2	3.00	21	25.4286	13.85125	3.02259
	4.00	40	29.2250	19.01752	3.00693
Judge4	3.00	21	18.6190	5.82646	1.27144
	4.00	40	22.0500	9.68199	1.53086
Judge6	3.00	21	41.3810	18.48642	4.03407
	4.00	40	51.0250	14.07396	2.22529
Judge8	3.00	21	36.7143	13.38336	2.92049
	4.00	40	39.7750	15.58679	2.46449
Judge9	3.00	21	16.8095	6.33734	1.38292
	4.00	40	18.6000	6.23801	.98632
Judge10	3.00	21	26.1905	10.69869	2.33464
	4.00	40	35.3250	13.15273	2.07963
Judge11	3.00	21	28.9524	12.48790	2.72508
	4.00	40	35.3250	16.25973	2.57089
Judge14	3.00	21	46.4762	13.81890	3.01553
	4.00	40	44.6750	17.06907	2.69886
Judge15	3.00	21	26.6190	10.51416	2.29438
	4.00	40	29.3750	14.03601	2.21929

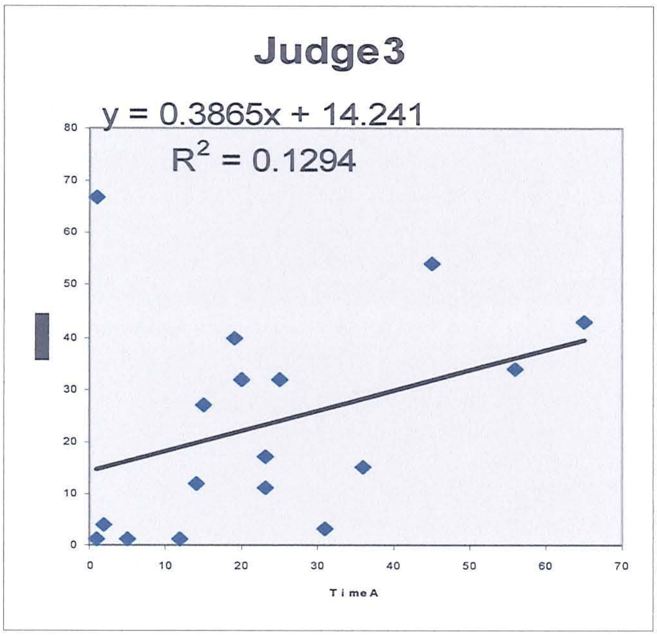
Independent Samples Test

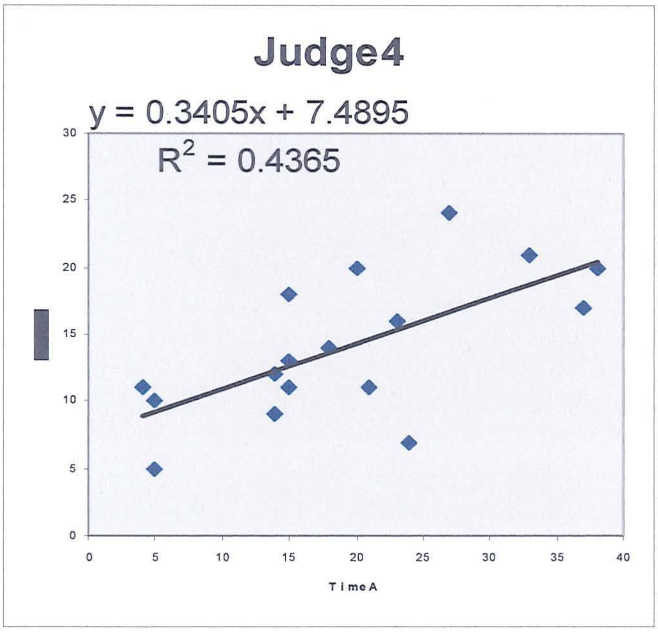
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Judge 1	Equal variances assumed	8.615	.005	-1.451	59	.152	-5.68690	3.92000	-13.53081	2.15700
	Equal variances not assumed			-1.716	58.734	.091	-5.68690	3.31329	-12.31741	.94360
Judge 2	Equal variances assumed	1.270	.264	-.808	59	.422	-3.79643	4.69933	-13.19977	5.60691
	Equal variances not assumed			-.890	52.704	.377	-3.79643	4.26353	-12.34911	4.75626
Judge 4	Equal variances assumed	7.393	.009	-1.485	59	.143	-3.43095	2.30986	-8.05298	1.19107
	Equal variances not assumed			-1.724	57.764	.090	-3.43095	1.98999	-7.41471	.55280
Judge 6	Equal variances assumed	6.235	.015	-2.278	59	.026	-9.64405	4.23330	-18.11486	-1.17324
	Equal variances not assumed			-2.093	32.481	.044	-9.64405	4.60713	-19.02301	-.26509
Judge 8	Equal variances assumed	.484	.489	-.763	59	.448	-3.06071	4.00890	-11.08251	4.96108
	Equal variances not assumed			-.801	46.527	.427	-3.06071	3.82138	-10.75041	4.62898
Judge 9	Equal variances assumed	.055	.815	-1.059	59	.294	-1.79048	1.69014	-5.17243	1.59148
	Equal variances not assumed			-1.054	40.189	.298	-1.79048	1.69861	-5.22300	1.64205
Judge 10	Equal variances assumed	.812	.371	-2.739	59	.008	-9.13452	3.33494	-15.80772	-2.46133
	Equal variances not assumed			-2.922	48.630	.005	-9.13452	3.12657	-15.41881	-2.85024
Judge 11	Equal variances assumed	1.778	.188	-1.567	59	.122	-6.37262	4.06568	-14.50802	1.76278
	Equal variances not assumed			-1.701	50.806	.095	-6.37262	3.74640	-13.89454	1.14930
Judge 14	Equal variances assumed	2.702	.106	.417	59	.678	1.80119	4.32279	-6.84869	10.45107
	Equal variances not assumed			.445	48.812	.658	1.80119	4.04688	-6.33212	9.93450
Judge 15	Equal variances assumed	1.726	.194	-.790	59	.433	-2.75595	3.48973	-9.73890	4.22699
	Equal variances not assumed			-.863	51.716	.392	-2.75595	3.19209	-9.16218	3.65027

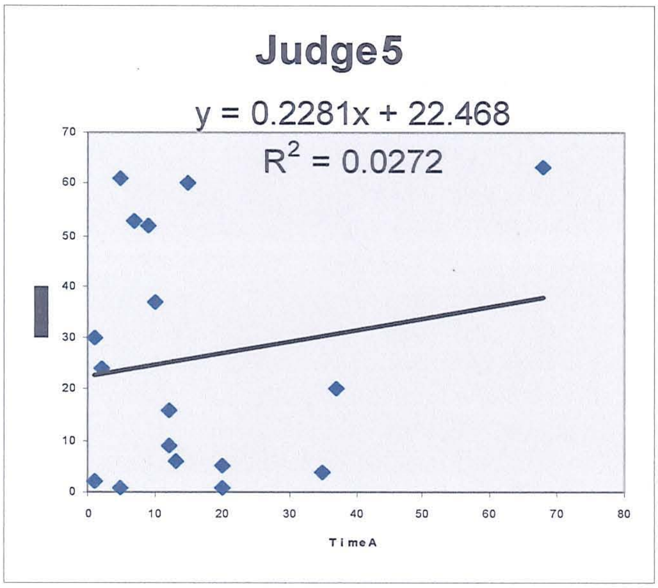
Appendix 15 Intra-judge reliability

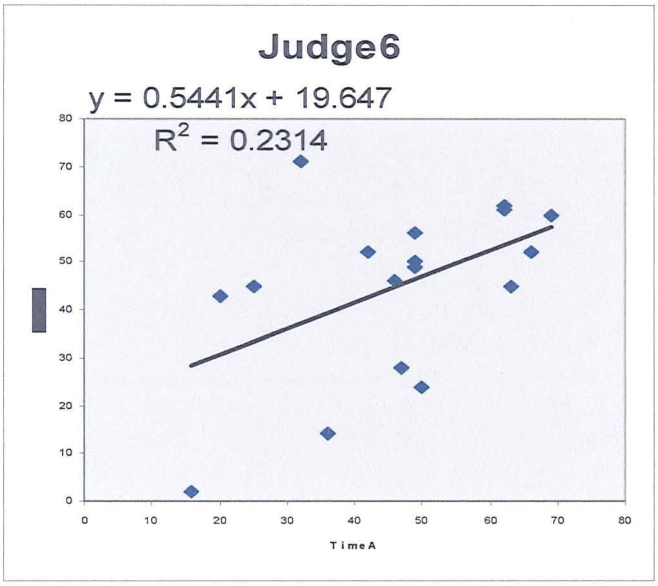


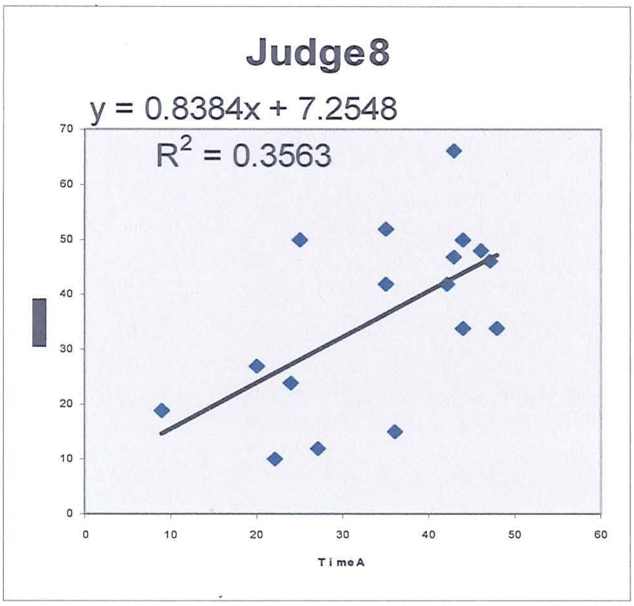


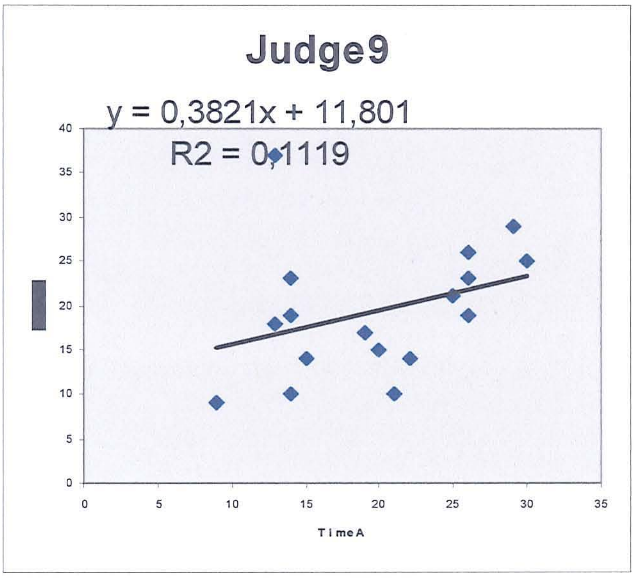

Judge3
y = 0.3865x + 14.241
R2 = 0.1294
0
10
20
30
40
50
60
70
80
0
10
20
30
40
50
60
70
TimeA

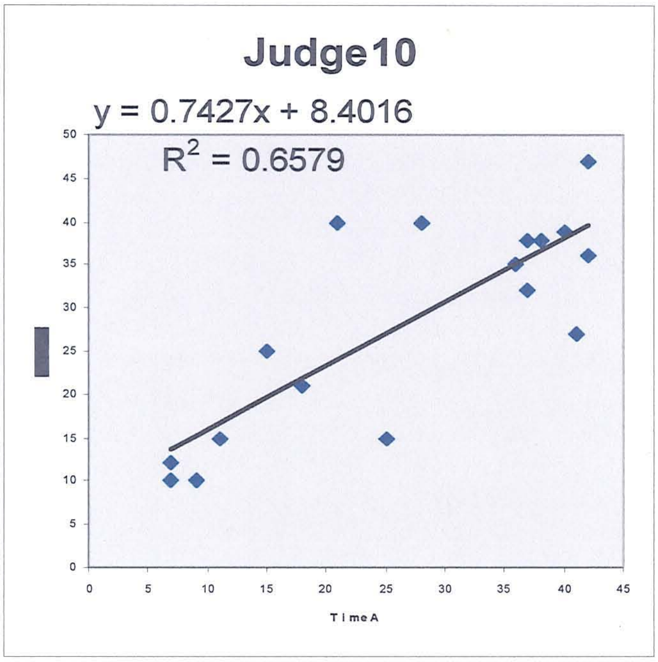

Judge4
y = 0.3405x + 7.4895
R2 = 0.4365
0
5
10
15
20
25
30
0
5
10
15
20
25
30
35
40
TimeA

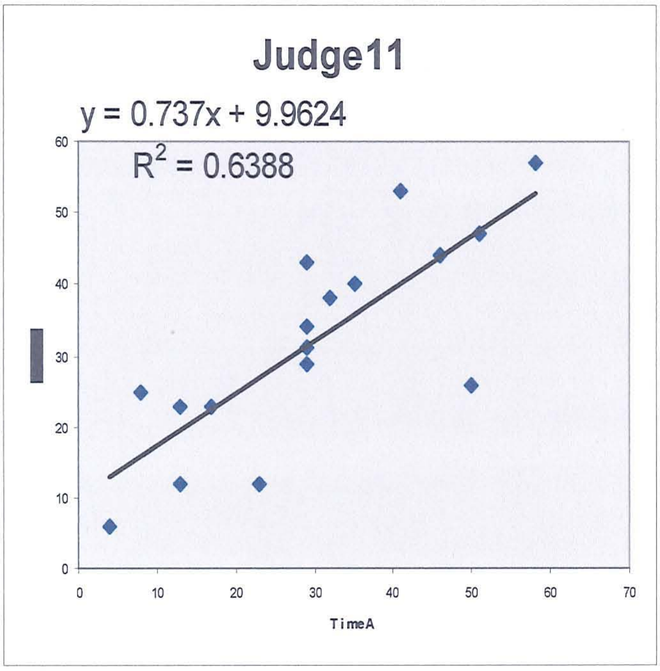

Judge5
y = 0.2281x + 22.468
R2 = 0.0272
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
TimeA

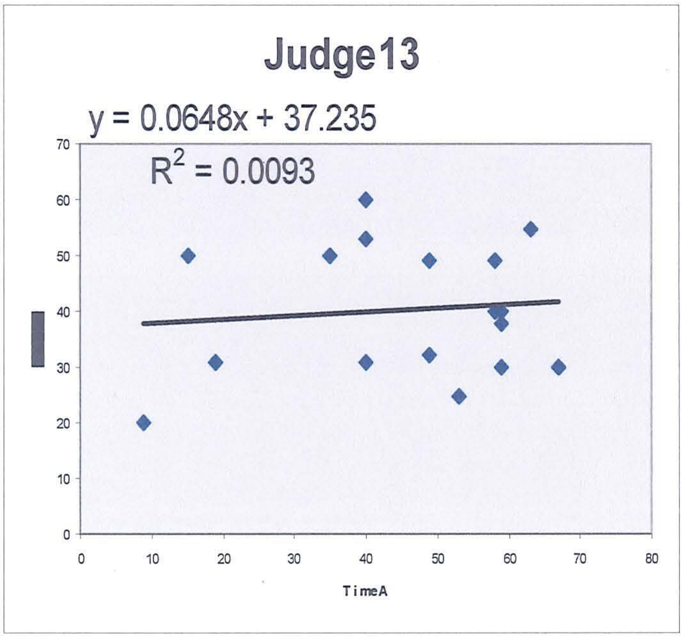

Judge6
y = 0.5441x + 19.647
R2 = 0.2314
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
TimeA

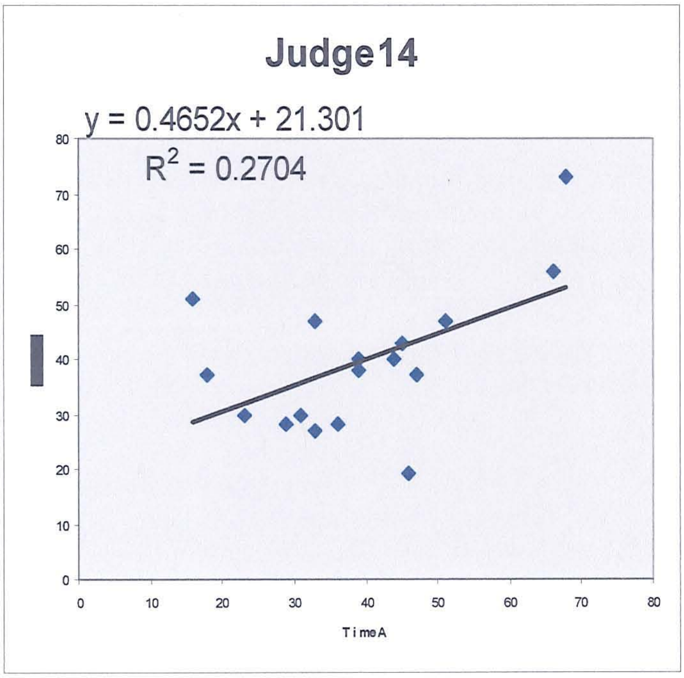

Judge8
y = 0.8384x + 7.2548
R² = 0.3563
0 10 20 30 40 50 60 70
0 10 20 30 40 50 60
TimeA

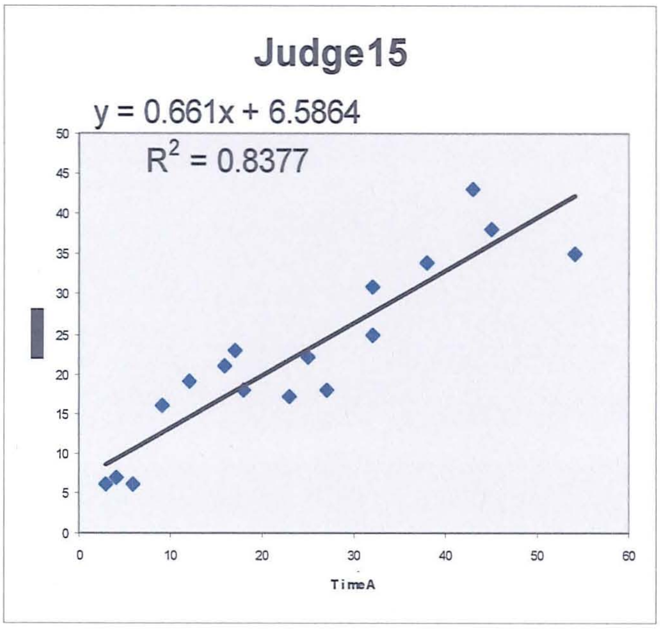

Judge9
y = 0,3821x + 11,801
R2 = 0,1119
0 5 10 15 20 25 30 35 40
0 5 10 15 20 25 30 35
TimeA


Judge10
y = 0.7427x + 8.4016
R2 = 0.6579
TimeA


Judge11
y = 0.737x + 9.9624
R2 = 0.6388
TimeA


Judge13
y = 0.0648x + 37.235
R2 = 0.0093
0
10
20
30
40
50
60
70
80
TimeA


Judge14
y = 0.4652x + 21.301
R2 = 0.2704
0
10
20
30
40
50
60
70
80
TimeA



Absolute difference between first and second rating of identical stimuli												
Judge												
1	**2**	**3**	**4**	**5**	**6**	**8**	**9**	**10**	**11**	**13**	**14**	**15**
0	8	28	3	5	0	10	3	1	5	0	6	7
4	32	12	4	29	20	21	2	14	0	9	10	5
5	13	2	7	4	19	0	5	10	6	9	7	6
1	4	9	10	17	18	25	0	5	2	18	27	1
17	4	66	17	22	10	7	0	4	11	8	1	3
4	11	2	2	27	1	0	4	1	17	12	8	7
5	4	0	5	19	14	12	5	3	1	35	14	3
4	18	6	20	43	1	2	5	12	24	21	1	9
5	6	11	0	1	23	15	1	5	2	11	4	0
10	25	22	18	45	9	23	24	1	12	28	5	0
19	6	4	12	15	26	10	9	10	6	13	1	7
28	4	22	0	56	14	6	7	1	1	37	35	7
12	11	21	7	7	0	4	11	6	10	15	2	3
1	4	12	5	4	0	14	4	0	4	20	4	6
4	32	7	4	3	39	1	5	5	2	29	1	19
25	15	12	3	31	7	7	8	3	14	19	10	4
10	3	21	2	46	22	17	0	19	5	17	19	0
Sum of abs diff												
154	200	257	119	374	223	174	93	100	122	301	155	87
High numbers inconsistent/unreliable judges,												
Low numbers = good judges												

Appendix 16

Visit to the choirs of Dresden and Leipzig, April 2003

Introduction

The tradition that boys' choirs should perform the music of the Liturgy in German churches dates from the 13th Century. Unlike the tradition in the UK, with adult voices on the alto, tenor and bass lines (this evolved as musicians replaced clergy as singers), the German choirs have boys singing all four choral parts. Sopranos are unchanged voices, altos are naturally low unchanged and early stages of changing, tenors and basses are young adult voices.

The daily routine of each tradition has a similar workload in terms of the number of hours, however the German choirs perform only at weekends, allowing more time for preparation in the weekday rehearsals. They seem to have a comparitively large number of concerts and tours and fewer recordings.

Since the reformation, the choirs have belonged to the city and not the church.

The Dresden Kreuzchor

The conductor of the choir for the last six years has been Roderick Kreile. He was originally based at the Munich Hochschule, teaching choral conducting. The choir, founded in 1216, has 140 boys in total: 48 sopranos, 18 altos, 18 tenors and 24 basses. This is a relatively large choir, enabling them to perform bigger repertoire such as the Brahms Requiem. They reduce their numbers to 80 for touring and sometimes to 40 for early music performances.

The main performing venue is the Kreuzkirche. This was bombed severely during World War II and was one of the few buildings to be re-built by the GDR. As a consequence of limited funding for renovation it has a rather austere interior. The church seats 3,200.

The Leipzig Thomanerchor

This originally belonged to the monastery of St Thomas, founded in 1212. After the dissilution of the monasteries it became a municipal school.
In Bach's time there were 55 pupils including residential and external. The Choirmaster was expected to teach 3 hours a day of vocal and intrumental music (Bach chose to pay a deputy to teach academic subjects like Latin). He also had to compose a new cantata for each Sunday plus motets.

The present day choir is smaller than the Kreuzchor, with 30 sopranos, 15 altos, 8 tenors and 17 basses. The school has moved to larger premises on the other side of Leipzig but the choir still sing in the Thomaskirche, which was beautifully restored in time for the 250th anniversary of Bach's death.

The rehearsal schedule

Unlike UK cathedrals, there is no early morning rehearsal as German schools begin lessons at 8am. The rehearsals for the choir are during the afternoon, as are the individual singing and instrumental lessons.

	Kreuzchor	Thomanerchor	St Paul's Cathedral
Rehearsal per week	SA 8 hrs, TB 5 hrs SATB 9 hrs Sop total 17 hrs	SA 9 hrs, TB 6 hrs SATB 8 hrs Sop total 17 hrs	Sop 12 hrs
Performance per week (music only)	1.5 hrs	1.5 hrs (+ 1 Sunday in 3)	4.5 hrs (some is repeated during the week)
Concerts and recordings	70 (may tour the same programme) 1 in two years	Not known	10 (different) 2 per yr

There is no day off in the week for the younger boys. The Kreuzchor have a weekend off every 4-5 weeks, the Thomanerchor have 2 out of every 3 Sundays off.

The conductor of the choir has trained as a choral conductor and is usually a professional singer; he has an assistant and senior boys. The Thomanerchor had a conductor during the 1940's who had trained as an organist and not as a singer, there was a significantly greater number of voice disorders during this time than either before or after.

Probationers

The boys enter as Probationers for one year and audition for the choir at the end of this, each year some fail to become choristers. They have a 45 min rehearsal each day, comprising hymn singing and learning basic theory. In addition to this, they have a half hour singing lesson each week. Probationers enter at the age of 7 or 8, there are no late entry members of the choir.

Individual training for choristers

Choristers have a 45 minute singing lesson each week. There are 8-10 singing teachers in each school, both male and female, all of whom are professional singers; they never work with the whole choir, only with individal boys. All singing teachers are required to learn teaching techniques at University, although there is no specific Child Voice Pedagogy available. The choirs have employed singing teachers for the choristers for the last 20/30 years. Before this time, if a boy developed vocal problems he had to leave the choir.

Instrumental tuition is seen as a supporting skill for the boys' overall musical development. Only one instrument is studied, most boys learn piano in half hour lessons with not much expectation of practice; if a boy shows real potential as an instrumentalist, he leaves the choir. The period of rest during voice mutation is often seen as a time to devote more hours to regular instrumental practice.

Voice change.

Boys move to Alto during pre-mutation and then leave the choir during mutation. This can be for anything from 6 months to two years. During this time they continue with singing lessons. They then return at the discretion of their teacher to either tenor or bass. All the tenors and basses in the choir have sung as trebles and all the trebles go on to sing either tenor or bass. Countertenor singers are extremely rare, maybe one every five years.

The earlier onset of voice change has implications for the balance of the choir as there are now a greater percentage of tenors and basses. One answer to this situation is to allow boys a longer period of voice rest during mutation. The other implication of this shift is that younger boys are now expected to lead the soprano and alto sections; they may have advanced physical maturity but not necessarily musical maturity.

The end of singing as a treble is not generally perceived as any sort of loss as the boys have plenty of role models amongst the senior members of the choir. The only time when a boy may try to disguise voice change is if there may be an exciting tour in the immediate future. Otherwise it is accepted as inevitable and most boys enjoy the opportunity to devote more time to their academic work and instrumental practice. Boys during this time are responsible for programme selling and organisation of perfomances; they remain in the community of the choir.

Voice Disorders

The percentage of voice disorders is consistent with those in the UK, it is rare to find hyperkinetic disorders in boys post-mutation. If a boy has a long-term or recurring problem (3 months or more) he has to leave the choir as boarding house places are limited. Boys with a viral infection will see a phoniatrician if the infection persists for more that one or two weeks. Boys who are 'off singing' do not attend rehearsals because of the phenomenon of 'inner singing': the vocal folds move when you listen to music, this is not rest. They have a special programme with a singing teacher when they begin recovery.

The incidence of athsma is lower than London choristers but the incidence of allergies is higher. It is possible that this could be merely due to differing diagnostic criteria within the medical professions in each country.

General schooling

Both of the schools are large day schools for many hundred pupils. The choristers are taught in their own classes and have the option to board.
Academic achievement is important, there are exams to pass at the end of years 10 and 13. If the yr 10 exams are not passed, the boy has to leave school to pursue vocational training; the smaller class sizes for the choristers makes this a more easily attainable target.

There is adequate time for play and for sport: one hour after lunch and time in the evening after dinner. Structured PE is only for two periods a week as German school children normally pursue sport after school (from lunchtime onwards). The choristers are not allowed to play football if they have a cold or if the weather is too cold; there is an indoor facility for sport in this event.

They may see their parents from Friday evening to Saturday lunchtime and for two out of every three Sundays (Thomanerchor).

Cultural and political context

The existence of the GDR for forty years had a mixed effect on the choral tradition. The funding for the choirs was still maintained, generous financial support was given to the arts at a level that was on show to the international community. There was huge competition to enter the choirs as it offered boys a chance to travel abroad. In the 1970's the Thomanerchor had 250 applicants for the 10 places available each year.
The State tried to introduce 'Socialist Music' into the choral repertoire, however, the tradition of performing music written specifically for the choir was too strong. In Leipzig the music of Bach and Mendelssohn predominates as in Dresden does the music of Schütz.

The general training was more disciplined and the choir was more hierarchical. The culture of the fomer East Germany is still different from the west. For example, the school lunch in the Thomanerchor was similar to English school lunches of the 1960's!

Comparitive standards and priorities in the choral singing

The standard of the choirs is high, the quality of choral singing is impressive. On hearing the individual sections and some individual voices, the level of ability and training is possibly not as great as the equivalent London choirs. The vocal technique is less detailed: for example, breathing is allowed to be predominately clavicular, the 'singer's formant' is not developed to any great extent and the soprano boys do not have a particularly strong mid to low range. The articulation of text is however, exemplary; the German style of singing requires strong consonants and real clarity of vowel colour. It was observed in the individual singing lessons that great attention was paid to vowel colour and not basic phonatory techniques.

Most of the repertoire is in German or German Latin. This gives a greater contrast of bright and dark vowel sounds, increasing the range of harmonics in the sound and giving it a naturally rich quality.

It was evident in the rehearsals of both German choirs that although the pace was efficient and disciplined, it did not have the speed of the UK choirs necessary for the larger proportion of perfomance time and the predominately adult presence. The comparitive luxury of a greater number of rehearsal hours did not necessarily result in a more polished performance.

The lack of mature adult voices in the German choirs gives them a distinctly different timbre. Young boys singing soprano are not required to match the power of mature adult voices. Secondly, the altos are naturally high voices singing at the lower end of their range (rather than naturally low voices singing at an artificially high pitch); this gives an overall feel of balance to the four-part choral sound. It is possible that the direct projected adult male alto sound may influence the boy sopranos with unfavourable results.

The overall impression of the choral singing was an easier sound, lighter and more facile. Although this is a far safer way of training developing voices, it did not have the excitement and fullness of tone produced by some English choirs.

Life after choir

Although the German choirs are training young men in their tenor and bass voices, a surprisingly small number continue to become professional singers (2%). There is no similar statistic available in the UK, although experience would suggest that the figure is higher than this. In order to compare these figures, one would need to take into account the number of ex-choristers in the UK who continue their singing as cathedral lay clerks. This option is not available to German singers who would have to pursue their professional singing at the higher standard required by Opera Houses.
It has been suggested that intensive choral training as a child and young adult can develop habits that preclude the singer from developing a soloistic voice. There was recently a case of a boy in the Kreuzchor with an outstanding tenor voice, who was advised by an external expert to leave the choir in order not to jeopardise his chances of becoming a first-rate soloist. There is no available evidence to suggest that damage occurs, likewise there are no statistics available to show how many ex-choristers become succesful in other areas of professional voice use, for example, teachers.

Although there are relatively few professional singers emerging from the German Boys' choirs and even fewer professional instrumentalists, up to one third of boys will pursue a career in music, either as conductors or as teachers. The Kreuzchor can still boast of ex-choristers such as Peter Schreier, Olaf Baer and Theo Adam.