Intonational Strategies
In
Ensemble Singing

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DECLARATION

By means of this declaration, I grant powers of discretion to the University Librarian to allow this thesis to be single-copied in whole or in part for study purposes only, subject to normal conditions of acknowledgement.

ABSTRACT

The aim of the research was to find out about intonational strategies in the performance situation. The singing voice was chosen as the appropriate subject for experimental work, due to its superior capability to define pitch as compared to other musical instruments. Ensemble singing was also required, as harmonic context may be important in the clarification of the issue.

Chapter One, as an introduction to the subject, considers tuning systems and temperaments and briefly reviews the experimental literature on the subject. It also states the aim of the research.

Chapter Two focuses on the theoretical aspects of the research, considering some relevant phenomena of psychoacoustics to the legacy of tuning systems and temperaments. Some thoughts on intonational strategies, reference frequencies and flexible temperament as desirable components of a sound intonational strategy are elaborated. An analysis of the motet Ave Verum Corpus, by Mozart, as the chosen music piece for experimental work is carried out.

Chapter Three deals with the delineation of experimental procedures for the evaluation of the intonational strategies adopted by singers in the performance situation. The recording sessions environment and the technical tools utilised in the experiments are described, as well as the technical procedures to carry out the measurements of the acquired data. As strict criteria had to be met regarding the performance situation, simultaneity of performance and the need to acquire individual data for analytical work, electrodes were attached to the neck of the singers, near the larynx, in order to carry out the recording sessions with the help of Laryngograph devices. Analytical issues are also considered in the chapter, namely technical problems, errors and mistakes, as well as the implementation of intonational analyses and reference frequency calculations.

Chapter Four presents a discussion on data measurements procedures, including guidelines for the determination of errors and mistakes and their symbology. Four recording sessions were carried out; two of them fulfilled all the necessary requirements. The singers' results are presented in chronological order: firstly, a quartet of singers from the Royal Academy of Music, and secondly, sixteen of the BBC Singers. Reference frequency results are also presented and discussed.

Chapter Five deals with the intonational strategies as defined by the experimental work. It was discovered that no *theoretical model* was followed throughout the music piece, but instead *intonational procedures* were guiding the singers while performing. Also, the two groups adopted different intonational strategies regarding reference frequencies. Alongside with the main issues of the research – intonational strategies regarding pitch behaviour and reference frequencies, pitch equalization within a choir section and text-related issues rank amongst the most important topics that have been revealed by the results.

Chapter Six comments on the new concepts brought about by the research. It also delineates some possibilities for future research work on the subject and related issues, especially vibrato singing, text articulation and absolute pitch.

The Appendices contain images of the experimental work, diagrams of studio disposition for recording sessions, and analytical scores alongside with tuning tables that make it possible to represent graphically analytical values. They also provide means of performing acoustical replications of the results of analysis and singers. The core of the appendices volume is formed by the results of the singers' fundamental frequencies results and their graphical representation.

Symbols and Abbreviations

Intonational analysis symbols

The intervals from the extended just intonation used in the analysis are described below. Cents values are deviations from the extended Pythagorean intonation.

- Subscripts 0: as originated in extended Pythagorean intonation;
- Subscripts + or – 1, 2, etc., refers to the *syntonic comma* ($\overline{k}$), which is equivalent to 21.506 cents, added or diminished from the Pythagorean interval (subscript 0);
- Subscripts $-\overline{z}$ refers to the *septimal comma* (-27.264 cents), and are used to adjust the seventh of dominant chords whose roots have 0 subscripts;
- Subscripts $-(\overline{k}+\overline{z})$ (-48.771 cents) furnish the minor seventh of dominant chords with –1 subscript applied to their fundamental;
- Subscripts $-\overline{y}$ (-6.775 cents) refers to the minor ninth of dominant ninth chords whose roots have –1 subscripts, and also the higher note of diminished seventh whose lower note has a –2 subscript;
- Subscripts $+(\overline{k}-\overline{y})$ (14.731 cents) gives the minor ninths of dominant ninth chords whose roots have 0 subscripts, and also the higher note of a diminished seventh whose lower note has a –1 subscript;
- Subscripts $+(\overline{k}-\overline{z})$ (-5.758 cents) refer to the minor seventh of dominant chords whose fundamentals have a +1 subscript.

Tables' results symbology

The following symbology is applied to the tables and charts with the singers' results.

Coloured text symbology	
Black	Good value for measurement (either **bold** or plain text)
Bold red	Possible technical problem of the device
Bold underlined red	Possible technical problem of the device, emphasised
~~Any strikethrough~~	Invalid measurement
Bold green	Researcher's judgement regarding substantial error or mistake
Outlined red	Missing or very weak signal (device's technical problem)
Coloured cells symbology	
Blue outlined cells	Value not included in the calculations, due to a technical problem or singer's mistake
Green outlined cells	Invalid measurement, according to the researcher's personal evaluation
Yellow outlined cells	The values are still used for calculations, in spite of any doubts the researcher may have about their validity

GLOSSARY

Absolute pitch: the ability to identify or reproduce any given note on demand; also called *perfect pitch*. However, the latter denomination is somewhat misleading, since it implies a state of perfection that is far from being true, either from the practical or from the theoretical points of view.

Arithmetic proportion: a procedure that is accomplished by dividing a string into equal parts. The arithmetic proportion produces sound waves which are the exact reverse in pitch than the ones produced by means of harmonic proportion.

Arithmetic series: a series of frequencies which are symmetrical to the harmonic series. It is built by the division of a monochord's string into (any number of) equal parts.

Beat detection (principle): the ability to detect beat phenomenon. In order to be workable, beat detection requires non-vibrato sound waves to act upon.

Beats: a kind of sound interference defined by the arithmetic difference between two sound waves of very near frequencies. Beats are perceived as a swelling and cancelling of the resulting sound waves' amplitude.

Categorical perception: Pitches defined over a perceptual continuum may be easily understood if an adequate insertion of the phenomena into well-delineated categories is made. This would imply that such categories would be clearly specified in terms of boundaries, widths, and centring of the pertinent events. It is not known for sure about the innate or learned qualities of such perceptual abilities. Musicians have developed the ability to perceive pitch categorically by spreading musical intervals into a number of discrete windows to the octave. Sundberg suggests seven of such windows (Sundberg, 1991: 62-63); the present writer, however, admits at least the most common 12 categorical pitches per octave, as depicted in the standard keyboard layout.

Commas: micro-intervals that are manifested as a result of the open structure of the harmonic series. Commas play a crucial role in the designing of tuning systems and temperaments.

Consonance: a specific quality of harmonic intervals of being well defined musically, presenting no beats to the perceiver. It relates to musical stability, and is akin to the frequencies' small integer ratios.

Critical bands: critical bands refer to the minimum musical interval that allows for two sine waves of different frequencies to be resolved perceptually into a consonant interval.

Dissonance: the aural sensation of roughness that comes into play when two harmonic sound waves are distant from each other by an amount smaller than a critical band. In common music practice, dissonance is almost always perceived in relation to the fundamental frequencies of complex tones. However, it also happens between sine waves. As a result, any harmonic series presents roughness (which characterises dissonance) between adjacent harmonics from the sixth or seventh upwards.

Electrodes: specialised devices utilised in the recording sessions of this research as the larynx excitation signals' sources monitoring. They integrate the Laryngograph equipment.

Extended keyboard: an extended keyboard presents an increased number of keys per octave, either as an accretion to the standard keyboard layout or as integrating a differently designed keyboard.

Flexible temperament (principle): temperament procedure that does not establish fixed or rigid music intervals, but rather allows for meaningful deviations to an authoritative model of intonation to take place according to musical needs.

Formants: a resonance curve that will enhance any harmonics lying within its frequency region. The singing voice presents generally four formants, being the first two or them responsible for the definition of vowels in text-singing; an extra formant called the singer's formant can be activated by (soloist) singers.

Generalised keyboard: a keyboard that is designed to be universally used with various types of either tuning systems or temperaments.

Harmonic proportion: mathematical principle that has its acoustical counterpart in the harmonic series. It is applied in traditional tuning procedures by means of dividing the monochord into progressively smaller fractions in order to define musical intervals.

Harmonic series: a fundamental frequency together with a collection of integer multiples of itself constitute the harmonic series.

Harmonic series principle: the harmonic series principle in this research relates to the conformity of intonational procedures to intervals taken from the harmonic series.

Harmonicity/inharmonicity: musical instruments produce complex tones whose partials may or may not completely agree in frequency with the harmonic series principle. Partials that coincide in frequency with the harmonic series principle present harmonicity, while those that do not conform to the harmonic series principle (they are usually slightly stretched in relation to the model) present inharmonicity.

Harmonics: all the frequencies that are integer multiples of and functionally related to a fundamental frequency tone.

Identity: also called prime number limit, it defines the limit of resolution of a given tuning system. For instance, identity 5 defines standard pure or just intonation, with the fifth harmonic (of the harmonic series) being responsible for its resolution; all triads will sound purely, while most dissonances will not.

Intonational strategies: the general tendencies regarding intonation followed by musicians during performance.

Just intonation (extended): procedures on intonation that completely agree with the harmonic series principle.

Laryngograph: specialised technical device utilised in this research for data gathering. According to the Laryngograph manual, 'the Laryngograph is an electro-glottograph that makes possible the examination of vocal-fold contact, rate of vibration and regularity during voice production, and without interfering with the processes of speaking or singing.'

Level of precedence: while performing, a singer defines musical elements according to their subjective hierarchical importance. Singers with different levels of musicianship, or belonging to different musical traditions may develop quite discordant musical hierarchies, which can lead to significant differences on intonational strategies.

Limits of discrimination: limits of discrimination refer to the perceptual borderline between two adjacent sine wave pitches, i.e., the point at which two sine waves of different frequencies are perceptually resolved into two discrete pitches.

Masking: Loud sound waves impair the perception of softer ones according to experimentally determined limits.

Meantone temperament: a regular temperament that aims to provide as much pure thirds as possible to the expense of slightly impure perfect fifths and fourths.

Monophony: a system of pure intonation devised by Harry Partch; a condensed version of its more than three hundreds pitches to the octave is presented in Partch's 43-tone scale.

Mutable notes: notes that share the same notation but sound at different pitches, which usually are distant from each other by a syntonic comma. They are utilised in the implementation of extended just or pure intonation.

Partials: the frequencies that are generated alongside a fundamental frequency; they can be harmonic or inharmonic, i.e., integer multiples of the fundamental frequency or not.

Pitch equalisation: intonational strategy utilised in choir sections, in which singers either seem to compensate for other singers tuning deviations, or cause other singers to compensate for his or her tuning deviations. As the pitch equalisation phenomenon was discovered in the research, further investigation is needed to clarify the issue.

Prime number limit: see Identity.

Pure Intonation (extended): tuning system that implements a higher resolution than the Pythagorean intonation; the exact degree of resolution can be varied according to the needs or convenience of use.

Pythagorean intonation (extended): tuning system that implements intervals based on identity 3, which defines the perfect fifth as the generator interval. Intervals that require a more advanced resolution will be out or tune, not following the harmonic series principle, thus presenting (harmonic) beats to the perceiver. The extended version of Pythagorean intonation could use up to 31 pitches (notes) per octave.

Reference frequency (principle): the tone used as the reference tone for a musical excerpt – a phrase, section, movement or even the entire piece. Traditionally, it is expected to remain constant throughout the entire musical performance; in this research, however, it was found out that it may either tend to remain constant or to shift according to a musically meaning interval, such as the *syntonic comma*.

Fixed reference frequency principle: it is the principle that asserts a tendency of the reference frequency to remain stable throughout a music piece or excerpt.

Flexible reference frequency principle it is the principle that asserts a tendency of the reference frequency to vary in pitch throughout a music piece according to musical needs.

Target notes: notes to which performers aim at while singing or playing.

Temperaments: proposed practical solutions for intonational problems brought about by the interaction between musical language and psychoacoustical principles. They look for practical ways to close the otherwise open succession of intervals that cannot match the octave in tuning systems.

Tuning systems: tuning procedures developed according the harmonic proportion principle. They aim to provide a (usually fixed) set of pitches for music practice. They are implemented according to a previously defined resolution (see *Identity*).

Twelve-tone equal temperament: tuning procedure that limits the number of pitches to the octave to twelve equally-spaced semitone intervals.

Vibrato: a nearly-sinusoidal variation in pitch that can be applied to sung tones with a frequency rate of about 5 to 7.5 Hz. A 'normal' vibrato amplitude oscillation is considered as being of about a quarter-tone in either direction (up and down) in relation to the perceived centre frequency. Vibrato is an important subject in relation to intonational strategies, because its use impairs beat perception, which can lead the performer to a markedly different intonational behaviour.

1 - INTRODUCTION

As a performing art, music evolves over time, never to be repeated again in the same fashion. This characteristic of the performing arts makes them tools to be resorted to with care and responsibility, for they represent most of our best efforts while striving for excellence and the exploration of higher human values. One of the important requirements of music performance is the constant attention that must be paid to its various technical aspects that are prone to constant variation. Time and pitch-related phenomena are perhaps the most important elements of the musical language in that respect. There is always a feeling of unpredictability regarding the results they tend to produce in a performance situation. This feeling is caused by the fact that most musical instruments present some degree of flexibility regarding intonation and they are not easily controlled. The human singing voice is well endowed in this respect, being the freer music instrument in relation to pitch flexibility.

This research work is committed to the exploration of the intonational strategies adopted by ensemble singing groups in a performance situation. Much has been said about intonational problems since western musical tradition began to develop. More yet has been done to solve those problems at a practical level, mainly through the development of innumerable temperaments – dozens of them in the Baroque period.

This chapter will point out some of the experimental work on the subject of intonation. It will begin by examining theoretical models of intonation, as determined from tuning systems and temperaments. Afterwards, the experimental work related to the subjects of solo and ensemble singing will be referred to, inasmuch as it is relevant to the research. Some ideas on the subject of intonation in a performance situation are examined and the aim of the research is defined to close the chapter.

1.1 - Theoretical models for intonation

It is believed by practitioners that music performance comes first and then theory follows. This is a reasonable assumption regarding western art music, where many examples may be pointed out. As music language kept evolving after its departure from the monophonic fabric of plainsong, new theoretical guidelines were periodically devised to ensure the best possible compositional results. Consequently, it can be found conflicting guidelines on the subject of composition throughout the historical periods of western music due to the adaptation of musical rules to new formal and harmonic procedures, as can be seen, for instance, in the treatment of consonance and dissonance throughout the western music historical periods. This kind of theory, nevertheless, came on usually after the compositional praxis had been firmly established. It might be described as a theory of consequences.

However, a different approach is needed for considering other musical facts on the relationship between theory and practice. For instance, the use of mixture stops in organ performance was implemented early in the western music tradition and consists of the addition of pipes that sound as harmonics of the pressed key. As they were devised upon the same principle used in Pythagorean intonation (harmonic proportion), but with a different kind of resolution, since many of the mixtures stops utilised pure thirds as components, it would be interesting to know whether they influenced the outcome of pure intonation or if it happened the other way around. Another issue regarding the same topic is to what extent it was mathematics or the perception of music intervals that determined the adoption of such procedures. After all, acoustic facts about the harmonic series were scientifically explored much later. There was no experimental support for pure intonation at the time mixtures were implemented in organ building, as far as the 10th century, at least[1]. Pythagorean intonation is tied up to the prime number 3 limit, and the implementation of pure intonation would depend upon a rupture with the Pythagorean limits or perhaps the perception of pure intervals by means of beat detection. It must be remembered that in early music periods intervals of the third and the sixth were considered dissonances (as they indeed are in Pythagorean intonation).

There were also cases in music history of theoretical attempts to determine and influence the future of music composing, as was the case with the dodecaphonic music of Schoenberg. Upon looking at the question of mutual interplay between theory and practice, the idea of one-way influence may not be sustainable. It seems that theoretic propositions may also have the power of determining how music production will behave. This seems to have been the case for the last two centuries regarding intonation practice. Theoretical models of intonation have been devised since the very beginning of the western music tradition, and it seems to be musicians' fate to comply with their demands.

Theoretical models pertaining to pitch may be of two kinds: tuning systems and temperaments.

1.1.1 - Tuning Systems

Tuning systems based on harmonic proportion have an acoustic counterpart – the harmonic series. They are considered in this work as the natural base for devising tuning procedures. It is not the mathematical principle of harmonic proportion that validates it, but rather the harmonic series principle that does so. Arithmetical

1 Peter Williams, in The New Grove Dictionary of Music and Musicians, refers to the Winchester organ, from the 10th century, which had mixture stops. In the Baroque period, the 'tierce' rank of pipes was often added to the mixture stops. A serious scientific research on the subject took place only in the 19th century, with Helmholtz.

proportion does not nowadays foster any intonational procedure . It does not bear an acoustic expression, at least overtly. Harry Partch (1974) states that arithmetical proportion could generate the minor tonality, because it produces partials in exactly the reversed order in relation to the harmonic proportion. Both principles (arithmetic and harmonic proportions) originate intervals compliant to pure intonation, and this fact is good enough to validate the principles herein presented.

One of the outstanding features of tuning systems is their openness, i.e., the quality they present of never repeating the same pitch (note) in the process of interval generation. This is precisely the characteristic that brings forth most of the intonational issues and misunderstandings that musicians, as performers, must deal with so often. The necessity of adjusting the octave division to a limited and fixed number of keys means that a much lower resolution than could be achieved in terms of tuning procedures must be implemented in order to appease the situation. Temperaments are the intonational procedures that make this kind of solution workable. Having inherited a fixed keyboard layout of twelve-keys per octave, together with the fact that keyboard instruments have dictated practical intonation for a long time, performing musicians accept the current state of affairs regarding intonation almost as a natural law.

1.1.2 - Temperaments

Temperaments are proposed practical solutions for intonational problems brought about by the interaction between musical language and psychoacoustical principles. They look for practical ways to close the otherwise open succession of intervals that cannot match the octave in tuning systems. Having to comply with a fixed number of pitches per octave, theorists devise all sorts of temperaments in order to minimise intonation problems brought about by specific issues related to music language, style and even instrumental resources.

The main goal of temperaments' technical procedures have been historically the minimisation of problems caused by the Pythagorean extra-wide major thirds and sixths, the extra-narrow minor thirds and sixths and their bondage to the perfect fifths' and fourths' purity in their harmonic relationship. If the thirds' and sixths' tuning problems are corrected, the fifths and fourths become severely mistuned, and the other way around. Consequently, no specific temperament can produce an entirely satisfactory response to the intonational problems arising from any piece composed and written in accordance with classical standard music notation.

From what has been said about temperaments so far, it turns out that they are imperfect solutions to tuning problems caused by the openness of tuning systems associated with practical limitations of keyboards. This situation has remained rather stable for about two hundred years now, since the adoption of twelve-tone equal temperament as the standard for intonation. Of course, many attempts have been made to implement extended pure intonation as the ideal solution for intonational problems.

This research began as one such enterprise. Before trying to spell out what it aims at, it would be useful to have a look at the main experimental work done on the subject of singing voice intonation that would be relevant to the matter. The reason why the singing voice is the preferred instrumental medium for the investigation will follow.

1.2 - Experiments on singing voice relevant to the subject

Ensemble singing has been scarcely investigated, perhaps due to the difficulty of performing experimental work with several people simultaneously. That must also be the reason why most of the choral research mentioned here is actually done with one singer at a time, as if they were soloists. For many of the experiments, this kind of procedure would be quite alright, but many crucial issues regarding choral and ensemble singing would only furnish valid results when experimental work is carried out in a performance situation. Pitch-related issues are particularly vulnerable to the experimental methodology employed. If the singer, for any reason, technical or not, is taken out of the context of the performance situation, the resultant values would not be legitimate. The reason for this is related to the utter necessity of preserving the harmonic context, aural feedback and live interaction between the performers as *sine qua non* conditions for the validity of the results.

Pitch-related experimental work

Sacerdote (1957) was the first scientist to study the degree of unison in an experiment with four sopranos. Narrow bandpass filters were used to assess the results. He found that the singers generated a distribution of phonation frequencies similar to that obtained when the bandwidth of the filter was 1.3 semitones.

Lottermoser and Meyer (1960) analysed phonograph records of choral music using a 1 Hz wide filter. The average of the bandwidth was +/- 25 cents (variation from +/- 50 to +/- 10 cents). The results depicted a tendency for wide major thirds and sixths by a near syntonic comma, narrow minor thirds and sixths by approximately a syntonic comma, perfect fourths and fifths resembling meantone temperament, and pure octaves.

Goodwin (1980) carried out a comparative experiment with soprano singers. They were asked to perform to create a choral blend as well as soloists. As soloists, they produced louder harmonics, perhaps due to the increased vocal loudness.

Hagerman and Sundberg (1980) performed an experiment with a barbershop quartet. Accuracy of intonation was very high, with mean errors below 3 cents. Results presented values close to pure intonation, even for the seventh of the dominant interval (which includes the utilisation of the septimal comma in its implementation). Intervals with a higher number of common partials were found to be easier to tune than intervals with fewer common partials.

Ternström and Sundberg (1988) measured the degree of unison in the bass section of a good amateur choir that sung a given musical cadence four times. Six basses were using contact microphones. There was no learning effect. Standard deviations varied between 10 and 16 cents, with an average of 13 cents. Deviations greater than 13 cents were rather unusual. Sundberg comments on the experiment:

> Apart from the skill of the choir, the vibrato is the factor that would most likely influence the result; ...the vibrato eliminates beats, which could serve as a cue for the individual choral singer's intonation, at least in small ensembles (Ternström and Sundberg, 1988).

Ternström and Sundberg (1982) carried out an experiment with 18 male choral singers, on interval accuracy singing. Sundberg comments on the experiment:

> The results supported the conclusion that low common partials, lack of vibrato, and high partials may all facilitate the tuning of harmonic intervals (Experiment carried out by Ternström and Sundberg, as described in Science of the Singing Voice–1987, pages 136-137).

On a later occasion, it was shown that not only the presence of common partials but also their sound levels influenced the ease of intonation. In Sundberg's words:

> The results showed that the singers agreed more closely in phonation frequency when the common partial was enhanced by a formant (Sundberg 1987, p. 137).

Sundberg suggests a procedure for enhancement of pitch agreement by resorting to a change in text for rehearsal purposes, according to the phonation frequencies of the tones of the chords. This is suggested in order to match the common partials of different notes of a chord.

Ternström and Sundberg (1987) performed an experiment with four choral singers, related to the masking phenomenon. In the experiment, described in pages 138-140, vowels [a] and [u] with a dynamic range of about 40 dB were chosen as reference sounds. Each was presented to the subjects who would sing along with a constant monitored level, and consequently the singers would be masked or would mask the reference sound at the extreme values of loudness. The vowel [u] showed big variations in pitch (about 70 cents!), while the vowel [a] remained comparably stable.

Rossing et al. (1985; 1986) carried out two investigations with singers, both male and female, concerning the issue of solo singing versus choral singing. A 'dummy head' recording technique for the experiments was used. The performers would join the choir recording as choral singers or would sing along with a pre-recorded piano accompaniment. The outcome revealed that solo singing presents generally weaker low partials and stronger high partials than choral singing. Results are slightly different for male and female singers.

Ternström et al. (1983) studied the intrinsic pitch of vowels. Its motivation was related to choral directors' complaints about the raising or lowering in pitch caused probably by vowel articulation in choral performances. As vowel articulation involves articulatory movements that might influence pitch accuracy, an experiment was designed to evaluate the hypothesis. Choral singers were asked to sustain long notes, shifting the vowels according to a given scheme. There were observed oscillations due to vowel articulation, but unfortunately some important vocal combinations were not included in the experiment.

Marshall and Meyer (1985) performed an experiment with a quartet of singers. They sung in an anechoic room with simulated room reverberation added. Strong early reflections of up to 40 msec. were appreciated which corresponds to a distance of approximately 7 metres from the singers. If this limit is surpassed, then the reverberation is considered more important in the acoustic feedback. Level of reverberation was considered much more important than reverberation time.

Experimental work on vibrato

Winckel (1953) found out that the amplitude of the vibrato undulation varies with loudness of phonation. Vennard et al. (1970) carried out EMG measurements on the laryngeal musculature of singers, trying to clarify vibrato mechanics. Analogous results were obtained by Shipp et al. (1982). The vibrato phenomenon is not well understood yet, due to the complex interrelationship between laryngeal muscles, breathing system concurrent phenomena and perhaps even auditory feedback, as has been suggested by Clarkson and Deutsch (1966) and Shipp et al. (1984).

Sundberg (1978) has investigated vibrato and non-vibrato adjustment of tones. Synthetic sung notes were used in the experiment. The subjects were supposed to adjust the frequency of a vibrato-free tone in agreement with the pitch of a preceding vibrato tone. The results showed that they succeeded in doing so with the precision of a few cents from the linear average. In addition, Shonle and Horan (1980) and Iwamyia et al. (1983) found out that it is actually not the linear but the logarithmic average that corresponds to the perceived pitch.

1.3 - Ideas on the subject of intonational strategies

From the above brief review of singing voice pitch-related investigations it is clear that experimental work on this topic is usually carried out in 'laboratory conditions', extremely useful to describe in textbook situations, but generally useless for helping singers' intonation in performance.

The widely acknowledged standpoint in relation to the performers' intonational behaviour is the adherence to a model, namely twelve-tone equal temperament, in the performance situation. This can be seen clearly in Barbour (1972:201), as quoted in 2.3.2, and also in Blackwood (1985), as quoted in 2.3.3. For period music, a minority of musicians sometimes expects the adoption of historical temperaments. In any case, however, the chosen model is considered a reliable guideline on intonation. There is an underlined principle always at work – there must be a *model*, i.e., a fixed disposition of pitches per octave as a guideline for performance. If necessary, it could even be an extended version of the model in use at a given time (usually a temperament), but *the existence of a pre-defined model is mandatory*.

Deviations from the model are expected and sometimes anticipated, as in the case of 'expressive intonation'. The extent of such deviations as well as their nature are not well understood in practice, as can be inferred from the results obtained with the experiments carried out in this research. It seems that in a performance situation conflicting guidelines are operational amongst the singers. As will be seen, with respect to the *level of precedence* (an intonational issue raised in this research), it seems fairly obvious that performers have different points of view in relation to what musical elements are more important so as to be given precedence in performance. Also, music and text-related issues are often in disagreement on the definition of the intonational strategy for a particular music passage.

Historical attempts to improve intonation

In music history, as soon as perfect triads were given status as consonances, the need to improve intonation was felt. There was an attempt to adopt pure intonation as a viable model for tuning procedures. As pure intonation calls for an increase in the number of pitches per octave, extra keys were added to each octave of some keyboard instruments, to provide the necessary pure intervals. This procedure opened the way to a most sought after technical solution for intonational problems in music history – extended keyboards.

There were many different extended keyboard layouts; some geared towards extended pure intonation, others to the implementation of extended temperaments. These keyboards were built following arrangements spelled out in grids or matrices.

The arrangements are well exemplified in the Duodenarium presented by Ellis in the book 'On the sensations of tone' and manipulated by theorists in varied forms that would depend on their degree of implementation of pure intonation. Some of the most famous examples are Colin Brown's Voice Harmonium, General Perronet Thompson's Enharmonic Organ, Henry Ward Poole's organ, amongst others. Bosanquet's generalised keyboard implements the 53-tone equal temperament, which provide values near pure intonation, as can be seen in Helmholtz (1954), pages 439 and 463.

Harry Partch developed his Monophony theory on pure intonation, in which matrices called 'tonality diamonds' are used to express the intervals that make up the pitch fabric utilised by him. A whole collection of instruments were built according to the requirements of monophony to perform Partch's music. His book *Genesis of a Music* (Da Capo Press, New York, 1974) presents the theory of Monophony alongside many diagrams and descriptions of instruments built according to the monophonic principles.

There is also an interesting approach to musical performance as expressed by Sundberg (1991) in his book *The Science of Musical Sounds*. The last section of the book deals with what he calls *performance rules*. As this approach seems to be related to what is being investigated in the present work, a more careful consideration must be given to the ideas therein expressed. Comments refer only to what is stated regarding pitch-related rules[2].

Firstly, the author makes a distinction between *meaningful deviations* and *meaningless deviations*, together with the idea that the performer must not invent principles, but abide by general principles that define performance rules. These principles are not well understood yet, due to lack of research. In spite of this, he delineates the guidelines for such performance rules. They would serve two main purposes: differentiation of pitch and duration categories, and grouping of tones that belong together.

In order to enhance the differences between pitch categories, the performers usually sharpen higher notes and flatten lower notes, thus stretching musical intervals. This procedure seems to explain the tendency of many singers to adopt Pythagorean intonation. It may also be reinforced by the psychoacoustical fact that two sine waves are perceived as a wider interval when played at higher volume.

Another important addition to the performance rules relates to melodically charged notes, which should not only be performed louder but also lengthened and with

[2] See Appendix 1: Performance rules—excerpts from the topic on the subject, taken from Sundberg's book (1991: 221-226).

more vibrato. Finally, to end the pitch-related performance rules, an increase in vibrato at the end of music phrases is prescribed.

Together with some extremely good ideas, there can be seen tendencies that do not pertain to the music as a whole, in the sense that a good performance rule for one style of music may be out of order when applied to another one, as will be considered in the next paragraphs. Attention must be drawn to these issues, not to run the risk of turning particular topics into biased and inadequate general guidelines.

Firstly, the distinction between meaningful and meaningless deviations is very well placed, since it occurs so often in music performance. Many of the meaningless deviations are accounted for as 'expressive intonation' by many performers, which would be corrected by a thorough study of the related topics together with conscious practice of the associated techniques.

The issues concerning interval stretching, the way that melodically charged notes are expected to be treated and the recommended vibrato increase at the end of music phrases are interconnected with the premises on musical practices as seen by Sundberg and his collaborator. It seems fairly clear that the author's conception is sculpted from the collected experimental results gathered in many years of work and research on related subjects. Generalisations are made, in spite of the nature of the collected data. This is a very important issue: the bulk of experimental work on the subject of intonation was done on solo singing or solo instrumental playing. Even choral research was often carried out with one singer at a time. The results from this kind of work may not be applied to ensemble singing or ensemble instrumental playing.

It must be remembered that western music relies on harmonic procedures as much or even more than melodic ones. Solo performances may be taken as guidelines only for soloists, never for group-related musical activities. Applying results from solo experiments to ensemble procedures is parallel to thinking of sine wave behaviour as valid for complex tones, something that is often not applicable. For instance, sine waves, when sounded loud and far enough from each other give rise to a pitch stretching perception; the same phenomenon with complex tones is practically undetectable. The real issue relates to the concept of consonance, which implies beat minimisation. In fact, beat minimisation takes place even in the presence of consonant intervals that may be perceived as stretched intervals, for example as referred to in the louder sine wave sounding case. If the singer or instrumental player stretches complex tones in the way described by Sundberg, the resultant interval will not conform to consonance requirements, which points once again to the important issue – the conformity or the absence of conformity to the psychoacoustical principles related to consonance and dissonance in harmony.

Finally, the assumption that vibrato must be ever active in musical practice is mistaken. This is a result of the romanticism that remains at the heart of established musical values, cherished by most performers. The idea that the romantic style must prevail in western musical technique is akin to the idea that operatic singing style constitutes the correct singing technique. Both are results of a mistaken judgement on what constitute musical premises, by identifying a stylistic procedure as a basic technique of sound production.

1.4 - Definition of the aim of the research

From the above considerations, it seems that to draw a picture of the intonational strategies adopted by singing groups in performance from a framework that is a result of mainly solo singing research is not reliable. If ensemble singing intonation is going to be assessed with the necessary confidence in relation to the results, some important conditions have to be met. They are dealt with in the third chapter of this work (3.2.3). Once the essential conditions for experimental work are satisfied, the results themselves will lead the way to a clearer understanding of tuning procedures making it possible to outline such procedures related to individual performers and perhaps to whole groups. This research goal can be expressed in the following way:

> **The aim of this research is the delineation of intonational strategies as defined by ensemble singing groups in performance.**

2 - THEORETICAL ASPECTS OF INTONATION

2.1 - Introduction

This chapter will deal firstly with what is relevant to this research in terms of pitch perception from the psychoacoustical point of view. Categorical perception and beat detection are referred to as the main tools for implementing and controlling intonation in performance. The concepts of consonance and dissonance are discussed in terms of their influence on intonational strategies from a psychoacoustical perspective. Vibrato singing is examined in relation to its implications for the beat detection mechanism, as well as the possibility of overcoming the shortcomings brought about by it. Masking and its characteristic interplay with pitch perception and control are then considered, to wrap up the main psychoacoustic phenomena pertinent to the subject matter.

The legacy from the history of tuning systems and temperaments is considered, and their most peculiar characteristic is pointed out: the fixed layout of pitches within the octave. Some other musical subjects relevant to practical intonation are also mentioned.

Intonational strategies are examined, taking into account the principles of consonance and dissonance, reference frequencies, extended tuning systems, mutable notes, and the need for temperament in music performance. In this section, the need for a flexible intonation is raised, alongside the means to implement it.

Finally, the motet *Ave Verum Corpus*, by W. A. Mozart, is analysed. It is preceded by a description of the symbology used throughout the analysis, as well as a discussion of the subject of reference frequencies applied to it.

2.2 - Perceptual aspects of intonation most relevant to the subject

In singing performance, intonation is heavily dependent on the singer's ability to control pitch by means of the aural feedback he or she is receiving from the acoustic environment. The habit of many singers to put one of their hands to the ear to form an acoustic shell in order to improve their self-perception is well known in choral groups. Indeed, the perception of what is being performed is the most important factor in the control of intonation, either as a referential device to correct faulty tones or to provide a reference for aiming at subsequent ones. It is necessary, however, to clarify the most appropriate way to approach the subject of intonation from the perspective of aural perception as related to psychoacoustical principles. This could easily be confused with the singer's learned abilities in dealing with intonation, which usually do not follow psychoacoustical principles. These abilities often rely on an extensive training based on twelve-tone equal temperament at the piano. It is widely assumed that learned behaviour based on cultural values and habits may greatly influence most musicians. Still, this does not constitute in itself reason to consider any current practice tendency as upholding correct guidelines regarding intonation.

Throughout music history, there have been a substantial number of musicians thinking in a different way to widely accepted and institutionalised practice in relation to intonation. Most of them were concerned with the possibility of improving intonation by extending the number of fixed pitches per octave; they advocated an increase in the number of intervals that would sub-divide the octave, making it possible to achieve a purer intonation. Just a few turned their attention to the use of mutable notes, in order to improve intonation as well as to devise a more flexible scale structure. This was a different way of thinking, in the sense that it did not necessarily promote a scale structure with a fixed number of notes per octave. Hence, it would not be necessary to think of a scale as dependent upon a rigid procedure designed firstly to solve keyboard pitch problems, but rather as a flexible one intended to support the music instead.

2.2.1 - Psychoacoustical approach to the subject

A psychoacoustical approach to the subject deals with the common heritage of humankind in terms of musical perception physiology. All of us share equally the perception of melodic and harmonic intervals by means of the same psychoacoustical principles, whereas the meaning and manipulation of the perceived sounds could undergo cultural influences. Musical traditions may differ from one another, notwithstanding the fact that they are based on the same perception mechanism. It could be possible to devise general guidelines based on these principles that would bring about a flexible yet coherent procedure regarding singing intonation. On the other hand, research based on cultural trends may produce different results from different populations, making any attempt to study intonation in this fashion an ephemeral affair, even within the limits of western cultures.

In this work, the perception of sound is considered the cornerstone of any attempt to deal with intonation in performance situations in a successful way. The perception principles involved are:

- *Categorical Perception Principle* and
- *Beat Detection Principle.*

2.2.2 - Categorical perception, Just Noticeable Difference, and other topics related to pitch perception

A perceptual continuum may be easily understood if an adequate insertion of its phenomena into well-delineated categories is made. This would imply that such categories would be clearly specified in terms of boundaries, widths, and centring of the pertinent events. It is not known for sure about the innate or learned qualities of such perceptual abilities. Parncutt (1989) refers to the categorical perception of colours as being primarily innate, due to the physiology of the eye. It could be inferred from this statement that the perception of music intervals would also be innate, due to the physiology of the ear, in spite of the fact that there can be an enormous difference between musicians regarding the ability to perceptually discriminate intervals. Culture-related categorical perception also seems to be developed by human beings. In addition, professional people are generally better trained to perceive facts pertinent to their speciality than lay people are.

As happens with time-related music phenomena (and others), intervals in music are perceived categorically. Categorical perception provides easy identification and understanding of melodies and harmonies, making it possible for the performer to have a quick interaction with the musical elements to be acted upon. This phenomenon together with beat detection constitutes the tools that would allow the performer to develop and implement a very sophisticated control of intonation.

Alongside with the concept of categorical perception, it must be taken into account that listeners appear to possess a well developed ability to discriminate between successive sine waves tones with near frequency values to each other. This ability is called *difference limen* or *Just Noticeable Difference* (JND). As Campbell and Greated (1987:94) write:

> ...We saw that for frequencies below 500 Hz a frequency difference of around 2 Hz was necessary for two pure tones to be reliably distinguished... Thus although the *frequency* discriminating ability of the ear for pure tones remains roughly constant at low frequencies, *pitch* discrimination deteriorates dramatically at low pitches.
>
> Maximum sensitivity to small pitch changes is found between C_5 and C_8, where the pitch discrimination threshold is around 6 cents. In other words, if the semitone between C_6 and $C\#_6$ (just above the treble clef) were divided into sixteen equal intervals, each of the seventeen notes spanning this semitone could be distinguished in pitch from its neighbours. In contrast, a tone of pitch C_2 (just below the bass clef) would have to change in pitch by half a semitone before the average ear became aware of any difference.

In addition, variations in timing and/or dynamics would cause the pitch discrimination acuity to become poorer than it is in experimental conditions, which would usually include a short gap of silence in between each pair of steady tones.

As the same authors also point out, pitch perception of sine waves is influenced by the amplitude of the vibrations. As a matter of fact, pitch perception of sine waves are prone to be influenced by several factors, such as the wave's loudness and duration in their relation to the frequency region.

Pitch perception of complex tones, especially the singing voice, can be affected by timbre, as is the case in the articulation of vowels (see Sundberg, 1987). This fact may lead singers to develop a compensatory intonational strategy, and that possibility may have been responsible for some of the results of the current research. However, in general terms, the pitch perception of complex tones (musical notes) can be reasonably assumed as corresponding to their fundamental frequencies.

2.2.3 - The concept of consonance and dissonance: critical bands and beats

Sundberg (1991:71) comments on the *critical band* concept:

> ...the critical band is some kind of smallest frequency difference that will allow two tones to be perceptually identified as two autonomous tones rather than as one single buzzing unit.

Critical bands define psychoacoustically consonance and dissonance. They constitute the mechanism that originates the aural perception of roughness or smoothness when listening to simultaneous musical notes. In this way, critical bands provide the most important guideline for the elaboration of procedures related to harmony and counterpoint in performance.

Consonance and dissonance are terms overcharged with different but related meanings, from the context of harmony and counterpoint to psychoacoustical perception. Helmholtz (1954:194) refers to the concepts of consonance and dissonance in the following way:

> When two musical tones are sounded at the same time, their united sound is generally disturbed by the beats of the upper partials, so that a greater or less part of the whole mass of sound is broken up into pulses of tone, and the joint effect is rough. This relation is called *Dissonance*.
>
> But there are certain determinate ratios between pitch numbers, for which this rule suffers an exception, and either no beats at all are formed, or at least only such as to have so little intensity that they produce no unpleasant disturbance of the united sound. These exceptional cases are called *Consonances*.

Blackwood (1985:7) refers to this subject also from the viewpoint of beat perception:

> The presence of beating intervals has generally been regarded as undesirable, especially in music in which major triads are treated as consonances. Intervals tuned so as to be free of beats are said to be tuned *purely*.

> ...The beat frequency is important theoretically, for it provides an accurate indicator of how subjectively out of tune an impure interval is, **even in situations where the beats themselves are virtually inaudible** (bold style applied by the present writer).

Although singers perceive pitch logarithmically, according to Shonle and Horan (1980) and Iwamyia et al. (1983), critical bands work in different ways in lower and higher frequencies, causing the perception of consonance and dissonance to vary from one pitch region to another. For instance, a perfect fifth is a dissonant interval if performed in an extremely low frequency region. The most important factor related to critical bands and intonation relies on the interaction between the harmonics up to the fourth or fifth, once beyond that there is always more than one harmonic in the same critical band, causing some roughness to be detected, if heard.

This phenomenon is also responsible for the so-called *definition* of harmonic intervals. The degree of perceived roughness or smoothness is determined by the closedness of the interval to pure intonation, together with the relative loudness of the harmonics and the masking effect. There will always be some roughness present even in the most consonant chord, as shall be seen shortly. According to Lloyd & Boyle (1978: 6-8, 12-13, 132), this is the very characteristic that gives definition to a given consonant interval, differentiating it from the correspondent sine waves in a harmonic series. Let there be considered a perfect major triad, as defined by the harmonic series up to the sixth partial. Such a chord made up by sine waves would probably convey an aural impression of just one complex tone (especially if the overtones are gradually attenuated in relation to the fundamental), with a perceived pitch associated to the fundamental (even if it is absent!). Alternatively, if the chord is built of complex tones its consonance would be sharply defined by the interplay of beats between their harmonics, while preserving the identity of each of their notes.

Consonance as a small-number ratios, beat minimised principle

Howard and Angus (1996:139-144) present the degree of consonance and dissonance for a perfect fifth, a perfect fourth, major and minor thirds, as well a whole tone, with all of these intervals being built upon a lower frequency of 220 Hz. In addition, the examples are extended to major thirds built upon 110 and 55 Hz. All of the examples are considered according to the degree of consonance and dissonance they hold. The examples show the relationship between the perceivable consonance, dissonance and the definition of an interval. From the interaction of each interval's harmonics it is clear that consonance and dissonance, from a psychoacoustical perspective, are perceived in relation to the presence of beats and the principle of critical bands. Beats in this context are very much dependent on relative loudness of the harmonics – whether they are going to be heard or not due to the masking effect, the frequency region in which the interval is performed, and the interval's closedness to a small number ratio. As beats would be present almost everywhere in a musical performance, the concept of consonance from the performance point of view ought to be based on *beat minimisation*, as it occurs in a perfect major triad in pure intonation, for instance. This is a very important issue, because it is clear that the absence or minimisation of beats at the level of the fundamental frequencies, as well as in as many harmonics as possible, effectively defines a consonant interval in nearly vibrato-free performance. Therefore, in practice, the musician could consider harmonic intervals as being consonant inasmuch as they express small-number ratios and comply with a beat-minimised criterion. The departure from consonance would be determined by the increase in complexity of ratio and beat rate, as well as of growing in proximity and inclusion of different tones in the same critical band.

However, how far does this approach go to determine what is consonant and what is not? Some musicians and researchers such as Partch (1974) are willing to extend the concept of consonance to prime numbered intervals up to eleven or so. In relation to his concept of Monophony, he writes (Partch, 1974:90-1):

> Theorised scale intervals, implying successive tones, have run the gamut from 1 to three-digit and even four-digit numbers in the history of music, but the story of consonance – that is, the story of man's acceptance of simultaneous sounds as consonances – has been much less adventurous. Even now, in our Western "golden age of music", we imply and comprehend, as a people, no odd number higher than 5 as a consonance, or – even if we accept certain claims regarding the so-called dominant seventh chord and the diminished triad... – at least no higher than 7.
>
> ...it requires both temerity and good luck to announce with impunity that Monophony extends its boundaries of consonance through the number 11. Yet the fact is that it does so...

This would extend the concept of consonance to rough intervals belonging to the harmonic series, indicating that roughness does not add to the problems of intonation if kept within the harmonic series' boundaries. In the current work, this concept is incorporated in the *harmonic series principle*. Therefore, the idea of definition of intervals and chords is emphasised; roughness does not compromise the definition of an interval so long as there is compliance to the harmonic series principle.

When it comes to the use of tempered intervals, however, the whole picture changes dramatically. The mismatching harmonics of the constituent tones would be far too evident to provide a sharp definition and smoothness to any interval. In early music, this fact gave rise to an endless number of temperaments designed mainly to minimise intonation problems for fretted string and keyboard instruments.

Therefore, it seems that the interaction of the harmonics plays a vital role in the improvement of performance practices in relation to consonance. Beat detection turns out to be the most appropriate tool for detecting impurities and for improving the definition of consonant as well as dissonant intervals.

Vibrato singing and beats

Beat perception is a tool that enables the musician to increase the resolution with which a harmonic interval is perceived. In this manner, it is also a helpful device to improve tuning in performance situations. In spite of all the help that beat detection represents, there is a very well established style in vocal singing that has the capacity of turning beat detection inoperative: vibrato. It has the effect of disguising beats by making it impossible to detect them between either the harmonics or the fundamental tones that constitute the performed interval. The situation is further complicated by the fact that, although there are alternative singing techniques mainly linked to choral and early music, there seems to be, in general, very little flexibility in the attitude of singers and singing teachers to exploring the issue of singing techniques from such a different perspective.

Another possibly interesting feature of vibrato singing is the information it brings about vowel formants. This happens due to the vibrato's fluctuation in pitch, making vowel identification easier, especially in a high phonation frequency range. This is done by means of revealing the formants while vibrato undulation takes place.

Experimental work on pitch perception carried out by Sundberg (1978) claimed to show that, in vibrato singing, the perceived frequency agrees with the linear average, within a few cents (see 1.2, 'experimental work on vibrato'). According to Sundberg (1987:171):

> The subjects' matching of the pitch of the same stimulus tones were almost entirely consistent regardless of the presence of the vibrato. Apparently, the vibrato did not reduce the certainty with which the subjects perceived the pitch.

Consequently, if the singer is willing to do so, he or she will be able to hold about the same level of control on intonation that would be more easily available to non-vibrato singers. Vibrato singing is no excuse to relax intonation.

Another extremely interesting experiment was carried out by Hagerman and Sundberg (1980), in which a barbershop quartet was assessed in relation to intonation. Sundberg comments (Sundberg 1987:178):

> Regarding the sizes of the intervals, ...this quartet uses values quite close to the pure or harmonic versions of the intervals. It will be recalled that it is only these pure intervals that do not generate beats.

He comments on the performance of the dominant seventh interval, sung very close to the harmonic version, and finishes (Sundberg 1987:179):

> The conclusion is that ensemble singing without vibrato raises high demands on phonation frequency acuity, but these demands can be met by trained singers.

Consequently, it seems that vibrato and non-vibrato singers are able to exercise tight intonation control regardless of their singing technique differences. Although they may have to resort to different tools to achieve equivalent results, further research is needed to clarify whether and how singers using different singing techniques may accomplish this.

2.2.4 - Masking and perception

Masking is an important ingredient in the perception of music intervals. Its main role in the context of pitch perception is related to the interplay between strong and weak harmonics. This kind of phenomenon works in all text-related situations, since the harmonics themselves are exposed to masking effects in all articulated vowels. Every time a cluster of harmonics is reinforced (what is termed a *formant*), the weaker higher harmonics that come after the formant may be masked by the stronger lower harmonics that belong to the formant. The shape of the formants determines not only the vowels but also contributes to the timbre of musical instruments, which establishes masking as an omnipresent phenomenon in music performance.

2.3 - Legacy from the history of tuning systems and temperaments

2.3.1 - Tuning system and temperament

A tuning system, as opposed to any temperament, is a procedure adopted to construct a musical scale. In fact, it can be said that there is only one tuning system based on harmonic proportion, which comprises several degrees of resolution that may be incremented according to a chosen prime number limit. In this fashion, Pythagorean intonation is based on the prime number 3 limit, whereas pure intonation extends this limit to at least the prime number 5. Therefore, it is possible to define different scales, such as Pythagorean or Just, by simply varying the prime number limit. The results would be implemented to twelve pitches or to an extended number of pitches per octave. Harry Partch acknowledges another principle for implementing intonation, namely arithmetic proportion, already commented upon in 1.1.1.

A tuning system reaches its limits out of necessity; otherwise, it could go an indefinite way in the process of creating new intervals. As with the harmonic series, there is a practical limit for a tuning system. Usually, it would comprise from 21 to 35 different notes to the octave, depending on how long it would be extended in relation to the use of double sharps and double flats. Blackwood (1985) includes 31 intervals (up to five double sharps and five double flats) in his tables for Pythagorean and pure intonations. However, the number of pitches per octave can be greatly increased when implementing pure intonation, as shall be seen in the analysis of Mozart's motet *Ave Verum Corpus.*

Partch (1974) and his Monophonic system of pure intonation, with 43 degrees to the octave, should be mentioned at this point. It is a condensed version from a total of 340 tones to the octave derived from his theory of Monophony. He goes up to the prime number 11 limit to build his system, as he comments in the following passage (p. 123):

> The reasons why Monophony proceeds to the limit of 11 are basic and quite specific, ...but the reason for resting at the limit of 11 is a purely personal and arbitrary one.

This feature of tuning systems defines their openness, as opposed to the closedness of temperaments.

A temperament is an intonational procedure developed around the urge to close an open system. It was within the constraint of twelve pitches per octave or equivalent that most of the temperaments were designed, to solve intonational problems related to the evolution of musical language (especially in terms of harmony), instrumental design and technique, as well as problems arising from the growing number of instruments in ensemble music.

Another essential feature of temperaments is the effort to minimise the imperfections brought upon the consonant intervals in the attempt to 'close' the octave range within a fixed number of pitches. This is the cause of the great number of temperaments, as well as the final destination of all of them: equal temperament. As the musical language becomes increasingly complex, the balance between consonance and the number of fixed pitches (keys) per octave turns out to be impossible to achieve without a compromise that composers and musicians were not willing to accept in earlier periods of music history. By the time equal temperament was adopted, there was no option left, if the number of pitches per octave was to remain constant and transpositions were to sound homogenised.

The main problem with temperament design: fixed disposition

The need to adhere to a limited number of pitches per octave is the real drive behind procedures to devise endless variations in temperaments. Di Veroli (1978:250-253) lists 178 temperaments and intonations citing Barbour's (1972) 'Tuning and

Temperament – a Historical Survey'. The vast majority of them are designed for the 12 keys to the octave keyboard or its equivalent for the lute.

Regular attempts were made to adapt the keyboard layout in order to accommodate more keys per octave. Technical and economical reasons rendered all of the efforts unworkable in establishing a more trustworthy way of implementing pitch correctness. Even nowadays, with all the facilities to build affordable electronic keyboard instruments, there is widespread resistance to adopting some of the more feasible solutions to keyboard layout, in any of the forms of generalised keyboards. It seems that tradition can be a blessing and a curse, concomitantly.

2.3.2 - Designing Temperaments

Temperament techniques

The central question of temperaments is how to get rid of acoustical impurities and at the same time to adhere to a given number of pitches per octave. A compromise has to be worked out between musical language and acoustical facts, since a thorough solution in this respect is not possible. The syntonic comma, being the micro interval responsible for most of the differences between Pythagorean and pure intonations, is the main target of the procedures designed to implement temperaments. It is consistently broken down to a short series of (mainly) equal parts in order to improve the thirds and sixths at the cost of the purity of the perfect fifths and fourths, as happens in the basic form of meantone temperament. In it, a succession of four fifths is flattened by 1/4 of a syntonic comma in order to guarantee pure thirds for the most common keys. In other temperaments, according to the needs of the evolving harmonic language, the syntonic comma is spread out in a variety of ways, sorting the best way out of trouble for the targeted instruments. Di Verolli (1978) gives a technically good account of most temperaments and intonations, evaluating them according to their deviation from pure intervals. This is a much better procedure than Barbour's (1972), who evaluates all of them against the twelve-tone equal temperament, out of a presumption that it is *the* intonational procedure to be taken as a gauge for evaluation. Barbour's standpoint is very clear not only as stated at the beginning of his book, but also as in the following remark (Barbour, 1972:201):

> This contemporary dispute about tuning is perhaps a tempest in a teapot. It is probably true that all the singers and players are singing and playing false most of the time. But their errors are errors from equal temperament. No well-informed person today would suggest that these errors consistently resemble departures from pure intonation or from any other tuning system described in these pages. Equal temperament does remain the standard, however imperfect the actual accomplishment may be.

It should be self-evident that a temperament cannot set a standard for intonation – this is a tuning system's prerogative! The adoption of any temperament as a standard for intonation was unthinkable in the Baroque period, because temperaments were always imperfect practical solutions for intonational problems, hence the great number of temperaments at the time. It could be permissible to use a different temperament whenever the performer was willing to do so, whatever the reason for this. There was no obligatory adherence to any temperament. Consequently, there is no reason whatsoever to think of twelve-tone equal temperament as a standard for intonation. Temperaments were always defined according to mathematical procedures, *not* to psychoacoustical principles (which perhaps would grant them legitimacy for such a status).

Butler (1992:55), writing about pitch recognition, echoes the most common view on how musicians behave in relation to pitch manipulation while performing:

> When listeners are instructed to concentrate on tunings of interval, however, there is some evidence that musicians possess a mental representation of pitch relations closely resembling equal temperament. When performance instruments are not locked into a preset tuning, it is commonly assumed that performers will stretch pitches somewhat sharp relative to the tonic and will bend pitches systematically according to melodic and harmonic context... There is still some disagreement, however, on how much (and how consistently) performers bend pitches to fit the musical context.

This view of pitch manipulation is misleading: it is also possible to assert that there is some evidence that musicians possess a mental representation of pitch relations closely resembling Pythagorean intonation. Pitch stretching could lead to any intonational procedure other than pure intonation that exhibits stretched intervals when compared with pure ones. Pythagorean intonation was adopted as the gauge for intonation for as long as polyphonic thinking was dominant amongst musicians. It also originates directly from the source for intonational procedures – a tuning system. *Deviation from a fixed tuning procedure is the real issue*, here. Musicians *do* deviate from fixed intonation models to allow for a procedure that may include some kind of temperament.

Fixed temperaments were designed for the music tools that needed them. This was never the case with the singing voice. It does not need to be bound by any kind of fixed temperament, because the singing voice is a thoroughly flexible instrument when it comes to intonation matters. Consequently, the following questions must arise:

- *Would a tuning system be able to provide a reference for intonation for the singing voice, either as a pure intonation or as a Pythagorean procedure?*

- *Would any kind of temperament be relevant as an intonational guideline for the singing voice?*

2.3.3 - Other musical subjects relevant to intonation

Music language

The history of intonation in western cultures is closely influenced by the evolution of harmonic language. As the thirds and sixths were pushing their way into hierarchically important chords, they demanded to be treated as consonances. This, in turn, puts Pythagorean intonation in check, calling for an increase in the resolution of the system. The problem at that time was that pure intonation could not provide for the needs of pure thirds and sixths within the keyboard's limits, which gave pure intonation a short lived period as a practical tuning system. Only temperaments could provide some purity to thirds and sixths while at the same time being workable with fixed layout instruments. But then, harmony kept evolving and new kinds of temperaments were called for, in a never-ending process of enlarging the harmonic language and providing for its practicability with musical instruments rigidly tuned.

As temperaments cannot deliver a real solution to the problems of intonation, there have been musicians and theorists advocating extended pure intonation or even some kind of extended temperament. These alternative intonational solutions would be implemented mainly through so-called *extended (or generalised) keyboards.*

Blackwood attempts to analyse various musical excerpts according to extended pure intonation. After considering an extract from the Symphony in D minor, by César Frank, he concludes (Blackwood, 1985:150, 153):

> In view of the great variety of notes and intervals, and the fact that a number of the harmonies have no pure tuning, we must conclude that just tuning is not the ideal for this example.
>
> It is hoped that after a careful study of the examples presented in this chapter, the reader will be persuaded – as is the author – that the quest for perfection in tuning of a given musical fragment is the pursuit of an *ignis fatuus.* The author has been unable to discover any major composer whose style conforms to the inherent limitations and properties of just tuning. Nor are there any theoretical writings giving practical instruction as to how to sing or play just intervals, or how to compose with them. It must be concluded that at present, just tuning is of no practical use with regard to the existing Western repertoire.

He also discusses Pythagorean intonation, pure intonation, meantone temperament, Werckmeister temperament and twelve-tone equal temperament. At the end, he says (Blackwood, 1985:244):

> In sum, of all the tunings discussed in detail thus far, only 12-note equal may be satisfactorily – if imperfectly – applied to all polyphonic music written up to the

> present time. The other temperaments are limited to particular historical periods, and just tuning, as we have seen, is inappropriate for any of the existing repertoire.

The absence of theoretical writings with practical instructions on singing or playing in pure intonation comes as no surprise once it is realised that pure intonation would not give all the answers that are needed on intonation matters. Perhaps if a theorist would have attempted to do so, he or she would have found out about the need of resorting to a temperament alongside extended pure intonation, or in other words, to allow for more than one intonational procedure to act as concurrent guideline for intonation in music performance.

Technical difficulties in performance

Performing outside the normal limits of the singing voice brings out an increase in stress to the singer and a degree of uncertainty for pitch, as do other technical difficulties, like *coloratura* passages, wide leaps, etc. There is always a mechanism for determining pitch, but understandably, it would not be so precise as when the singer is singing within normal conditions of *tessitura* and technical demands. This is one of the main reasons why the motet *Ave Verum Corpus*, by Mozart was chosen for experimental work in this research. It presents no *tessitura* problems, articulation speed or text pronunciation difficulties; it remains at the heart of the standard choral repertoire and presents no special problem for performance in any way. In addition, it provides what is needed for the research in relation to classical harmonic language.

Technical difficulties may be of a different kind, however. Intonational behaviour brings forth more subtle and constant requirements that need to be continuously met by each performer. Barbour commented on an article by Norden (1936), on choral singing in pure intonation (Barbour, 1972:196-198):

> The contention has often been made that unaccompanied voices sing in just intonation. ... Lindsay Norden said, 'As we shall show, no singer can sing a cappella in any temperament.... A cappella music, therefore, is always sung in just or untempered intonation.'
>
> Let us see what is implied by these statements. In the first place, singers must be able to sing the thirds and sixths purely. This may sound like a self-evident truth, too absurd to discuss. But scientific studies of intonation preferences show that the human ear has no predilection for just intervals, not even the pure major third. Alexander Ellis declared that it was unreliable to tune the pure major thirds of meantone temperament directly, preferring results obtained by beating fifths. Hence the singers must be highly trained to be able to sing the primary triads of a key justly.
>
> In the second place, the singers must be able to differentiate intervals differing by the syntonic comma, 1/9 tone. ... But studies at the University of Iowa have shown that there is no such thing as stability of pitch among singers: scooping is found in almost half the attacks and averages a whole tone in extent; portamento is very

> common; the sustained part of the pitch varies from the true pitch by a comma or more in one-fourth of the notes analysed. If we add to these errors the omnipresent vibrato, with an average extent of a semitone, it would seem that the ambitious and optimistic director of an unaccompanied choir has an impossible task.
>
> ...If the music contains much chromaticism and remote modulations, even the best-trained choir would probably flounder...

This is a very interesting example of how a biased assumption would force any fact to conform to the intended picture of a phenomenon. The author's thinking deserves a closer look.

Firstly, Barbour states that 'scientific studies' do not support pure intonation in the sense that the human ear does not prefer pure intervals. Experiments with soloists – players or singers – would quite easily reflect their training practices based on piano tuning. He should have made clear what kind of scientific studies he was referring to, and whether the results were applicable to choral singing.

Then, he says that 'the singers must be highly trained to be able to sing the primary triads of a key justly'. In fact, it would be much more difficult to comply with equal temperament, as there is not a single clue to corroborate its correctness, while with pure intonation there will always be beat detection to help check out intonation.

Following the argument, he asserts that singers must be able to differentiate intervals up to a syntonic comma. Indeed, it would be much simpler to detect the syntonic comma through beat detection than try out the twelfth root of two in order to tune to an equal tempered interval, with no practical tool for checking it while performing!

Barbour goes even further, when referring to studies at the University of Iowa, about the instability of pitch among singers. All of the mentioned problems would be the same for either pure intonation or equal temperament. On the other hand, is he advocating that the practice of equal temperament should be imperfect as a matter of principle? In addition, it is important to note that scooping and *portamento* are features that could be present independently of any intonational strategy adopted by the singers. The sustained part of the pitch is the one that counts in any evaluation's procedure. Even so, there are many variables to be considered, such as target notes, text articulation, technical difficulties, the presence of any instrumental accompaniment, etc. In spite of the fact that none of these important conditions was clarified by the author, he still concluded that the results were applicable to choral singing.

Then, it comes to the 'omnipresent vibrato' question. For the first time, something relevant to the subject is said, but as seen in 2.2.3, it would be possible to overcome this predicament by means of an adequate training.

Finally, he refers to chromaticism and remote modulations. Here, flexible intonation has to be asserted as the way 'not to flounder'. All of the other ways could do so in free intonation performance. If by 'flounder' is meant to lower or to raise intonation, the argument touches another highly important topic on the subject – reference frequency. As it will be seen in the fourth and fifth chapters, one of the most important findings of this research is that the reference frequencies may be rightfully changed during the performance. Hence, the argument is the consequence of a biased stand regarding intonation.

Apart from the kind of argument presented by Barbour, there are some technical styles in performance that may interfere with the principles of intonation exposed in section 2.2. Vibrato singing ranks very high amongst them.

Instrumental evolution

The history of temperaments is chiefly the history of their adoption by keyboard instruments. Blackwood (1985:226) defines equal temperaments with the following words:

> Phrased in the most readily comprehensible musical terms, the equal tuning theorem states that if all the pitches forming any closed circle of intervals are reproduced in all registers by octave transpositions, the result is an equal tuning.

This amounts to the fact that when the circle is not closed (what might be called a broken circle), subsequent intervals will evolve as in a spiral, and the conditions for the reproduction of the pitches by octave transposition cannot be met. Such conditions are prevalent in most of the so-called *unequal temperaments*, and that is the reason they present the 'wolf fifth'[3] when their limit is set to 12 notes per octave. They do not suit well performance in all keys. *Circular temperaments* (Kirnberger, Valotti, Young, Werckmeister, etc.) can be performed in any key, although with better purity in some of them. Also, circular temperaments present no 'wolves'; their intervals, however, are not uniform. They constitute special cases, as they were intended to be restrained to the limits of twelve notes per octave. Unequal temperaments usually may be extended, if so desired, in the number of pitches per octave. These conditions also apply to Pythagorean and pure intonation.

Unequal temperaments survived all the way from their beginnings to classicism, in spite of all of the changes that took place with string instruments and winds. As long as keyboard instruments were easy to retune, twelve-tone equal temperament was kept at bay. Not even its early adoption by the fretted strings was of any value in

[3] The denomination 'wolf fifth' is believed, by some music writers, to refer to the howling effect of the mistuned interval. To others, it indicates that the tuner is forced into a dilemma, since there is no good solution for the tuning of the interval. This situation would be well described by the ancient dictum 'to have a wolf by the ears', which means that the holder of the 'wolf' is both unable to hold it and afraid to let it go.

convincing the music community of its advantages; it was forgotten as soon as the family of violins took over the position formerly occupied by the (fretted) viols. The lute was destined to have its own set of temperaments. Equal temperament was compelled to wait for a more appropriate time for its emergence into the music scenario in much more favourable circumstances. Apart from the expansion of music language, which by itself would eventually lead to the adoption of equal temperament, there was another important factor in this respect: the evolution of keyboard instruments.

Perhaps with the development of new social ideas and increased public access to theatres, newly built performance venues were larger and more demanding in acoustical terms than before. Instrumental changes were due, in pursuit of a more powerful sound. In addition, the orchestra was already mature and well established at the very heart of musical life. Instruments were to be perfected and adapted to the new conditions. There had been a long evolution leading to the harpsichord, but as it was no longer coping with the new acoustic demands, a new breed of keyboard instrument was taking over its position. When the piano was finally established as the leading keyboard instrument, all of the main changes that would be relevant to the adoption of equal temperament were accomplished: musical instruments in general exhibited a much improved dynamic range, with the result of an overall darkening in the spectrum, making it more difficult to perceive the interaction between higher harmonics. Furthermore, the piano, being a much bulkier instrument than the harpsichord, as well as a multi-stringed instrument, was no longer pliable enough to be quickly re-tuned. On the whole, the larger dimensions of musical instruments, if not of music life itself, would not allow anymore for the intimacy and subtlety necessary to carry on performing with such a diversity of temperaments.

2.4 - Hypothesis concerning intonational strategies

According to Blackwood (1985:3),

> ...the structure of recognizable diatonic tunings is basically an array of intricate interconnections among acceptable approximations to intervals, certain of which may be tuned individually so as to be free of beats produced by interacting harmonics. These interconnections, which are the very foundation of what is perceived as tonal harmonic motion, are shaped by the short-term span of human memory, the tolerance range of the human ear, and the peculiar manner in which intervals are perceived.

Intonation presupposes performance. Tuning systems and temperaments are taken as models for intonation in performance and implementing them on free or nearly free intonation instruments is an arduous task. Very often, the intonational strategy adopted by the performer would not agree with the pitch grid that belongs to the chosen model of intonation. This fact is emphasised by the criteria upon which the models are created. Since far back in occidental music history, the natural basis for intonation has been tampered with in an attempt to conform music intonation demands to rigidly fixed models. This is not dangerous to music and art by itself, provided that the nature of this kind of manipulation is well understood, and a model is not erected as a gauge against which any musical interval would be judged. Since the adoption of twelve-tone equal temperament as the basis for fixed intonation instruments, there has been a gradual transformation of its role from being just another temperament to becoming the established model that sets the standards in pitch, not only in performance, but also in the theoretical field. The monumental work of Helmholtz was not completely successful in establishing a proper perspective on intonation within the musical community. By the twentieth century, only solitary musicians like Partch and a few others were willing to raise their discordant voices in relation to this situation—twelve-tone equal temperament has been unquestionably the absolute ruler on intonation, accepted by most musicians and defended by most theorists as the authoritative guideline on intonation matters. Taking a look at the time when intonation was more flexible, it can be seen that the seed that led to equal temperament was planted in the heart of all temperaments, but at that time musicians were aware of the temperaments' fleeting nature.

There has been a long going misconception in relation to what constitutes a sound intonational strategy. Whenever a theorist attempts to devise a model or guideline for intonation, it always ends up with some kind of temperament or even an extended tuning system which presumably has to have either a fixed number of pitch degrees per octave or even a variable number of them, as is the case in extended models, provided they are very well defined and restrained to that particular model. In other words, there may be several frames of reference regarding intonation (tuning systems or temperaments), but a musician is expected to perform within the limits of one such frame, its substitution not being allowed during music performance. Not a single tuning procedure has been built based upon the possibility of allowing for an interaction between different frames of reference, for instance, between tuning system and temperament, or even between two different resolutions of a tuning system.

Di Veroli (1978) provides instructions under which a singer can learn to perform according to various temperaments. He says (Di Veroli 1978:223 a-b):

> The singer wishing to learn an unequal temperament should practice with keyboard accompaniment. A clavichord is not recommended because its pitch depends on the finger pressure. A harpsichord or virginal is instead most satisfactory and a pipe organ with a steady wind pressure is best. Early wind instruments have always some

> flexibility of intonation and hence cannot be used for this purpose. Fretted strings are also unreliable because no perfect fretting can be obtained except for circular-nearly-equal temperaments.
>
> Singers or Medieval music should master Pythagorean intonation... The singer should be careful to produce pure fourths and fifths, while the major thirds should be very obviously sharp, almost twice as deviated as equally tempered thirds...
>
> Singers of Renaissance and Baroque music should be able to sing in standard meantone. The singer should first learn the usual 1 note meantone compass and only afterwards proceed with sharp/flat alternatives... Major thirds should be sung pure, fourths slightly sharp and fifths slightly flat. The difference between a sharp and its flat equivalent should be very noticeable.
>
> Just intonations may also be useful sometimes: they are not difficult to learn for singers familiar with either Pythagorean intonation or standard meantone temperament.
>
> Once standard meantone is mastered it is quite easy to sing in extended or in homogeneous meantone and also to become quickly proficient in most circular temperaments, both French and 'good'.

One cannot help but wonder how the singer would be sure what temperament he or she is following. This procedure must be performed each time a note is sung, since the various temperaments are tuned, as a standard procedure, by beat counting, a task that takes time and effort to accomplish. It must be considered that after an entire life of pitch training under the influence of equal temperament, a singer may still not be able to comply with its demands! It looks like it is an over-enthusiastic approach to assume that a singer can replicate a procedure meant for fixed-layout instruments, built on purely mathematical principles with no psychoacoustical backup in terms of perception other than beat counting. Finally, it must be added that beat counting is not feasible in a performance situation, even in vibrato-free conditions, for obvious reasons.

It seems self evident that the western rigid attitude towards any intonational model has been heavily influenced by the fixed layout of the keyboard. As a consequence, or in spite of this fact, it also reflects the presumption that deviations from any established theoretical model would constitute a mistake, an imperfection; therefore, these deviations are not meant to be investigated seriously, but rather ignored by performers aiming for musical excellence. There is a striking paradox revealed in the attempt to build hundreds of temperaments, all of them inherently imperfect, while at the same time not providing for a flexible procedure towards intonation.

2.4.1 - Reference frequencies

In the process of devising any scale, tuning system or temperament, a specific note is taken as a reference for intonation. That reference note is expected to remain unchanged in pitch throughout a performance. This is mandatory for fixed pitched instruments. It is generally accepted that in tonal music, the tonic (at least) would uphold the same frequency during the whole performance. Several examples from the literature on behalf of this idea are referred to in 4.3.5 (general evaluation). It seems that for modal and atonal music the expectation is indeed the same. No statement contrary to this assumption was found in the examined literature related to the subject. Such a procedure tends to establish fixed intervals between all of the notes involved; hence, the tendency to elaborate theoretical scale models with rigid interval structures as a rule in music history.

Performing music by means of a flexible intonation instrument, or likewise by means of a free intonation one, as is the case with the singing voice, is indeed another matter. The necessity or the value of complying with a reference frequency is not apparent at all. It may be that a purer intonation, if desired, would dislocate the reference frequency, as can be implied by the principle of mutable notes, as shall be seen shortly.

In order to secure a clear conception on this subject, it would be helpful to name the two distinct possibilities of using what can be called the *reference frequency principles*, as follows:

- The *fixed reference frequency principle*
- The *flexible reference frequency principle*

The first one would advocate the establishment of and compliance to a reference pitch with a fixed frequency value. The reference frequency would be applicable to the whole of the music piece. The second one would contemplate a change in the reference frequency during performance, according to the needs of an intonational strategy to be decided during performance. This would be accomplished at least within the limits of a minimal structured unit for such a purpose, like a musical phrase. Even if it seems difficult to allow for such a strategy, it would help to explain some of the results of experiments carried out in this research.

2.4.2 - The underlying principles of intonation practice

The notion of consonance and dissonance in music performance is a most important one when it comes to defining strategies for intonation. It must be remembered that temperaments were devised as a mean of minimising problems brought about by Pythagorean thirds as well as the openness of tuning systems (indicated by the 'wolf' fifths), and because pure intonation was not able to fulfil this requirement within the confinements of a keyboard layout. It shall be seen that pure intonation cannot provide a solution for this matter in other ways, as well.

Consonance

It is universally accepted that absence or minimisation of beats defines consonance in psychoacoustic terms. The most important difference between pure intonation and temperaments regarding this issue is focused on the presence of beats not only at the level of the fundamental of chords, but especially at the level of the harmonics. It could be compared to a device that can switch between low and high definition settings in relation to the same event, that event being the harmonic interval or chord that is assumed as being consonant. It is unavoidable to conclude that the greater the definition, the more consonant would the interval or chord be perceived. Carlos (1987) illustrates various instances of interaction between harmonics, as can be seen in appendix 2: harmonic and inharmonic spectra.

The superiority of pure intervals over tempered ones in terms of acoustic definition and resolution is clear.

Dissonance

Dissonant intervals do suggest a slightly different approach regarding acoustic perception. The main tool for evaluating good intonation is still beat detection, only that in this situation it will coexist with the perception of roughness, which gives to dissonance its character in the first place. It must be recalled at this point that the difference between beats and roughness is firstly a question of quantity and then a question of quality. However, it must be taken into account that beat perception is related to the arithmetic difference between the involved frequencies, while the perception of roughness is logarithmic, as happens with intervals. Beat detection is infrasonic, within the frequency range up to approximately 15 to 20 Hz; the interacting frequencies are perceived as only one sound with a pitch that corresponds to the average of the frequencies. Roughness takes place in an upper range, in which the interacting frequencies can be perceived as separate sounds enclosed in the same critical bandwidth; this kind of phenomenon originates the aural perception of dissonance.

As roughness depends on critical bands and beat perception coexists with it in the presence of dissonant intervals, it is easy to assume that when it comes to dissonance, it does not make much difference how it is originated, as beats and roughness would be present anyway. However, it would help to consider that dissonant intervals are able to manifest themselves in one of two ways:

- Dissonance with intervals tuned according to the harmonic series (all of the roughness but no extra beats). These intervals can be considered as being compliant with what can be named as

- ◆ the *harmonic series principle*;
- Dissonance that sounds inconsistent with the harmonic series principle (all of the roughness plus extra beats).

Listening to a harmonic series with linear partials, as opposed to having them tuned to equal temperament, as is presented in the following example, makes it clear that dissonant intervals furnish different results dependent not only upon roughness but also on beats. In sound example 1, sine waves partials of A1, up to the 10th, are sounded, first tuned to the harmonic series and then to twelve-tone equal temperament. The procedure is repeated again with partials from the 4^{th} up to the 10^{th}. Afterwards, the whole procedure is duplicated with a synthesised organ sound, with full harmonic content.

As can be heard in the example, adherence to the harmonic series defines a procedure that will enhance pure intonation even for dissonant intervals, granting them the best possible definition. Pure intonation is not just about procedures to ensure pure consonant intervals, but can be applied effectively also to dissonances. Furthermore, beat detection is the tool of choice for checking and controlling intonation, the toll that enables performers to be instantly aware of any undesirable deviation from the harmonic series principle.

2.4.3 - Extended tuning systems and temperaments

The continuity of the harmonic series principle is pursued through the extension of a tuning system to a practicable number of pitches per octave. This is also the idea behind extended and generalised keyboards, which are intended to provide for fixed intonation instruments an opportunity to replicate extended pure intonation to a great extent. Extended temperaments aim for an analogous result because they, too, may provide some approximation to pure intonation while ensuring that the octave remains closed at the same time. However, extended tuning systems or temperaments have been theoretically not only extended, but also rigidly fixed.

The most obvious application for an extended model would naturally be the implementation of pure intonation. One basic concept that led to the idea of a flexible intonation is termed *mutable notes.*

Mutable notes

Lloyd (Lloyd & Boyle, 1978:45) endorses the idea of extended pure intonation in the following statement:

> Mutable notes are produced by concords sung with true intonation; they therefore cause no difficulty of intonation. All that is necessary is that they should be sung or played perfectly in tune and they will then find their own positions. But they

presented a problem for the tuner of a keyboard instrument. Readers should be warned that in physics textbooks, which attempt to describe scales, no mention is made, as a rule, of mutable notes. Yet they are the main reason why the scales of music are flexible in intonation, from which arises the need for tempered intervals that physics textbooks accept for keyboard instruments with their rigidly fixed intonation.

Likewise, the idea of mutable notes can be found in Stanford (according to Lloyd & Boyle, 1978), who mentioned that not only the second degree of the major mode, but also the second and the seventh degrees of the minor mode are the most common mutable notes. In fact, to determine how many notes would have to be mutable in order to ensure the closest approximation to the harmonic series principle would depend on how complex a music piece's harmonic language is.

Mutable notes are natural events in enharmonic passages. The need to conform to a new tonal reference dictates the procedure to mutate the pitch of one or more of the sounding tones. There may be a choice of how to determine the mutation of the notes of the enharmonic passage. There may also be a few possibilities in terms of pitch selection in compliance with the harmonic series principle; this would depend on which note of the chord is the pivot of the mutation. Even when listening to a keyboard instrument with its fixed pitch layout, a musician cannot help but anticipate the enharmonic passages as changes in pitch.

It is implied in the former paragraphs that all singing practice techniques are considered possible to be implemented within the boundaries of extended pure intonation. This is a reasonable assumption to make once the idea of a more flexible intonation with the mutable notes is accepted. At first, it seems logical that alongside the increase in the practicable number of notes per octave, all intonation problems brought about by a rigidly implemented tuning system or temperament may be solved within the limits of pure intonation. As shall be shown, this is not possible.

2.4.4 - The need for temperament

Target notes and harmonies

The analysis of a given piece of tonal or modal music might attempt to clarify the relative tonal hierarchy according to various levels of importance. Harmonic structure, rhythm and phrasing are just a few of all the elements that can be lined up to determine which notes and chords should be targeted in performance in order to ensure good intonation. Occasionally, technical difficulties may be found amongst notes that are highly valued as target notes, rendering them inappropriate for intonation assessment and evaluation.

Passing notes and harmonies

Notes that are not regarded as yielding a high hierarchical value are prone to be treated less accurately in terms of intonation. They are the ones that will be perceived within the boundaries of categorical perception. This procedure would be applied not only to passing notes and passing harmonies alongside other categories of melodic notes and embellishments, but also to the ones that are technically demanding. Technical difficulties for the singing voice would include extreme high *tessitura*, difficult breathing phrases, coloratura, and other conditions that would add an inordinate amount of stress to the singer, lessening his or her ability to exercise the most accurate control of intonation.

Ambiguous harmonies

Triads that are not perfect cannot hold consonance. Alongside the diminished seventh chords originating from diminished fifth triads, triads that are not perfect have ambiguous harmonic meaning. Each of their notes can assume different tonal functions, according to the continuation of the harmonic passage. In this manner, a note that belongs to a diminished fifth or diminished seventh chord may be taken as a leading note or as a fundamental of the next chord. This ambiguity is revealed also in the common practice of writing these chords rather loosely in relation to the actual meaning of the harmony. For instance, a C-Eb-F#-A chord could be followed either by a G (Major/minor) or Eb Major consonant triads, as well as going for a plain C Major/minor chord. The latter option would have to be written C-Eb-Gb-Bbb, if it was to be considered a C diminished – C Major/minor sequence.

However, the harmonic series principle can be applied to them, as happens with most of the dissonant chords, thus minimising beats and improving the definition of the interval. Their position in relation to the harmonic series principle would depend on which harmonic series such a chord should be fitted on. If a particular chord can belong to a harmonic series in use as reference at the time, it will comply with the harmonic series principle with no need of looking further for a new series. In the case that it does not belong to the harmonic series in use as reference at the time, the harmonic series principle demands that there should be a change in the series used as reference for the passage. If this is not possible or desirable, a temperament must be called for.

As mentioned in 2.3.3 with reference to the Blackwood (1985) analysis of an excerpt of César Frank's Symphony in D minor, extremely modulating passages do not adjust themselves easily to the harmonic series principle. Another interesting example in this respect is the diminished chord found at the beginning of the third phrase of the motet to be analysed. Alongside the diminished fifth/seventh chords, other dissonant harmonies may not easily submit themselves to the harmonic series principle, thus reinforcing the need for a flexible temperament.

According to what has been discussed, extended pure intonation does not deliver the solution for all intonation problems. Some of the harmonies in tonal music cannot hold pure intonation to all of the intervals. In a modulating phrase, a reference according to the new key has to be established, perhaps retaining a direct frequency relationship with the former one – a common pitch, for instance – *but not necessarily* – as can be seen in the third phrase of the *Ave Verum Corpus* motet. In this case, a different strategy would be required in pursuit of the best possible intonation. It may not be possible to apply the harmonic series principle based on the same fundamental tone; then, the series would have to be transposed to line up with a new fundamental frequency. Here lies the crucial point in relation to intonational strategies to be adopted by the singer; here resides the dividing line between any fixed pitch procedure, extended or not, and the real needs of music performance.

2.4.5 - The case for a flexible intonation

The problems with adhering to a tuning system or temperament

Some theorists defend the idea (apparently supported by experimental work) that major thirds and other intervals are commonly played or sung stretched, like in Pythagorean intonation, in this way implying the inadequacy of pure intonation as a gauge for intonation in performance. The last paragraphs of Barbour's *Tuning and Temperament* illustrates this point of view very clearly; Sundberg's *The Science of Musical Sounds*, pages 211 and 222, brings forth the virtues of stretched intervals and the need to perform stretched intervals; Pierce, in *The Science of Musical Sound*, page 74, also states that, according to experimental work carried out by Max Mathews, people like 'out-of-tune' (wide) major triads, because they sound 'brighter'. Of course, it would be worth knowing exactly the conditions under which the experimental work was done. This is mentioned only as forethought, as experiments with soloists might easily provide results in agreement with such statements, once there would be no sounding harmony to be perceived. Pythagorean-like results would be highly probable in this kind of performance. Furthermore, soloists may reflect cultural influences more fully than other performers, as a result of long practice time bound to piano tuning, extensive use of vibrato, etc. Finally, research that only reflects cultural preferences cannot be considered a reliable source of knowledge for the determination of trustable principles regarding music performance.

Let there be considered a very simple case of harmonic progression in which a dissonant dominant chord (a dominant seventh chord, for instance) is followed by a consonant tonic chord. In this case, the dissonant character of the dominant chord would allow for the use of a stretched major third as the leading note leaning towards the tonic, the fundamental of the next (consonant) chord. Roughness prepares the ground for the stretched major third in its melodic role as a leading note; in doing so, it takes advantage of the dissonant character of the harmony. The resolution of the dissonance into a consonant tonic chord, however, calls for a radical change in attitude. The purity of its major third must be regarded as of paramount importance in the establishment of not only the consonance pertaining to the tonic chord, but also its position as the hierarchical centre of the passage and its functional stability. A Pythagorean third would introduce unwanted beats and undermine the most needed definition of the chord. Dissonant chords possibly can afford Pythagorean thirds, due to their inherent roughness. There is a possibility that in music belonging to earlier historical periods, thirds were not only considered dissonant intervals (deservedly so, due to the Pythagorean intonation in use at the time), they may actually have been intended as dissonances!

Pure intonation according to the harmonic series principle demands allegiance to the reference frequency perhaps for the entire musical phrase as far as it does not modulate. Upon taking a close look at the harmonic series, it turns out that it is confined to one big structural block, which is equivalent to an extended dominant chord. This 'extended dominant chord' does *not* contain the note of resolution, i.e., the related *tonic*. When a harmonic resolution or a modulating process takes place in a piece of music, the whole pitch reference according to the harmonic series principle has to be changed to a new corresponding structural block – a new harmonic series. From this fact, it can be inferred that a simple dominant-tonic cadence (V-I degree chord progression) calls for a change to a new harmonic series, if purely tuned. In the opposite procedure – half cadence (I-V degree chord progression), the reference related to the harmonic series may be maintained, if no further exploration of the dominant harmony is undertaken, since the harmonic series of the tonic contains the pure fifth (dominant) interval. In the case of a modulating phrase, it may not be possible to maintain the reference frequency throughout the phrase, as the establishment of a new tonic could entail a change in the reference frequency according to the new key in unexpected ways. It may happen that this procedure transposes a little the reference frequency of the musical passage, thus bringing forth a procedure we might call 'flexible temperament'. This happens very often with augmented or diminished modulating chords, as well as in chromaticism. It can be inferred here, as a remark on the beauty of musical procedures, that the harmonic chords or sequences that carry double meaning, conveying surprise and a sense of the unexpected to the music, do benefit from the different possibilities of intonational strategies available to performers. This will be illustrated in the analysis of the motet's third phrase.

Changing or keeping the reference frequencies

As shall be seen in the analysis of the piece chosen for the experiments, it is possible for singing ensembles to define a different reference frequency for each phrase of the music in live performance, or alternatively keep the same reference frequency throughout the entire piece. In each case, there is a reason for doing so. When a piece of music is sung with instrumental accompaniment, the reference frequency will be maintained throughout the piece, in agreement with instrumental constraints on pitch variation. It would be reasonable to assume that this procedure might also be adopted in *a cappella* singing. Nevertheless, this was not the case in the experiments carried out in this research, where both strategies were verified (see 5.3.1 to 5.3.3).

The possibility of having a choice between two or more reference frequencies for a musical segment (either a phrase, a half-phrase or so) is a challenging one. Changes in reference frequencies are usually considered unacceptable, and consequently musically wrong. A new attitude regarding flexibility of intonation practices would have to be seriously considered if these changes could be proved practicable as well as musically effective. Furthermore, the procedure for implementing the reference frequency change would have to make use of a kind of temperament. In this work, such a procedure is called

- The *flexible temperament principle.*

Tools for intonation control and improvement

As mentioned earlier, there are two main tools to be used in the pursuit of the best possible intonation in performance. They can function in two different ways: it is possible either to resort just to the first one – categorical perception – or to allow both – that and beat detection – to work in tandem, in order to increase the resolution of the intervals. The second tool enhances the perception of beats through aural feedback, making it possible for the performer to minimise beats. This second type of intonation control may be increasingly effective in accordance with the hierarchical importance of the chords being performed. Perfect triad consonances would require greater control, whereas dissonant chords, especially extended dominant chords would allow for a more relaxed beat control.

Partch (1974:84) illustrates the deviations of the 'so-called diatonic intervals' (as he puts it) of twelve-tone equal temperament in relation to pure intonation. From the tonic, as in C major, they are:

Intervals	I	I-IIb	I-II	I-IIIb	I-III	I-IV	I-IV#	I-V	I-VIb	I-VI	I-VIIb	I-VII
Ratio	1/1	16/15	9/8, 10/9	6/5, 7/6	5/4	4/3	7/5, 10/7	3/2	8/5	5/3, 12/7	16/9, 9/5	15/8
Deviations in Cents	Unison	–12	–4, +18	–16, +33	+14	+2	+17.5, –17.5	–2	–14	+16, –33	+4, –18	+12

Tables showing an enlarged list of intervals for the implementation of pure intonation are given in the sub-section 2.4.6 ('Applying the harmonic series principle to intonation').

Categorical perception

The first tool in the performer's armoury is related to the way intervals are perceived in the first place, by means of *categorical perception*. This phenomenon is used in conjunction with the performer's learned musical abilities that are the result of training practice, done most of the time with the aid of a fixed tuned instrument, such as the piano. Whatever these learned abilities are for a singer, he or she is presumably able to discriminate categorically any musical interval relevant to his or her performance. It is an undifferentiated perception of any musical interval in relation to its microtonal characteristics. In this sense, a major third will always be a major third in spite of the fact that it can be a pure interval, a widened Pythagorean major third, or an equal-tempered one. Learned abilities may exert influence in the way intervals are approached and acted upon, but do not impair categorical perception.

Beat detection

Beat detection allows for a more detailed appraisal of intervals, in the sense that it is the device that makes it possible to control the degree of purity of an interval in at least two ways:

- by bringing consonant intervals nearer to their pure version, through beat minimisation, and
- by bringing dissonant intervals to abide by the harmonic series principle, also through beat minimisation.

In the presence of vibrato singing, the ability to detect beats becomes inoperative. But in that case, as mentioned earlier (see 2.2.3), it may be possible to make up for this kind of limitation by means of a thorough training based on beat perception, that entails a training *without* the use of vibrato. In spite of the fact that it would not guarantee beat perception in vibrato singing, it could at least provide a firm background for an intuitive procedure while vibrato is operational. This is not the subject of this research, but it is worth mentioning here that it should be possible, in spite of the fact that it has not been developed yet as a training technique. The basis for this assumption is provided by experimental work carried out by Sundberg (1978), Shonle and Horan (1980) and Iwamiya et al. (1983), on the perception of vibrato notes.

It is also worth mentioning the fact that vibrato was considered an embellishment in earlier periods of music history. It was not considered to be a natural technique to be used with nearly every single note during performance, but was employed as an ornament, an expressive device not to be made banal through over-use. Nowadays, it may work to disguise pitch problems as much as an expressive device in operatic singing style.

2.4.6 - Intonational strategies

The utilisation of the two intonational principles would be a natural consequence when singers make extensive use of the two perception principles, namely the categorical perception principle and beat detection principle. These two intonation principles bring forth the possibilities discussed earlier, of either maintaining the same reference frequency throughout the piece or changing it into a new one using a flexible temperament.

Applying the harmonic series principle to intonation

Intonation should follow the harmonic series principle, inasmuch as it is possible to do so. The extent to which the harmonic series principle would be followed and temperament would be implemented is a matter to be decided by the singers in the performance situation.

In the table presented in Appendix 8.1, most of the necessary intervals that can be applied to an intonational strategy based on traditional harmony are listed. It provides values expressed in cents for two hundred and seventy nine pitches to the octave according to extended pure intonation, and is aimed at the harmonic language used in the motet. It must be kept in mind that as the harmonic series principle is based upon the raw material used to define tuning systems, it is also open-ended. Therefore, it shows its pitch number limits out of necessity. Only eighty-seven pitches are needed to implement the two versions of the intonational analysis for the *Ave Verum Corpus* motet, as described in the following section (2.5).

Nevertheless, bringing most of the notes to the binding relationships contained within the harmonic series may produce some unexpected results, as can be seen in the synthesised versions of the *Ave Verum Corpus* motet (see analysis sound examples in 2.5.3 onwards). This does not mean that it is not a good procedure. On the contrary, it probably points to the fact that the harmonic series embodies not only the guidelines necessary for the kind of music we make, but also it provides for an extended implementation of music within its principle, and therefore for a much more detailed tonal structure of the musical language than we are used to nowadays. These resources are available to us, inasmuch as we may wish to explore them. It must be recalled that there is no other authoritative procedure to be resorted to. Fixed temperaments – extended or not – are not considered here as trustworthy models, as their main function is to provide (imperfect) solutions for intonational problems.

Applying temperament to intonation

The harmonic series principle is able to provide a guideline for a sound intonational strategy, but is not able to keep performance restricted to the same reference frequency throughout the piece, or perhaps even for a phrase. This is not difficult to realise: a quick consideration of the basic harmonic functions will help in the understanding of the principles involved in the situation. The two main tonal functions – tonic and dominant – are responsible for the main features that define intonational behaviour in performance: tension and resolution. Tension relates to the dominant, which is the dissonance-related function; resolution is connected to the tonic, usually bound to consonance and stability. The interaction between the two functions or their related counterparts usually takes place within the span of a musical phrase, with the aid of cadences to punctuate them. As a harmonic series based on the dominant does not contain the pitch of the tonic, it is obvious that the harmonic series for the resolution will have to be based on another fundamental frequency. However, the harmonic series of a tonic includes the dominant note. It would be possible to maintain the reference frequency for the phrase if there are no complex harmonic situations arising from modulations to distant keys. If this were the case, a change in the reference frequency would probably happen.

The intonational strategy that would allow for such changes would require the use of temperament – not a fixed temperament, as historically temperaments have been defined, but a flexible one. This procedure would not constitute a model for intonation; instead, it would be an intonational strategy for aiming at the target harmony. It would usually take place between chords that belong to different harmonic functions. In addition, augmented and diminished chords are the ideal opportunity for resorting to temperament, in any situation, due to the ambiguity and lack of definition of such harmonies. Even in conventional music writing this tendency is revealed – this type of chord does not usually follow the rules of notation according to the key in use (as seen in 2.4.4: Ambiguous harmonies), a procedure that may indicate its tendency towards temperament.

Temperament could occasionally be called for even within the working limits of a harmonic series in a phrase. Upon listening to the synthesised recordings based on intonational analysis it seems likely that, as they sound at parts different from what would usually be expected, intonational strategies resort to temperament more often than would normally be necessary from the harmonic series principle's point of view. This probably happens due to the desire to prevent repeated notes becoming mutable notes, as will be considered later in the analysis and discussion of the experiments.

Keeping or changing the reference frequency

One of the most striking features revealed by the measurements in this research is the ability of singing ensembles to determine whether they will keep or change reference frequencies throughout the piece. As both possibilities were consistently explored by the groups, as was shown in the experiments, a flexible approach to intonational strategies must take into account this possibility. The opportunity to change or keep the reference frequency is brought about in the first half of the motet's third phrase, in which there is a choice for maintaining the 'A' with 0 subscript or changing it to a -1 subscript (see 2.4.1). The latter indicates that the reference frequency will be flattened by a syntonic comma.

The measurements revealed that one of the groups, which had a few singers with absolute pitch, maintained the reference frequency throughout the piece, while another group changed the reference frequency by nearly a syntonic comma. The first mentioned group, however, used more vibrato than the other, a fact that adds to the complexity of the subject.

The process of decision making

The previous paragraph gives rise to the possibility of absolute pitch being a desirable asset to make sure that the reference pitches would always be kept constant. Nevertheless, it also can be said that relative pitch would encourage a more faithful rendering of the piece according to its written harmonic language, by allowing changes in reference frequencies when necessary or desirable. The use of vibrato may change the way perception would naturally take place in relation to the reference frequency issue. If there were no singers with absolute pitch capabilities, would the reference frequency remain the same in the presence of full vibrato singing? This kind of question needs further research in order to build up a clearer picture of the process of definition of intonational strategies.

Many variables can influence the way singers approach performance-related issues. The interaction between the singers, their habit of singing together and their perception of each other's reactions to the music would greatly influence their ability to decide on the strategy to be followed. The presence of vibrato may influence intonational strategies, but is not safe to assume that, as vibrato does impair beat perception, it also would lessen tuning accuracy.

A thorough training in beat detection would probably greatly improve the situation regarding the process of decision making on intonation. In addition, the more the performer consciously knows the subject, the better would be his or her ability to implement a sound intonational strategy.

2.5 - Intonational analysis of *Ave Verum Corpus*

In the motet chosen for the experiments, there are five phrases, as follows:

- **First Phrase**

The first phrase presents a very straightforward statement in D major, the motet's key. It begins with a tonic chord and ends with a dominant chord, all within an optimal range in respect of vocal technique and musical demands, as happens throughout the whole piece. The reference frequency for this phrase is D_3.

- **Second Phrase**

The second phrase is written in the key of the dominant. It contains a diminished chord in the key of the relative minor (F# minor) that brings about more than one possibility for the implementation of intonational procedures. It is expected, nevertheless, that the reference frequency would remain the same at the end of the phrase as it was at the beginning. The reference frequency for this phrase is A_2.

- **Third Phrase**

This is by far the most complex harmonically of all of the motet's phrases. From the key of the dominant it modulates firstly to F major, and then comes to the main key of the motet, in its minor mode, exploring both the melodic and harmonic forms in its way back to the key of D in its minor mode. The number of opportunities for decision-making on intonation is far greater than before. The reference frequency for this phrase is A_2.

- **Fourth Phrase**

Back to D major, the fourth phrase offers just one opportunity to move outside the range of the diatonic notes, with the secondary dominant (E^7). It is written in a contrapuntal style, in a canonical procedure at the interval of a fifth, by pair of voices. Finishing in an interrupted cadence together with the use of the first inversion of the destination chord, it provides the expectancy that prepares for the climax on the final phrase. Its reference frequency is D_3 again.

◆ Fifth Phrase

The last phrase shows again at least one chance for the use of temperament, when the diminished seventh chord of $D\#^{-7}$ prepares the second dominant E^7. The reference frequency for this last phrase is D_3.

2.5.1 - Symbology used in the analysis

The intervals of extended pure intonation used in the analysis are described below. The values, in cents, express deviations from extended Pythagorean intonation, which is, traditionally, the basic procedure for the generation of intervals.

- Subscripts 0: as originated in extended Pythagorean intonation;
- Subscripts + or – 1, 2, etc., refers to the *syntonic comma* ($\bar{k}$), which is equivalent to 21.506 cents, added or diminished from the Pythagorean interval (subscript 0);
- Subscripts $-\bar{\bar{z}}$ refers to the *septimal comma* (-27.264 cents), and are used to adjust the seventh of dominant chords whose roots have 0 subscripts;
- Subscripts $-(\bar{k}+\bar{z})$ (-48.771 cents) furnish the minor seventh of dominant chords with –1 subscript applied to their fundamental;
- Subscripts $-\bar{y}$ (-6.775 cents) refers to the minor ninth of dominant ninth chords whose roots have –1 subscripts, and also the higher note of diminished seventh whose lower note has a –2 subscript;
- Subscripts $+(\bar{k}-\bar{y})$ (14.731 cents) gives the minor ninths of dominant ninth chords whose roots have 0 subscripts, and also the higher note of a diminished seventh whose lower note has a –1 subscript;
- Subscripts $+(\bar{k}-\bar{z})$ (-5.758 cents) refer to the minor seventh of dominant chords whose fundamentals have a +1 subscript.

Blackwood (1985:100, 129-30) describes the principles involved in an extended pure intonation analysis in the following way:

> The just tuning of such combinations involves the following principles:
>
> Perfect fifths, perfect fourths, and octaves must all be pure; hence, two notes forming any of these intervals must have the same subscripts.
>
> Major triads must all be pure; hence the third of a major triad must have a subscript one less than that of the root and fifth.

> Minor triads must all be pure; hence, the third of a minor triad must have a subscript one greater than that of the root and fifth.
>
> Thirds and sixths in which both notes have the same subscripts are Pythagorean, and should be avoided if possible.
>
> The root and fifth of a major triad should generally have *zero* subscripts; the root and fifth of a minor triad should generally have -1 subscripts. This arrangement tends to minimise the occurrence of the syntonic comma as a melodic interval.
>
> In just tuning [of the family of minor keys], we choose subscripts so that the scale has the maximum number of notes in common with its relative major.

2.5.2 - *Ave Verum Corpus* motet reference frequencies

The reference frequencies for the motet's phrases were chosen based on the chords considered musically the most important in each phrase (see appendix 7.5: reference frequencies score).

The squared notes are the ones chosen for determining the reference frequencies. They could be:

- taken from musically important consonant chords;
- taken from musically important consonant and dissonant chords; or
- taken from musically important consonant chords unambiguous in performance.

The choice was made according to the last of the mentioned possibilities, for the following reasons:

- Musically important consonant chords may have technical shortcomings that would render them inappropriate for use as a source for determining the reference frequency. This could be the case in the first phrase with the D major chord of the second beat of the first bar, where the second syllable of the word "A-ve" is not musically stressed as is the first one, and the singers are preparing themselves for the following repetition of the word. The preparation would possibly comprise a caesura, which would shorten the value of the notes. If it was to be decided that the frequencies of this chord should be used for reference frequency calculation, the last soprano note at least should be left aside, because it would be much too short to be accounted as a reliable source for this kind of measurement. The same rationale applies to the D major chord on the second beat of the fourth bar, the A major chord of the fourth crochet of the fifth bar, and the D major chord in the second beat of the seventh bar.

  In the following phrases, this reasoning applies to the chords belonging to: the last crochet of bar 9, second beat of bar 12 and the third and fourth crochets of bar 15; fourth crochet of bar 17, second crochet of bar 20; fourth beat of bar 25, fourth crochet of bar 26; and third crochet of bar 36.

- Important dissonant chords must be discarded in this kind of procedure. Taking into account that there is a variation of about 27 cents between the sevenths of a dominant chord in Pythagorean and pure intonation, plus the fact that the presence of beats would be increased due to the dissonant character of the chord, it is hardly believable that dissonant chords would help to bring forth the best possible reference frequency.
- Consonant chords unambiguous in performance are the best option to determine reference frequencies. They avoid the problems pointed out above, and provide more consistent results throughout the various recording takes, being less prone to errors and mistakes.

Chords such as A major in the first beat of bar 10 are more a harmonic *appoggiatura* of the following E dominant chord than a proper consonant chord. It may work well as a harmonically strong reference chord for one group of singers, but not necessarily for another. In the end, the simpler the choices that are made, the clearer the results. It was decided to use the most important consonant chords that do not show any technical shortcomings. The only remaining points are:

- Changing the reference frequency would result in the displacement of the thicker red line (the singer's results) up or down with respect to the 'y' axis displayed on the graphs. The other lines would remain unchanged. The red line's overall shape is not modified in any way. If, for any reason, the reference frequency could be thought off as being inexact, the singer's curve would remain truthful to the measurements; consequently, a 'best fit' approach to the results would remain valid.
- Is it advisable to measure all intervals belonging to the chords, which amounts to measuring all of the voices, or is it better to take the thirds out of the calculations? The difficulty here is that thirds would have to be calculated in terms of their acoustical behaviour, as if they were indeed pure thirds, when in fact the singer could have meant a tempered interval. It is not possible to determine this kind of fact prior to the analysis. An equal tempered major third is about fourteen cents wider than a pure major third; this fact could affect reference frequency results if singers intended to sing one instead of the other. On the other hand, perfect fifths and fourths have a variation of only two cents between equal temperament and pure intonation. For this reason, all reference

frequencies are calculated both ways (including and not including thirds), for the sake of completeness and correctness of the results.

The selected chords for determining the reference frequencies, as can be seen in the reference frequencies general score, are considered as being the best suited to the job. In the third phrase, the A_3 taken as the reference frequency was considered the best option, since A chords start and finish the phrase and are closely related to the keys involved – A major and D minor. In the fourth phrase, it was necessary to make a displacement in time in relation to the female and male voices, which results in two different harmonies being selected for them: D major and G major. In addition, the two remaining chords selected are not in their fundamental position; the D major chord is presented in its second inversion and the G major chord in its first. Nevertheless, they are considered the best choice, and a look at the measurements would confirm their credibility. In the last phrase, the initial G of the soprano staff was considered a valuable addition to the chosen notes; the G minor chord on the first beat of bar 34 is presented in its first inversion, as is the D major chord in bar 38.

2.5.3 - The analysis

Appendices 7.3 and 7.4 show the analytical scores. Squared notes' results do not support the harmonic series principle. It is interesting to note that they do not belong to the harmonies they are inserted in; the first two notes can be considered as double *appoggiaturas*, while the natural 'C' of the tenor anticipates the next harmony. Temperament must be called for at these places.

Appendices 8.2 and 8.3 represent tuning tables 01 and 02 that show the values regarding the two intonational analyses' notes and their deviation from equal temperament.

The analytical details are:

First phrase

In sound examples 7-10, the motet's first phrase is presented; firstly, in Pythagorean intonation followed by meantone temperament, equal temperament, and extended pure intonation.

According to the symbology adopted for the analysis, applying 0 (zero) subscripts or equivalent relationship between intervals (through the use of the same subscript value for the notes involved) indicates Pythagorean intonation. It provides octaves, fifths and fourths in their pure versions – the so-called 'perfect' consonances. Pure major and minor thirds and sixths must be provided by an increase in the resolution of the system. Therefore, in the first chord of the motet, all of the notes have subscripts 0 except the alto, with an adjustment of -1 to its F# in order to provide a pure major third. This rationale applies to the remaining notes of the first bar, and to bars 5 and 8.

The first opportunity to consider options on intonation arises in the first half of the second bar. The alto note – E_{-1} – defines the fundamental of the chord based on the second degree of the scale; it should therefore present a subscript -1, which is the most appropriate for the fundamental of a minor chord (see analytical principles above). It is the first mutable note of the motet. This fact presents a problem for the two soprano notes – A and G# – which cannot be pure-tuned to the alto E_{-1}, the tenor A and the bass D. Reason calls for allegiance to the stronger consonances, and the 0 subscript is applied to the soprano A, while a -1 subscript is attached to the G#, leaving the impure intervals between the two female voices. In addition, this could be the first opportunity for the use of temperament by the soprano voice. Besides, a total agreement with the harmonic series principle in this passage is not possible. Also none of the other possibilities comply with the harmonic series principle: a B_0 for the tenor would define a Pythagorean major sixth between tenor and bass, and a E_0 for the alto would result in a faulty perfect fourth with the tenor as well as create a Pythagorean minor third with the soprano on the second beat. Consequently, this passage constitutes the first one to call for flexibility in intonational strategy.

In the third bar of the motet, the use of the septimal comma in the soprano voice creates a mutable note; a mutation also happens in the E_0 that belongs to the alto. All of the other notes of the bar follow the harmonic series principle. Bar 7 shows another mutable note in the soprano melodic line.

Apart from the first half of the second bar, everything runs straightforwardly in relation to the harmonic series principle. Mutable notes happen as a consequence of switching back and forth from the tonic-based series to the dominant-based one.

Second phrase

In sound examples 11-15, the motet's second phrase is presented; firstly, in Pythagorean intonation followed by meantone temperament, equal temperament, and extended pure intonation , according to analysis I and II.

The second phrase belongs to the key of the dominant. Only the tenor voice has subscript -1 to provide a pure major third for the chords in bar 9 and the first crochet of the next bar. For the remainder of bar 10 and the next, the E^7 dominant chord is presented, leaving the soprano and tenor voices to be adjusted to the harmonic series principle, with the -1 subscript for the pure major third and $-\bar{z}$ for the seventh of the chord.

In the first beat of bar 12, a diminished seventh chord presents the motet's first criss-cross puzzle related to intonation. The most direct approach would consider this chord as C#$^{-9}$ with no fundamental tone. This procedure determines mutable notes for the soprano and tenor voices. They furnish a seventh from the dominant chord lowered by a syntonic comma ($-(\bar{k}+\bar{z})$), as well the minor ninth of the dominant lowered by a syntonic comma. The acoustical result, as presented in the replica of Analysis I, is controversial. A second analytical possibility is to consider the diminished chord as a harmonic *appoggiatura* of the relative key F# minor, as is done in Analysis II. In this case, it happens as if the E^7 dominant chord is being repeated, with the bass line proceeding chromatically towards the tonic relative F#. The following chords of the bar reveal a straightforward analytical procedure.

The soprano's D from bar 13 is considered as being adjusted by a septimal comma, as is the tenor's D, also. Alto and bass provide the remainder of the diminished fifth chord (dominant seventh with no fundamental).

The last three bars of the second phrase behave like 'textbook' examples.

Third phrase

In sound examples 16-20, the motet's third phrase is presented; firstly, in Pythagorean intonation followed by meantone temperament, equal temperament, and extended pure intonation, according to analysis I and II.

The third phrase comprises all the main features of tonal harmony: it modulates from the initial A major key to F major, and then to D minor. F major is D minor's relative key. It can be said that the phrase is bound to the tonality of the piece, but its development happens under the influence of the minor mode, underlining the meaning of the text through not only the use of the minor mode, but also from the extent of its modulation and the descent of its melodic lines. The tenor's final note is the definitive evidence of this procedure: instead of smoothing the melodic line by singing a C#, in which case the alto would sing the low A, the tenor goes all the way down to the E, giving depth to the meaning of the text and darkening the overall sound. It also doubles the fifth of the chord instead of the octave, imparting an aural impression of a thicker and less stable harmony.

Bar 17 opens with a straightforward statement in A major, giving the impression that the music still holds A major as the tonic, as in the former phrase. Soon it will become clear that, in this phrase, the tonal procedure will be developed in a totally different way than before. The second half of the first beat of bar 18 would unsettle the certainty upon which the music has developed until then. This procedure goes even further in the second half of the second beat, in which the tenor's C natural defines the harmony after the ambiguity of the diminished chord, as well as raising expectations in relation to the way ahead. This fact can be seen in at least two different ways depending on how the performers intend to establish the temporary F major key. It leads to two different possible intonational strategies:

- The 'A' note is lowered by a syntonic comma;
- The 'A' note is maintained throughout the entire phrase.

The tenor's choice of the C natural may define the intonational strategy ahead. It must be kept in mind that the tenor is actually anticipating the next fundamental of a C7 chord, the F major dominant harmony. This anticipation is done by means of temperament, since it is not possible for the tenor to tune the note in accordance to the harmonic series principle. Therefore, the two main intonational strategies for this passage are provided by procedures based on temperament. This is clear evidence of two very important guidelines of music intonation:

- Temperament must be flexible;
- Temperament provides the means for a variety of choices of intonational strategies.

Consequently, the two principles - the harmonic series principle and the flexible temperament principle - provide the technical means for any needed or wanted intonational strategy – one provides stability whilst the other provides the ability to change.

It must be taken into account that the motet has a rhythmic structure comprising two beats per bar. Harmony is expected to change accordingly, hence the motivation for some of the comments ahead. According to what was said in the former paragraphs, two different intonational analyses can be drawn for bars 18 to 20. They are:

Analysis I: The soprano's Bb in bar 18 is considered to be a minor ninth of the A dominant chord (A_0), hence its $+(\bar{k}-\bar{y})$ subscript. The bass's G natural functions as the seventh of the dominant, with a $-\bar{\bar{z}}$ subscript. The strategic choice is made by the tenor C natural. In this case, it defines C_0, what makes the fundamental F assume a 0 subscript also. The following As will be given a subscript -1, according to the F major key. The other notes follow the harmonic series principle. The first soprano note in bar 19 is a mutable note, adjusted to its function of seventh of the dominant. The first alto note of the same bar (E_{-1}) is also a mutable note, as a major third of the dominant chord. From then on until the end of bar 20 the subscripts' definition is straightforward.

Analysis II: Bar 18 shows the same subscripts as analysis I, except for the tenor C natural that assumes a +1 subscript. This entails that F will also share the same subscript, while A will remain with the 0 subscript. As the bars 19 and 20 would be higher by a syntonic comma in relation to analysis I, the related subscripts will reflect this fact. Consequently, the soprano Bb will have the $+(\bar{k}-\bar{z})$ subscript, also shared by the tenor Bb. The soprano presents a mutable Bb (first note of bar 19), while the alto does not mutate this time. All of the other notes that belong to bars 19 and 20 comply with the harmonic series principle.

The second half of the third phrase does not vary in analytical terms, but does offer yet another interesting possibility in terms of intonational strategy. Since the A was lowered by a syntonic comma in the first half of the phrase, it is prone to remain lowered as a reference frequency for the second half of the phrase. Therefore, the strategy adopted by the singers will decide the reference frequency for the second half of the phrase. The musical examples for this phrase include an extended pure intonation version with the second part of the phrase lowered by a syntonic comma.

In analytical terms, the distinctive points are: mutable notes for the bass at the beginning of bar 21 and the soprano at the beginning of bar 22; the bass mutates to the seventh of the G^7 dominant chord, and the soprano to the diminished fifth of the chord (A^7 dominant chord with no fundamental). Bar 23 has two diminished seventh chords: the first is considered to be an A^{-9} dominant chord with no fundamental, and the other an E^{-9} dominant chord also with no fundamental. Nevertheless, both diminished chords have ambiguous meaning. The first one, for instance, can be treated as a harmonic *appoggiatura* in relation to the next D minor chord. The second of the two quavers for both soprano and alto (E and C#) is a passing note that is pure tuned in the analysis.

Fourth phrase

In sound examples 21-24, the motet's fourth phrase is presented; firstly, in Pythagorean intonation followed by meantone temperament, equal temperament, and extended pure intonation .

The fourth phrase consists almost entirely of a canonical procedure at the interval of fifth, developed between the pairs of female and male voices. Each pair of voices maintain an interval of a third between themselves, being their intonational procedures made according to the harmonic functions of the notes of the phrase. The soprano strategy calls for a mutable note in bar 27, when the G note is articulated first as the third of a second degree chord (with 0 subscript) and then as the seventh of the dominant (with $-\bar{z}$ subscript). The alto behaves similarly to the soprano in the same bar, as the fundamental of the second-degree chord (with -1 subscript), and then as the fifth of the dominant (with 0 subscript). In the last crochet of bar 30 the subscript for both voices is 0 (zero) due to the harmony that belongs to the secondary dominant E^7.

Tenor and bass follow the standard procedure within the guidelines of the harmonic series principle, thus providing a -1 subscript for the bass E note. In the last crochet of bar 30, the tenor resorts to the $-\bar{z}$ subscript for the mutable D, while the bass uses $G^{\#}_{-1}$, both from the secondary dominant chord E^7.

Fifth phrase

In sound examples 25-28, the motet's last phrase is presented; firstly, in Pythagorean intonation followed by meantone temperament, equal temperament, and extended pure intonation .

Bar 33 defines a D7 dominant chord, which causes the $-\bar{z}$subscript to be used for the tenor. In the second beat of next bar, a B^{-9} secondary dominant (with no fundamental) defines the $-\bar{z}$ subscript for the bass, a $+(\bar{k}-\bar{y})$ subscript for the tenor, as well as the other two rather more expected subscripts for alto and soprano. In bar 35, the secondary dominant is E7, providing for the $-\bar{z}$ subscript for tenor and soprano voices. The bass is the next voice to make use of the $-\bar{z}$ subscript, in bar 36, when the main dominant is active again. The last two bars present no surprises; the analysis points to a straightforward procedure of intonation.

3 - EXPERIMENTAL DESIGN

3.1 - Introduction

This chapter deals with the delineation of experimental procedures for the evaluation of the intonational strategies adopted by singers in a performance situation. It starts by pointing out the advantage of the use of the singing voice as the instrument of choice for the performance of experiments related to the subject. It analyses important technical limitations connected with this kind of research, focuses on the conditions to be met for successfully carrying out experiments, and describes the routine to be followed in each recording session.

The recording sessions' environment is described, from the venue at City University to the studio setup designed for quartet and choir experiments. The technical tools utilised for recording and manipulation of the recorded signals are also considered.

The measurements of the acquired data were performed in the laboratory of the Clinical Communications Department of City University. The technical procedures to carry them out are outlined, together with the laboratory setup, instruments and methodology utilised in the measurements.

Analytical issues are considered, namely technical problems, errors and mistakes, as well as intonational analyses and reference frequencies. A description of the instruments designed for analytical purposes, together with their objects, is also made. Instruments that are not specific to quartet and choir, as well as quartet and choir analytical instruments are fully described, to end the chapter.

3.2 - Data gathering

The singing voice is the ideal instrument for the investigation of intonational strategies in a performance situation, due to its absolute freedom of intonation. As occidental music makes use of harmony practically all the time, such investigation must take into account ensemble performance. The recording, measurements and analysis of a representative piece of vocal music should enable the researcher to build up a picture of vocal intonation strategies.

Experimental limitations related to commercial recordings

The first thing that naturally comes to mind in relation to this kind of experiment is to measure and analyse the vast supply of commercial recordings that is available nowadays. There are some technical limitations, however, to be considered. In the absence of discrete signals, data cannot be analysed by computer means, according to the requirements of this research. This fact not only invalidates the use of stereophonic signals (or monophonic ones, as is the case with old recordings), but also does not accept single melodic lines performed by several singers at the same time. It may be that in the near future computer software will be able to deal with mixed sound signals for the analytical purposes of this kind of research, and the enormous wealth of commercial recordings would become available for analysis. As it stands now, only discrete signals can be measured and analysed to provide a reliable source of information on intonation practice.

3.2.2 - The subjects

As stated earlier, occidental music is essentially harmonic, raising the need to design experimental procedures that take this fact into account. Solo singing would not be sufficient for this kind of investigation, because it would not convey a full picture of intonation; hence the necessity of using ensemble and choral singing groups in experimental work. Three classical quartets and one choir of sixteen singers were the subjects in this research.

3.2.3 - Experimental procedures for the experiments

Experimental work on the subject of intonation in performance is extremely demanding in relation to the conditions to be met in order to acquire valid data for measurements and analysis. As seen in the introductory chapter, most of the experimental work done on vocal intonation is performed under laboratory conditions, which are very convenient and allow for tight control over the variables that need to be kept restrained. Good results are generally guaranteed by this kind of procedure, which also gives continuity to researches that can benefit from the near ideal conditions attained in laboratory conditions. For instance, there is much more study carried out on solo singing than on choral singing, perhaps for mixed reasons. It may be that the vocal technique used by the soloists is considered to be superior, or based on the "correct singing technique", or maybe it is easier to control experiments with one singer than with a quartet or a choir. Whatever the reason is, there is a larger body of knowledge on solo singing than on choral singing, in spite of the fact that choral singing is the most widely spread musical activity in the world.

Conditions to be met for the experiments

Investigating intonational strategies in ensemble singing demands an open-minded approach in terms of experimental design, needing also the assurance that the reliability of the devised procedures would meet the strict conditions required to give it coherence and consistency. The conditions to be met for successful experimental work in a recording session are: the utilisation of a real piece of music, performance situation conditions, simultaneity of performance and discrete signal recordings.

Piece of music

Most of the experiments on singing voice are performed not only under "laboratory conditions" but also with the use of raw musical materials that do not meet musical demands, i.e., that cannot be considered as belonging to a proper piece of music. That sort of material could be appropriate for assessing technical issues, such as vibrato production and control, consonantal and vocalic articulations and many other vocal features that do not have a direct connection to music-related material. Nonetheless, this kind of investigation may be insufficient to provide a full picture of musical phenomena if the evaluation of musical events is desired. For instance, the way that vowel articulation evolves over time while a text is sung could be significantly different in performance than in a "textbook" model. It could not be good enough to sing only isolated notes, scales or *arpeggios*. Musical context, both melodic and harmonic, often plays a very important role that can determine the way a musical note or phrase is articulated, pitched, coloured, etc.

Performance situation

Any other situation for data acquisition could be misleading, because it would not guarantee that the intonational strategy defined by a singer would be matched in a performance situation. The singer must sing in a conventional way, as he or she would do when performing. In the case of experiments that presuppose the use of harmonic material, it certainly would be undesirable to utilise *a priori* recordings in order to analyse takes with a single singer within a harmonic context. Recordings made with the so-called "dummy head" technique would not help in this case, since the live interaction between the singer and the environment is taken out of the experiment. The use of replay techniques, headphones, or any other procedure that could give a different acoustic feedback than the singer usually gets should also be banned from the experiment. Even visual contact may be relevant for the outcome of the results; a facial or bodily expression may indicate the singer's intention of singing higher or lower in pitch, thus providing a clue of his or her intentions to fellow singers.

Room acoustics and spatial interaction are crucial factors related to the performance situation. The relationship between the live feedback and reference sounds may be highly relevant to the results. Here, *feedback* refers to the perception by the singer of his or her own voice, while *reference* means the perception of the other singers' sound by the singer. In performance, the conditions may vary constantly in many ways that are not feasible in artificial circumstances, like running experiments with pre-recorded material. It may be possible, at the end of a great number of experiments, to conclude that controlled experimentation with artificial acoustic constructs and pre-recorded material would produce equivalent results. However, as the situation stands at the time of this research, it would be unacceptable to jump to such conclusions with a minimum of experimental work done under strict conditions on the subject.

Simultaneity of performance

Simultaneity of performance is a very important condition for experiments on intonation that presuppose harmonic as well as melodic interaction. Acoustic feedback makes beat controlling feasible. Other mechanisms of feedback and interactive information about intonational procedures could still be available for improving the chances of achieving good results if the singers make heavy use of vibrato, thus eliminating the possibility of controlling beats.

It could be true that a choir section would have more opportunities to sing mistakenly, as well as producing greater deviations from the target pitches, making it more difficult to attain good intonation than it would be for a single singer. However, it could also be true that singers would have many more clues for controlling beats and other musical parameters, which amounts to having better chances of improving intonation.

Discrete signal recordings

Discrete recording of each individual singer is of paramount importance, because it makes it possible to perform very precise measurements on acquired data. It is an essential condition to carry out research on the subject, and the source of some of its greatest designing difficulties.

In the first experiment of this research, an attempt was made to measure the results of the larynx excitation signal recorded from a quartet of singers as well as from the acoustic microphones' signals. The utilisation of acoustic signals for measurements purposes turned out to be unfeasible. While the soprano results were very close to the larynx excitation values most of the time, as the measurements were performed on signals belonging to lower pitched voices, they became increasingly unreliable and mistaken. Perhaps it would be possible to measure each note through the use of a bank of narrow band filters, but as there is always cross-talk between acoustically recorded signals, one might pose the question of whether a particular soprano signal is being confused with a strong partial of a lower voice and therefore wrongly measured. Consequently, the use of acoustic microphones is ruled out by this condition, due to the cross-talk that almost certainly will be present in the recordings. The signal would become non-linear by the addition of two or more different signals on one recorded track, or by the combination of the signal of a higher voice together with strong harmonics that belong to a lower voice. In any case, the results would almost certainly not be adequate for analysis by the current software available.

Acquiring reliable data for measurement and analysis is a procedure that must guarantee a complete separation of the recorded signals. There is no need to evaluate harmonics if the fundamental frequency is all that is needed to assess intonational strategy. It is useful to remember that the perception of pitch is a complicated affair, not totally understood yet. However, it seems that the pitch of a complex periodic tone is always equivalent to the fundamental frequency of the harmonic series, even if the first partial (fundamental) is not actually there! In the case of the singing voice, the fundamental frequency is always present, bringing no further thoughts about any possible problem related to its absence in relation to the perceived pitch of any sung note.

Routine to be followed in the recording session

A routine was outlined for the recording sessions. The procedures are described here independently of the technical studio set up, fully detailed in 3.3.2.

The singers have to be able to sing with electrodes attached to their necks, near the larynx. In this way, the larynx excitation signals can be recorded. Details about the electrodes and related technical devices are given in 3.3.1 and appendix 5. Acoustic microphones provide acoustic signals that are used for reference throughout the experimental work. All the signals are fed separately to individual tracks of a multitrack tape recorder (ADAT).

As the session moves on, recording takes are carried out. Prior to their beginning, an A_4 (440 Hz. – tuning fork standard tone) is sounded to the singers as a reference pitch. It should pose no problems for them to get to the first chord of the chosen music piece, as it begins with a D major chord. Each take should develop as a non-stopping performance until the end of the motet, which lasts about two minutes. The takes may be conducted or not. In addition, non-vibrato renderings could be asked for, as well as full-vibrato ones.

The chances of achieving the best results are directly connected with the number of recorded takes – the greater the number of takes, the better the general view of intonation would be. In the present research, one quartet and one choir fulfilled the requirements for providing valid results for analysis. The first two quartets were not successful in the sense that it was not possible to adhere to all the requirements above mentioned. They will be referred to in the next section and the reasons they could not abide by the rules will be given in the next chapter, when dealing with the results and analysis. While discussing performance results, quartet singers will be referred to according to their voice denomination. As for the choir, the section name will be referred to, followed by a roman ordinal when indicating individual singers.

3.3 - Recording sessions

Four recording sessions were held at City University, in London. The first two of them were performed with the collaboration of two quartets of singers that were either studying at the university or former students at the institution. The third quartet consisted of singing students from The Royal Academy of Music. The BBC Singers were the last group to collaborate with the experiments, with sixteen of their performers.

3.3.1 - Technical tools utilised in the experiments

Two crucial pieces of technical equipment made experimental work possible. They were the best, if not the only, found solution for the problem of discrete signal recording of ensemble singing in performance situation. They are:

- Laryngograph
- Electrodes (utilised in pairs)

The Laryngograph, together with pairs of electrodes, constitute the specialised equipment that make it possible to record discrete signals of singing voice simultaneously.

Ideally, the devices should fit as comfortably as possible, as well as keep contact with the larynx at all times during the recording takes. After the adjustment of the electrodes, a technician would test the voiced signal generated by each singer with an oscilloscope, to ensure they are working well. After the signal output has been checked, it would be routed to the recording path. Afterwards, all of the larynx excitation signals have to be checked and balanced at the main studio mixing-desk. Appendix 5 presents a technical description of laryngographs and electrodes, together with photos of the devices.

Standard studio equipment was also used in the recording sessions: recording devices, acoustic microphones and all the necessary peripheral tools.

3.3.2 - The venue: the Performance Area and Recording Studio at City University

The first session was held in the Isolation room attached to the studio of the Music Department. The article of the City University Annual Report from the years of 1994-1995, at pages 17-18, shows photographs from this session. The utilisation of electrodes, attached to each singer's neck, can be seen (see appendix 13: City University Annual Report, 1994-95).

The Isolation room is a small, almost triangular room that has just enough space for a quartet of singers plus the researcher and the necessary equipment to carry out the experiment. The room is acoustically isolated (hence its name), which makes it a good option for many recording procedures. The acoustic environment is dryer than usual, although singers can listen to each other very well.

The remaining recording sessions (including the valid ones) were held in the Performance Area of the Music Department of City University. Some photos from the third recording session (the Royal Academy of Music quartet) show the set up for the quartet of singers (see appendix 3: Royal Academy of Music quartet's photos). The Performance Area is a venue for musical events held by the Music Department. It has a stage with enough room for a small chamber orchestra or a chamber choir. The audience area may support about sixty seated people. This area was used for all of the recording sessions except the first one, because there is enough space for the singers, conductor, assistants and all the necessary equipment for the experiments, as well as a good acoustic response. This area is fully linked with the Recording Studio of the Music Department, allowing professional quality recordings to be carried out. Appendix 4.1 shows the choir's disposition diagram. The quartets were placed in front of the stage. The singers were positioned according to a bent line layout, with the conductor at the centre of the area. The Soprano was located at the left side of the conductor, with the other voices accordingly spread to the right of the conductor.

The Performance Area and Recording Studio complement each other as a full-fledged recording studio. The devices used in the experiments are mentioned and commented upon, as necessary, from 3.3.3 onwards. Signal manipulations necessary for the continuation of the experimental work were carried out in the Recording Studio facilities. They include data back up, its transference from ADAT to DAT formats, as well as some basic equalisation procedures that would facilitate laboratory work at a later stage.

Studio set ups

The studio set-ups for the experiments were designed according to the needs of the different participating groups. The setups are based on the Recording Studio resources, which are centred on a mixer desk comprising 24 input channels and multitrack ADAT recording machines, alongside DAT recorders, DSP processors and other peripherals. What concerns the experiments is described below.

Quartet set up

In the quartet set up, each singer has a pair of electrodes attached to the neck, carefully located for maximum larynx contact. The neck collar that maintains the electrodes' position is adjusted to be as comfortable as possible as well as tight enough not to allow the electrodes to lose contact with the skin. There is an acoustic microphone next to each singer, for the acquisition of a signal used as acoustic reference. The four acoustic signals are routed through a Yamaha MLA7 interface to the studio mixer and the first four tracks of an Alesis ADAT multitrack recorder by means of a patch bay connection. The four pairs of electrodes are first connected to the laryngograph that functions as described in the choir's diagram disposition that is referred to above. Signals originated from the laryngographs are then individually monitored and checked by an oscilloscope. The laryngographs are connected to a balancing box and the signals directed to the studio mixer. Then, via a patchbay connection, the signal is routed to the next four tracks of the ADAT. The quartet studio set up diagram can be seen in appendix 4.2.

Choir set up

The studio set up for the choir recording session follows the quartet set up with a few differences, not to mention the number of devices. The first departure from the former setup is related to the acoustic microphones. With sixteen singers, it is advisable to lessen the number of acoustic microphones, instead of providing one for each singer. The set up allows for six microphones, four of them positioned in the centre of the area, each of them directed to a section of the choir, plus another two microphones in front of the stage line, as can be seen in the diagram. It must be recalled that acoustic signals are recorded as reference guides and not for analytical purposes.

Twenty-two tracks must be simultaneously recorded during a recording session of the choir. Two Fostex ADAT recorders were added to the Alesis, to provide the sixteen larynx excitation signals plus the six acoustic ones. One of the Fostex was chosen as the master device, while the other Fostex and the Alesis were synchronised to it as slaves (see appendix 4.3: choir studio set up diagram).

3.3.3 - Manipulation of the recorded data

From ADAT recorder to DAT recorder

Singers' data was recorded onto ADAT multitracks recorders, just an Alesis in the case of quartets or two Fostex plus the Alesis in the case of the choir. ADAT machines are scarce and not usually available for sound manipulation in everyday laboratory work. Recorded data had to be transferred to a more commonly available format, like DAT, that was accessible not only in the Recording Studio, but also in the Clinical Communications laboratory, where the measurements and analyses work were to be performed. The routine procedure for this task consisted of routing the acoustic and laryngographic signals pertaining to the same voice, phrase, and take to stereo acquisition by the DAT machine. Then, a second pair of signals would be coupled, and so on. However, before proceeding, after the ADAT machines have been set up for transfer, a basic mixing has to be carried out to balance as much as possible all signals. The reason for that procedure is that eventually sound tracks would be prepared for listening, either just as an acoustic reference or even for presentations and seminars. It must be considered that manipulation of amplitude of the recorded signals would not affect in any way the measurements to be performed. Of course, backups of the original tapes were also kept as a primary source of data.

From DAT recorder to the laboratory computer, for measurement

The next stage of the research work was carried out at the laboratory of the Clinical Communications Department of City University, London. The acquired data, stored on DAT tapes, was taken to the laboratory to be transferred to the Macintosh computer for analysis. The data was transferred by means of a Tascam DAT recorder and acquired by the computer via software named SoundScope.

From ADAT to hard disk, for sound manipulation and storage

The original signals (from the ADAT tapes) were copied to a Macintosh computer, via Korg 1212/IO sound card and CUBASE VST software. After being put together by Cubase, the data was recorded onto CDs to provide a readily available data source. They were also useful for the preparation of the examples that were utilised in this work.

3.4 - Measurements of the collected data

Measurements of all of the acquired data were performed in the laboratory of the Clinical Communications Department of City University. As expected, the laboratory was built with the spoken voice as the main target for study and research. It presented no problem for the manipulation of signals originated from singing voice; furthermore, it offered the best technical solutions to the analytical requirements of this research.

The motet *Ave Verum Corpus* has 357 notes. This is the number of notes that a quartet of singers performs in one take. In the case of a choir of sixteen singers, the number of notes per take increases to 1,428. The details of the valid data assessed in this research are given in the following table:

	Notes per take	*Number of takes*	*Total of notes*
Quartet	357	12	4,284
Choir	1,428	19	27,132
		Grand total	31,416

All of these notes had to be measured individually. The onset and release parts of the notes had to be avoided in the measurements. In fact, any part of the note that presents consonantal articulation should not be measured. It is self-evident that the mentioned portions of a note will most certainly bring forth great variations in the results due to pitch instability at the onset and release of the tone, the presence of transients, inaccuracy at the beginning of the attack because of consonantal articulation, etc. Therefore, only the body of the sound would be measured, as it is made up of a sustained vowel. Each note would present a particular configuration in terms of peculiarities of articulation and recording technicalities that may call for an adjustment of the part of the sound that should be measured. This adjustment will be referred to later, when dealing with the SoundScope instruments.

Laboratory set up

According to the needs of the research, the laboratory is set up with the following technical resources:

- A Tascam DA-30 DAT recorder
- An Apple Macintosh computer
- SoundScope software, together with a sound card installed in the computer and capable of 16-bit stereo data acquisition at 44.1 KHz sampling rate.

Instruments for measuring the singers' signals

SoundScope software was employed for computer acquisition and measurement of the collected data. The software is based on some basic blocks that can be manipulated as needed or desired by the user. Some extracts from the SoundScope User's Manual will clarify its possibilities; they can be examined in appendix 6.

In accordance with the device's processing power and memory limitations, the SoundScope instruments were designed to provide measurements of the motet's notes on a 'one singer–one phrase' basis. In that fashion, a maximum of 28 seconds of stereo signal would be acquired and processed by the program at each instance. Based on these considerations, there were built twenty instruments together with a few appropriate tasks (macros) to perform the signals' measurements. Each instrument was designed to perform the analysis of one of the motet's phrases for each singer.

The instruments for the research, named *Two channel analysis instruments*, were built to provide a practical way to measure and display the acoustic and laryngographic signals. The following SoundScope objects were used as the building blocks for the instruments:

- **Wave plot:** this is a window that displays an acquired wave, which can be an acoustic signal wave or a larynx excitation signal wave (Lx). There were two wave plots, one for each kind of signal.
- **Analysis display:** this is used to display the results of the fundamental frequency (F_0) pitch extraction calculations in the designed instruments. This functions only as a visual aid, not being significant to the results.
- **Markers:** as they are the main reason for the instruments' design, the markers delimitate the *segments* to be analysed. Each pair of markers determines the beginning and end of a segment. It is necessary to take the utmost care not to alter the markers order while building the instruments or afterwards during manipulation, otherwise the segments would be wrongly delimited, furnishing incorrect values as results. In the soprano's first phrase, for instance, there are twenty-three sung notes, thus requiring forty-six markers to delimitate the notes segments for analysis. Each phrase of each singer would have its own markers and segment configuration.
- **Journal:** named *notes*, the journal text holds the results of F_0 calculations. In the soprano example above, there would be twenty-three values in the journal notes, ready to be transferred to the corresponding *worksheet* (an Excel document designed to hold the F_0 results for a whole take).
- **Tasks:** the designed tasks are called *Play* and *Averages*. The *play* task was a great time-saver in acoustically checking all of the markers. It made it possible to listen to all of the segments at once after the markers had been checked in relation to their positioning. The *averages* task is a core sequence for the research, because it co-ordinates all of the F_0 extraction pitch process. It tells SoundScope to process the first segment, then to go on to processing the second segment, and so on, copying all the results to the *notes* journal (see appendix 6.4: SoundScope instrument sample).

Method utilised for measurements

The fundamental frequency pitch extraction method utilises a peak-picking algorithm, considered the most precise for this kind of analysis. There is a description of the F_0 pitch extraction by peak-picking algorithm in appendix 6.3.

Each acquired larynx excitation signal has to be prepared in advance for measurement. Each take of the motet lasted for about two minutes, sometimes a few seconds less, sometimes up to twenty seconds more. There may therefore be some substantial time differences for each of the motet's phrases. After loading the signals, each syllable has to be checked in relation to the positioning of the markers. This is manually done due to the necessity to rely on adjustments that have to take into account any technical or musical problem that might have occurred during that particular recorded take.

An important decision had to be made in relation to the positioning of the markers. There was a possibility of applying just one marker for each note and performing a snapshot analysis of a few milliseconds window centred on the marker, to extract the fundamental frequency. However, it was noted that for vibrato singing this was not a very sound solution, as vibrato rates could vary from one singer to another, causing a potential inaccuracy in the measurements. Consequently, it was considered advisable to measure a portion of the main body of the sound big enough to minimise vibrato-induced errors in the process of pitch extraction. In addition, a technical problem like loss of electrode contact could eventually reduce the note length eligible for measurement. In that case, a manual adjustment of the markers is mandatory. In an extreme situation, the resultant value would have to be excluded from the results.

After completion of each phrase's measurements, the F_0 values are transferred to the *notes* journal, being immediately copied and pasted to an Excel worksheet, as raw data for further processing. Afterwards, spreadsheet instruments manipulate the imported data, in an attempt to make some sense of it.

3.5 - Analysis tools

Analytical issues

Technical problems, errors and mistakes

Spreadsheets are useful tools for all sorts of operations. In the case of this research, several analytical procedures were carried out, which are described in detail in the following paragraphs. Some of the imported data had to be carefully considered in terms of its correctness for being manipulated by the analysis instrument. On occasions, there may have been problems caused by technical failures. Sometimes there was clear evidence that the potential problem was singer-related. This issue is deeply considered in the next chapter, with a description of the symbology used to identify real and potential technical problems in the measurements imported from SoundScope.

Intonational analyses

Intonational analyses were devised to provide comparative models of intonation to the singers' results. They were considered necessary for the analytical process because they provide a valuable reference source in terms of hypothetical intonational behaviour. Without them, only a theoretical equal temperament would be available for comparison. Furthermore, not only the mathematical values but also their pictorial representation would be useful in the analytical process. It is mainly the possibility of performing their acoustic replication that brings the best out of their use. A direct comparison between the sound of some known models and the singers' results would help in clarifying technical questions in a more profound and satisfactory manner – the musician's way – by listening to it.

Reference frequencies

Reference frequencies were intended to provide a common ground for evaluating the notes' deviations from equal temperament. The main expectation regarding the reference frequencies' results was to obtain as clear a picture as possible of intonational procedures and stability of pitch throughout the motet's phrases. Reference frequencies would provide values used as the basis for the calculations of the notes' deviations, values that position the deviation results higher or lower in relation to the intonational models - although it does not affect the results' absolute relationships with each other within the confinements of each phrase.

Analytical instruments

Analytical instruments devised as spreadsheets are used in the research to manipulate the singers' data to reveal any possible intonational strategy. These instruments comprise several worksheets described below, which can be either tables or charts. It must be remembered that a spreadsheet document can hold several worksheets. This research's analytical instruments can hold up to twenty-six worksheets — one lengthy table and twenty-five charts.

The first kind of spreadsheet document utilised was made up of just one *basic worksheet*. Its role was the simplest of all: just holding the values imported from SoundScope. In that sense, it was not a purposefully designed instrument. All of the other instruments that make use of the worksheet's data were built specifically for analytical purposes.

Before dealing with the instruments themselves, it would be useful to look at their *objects*, the specific spreadsheet's components responsible for their functionality.

Analytical instrument objects

◆ **Data**

Acquired data is imported from the basic worksheet and stored in tables. It is organised by singer and by phrase, displayed in rows, and constitutes the source of all manipulations that depend on recorded data. As mentioned earlier, some of the acquired data may present technical or musical problems. The values are labelled in various ways that denote how they would be treated in relation to instrumental manipulation. The labelling is intended for the identification of potentially problematic values, from just a simple warning of possible technical or musical problems to their withdrawal from the calculations. All of the related labelling is referred to in the next chapter.

◆ **Formulae**

Formulae are used throughout the spreadsheet instruments to perform all necessary calculations.

◆ **Averages**

The singers or section averages are always calculated by phrase. The arithmetic mean of the relevant data is performed. Mistakes, large errors and technical problems may determine that some of the values should be taken out of the formula that performs the calculation.

◆ **Deviation results**

The deviation results are expressed in cents. Consequently, equal temperament was used as the deviation reference. The reasons are twofold:

- Equal temperament may be divided into cents, the universally accepted unit for interval measurements. Ellis devised the cent unit of interval's measurement around the concept of equal temperament. Therefore, the unit furnishes round values for each interval of the equal tempered scale.

- The intonational procedure in performance was the subject to be investigated. There was no firm hypothesis about the expected results. In that sense, it would not be advisable to use pure intonation or even Pythagorean intonation as the gauge for the (unknown) results to be compared with. They would not provide an easily readable scale; the results would still be expressed in cents, which are connected with equal temperament. Furthermore, from the intonational analyses of the motet, a compliance with either pure intonation or Pythagorean intonation was not expected *a priori*.

There are two kinds of results for the same values: one that considers the reference frequency values with thirds taken into account, and the other that is based on the reference frequency values without thirds (see 4.3.4). The latter values are expected to be more reliable, because they do not use the notes that may present the greater variation in relation to possible intonational strategies.

◆ **Pythagorean, meantone and equal temperament values**

The values attributed to Pythagorean intonation, as well as to the meantone and equal temperaments are common knowledge. They range from the constant *zero* values of equal temperament (that refers to deviation in cents from each of the twelve tones of its chromatic scale) to the thirty-one pitches per octave for the Pythagorean intonation and meantone temperament. The extended Pythagorean intonation and meantone temperament's pitch repertoire covers from five double-sharp to five double-flattened notes that are more than enough for musical demands on interval notation (as well as for pitch differences to the octave).

◆ **Intonational analyses values**

The procedures utilised in the implementation of the intonational analyses based on extended pure intonation were described in chapter two, and were based on Blackwood's book 'The Structure of Recognizable Diatonic Tunings' (1987).

◆ **Singers and section deviation values**

The values attributed to the singers and choir sections always refer to the averages of all takes. Individual measurements would not be used for this kind of procedure. It would be possible to calculate the deviations for each singer regarding each take, but this would be rather meaningless with relation to the building of a picture of the intonational strategies that rely on general tendencies rather than on specific results. As happens with intonational analysis values, each phrase of the motet would have to have the values corrected according to a reference frequency value average, since it fluctuates slightly from take to take.

There are two rows of singers or sections deviation values: the first uses the reference frequency averages with thirds in the formulae, while the second takes the thirds out of the calculations.

- **Reference frequencies**

A list with all of the notes used to determine the reference frequencies is referred to in 2.5.2. They are notes of a chord that belongs to one or more of the main harmonic functions of the phrase that present no special problems either in singing technique or musically related difficulties.

The motet was divided into its constituent phrases for the sake of analysis and manipulation. The most important notes were chosen in each phrase to produce a reliable value to be used as the reference frequency for the phrase. The process of choice was already discussed in 2.5.2. After the notes have been selected, each one of their results would be calculated to match the value that corresponds to the note to be used as reference frequency for the phrase, and their average would be determined then. For instance, in the first phrase, the soprano note is an A_4, the alto note is $F\#_4$, the tenor note is A_3, and the bass note is the chosen reference frequency note D_3. Knowing the ratios of the intervals, it is a straightforward procedure to transform ('transpose') A_4, $F\#_4$ and A_3 results into a D_3 value. The actual reference frequency would be calculated by the average of all of the notes frequencies, expressed as D_3 frequency values.

This procedure is carried out according to the harmonic series principle. There is a twofold reason for this: firstly, the resolution of intervals at the hearing level is done according to psychoacoustical principles that agree with the *harmonic series principle*; secondly, there is only one system for building tuning models: the Pythagorean system and the pure intonation system are, in fact, variations of the procedure based on the harmonic series principle, that can be also expressed by mathematical means (harmonic proportion). Therefore, there is only one tuning system, all of the other tuning procedures being temperaments. No temperaments are eligible for the task of reducing the aforementioned notes to the reference frequency value, because they are not related to any natural process that could be relevant to this subject matter.

Finally, each table displays two kinds of reference frequency results: one that holds the values including the thirds of the chosen chords, while the other takes the thirds out of the process. Again, this happens due to the need for great caution, as the results could not be reasonably anticipated beforehand. Quite a few different intonational strategies might emerge from the experiments, and the thirds rank high as a kind of interval most capable of presenting large variations. As some studies have suggested that deviations towards Pythagorean thirds as well as pure ones are bound to be found in experimental working, a version of the formulae without thirds was devised, for the sake of completeness and clarity.

There is also an important methodological issue to be considered at this point: the assumption that the reference frequency should remain the same for the duration of the phrase. It is possible, even expected that some pitch variation would occur in relation to the reference frequency throughout the phrase in performance. When singers perform a musical phrase that changes its reference frequency pitch, this may happen suddenly or gradually, according to the intonational strategy followed by the performers. It may be that even if no change in reference frequency had been detected, some fluctuation may have occurred. This poses no problem for depicting the results with accuracy. The reference frequency value only affects the vertical positioning, so to speak, of the singer's values taken as a whole.

Charts

Charts, being graphic representations of a table's data, can illustrate it in different ways. In this study's case, results are depicted through various series of dots representing the values, laid out in a grid with lines linking the values that belong to the same series. It is important to note that the lines do *not* intend to convey the idea of a mathematical function. Their only purpose is to make sure that one stream of values is not confused with another, thus facilitating the following of a stream of related values. This procedure is implemented in the following way:

- Singers, sections averages and general overview – each singer or section deviation's results are represented within a range from –70 to +70 cents, which is wide enough to clearly show every possible deviation occurring during the whole experimental work. By making all of the charts show the results within the same variation range facilitates the overall visualisation of the results.

- Reference frequencies – in this kind of chart, the lines link values that belong to the same phrase but not to the same take, as it happens in the charts above mentioned. Here, reference frequencies are the analytical target, therefore being defined by phrases. The range is delimited according to the chosen note. The D_3 reference frequency charts range from 142 to 150 Hz, whereas the A_2 charts display range from 107 to 112 Hz.

Instruments that are not specific to quartet or choir

Extended intonation tables

These tables constitute the basis for the implementation of intonational analyses. They are expressed in two ways: cents or frequency values. Each of them constitutes one worksheet. The formulae are centred on three possible values, which are intended for extended Pythagorean intonation, extended pure intonation and extended meantone temperament. These three values are processed independently from each other. Pythagorean and the meantone values functions are easily understood, whereas the extended pure intonation values require some elucidation in order to clarify their purpose.

In order to implement pure intonation, the notes must be adjusted to the required interval size. Considering diatonic melodies, the thirds and the second degree of the major scale are the first intervals to be changed by a syntonic comma. In chromatic music, many of the intervals might be accommodated to pure intonation. However, the syntonic comma is not the only amount by which intervals may be modified. There are a number of commas and variations of all of the octave intervals that can be adjusted; for instance, the septimal comma plays an important role in the dominant harmony, if it is to be justly tuned. The repertoire of pitches needed for the implementation of pure intonation, at least in classical harmony, is given in these tables, for a total of 279 steps (pitches) per octave. They are further considered in the second chapter (2.4.6). Appendix 8.1 shows the pertinent extended intonation table.

Analyses and performance average replication tables

Analyses and performance average replication tables are the tools used for calculating the values utilised in sound manipulation to replicate the pure intonation analyses and the singers' performance averages. The five phrases of the motet have two reference frequencies based on the notes D_3 and A_2. The intonational analyses values were based on the intonational analyses I and II scores, which were elaborated from the extended intonation tables. They were implemented in a straightforward manner, with only the necessary adjustments in cents being made to the values according to their pitch-flattening deviation from equal temperament. All of the values were calculated based in an equal tempered rendering of the motet. In the analytical scores, the symbols are expressed taking into account all analysis variations, together with the reference frequency differences between the phrases. The tables' formulae would hold the *analytical values*, which pertain to the original analysis symbology, and the *adjustment values*, which refer to the necessary corrections that are to be made in each phase. They would perform adjustments to the analytical values due to differences between the phrases' reference frequencies. For instance, in phrase two, the reference frequency is A_2, and all of the analytical values must then be raised by 1.95544 cents, the difference between equal temperament and pure intonation for the perfect fifth.

The third phrase holds two analytical variations, one of them devising a lowering of one syntonic comma during the first half of the phrase. This important feature of the analytical process causes the two remaining reference frequencies of the motet to be lowered also by a syntonic comma. The two Ds of the fourth and fifth phrase would differ from the one that belongs to the first phrase, then, by that amount. All of the corresponding values would have to be adjusted accordingly. Not only the chart displays would be affected by this procedure, but also the synthesised replicas of the analyses.

All of these values were calculated in the 'Analyses and Replications' instrument, under the worksheets named 'Analysis I' and 'Analysis II' (see appendices 8.2 and 8.3: extended pure intonation analyses I and II).

The following tables were built on the extended pure intonation principles presented in Blackwood's book: the intonational analyses and the keyboard layout tables.

- **Intonational analyses tables** – Two analyses based on extended pure intonation were used as reference for sound editing performed in Cubase/Time Bandit software. The Yamaha SY 99 synthesiser performed the original equal tempered signal. These replications of the intonational analyses were carried out within a one-cent precision range.
- The replication tables – average deviations of the Royal Academy of Music vocal quartet and average deviations of The BBC Singers are shown in appendices 9.1 to 9.6.
- **Keyboard layout table** – This was built upon the possibility of implementing the analytical replications by means of a Yamaha SY99 synthesiser, which holds a precision of 1.171875 cents per tuning step (each octave is divided into 1,024 steps instead of the 1,200 required for one cent precision tuning steps). It is made up of an array of eighty-seven pitches, laid out from B_{-1} to $C\#_7$ (the subscripts in the table follows the Yamaha convention, with middle C being numbered C_3). The keyboard layout for the implementation of intonational analyses on a Yamaha SY-99 is shown in appendix 8.6.

The keyboard layout table displays several columns that are:

- The notes column, most of them showing more than a single pitch, each of them related to a different analytical value;
- Sub-indexes column, that define all of the symbols pertinent to any specific note;
- Reference frequencies column, that refers to the reference frequency of the notes;
- Cents from equal temperament;
- Yamaha SY 99 steps related to their difference from equal temperament.

- Keyboard key – this column indicates which key is to be played on the instrument to replicate the analysis.

As a result of this keyboard layout, two special scores had to be prepared to replicate the intonational analyses with a Yamaha SY 99 synthesiser.

The performance averages replication values tables were built on the same general principles applied to the analyses tables, with a few amendments. The formulae would have the *measurements values* together with the *adjustment values*. The first ones are defined either by the individual singers averages, as is done in all of the singers tables except "The BBC Singers average deviations", or by the whole sections, as is the case of the mentioned table. The "Reference frequency general averages" tables as described in the next paragraphs give the adjustment values. They are defined by phrase, according to the variations in their reference frequencies.

Reference frequency values without thirds were used for all of the calculations in these tables, because they are expected to be more reliable and accurate than reference frequency values with thirds. This was just a precaution measure taken due to possible variations of the results from the thirds of the chords, since Pythagorean and pure thirds differ from each other by a syntonic comma, while perfect fifths and fourths would do so by only near 2 cents.

Reference frequencies averages and reference frequencies general averages instruments

The *reference frequencies averages* spreadsheet provides an overview of the reference frequencies for each of the groups. The table holds all of the reference frequencies for all the takes, calculated with and without thirds. Furthermore, it also supplies the general average for the group. The charts follow the general design model used by the analytical instruments in this research. The dots are placed by take and linked to the other ones that belong to the same phrase, for the sake of clarity.

The *reference frequencies general averages* spreadsheet provides an overview of the reference frequencies for the Royal Academy quartet and The BBC Singers, by phrase, with and without thirds, presenting also the general averages for the two groups as a whole.

In addition, the table presents the final variation in cents for each group regarding the reference frequencies pertaining to each phrase. Variations were calculated with formulae containing thirds as well as taking them out. Results without thirds correspond to the adjustment values used in the replication tables. Reference frequency differences were calculated according to analytical needs, as follows:

- Differences between the first and second phrases, to determine how much the second reference frequency differs from the first one (D_3 to A_2);
- Differences between the second and third phrases, to verify the A_2 reference frequency variation;
- Differences between the first and fourth phrases, to check the stability of the D_3 reference frequency;
- Differences between the fourth and fifth phrases, to determine a possible variation in the reference frequency (D_3) of both phrases.

All of the variations are depicted in the charts, which constitute a helpful means for an easy understanding of the reasoning that upholds some of the decisions taken in relation to the analysis results. It was through the results of both kind of reference frequency spreadsheets that the use of reference frequencies calculated without thirds was considered to be a better option for analytical purposes than the results achieved by calculations with thirds.

Quartet analytical instruments

Quartet tables concerning the takes and overview comprise two main regions: the *reference frequency region* and the *phrases region.*

The reference frequency region calculates the reference frequencies for each phrase with and without thirds. The notes for determining the reference frequencies were defined in the theoretical chapter (2.5 onwards). The phrases' regions are divided into five sub-regions, one for each phrase. Their contents are described under the specific headings.

Quartet takes

The reference frequency region of these tables makes use of the formulae devised for reference frequency calculations. The results would be exported to the reference frequency overview table in order to determine their average, which is to be used in the quartet overview instrument. The formulae to determine the reference frequencies are built around the chosen values for the task; they have been commented upon earlier.

The phrases' regions are divided into five sub-regions related to the phrases of the motet. Each phrase's sub-region is designed with simplicity: it contains one row with the notes numbers, and a few rows for indicating the voices and holding their data values. The whole spreadsheet is constituted by just one worksheet.

Quartet reference frequencies overview

The table gathers all of the reference frequency values of individual takes into one single document, making it possible to calculate their averages. They present results with and without thirds, following the general procedure adopted in this research regarding reference frequencies.

The resultant charts bring forth a clear image of the reference frequency differences. They are very important as an aid to understanding intonational strategies. Furthermore, their averages will be exported to the quartet overview spreadsheet to be used as the reference frequency values for the group as a whole.

Quartet Overview

The reference frequencies region holds values imported from the *quartet reference frequency overview* instrument.

The following rows make up the contents of each of the phrases' regions:

- **Notes** – a row with the numbers of notes pertaining to the phrase is displayed.
- **Measurements** values – the raw data imported from SoundScope via the basic worksheet. These are the source of all of the experimental procedures, except for the theoretical calculations.
- **Averages** values – these are determined by all of the measured data related to any particular note of each singer. The averages are calculated from the values of all of the takes related to the note indicated in the higher row of the phrase sub-regions.
- **Deviation** in cents – here the formula performs a transposition of the sung note value to the reference frequency of the phrase, expressing the results in cents. Therefore, the resulting chart shows the general pitch deviation contour of the singer, perhaps indicating his or her intonational strategy related to the notes, chords or intervals of the piece.
- **Pure intonation analyses I and II** values – these constitute a direct transposition of the values defined by the extended pure intonation analyses. The reference frequency differences are not included in the formulae, because they are only relevant to the relationship between the phrases. When considering the big picture – the whole motet – the differences in reference frequencies are significant as they show the changes of pitch level from one phrase to another.
- **Pythagorean intonation** values – established according to the common knowledge procedure to an extent of thirty-one pitch steps per octave.

- **Meantone temperament** values – the same kind of procedure as with the Pythagorean intonation repertoire of pitches.

The quartet overview charts were devised for easy appraisal and understanding of results, as the reader could easily be overwhelmed by the sheer quantity of values held in a great number of documents. The charts were designed for two different purposes: for presentation and for printing. The presentation charts were created individually, for a total of twenty, one for each singer in each phrase. The printing charts were collected in one worksheet by phrase, which made it possible to place the symbology description alongside the bass chart, while distributing the space as evenly as possible for all charts. This solution facilitates the view of each phrase's results.

Choir analytical instruments

While the quartet analytical instruments provide all of the necessary procedures related to a group that comprises one singer per voice, the choir analytical instruments have to provide for four times as much, which necessitates the modification and extension of some of the instrumental resources. The main need sprang from the fact that a choir brings plurality within the confines of each of the motets' voices, which calls not only for a procedure to compare the singers that perform the same melodic line, but also for a way to extend this evaluation to the whole group. To deal with this, one more kind of analytical instrument was created to assess the choir sections' performances. Thus, the manipulation of the choir data goes through several steps (utilising instruments in doing so) to evaluate the singers' intonational strategies. The analytical instruments for the choir comprise *choir takes*, *sections*, *reference frequencies* and *overview*.

The *overview* instruments consider voice values as averages of all of the section results, treating the four singers of each section as a unity. The *sections* instruments treat each singer individually, providing the opportunity to assess individual intonational strategies as well as differences between the singers that belong to each section. These procedures may clarify the question of beat detection at the fundamental frequency level as opposed to beat detection at the level of the harmonics or partials, as shown in the synthesised replications of the choir performance. It may also shed light on vibrato singing and pitch matching.

The choir analytical instruments are divided, as are the equivalent quartet instruments, in two regions: the *reference frequency region* and the *phrases region*. Both handle the same kind of objects, but they work in a slight different way, according to the document.

Choir takes

As happens with the quartet takes documents, the reference frequency region provides the reference frequency calculations, with and without thirds, which are destined to be exported to the reference frequency overview document for the averages calculations. The results will be transferred to the choir overview document.

The phrase regions are divided into five sub-regions, one for each phrase. The phrases sub-regions comprehend several rows, as follows:

- **Notes** – a row with the numbers of notes pertaining to the phrase displayed.
- **Measurement** values – imported from SoundScope via the basic worksheet. These display the values for each of the singers that belong to the same section of the choir. Individual values may be labelled if presenting any technically or musically related problem. They would also be labelled when showing any potential problem, in spite of furnishing good reading values, in which case, the values could hold validity. Labelling would indicate that that was the case.
- **Average** values – these calculate the singers' average values for a particular take and phrase.
- **Deviation** in cents – the formula transforms the sung note's average value into a value that corresponds to the reference frequency of the phrase, showing the result in cents, as described earlier (see 'analytical instruments objects'). In that case, the resulting chart would depict the general pitch deviation contour of that particular choir section.
- **Pure intonation analyses I and II** values,
- **Pythagorean intonation** values, and
- **Meantone temperament** values – as commented upon above.

The fundamental difference between the *quartet overview* charts and the *choir takes* charts is that in the first each singer's results are displayed, while in the latter results pertaining to each section of the choir are displayed.

Choir reference frequencies

Devised in exactly the same way as the quartet reference frequencies instrument, the choir reference frequencies instrument constitutes an important aid to check reference frequency fluctuations, their coherence and consistency, and whether it is advisable to use the reference frequencies with or without thirds as the main reference regarding intonational strategies. They are also used as source values for the choir sections analytical instruments.

Choir sections

Choir sections analytical instruments were designed to portray the results of each section of the choir pertaining to each phrase of the motet. In order to disclose a complete picture of the motet four full documents would be necessary. Each of the documents would deal with one of the sections of the choir, summing up all of the values from all of the takes, their averages, plus the pertaining calculations in terms of deviations and the intonational analyses for comparison.

The reference frequencies region exhibits the reference frequency values of the choir reference frequencies instrument. It would be possible to calculate all of the reference frequencies from scratch, but that would mean preparing all of the formulae again, not only for the choir sections instruments but also for the choir overview instrument, with no real need for doing so.

Objects similar to the *choir takes* instruments comprise each phrase sub-region, with the following remarks:

- **Measurement values** – are imported from the *choir takes* instruments. They display all the results of a particular singer. For instance, the first phrase would display the values for soprano I. After the averages and all relevant calculations, it displays the values for soprano II, and so on. As a result, the sub-region Phrase 1 displays all of the sopranos' results individually. The same procedure is extended to the altos, tenors and basses.
- **Averages values** – calculate the averages of the values of each singer, considering all takes. This procedure allows us to assess each singer's intonational strategy, which can then be compared with the section's strategy as a whole, as presented in the *choir overview* instrument.

These instruments' charts portray the intonational strategy followed by each of the singers of the choir.

Choir Overview

The choir overview analytical instruments were devised in the same way as the choir takes analytical instruments, with the sole difference that they deal with the singers' averages instead of individual results. Furthermore, there are no markings in relation to possible problems regarding the results. In one sense, it is the most revealing of the choir instruments, the one that brings out the general strategic procedures of the group as a whole.

4 - RESULTS AND ANALYSES

4.1 - Introduction

The results and analyses are preceded by a discussion on data measurement procedures. The discussion includes guidelines for the determination of errors and mistakes, related either to technical devices or to performers, with the associated symbology.

The results are presented in chronological order according to the recording sessions. The two groups that hold valid results are differently structured. There is a quartet of singers from the Royal Academy of Music and sixteen of The BBC Singers performing as a choir. The musical unit throughout for analytical purpose is the phrase. Groupings of singers are defined as subject's units for analytical purposes, as follows: the quartet results are presented by phrase (by singer within each phrase); the choir results are presented also by phrase, firstly by choir sections within the phrase and secondly by (individual) singers within the sections.

Reference frequency results are given and commented upon, including a procedure that equalises all of them in order to appreciate possible variations in relation to the intonational strategies revealed in the whole motet. A general evaluation on the subject of reference frequencies concludes the chapter.

4.2 - Data measurement procedures

Pitch perception of a voiced sound is a complex phenomenon. In this work, the main concern is to determine what the fundamental frequencies of sung notes are in order to attempt the delineation of adopted intonational strategies in performance. The immediate question to be resolved relates to the part of the sound to be chosen for measurement. The onset of notes usually brings out inharmonic partials, as most of the time music notes are articulated together with text. They may present initial portamento or one of the many peculiarities related to text articulation. The singing voice is much more complex than any other musical instrument in this respect.

The release portion of a voiced sound may also present pitch-related problems. Consonantal articulation, if present, is bound to present inharmonicities, articulation difficulties, etc. Even when there is no consonantal articulation the last portion of the sound must be avoided due to possible pitch instability while ending vowel articulation. Therefore, the main part of the sound is the safest portion to be taken for fundamental pitch tracking. It guarantees the necessary degree of confidence regarding the measurements, thus allowing us to delineate a picture of intonational strategies in performance. The sustained part of the sound is a vowel, which can be as steady in terms of articulation as the singer is able to make it.

The next step is to consider how to solve technical problems that may occur during data measurement.

Guidelines for determining errors and mistakes

All of the analysed notes are expected to show some deviation in relation to the average of the measurements. Chiefly, the amount of deviation will determine if the measurement denotes an error or a mistakenly pitched note. It is possible, however, that other factors might influence the results. Some of these may be related to the singing technique utilised by the singer, others may pertain to the musical domain, while the remaining ones may be linked to the technology employed in the experiments.

Vibrato

Vibrato is a regular periodic variation of pitch over time. When analysing a vibrato note, the instrument that is performing the measurements will calculate the average of the values within a selected range of the note. This range is always comprised within the main body of the sound, as stated earlier. Experiments have established that it is the logarithmic average of the frequencies that determines the perceived pitch. Vibrato must be regularly varied in pitch at a rate from 5 to 7.5 Hz. to be considered within normal limits. A slower rate is perceived as a wavering pitched sound, whereas a higher rate vibrato is still perceived as one pitched sound, but generally is considered as being a result of a poor vocal technique. As vibrato impairs beat perception, it may disguise inaccuracies of intonation when strict pitch control is desirable. If this happens, interval definition is affected.

Musical difficulties related to pitch

Notes that belong to a meaningful musical unit, such as a phrase, may present various degrees of reliability regarding intonation. The most important notes can be regarded as *target notes*; when they are free from singing technical problems, they should constitute the most reliable events for assessing intonational procedures. Notes that rank lower in the harmonic, melodic or structural hierarchy of the music would be less reliable for taking as reference in pitch-related strategies. Passing notes, especially short ones, are even less reliable, since they are not as sharply focused by the performer as target notes, neither have they the same harmonic and/or melodic importance. The more accomplished the singer is, the more coherent and consistent will be the results taken from less important notes in the musical hierarchic structure.

Duration of the notes

Even target notes can present reliability problems. For instance, in the second phrase of the *Ave Verum Corpus* motet, in bar twelve, the third note of the soprano cannot be considered as reliable as the third notes of the other voices. The reason for this is that the singer has to breathe to get on with the phrase, preparing herself for the long higher note that follows. In addition, the text syllable 'TUM' has a final [m] which shortens significantly the vowel [u]. The consonant [m] belongs to the decaying part of the note, and as such it is not eligible for measurement, and has to be cut short to allow the singer to breathe. The result is that the soprano's third note of bar twelve may present a greater deviation than the other singers' notes, which have enough time to sustain the sound until its very end. They still have a rest afterwards, allowing them to be prepared for what is coming ahead. Short melismatic passages in music pieces would not be considered truthful in terms of intonational strategy because of the variable deviation values they are prone to present, according to Sundberg (1982).

Singing technical problems during recording

It could happen at some point that a singer might not sustain a note steadily. In this case, the options would be either to choose a portion of the main body of the sound that is audibly acceptable, or to reject the entire note for the purpose of measurement if judged as mistakenly sung. In the experiments carried out in this research this was very uncommon, and caused no trouble regarding the credibility of the results. There were a few mistakes, probably due to a lack of concentration caused perhaps by the repetition of recording takes. These occurrences did not affect the experiment as a whole. A look at the tables and charts makes it clear that the overall results were not influenced substantially.

Singing technique helps the singer to achieve the goal that he or she has in mind, for instance, the articulation of notes with a good intonation. However, there is not a clear-cut conception on what constitutes 'correct' singing technique. What seems to be correct in technical terms for many professionals of operatic singing, for instance, may denote a strong cultural influence based on a tradition of solo singing and strict conditions of sound production. When a student wants to learn vocal technique, he or she is usually encouraged to study a vocal technique geared to operatic singing. This means that a specific singing style is taken as a gauge for the study of vocal technique. These technical principles may not need to be applied for *a cappella* choral singing. In addition, operatic singing fosters a constant vibrato production that goes handin hand with loud voice production, two factors that do not facilitate pitch control. The results can be heard in many available operatic recordings.

Perhaps one of the problems occidental musicians have nowadays is that it seems that everything in occidental music has evolved from simple to complex, from less sophisticated to more sophisticated. In that train of thought, operatic singing would appear to be the apex of what has been accomplished throughout (occidental) music history in terms of singing technique. When the 'early music movement' took over the task of re-establishing a sounder manner of performing early music, the last affected area was singing. Vocal solutions were of two kinds: either everything was changed, or nothing. What resulted was a complete split in thinking of voice tone production for so-called 'serious singing': one advocating the ancient style, whatever that might be, and the other upholding the operatic (or 'lyric') style, with virtually nothing standing in-between.

Electret contact problems

As the electrodes of the laryngograph were designed with spoken voice in mind, they are not always able to cope with the large larynx movements that are prone to happen during singing performance. Some of the singers have difficulty in keeping good contact with the electrodes, mainly due to a layer of fat in the neck. Treble voices tend to show a higher larynx position in the upper range of the notes. These technical limitations of electrodes might be overcome by a more appropriate design, bearing in mind that it would demand perhaps a newly designed device – more flexible and better adapted to singing assessment. By any means, poor electrode contact was the main limitation that was observed. In a few cases, the signal was completely lost, while in the vast majority of them the signal was only weakened without losing its measurability. It must be said that SoundScope software is quite forgiving in this respect, being able to process faint signals with precision. Nonetheless, all of these weakened signals were marked with a symbol in the tables, just in case further consideration would be required in relation to their validity.

Laryngographs interference

Three different models of laryngographs were used in the experiment with The BBC Singers: the standard laryngograph, the portable laryngograph and the field laryngograph. They were distributed among the singers, from the soprano section all the way to the bass section. The laryngographs were distributed at an even distance from the singers, attempting to avoid any unnecessary proximity to them. It turned out that the laryngographs utilised by the soprano and alto sections produced some kind of interference, detected and recorded most of the time as a very high frequency noise. It may be that one of the models used (the standard model) was more likely to cause this kind of artifact. As the experiment with The BBC Singers was the first of its kind to gather sixteen laryngographs simultaneously for a recording session, this kind of behaviour was not known nor expected beforehand. As much as can be inferred from the laboratory work, this problem was solved by the use of low pass filters during the measurements. It must be remembered that only fundamental frequencies were examined in the analytical work.

It will be seen that in spite of all of the above-mentioned limitations, the results of the experiments were coherent and consistent with the hypothesis presented in this work. In the next paragraphs, it will be described how the results were treated in relation to problems brought about by measurements.

Symbology regarding errors and mistakes

The BBC Singers *takes* and *sections* instruments hold the results imported from the *data worksheet.* The first instance for the manipulation of these values is the *take* instrument. It was observed that some of the values did not correspond to what was expected of the measurements. From that first appraisal, all of the recordings were listened to in order to make a list of all problems that could have occurred during the recording session. The possible causes could be either technical failure of the devices or singer-related mistakes. The results of this survey were colour-labelled according to the following table:

Coloured text symbology	
Black	Good value for measurement (either **bold** or plain text)
Bold red	Possible technical problem of the device
Bold underlined red	Possible technical problem of the device, emphasised
~~**Any strikethrough**~~	Invalid measurement
Bold green	Researcher's judgement regarding substantial error or mistake
Outlined red	Missing or very weak signal (device's technical problem)
Coloured cells symbology	
Blue outlined cells	Value not included in the calculations, due to a technical problem or singer's mistake
Green outlined cells	Invalid measurement, according to the researcher's personal evaluation
Yellow outlined cells	The values are still used for calculations, in spite of any doubts the researcher may have about their validity

It can be seen, from the table contents, that red coloured values would be measured, except the strikethrough ones and any value with blue or green coloured cells. This stems from the fact that, in spite of possible technical problems detected in some notes while hearing the recordings, when compared with values from other takes they turned out to be perfectly acceptable results. SoundScope software is very effective in the processing of imperfect sounds; even weak sounds or sounds with a slight interference would often still furnish coherent results.

4.3 - Results and Analysis of measured data

The results will be presented and commented upon with an open-minded approach, since a vast range of possibilities is open for interpretation. Frequently, as happens with musical content itself, a double-meaning strategy may be adopted which could be interpreted as a refinement of temperament-based procedures.

The deviations are evaluated according to their contour and/or proximity to any of the models. When models' values are nearly identical, it may be difficult to confirm any particular intonational strategy. A difference of about 7 cents is the minimum that can be perceived, which amounts to approximately one third of a syntonic comma. This micro-interval is coincidentally the same used for implementing many of the meantone-based temperaments. This issue is further commented upon in 5.3.

Analyses of the results are done according to the natural groupings of notes, in each phrase. The analytical levels are defined (from larger to smaller units) firstly by phrase, then by section and finally by singer. In the quartet's case, the values of the singers are equivalent to sections' results. Of course, there is a practical difference – the quartet's results tend to present greater deviation values. This happens because each choir section results are determined by four singers, which takes into account four times as much data for the calculation of equivalent values, thus 'smoothing' the final result.

4.3.1 - City University quartets

First quartet

- Soprano: Claire Rowden
- Alto: Charlotte Shorthouse
- Tenor: Brian Inglis
- Bass: Edward Bhesania

- Date and venue: the experiment was carried out on June the 19th, 1995, in the Isolation Room of the Music Department.
- Duration: about one and a half hours.
- Number of takes: seventeen takes in total, four of them being whole takes of the motet.

By the time of the first recording session, the four laryngographs and the acoustic microphones were lined up side by side as the only available option due to the size and shape of the room. The researcher, doubling as conductor, was positioned in front of the singers. There was no help from a technical assistant, the conducting and equipment manipulation being carried out by the researcher. The setup for the recording session was based on the *quartet studio setup* adapted as for a portable studio.

Unfortunately one of the laryngographs failed to function properly right at the beginning of the session. All of the recorded signals, in spite of being technically adequate for measurements, were considered unfit for research purposes. As one of the signals was missing in all of the takes, it would be unacceptable to consider these values as satisfactory as the ones from the technically approved recording sessions. Nevertheless, the session was very useful to test the methodological scheme devised for the experiments.

Second quartet

- Soprano: Fiona Tanner
- Alto: Charlotte Shorthouse
- Tenor: Paul West
- Bass: Colin Salway

- Date and venue: February the10th, 1996, in the Performance area of the Music Department.
- Duration: about one and a half hours.
- Number of takes: eleven, of which eight were whole takes of the motet.

This was the first experiment with all devices performing as expected. There was technical assistance, which made it possible for the researcher to concentrate on directing the experiment and conducting the singers. Yet, the recording session has not met all of the required criteria for integrating the body of data that was to be further analysed. Technical problems, alongside a lack of continuity in some of the takes did not allow them to be considered appropriate for evaluation. Nevertheless, this recording session made it possible to probe all of the procedures utilised from then on. The Performance Area was fine-tuned technically for this kind of experimental work, alongside the Recording Studio facilities, paving the road for the remaining sessions.

4.3.2 - Royal Academy quartet

- Soprano: Alison Chryssides

- Alto: Diana Moore
- Tenor: Stefan Berghammer
- Bass: Benjamin Davies (baritone)

- Date and venue: April the 24th, 1997.
- Duration: about one and a half hours.
- Number of takes: twelve complete takes.

This was the first recording session of the research that was considered valid regarding all requirements. The subjects were singing students at the Royal Academy of Music. All of them come from musical backgrounds that largely share the relevant musical approach. The *Ave Verum Corpus* motet's numbered score is shown in appendix 7.2. Appendix 10 shows The Royal Academy of Music vocal quartet's tables and charts. Table "RAM voice's table" and charts "RAM Voice's Charts – Phrase 1", as well as "2", "3", "4" and "5" (appendix 10.1), show the results for each phrase/singer in relation to reference frequencies *as determined by the singers*, each phrase being considered as a discrete unit in terms of representation of results. They make it possible to follow the analytical comments, which are structured in two columns: numbered notes and comments on intonational strategies, as follows. The acoustic CD brings the relevant sound examples. Tracks 29-30 present the acoustic and larynx excitation signals taken from the recording session. Tracks 33-37 present the replications of the quartet's average results by phrase. It must be taken into account that the source signal is an organ-like sound with total absence of vibrato; consequently, beats will be easily perceived as a result of pitch deviations from pure intonation.

First phrase

Soprano

Notes	Intonational strategies
1-4	The first four notes proceed according to pure intonation. Note 4 may also be seen as connected with a stressed syllable (*appoggiatura*), which probably caused a rise in pitch.
5	Pythagorean intonation is the most plausible interpretation for this procedure, after considering the continuation of the phrase.
7	This note shows a slight tendency to pure intonation or a tempered procedure.

10-12	Pure intonation is possibly adopted in this passage.
11	This note can be viewed as a stressed syllable that also begins with consonantal articulation.
13	Consonantal plus vocalic articulation; the vowel [u] may cause the pitch to rise. This vowel would provide less pitch-related information than brighter vowels, because of lower harmonics' reinforcement and the weakening or masking of the higher harmonics. Perhaps the combination of the (strong) consonantal articulation with the [u] vowel would cause the pitch-sharpening that would not take place otherwise. [m]
15	Consonantal plus vocalic articulation – again, the [u] vowel may be playing its role in the pitch rising. It is a short note. The [m] articulation at its ending could also favour pitch rising by shortening the vocalic articulation, thus making pitch control more difficult.
16-21	Pythagorean intonation is used in this passage. Consonantal articulation must be noticed in note 16, which may cause a slight pitch raising, as well as pitch-flattening in note 19 due to vowel articulation [a] in an unstressed note.
22	Unstressed vowel exhibiting pitch-flattening, albeit it may also be considered as a meantone temperament procedure, together with the next note (last of the phrase). If this is the case, Pythagorean intonation and meantone temperament would share both F# (thirds of the key) at the end of the phrase. This is the first of many examples of double-meaning intonational strategies that permeate the performance.

Alto

Notes	Intonational strategies
1-11	Chiefly, Pythagorean intonation is adopted in this passage, with additional comments as follows.
1-2	This is probably a procedure based on equal temperament.
9	Stressed syllable with consonantal articulation possibly induces pitch-sharpening on this note.
11	Consonantal and vowel [u] articulation may have caused pitch-sharpening. This procedure is mirrored in the soprano results as well as in the soprano section results of the choir.

12 This pure intonation strategy possibly also happens in the alto section of the choir.

13 Consonantal and vowel [u] articulation probably causes pitch-sharpening on this note. This procedure is mirrored in the soprano results as well as in the correspondent notes of the soprano and alto sections of the choir.

14 Probably this note was thought of in connection with a musically stressed syllable which may have caused its pitch-sharpening.

16 This is probably the same case as in note 14. The vowel [i] may have helped to increase the effect (this would apply only for the quartet's alto, since it works differently for the alto section of the choir).

17 It seems that the unstressed vocalic syllable causes a slight pitch-flattening, since the same occurs with the alto section of the choir. Another possibility is that the [a] vowel may have determined the pitch-flattening, in line with an experiment by Ternström and Sundberg (1986).

18 Probably this note was thought of as a musically stressed syllable which could cause pitch-sharpening. The vowel [i] may have helped to increase the effect (this would apply only for the quartet's alto, since it works differently for the alto section of the choir)

21 Pure intonation strategy is applied here. This procedure is mirrored in the alto section of the choir.

Tenor

Notes	Intonational strategies
1	The first note is slightly raised in relation to any of the models, possibly due to the musically stressed position of the first note.
2 and 4	These two notes are lowered in pitch with respect to the previous ones, probably due to unstressed syllables and perhaps with the help of the [e] vowel. See comments of note 17 of Alto's first phrase.
3-4	Pure intonation strategy is utilised here.
8	Consonantal and vowel [u] articulation, causing pitch rising, defines the strategy applied to this note. This procedure is mirrored in the tenor section of the choir. Already commented upon in note 13 of the soprano's first phrase.

10 Consonantal and vowel [u] articulation, causing pitch-sharpening, defines the strategy applied to this note. This procedure is mirrored in the soprano and alto results

11 Probably this note was considered in connection with a musically stressed syllable which may have caused the pitch-sharpening.

14 Probably the unstressed vocalic articulation caused the pitch-flattening, as happens with the other singers of the quartet.

16 Consonantal and vocalic [i] articulation may have caused the note's pitch-sharpening. Another possibility relates to the way the singer could have intended to stress the note (a music-related issue).

Bass

On the two occasions the leading note was sung, the first one was biased towards pure intonation while the second tended to Pythagorean intonation.

Notes	Intonational strategies
3	Unexpected behaviour, possibly due to the stressed syllable (pitch-flattening in a low register note?) or perhaps as a result of harmony changing.
5	Probably pure intonation is adopted here. Another possible (but less probable) strategy points to Pythagorean intonation. In that case, the pitch-flattening would have the same cause as in note 3, while the next note (6) would be considered as tending to Pythagorean intonation. This possibility is pointed out here because of the alternative interpretation regarding the pair of notes 13-14.
6	Consonantal and vocalic [u] articulations on a musically unstressed note may have caused the pitch-sharpening. This interpretation agrees with the first option of the previous note strategic procedure, which is probably correct.
7	Unexpected behaviour is presented at this point, possibly due to the stressed syllable that may have caused pitch-flattening on a low register note (same case as in note 3).
8	Consonantal and vocalic [u] articulation on an unstressed syllable may have caused pitch-sharpening.
10	Consonantal and vocalic [u] articulation on an unstressed syllable may

have caused pitch-sharpening. It must be noted that the pitch-sharpening may have been increased by the shortening of the vowel [u] together with the articulation of the consonant [m].

13	Stressed note with bright vocalic [i] articulation may have caused pitch-sharpening in relation to pure intonation. A second alternative, related to what was described in note 5, is a tendency towards temperament, with pitch-flattening on note 14 (unstressed vocalic articulation).
14	Unstressed syllable (causing pitch-flattening) is the likely reason for the resultant value.

Second phrase

Soprano

The soprano singer utilised mainly a Pythagorean intonational strategy, with the following remarks:

Notes	Intonational strategies
1-3	This passage shows (unexpected) pitch-flattening on the first note followed by pitch raising on the next two notes, which may have been caused by the perfect fourth's leap upwards. (Is this pitch-stretching example of Sundberg's performance rules?)
5	Consonantal and vocalic [u] articulation may have caused pitch-sharpening. This procedure is mirrored in all of the other singers.
7	This is possibly a temperament-based procedure or perhaps a tendency to pure intonation.
11	A very short note may have caused pitch-flattening. This was due to the consonantal articulation plus the final consonantal [m] articulation, together with air intake in preparation for the next half-phrase's upbeat articulation.
13	Stressed syllable with a perfect fourth's leap upwards may have caused pitch raising. This procedure is also mirrored in the choir's soprano section.
14-20	Pythagorean intonation strategy is adopted here, with a slight deviation in notes 16 and 17.

Alto

Notes	Intonational strategies
3	The Stressed syllable may have caused pitch-flattening. This may have been helped by the consonantal articulation.
4	Consonantal and vowel [u] articulation may have caused pitch raising. This procedure is mirrored in all of the other singers.
5	Pitch-sharpening may have been caused by the musically stressed vocalic [i] articulation. It may also be considered as an unexpected intonational behaviour. It is meaningful, however, since it is also exhibited in the choir section.
6-8	Pure intonation is used here, with a slight deviation in note 8.
10	A tempered intonational strategy is utilised for this note.
11-16	There is here an undetermined strategy that cannot be clearly defined as Pythagorean or pure intonation (or even equal temperament), mainly due to the results of notes 12 and 14.
13-14	The deviations are probably caused by vowels with low partials predominance .
15-16	The deviations are probably caused by vowels with high partials predominance.

Tenor

The tenor adopts mainly a pure intonation strategy.

Notes	Intonational strategies
1-3	Pure intonation is brought forward here, with a slight rise upon the stressing on the third note.
4-5	Temperament is employed in this passage.
7-10	Pure intonation is the strategy utilised in this passage. The value of note 7 agrees with what happens to the alto's note 6, being slightly higher than the next note. This possibly happens due to the kind of articulation of the syllable '-MOL' (does the consonant [m] cause pitch-sharpening in principle?).
11	The strategy for this note is temperament (very much like the alto's note

10).

11-17 Overall, a pure intonation strategy is used here, with perhaps a glimpse of meantone temperament (notes 15 and 16).

Bass

Notes	Intonational strategies
1-5	These notes present a tendency towards meantone temperament, with the following remarks:
4	Unstressed vocalic articulation may have caused pitch-flattening. This also happens with the tenor, although by a very small value.
5	Consonantal and vowel [u] articulations may have caused pitch-sharpening. This procedure is mirrored in all of the other singers.
6-10	Tendency towards meantone temperament/pure intonation is displayed in this passage, with the following remarks:
7	The value of note 7 is higher than expected. It possibly happens due to the kind of articulation of the syllable '-MOL' (as commented upon on tenor's note 7).
8	This note sounds a bit sharper than pure intonation and meantone temperament. Nevertheless, it fully agrees with them, unless a slight deviation towards a temperament strategy would be desired as an alternative interpretation.
11	Temperament is defined as the intonational strategy for this note.
12-17	Chiefly Pythagorean intonation is adopted in this passage, at least as far as the contour of the results would show, with two remarks:
14	Unstressed but consonantal articulation may have caused pitch-flattening on this note.
16	Unstressed articulation together with consonantal [m], bright vowel and consonantal [n] articulations may have caused pitch-sharpening (see comment on tenor's note 7) on this note. This also happens in the quartet's soprano and tenor and in all sections of the choir.

Third phrase

A tendency to have the earlier notes' results raised in relation to the last values of the phrase is explained by the fact that the reference frequency appears to have changed throughout the phrase. As the reference frequency is calculated with just one value for the whole phrase, the results' graphics in the charts are somewhat sharpened at the beginning and flattened at the end.

Soprano

Pythagorean intonation is followed by the soprano singer throughout the phrase, with relevant deviations as described ahead.

Notes	Intonational strategies
1 and 3	Display pitch-sharpening with relation to the models, possibly caused by a musically stressed consonantal articulation.
2 and 4	Pitch-flattening is possibly caused by a musically unstressed vocalic articulation.
6-8	A lowered meantone temperament seems to be the intonational strategy utilised in this passage. Another possible explanation is related to Pythagorean intonation with pitch-flattening on note 7.
8-12	Pythagorean intonation is used here, with an unstressed vocalic articulation causing pitch-flattening on note 11.
13-19	Lowered Pythagorean intonation is brought forth in this passage, with the following remarks:
14	Unstressed consonantal articulation may have caused pitch-flattening.
18	Shortened syllable with consonantal ending may have caused a slight pitch-flattening.
20-23	Pure intonation strategy is adopted in this passage. The values are situated in-between the two intonational analyses based on extended pure intonation, which is equivalent to a temperament-based procedure.

Alto

The alto singer follows chiefly a Pythagorean intonational strategy, with an important incursion into pure intonation.

Notes	Intonational strategies
1-4	Pythagorean intonation is utilised here, with raised notes 1 and 2, perhaps following the strategy adopted by the soprano (musically stressed consonantal articulation). Another (less probable) interpretation would call for the flattening of notes 3 and 4, perhaps anticipating expected

harmonic changes.

5-7 Pure intonation strategy is followed in this passage, which agrees with the first intonational analysis based on extended pure intonation, the one that foresees a syntonic comma lowering of the phrase's reference frequency. The important feature of these notes is the decidedly descending deviation that agrees only with the mentioned pure intonation analysis. It must be noted that the soprano strategy shows a great flattening in this part of the phrase, which is also lowered in the tenor and bass lines.

8-9 Again, Pythagorean intonation is displayed, with an unstressed vocalic articulation in note 8 possibly causing pitch-flattening in relation to the model.

10-14 Pythagorean intonation is used, with note 14 greatly sharpened possibly due to consonantal articulation plus consonantal ending of a very short syllable, since it was marked as a breathing place for the preparation of the last part of the phrase.

15-20 Mixed intentions in relation to the possible models are displayed here: notes 15 and 16 point to pure intonation, while notes 17 to 20 denote a bias to Pythagorean intonation. The movement from note 16 to 17 follows meantone temperament, making it difficult to define a clear strategy. The overall strategy of this passage is not just a matter of temperament, also, since the shape of the Pythagorean intonation and pure intonation models for the notes 18 to 20 is the same. Both could be targets of these final three notes, at least in terms of a prevailing tendency.

Tenor

Pure intonation is generally adopted by the tenor in the third phrase.

Notes	**Intonational strategies**
1-5	Pure intonation prevails in this passage, with the following remarks:
1 and 2	There is a small pitch-sharpening on note 1 and pitch-flattening lowering on note 2 as happened with soprano and alto singers. This occurs probably due to stressed consonantal articulation and unstressed vocalic articulation, respectively.
3 and 4	Together with alto and bass, the pitch-flattening probably anticipates harmonic changes that immediately follow these notes.

6-12 Pure intonation I and temperament are utilised in this passage, with the following remarks:

6-8 Pure intonation is used, with a slightly flattened first note, which is the root of a dominant chord just defined by the tenor's note 5, tempered by definition (see intonational analyses). In that sense, note 6 is quite unpredictable in terms of actual pitch definition.

9-12 Temperament leading to pure intonation is the best explanation for what happened in this passage.

13-17 Temperament leading to pure intonation is the adopted strategy here. From an early attempt to adopt Pythagorean intonation in note 13, the intonational strategy loosely points to meantone temperament, with an unstressed consonantal articulation probably causing pitch-flattening on note 14.

18-22 Pure intonation I is utilised in this passage, with the following remarks:

18 Unstressed, very short syllable, with a consonantal ending articulation, probably may have caused pitch-sharpening.

21-22 Is it a meantone temperament strategy adopted within a pure intonation pitch level? Probably not, due to the small amount of deviation (which would be very difficult to control). Hence, pure intonation is the best option.

Bass

A clear example of pitch-flattening throughout the phrase is given by the bass results. The singer resorts to the Pythagorean model most of the time. The third phrase of the motet is the one that explores modulation the most. This is probably the reason for the change of reference frequency in the piece having its origin in it.

Notes **Intonational strategies**

1-5 Pythagorean biased intonation is employed in this passage, with the following remarks:

2 It seems that the singer approached this note in the opposite way to the other singers. The most probable explanation for this unexpected behaviour has to be based on either a vocal technique or text-related issue.

3 The pitch-flattening of this note agrees with the tenor and alto strategies.

5 As happens with the soprano strategy, the bass raises the pitch here. The tenor also adopts this pitch-sharpening strategy, in spite of a different text articulation. Nonetheless, it appears that there is a similar behaviour amongst them all.

6-10 Pythagorean intonation is used here, with pitch-flattening on the unstressed syllables, as well as pitch-sharpening on the last note. This is probably caused by a consonantal articulation together with [u] vowel plus ending consonantal [m] articulations.

11-17 Pythagorean intonation followed by pitch-flattening is utilised here, as happens with the soprano singer. Apparently, this behaviour agrees with the general flattening of the phrase's reference frequency.

18-20 Pure intonation or meantone temperament strategy is employed in this passage. In the case of pure intonation, the chosen strategy agrees with the second intonational analysis (based on extended pure intonation).

Fourth phrase

Soprano

The soprano singer followed a Pythagorean intonational strategy for almost the entire fourth phrase, with some interesting remarks and at least one meaningful exception.

Notes **Intonational strategies**

2 Slight sharpening of the note happens here, probably caused by consonantal articulation.

4 Unstressed vocalic articulation may have caused pitch-sharpeningon this note.

5 Musically stressed consonantal articulation together with bright vowel [i] may have caused pitch-sharpening on note 5. This phenomenon also occurs in the soprano section of the choir; apparently, this is a phenomenon that happens to different singers, not only to the quartet's soprano.

8 Slight sharpening of the note has taken place, caused probably by an unstressed consonantal articulation plus [u] vowel.

10 Pitch-flattening of the note happens here, probably due to an unstressed syllable articulation.

11	Pitch raising of the note is probably caused by consonantal articulation together with a short [u] vowel and [m] consonantal ending articulations.
12-13	Both notes should have the same pitch, but they do not meet the demand. The possible cause of this may point to the differences between the [i] and [u] vowels. Further research would be required to clarify this issue.
16-18	This seems to be the only pure intonation strategy utilised by the soprano in this phrase .
18-20	Pythagorean intonation strategy, with an exaggeration on note 19, probably related to the vowel [i].

Alto

As happens with the soprano, the alto singer also followed a Pythagorean intonational strategy in the fourth phrase, with the following remarks.

Notes	Intonational strategies
1-3	These are exceptionally sharpened notes that do not have any justification from the point of view of the other singers. However, the results seem to be an attempt to establish a pure major third interval in relation to the soprano intonation. Further research is needed for clarification.
4, 6, 10	These are unstressed vocalic articulations that present pitch-sharpening. A diminuendo dynamic articulation may contribute to the results.
11	Surprisingly, this note does not suffer pitch-sharpening, as happens with the other singers.
12	Very slight pitch-sharpening is noted here, possibly due to the short vocalic articulation with a consonantal [n] ending that will be followed by a consonantal [m] articulation on the next syllable.
14, 18	These two pitches are defined a bit flattened in relation to the model. In note 14, perhaps this is due to the unstressed vocalic articulation, whereas in note 18 it could be the result of a tempered intonational strategy. If this is the case, note 19 would be the one that presents pitch-sharpening by virtue of a combination of consonantal articulation plus vowel [i] followed by an ending consonantal articulation [n].

Tenor

Again, the tenor intonational strategy seems to adhere to pure intonation, with a few remarks.

Notes	Intonational strategies
5	This note has proved to be one of the odd notes of the motet. The most plausible explanation for the pitch-sharpening is related to the note's consonantal and vowel [i] articulations. The tenor shares this phenomenon with the quartet's soprano and bass; also, the same happens with the choir's soprano, tenor and bass. Neither altos follow this strategy without any apparent reason.
6, 8, 10	These notes display pitch-sharpening probably due to an unstressed articulation. In note 6, the effect is not very clear because of the previous anomalous sharpened note.
9	This note presents pitch-flattening probably caused by the highly stressed syllable.
11, 14	Pitch-sharpening probably caused by the short consonantal and vocalic articulation with an ending consonantal [m] articulation. There could be a caesura just after the notes, which would help the shortening effect.
13	Pitch-flattening that may have been caused by the stressed consonantal-vocalic articulation. The vowel of the note is [o] which is located in between two [i] vowels - which may be meaningful to the result.
15-18	Double-meaning results are presented in this passage. It could be that notes 15 and 16 are related to a lowered Pythagorean intonation, while notes 16 to 18 relate to a lowered meantone temperament. It could also be that note 17 is flattened due to an articulation-related issue, in which case all of the notes would adhere to a Pythagorean strategy.

Bass

The singer tends to use Pythagorean intonation throughout the phrase, with a short passage performed according to pure intonation. In fact, both models share most of the notes. The following remaining notes would define the singer's strategy: notes 4, 5, 11-13 and 15.

Notes	Intonational strategies
4-5	These two notes define a Pythagorean strategy.

5 Together with soprano and tenor of the quartet and soprano, tenor and bass of the choir, this is an unexpected result. See comment from tenor's note 5.

7, 9, 11 The singer's strategy is quite different from others, already described above – he seems to define pitch-flattening for the stressed consonantal articulations of these three notes. The only possible explanation at this time would be related to the singer's personal point of view regarding musical issues.

12 The singer seems to have caused pitch-flattening perhaps in the process of preparation for the next sustained syllable. Accordingly, the passage from note 10 to note 14 would agree with Pythagorean intonation.

14-16 This is the above-mentioned passage that agrees with a pure intonation strategy.

16-18 Pythagorean intonation is utilised to end the phrase.

Fifth phrase

Soprano

In the last phrase, the singer tends to stretch out the intervals and display a mixture of behaviours.

Notes	Intonational strategies
1-4	The overall feeling points to pure intonation or meantone temperament (alternatively) in notes 2 to 4. Decidedly, note 4 is over-stretched by about two thirds of a syntonic comma in relation to pure intonation.
5	As if responding to the upward movement of note 4, this one deviates accordingly downward, perhaps indicating meantone temperament. (Would it be just a stretched leap downwards, according to Sundberg's 'performance rules'? The choir section does not subscribe to the ideal)
6-10	This passage is clearly geared towards Pythagorean intonation, with a little deviation in notes 8 to 10, but nothing to worry about in terms of strategy definition.
11	This is a special result, since it is also reproduced, although in a subtler manner, in the soprano section of the choir as well as in all of the corresponding notes of the other voices of the quartet and choir sections. Perhaps the leap upward by a perfect fourth together with the

articulation of the [i] vowel preceded and followed by strong consonantal articulations has caused the big deviation that does not correspond to any of the models. It must be noted that a *caesura* is performed after the note, thus shortening its duration, which may have been an important factor in the determination of the result.

12-16 Apparently, a pure intonation strategy is followed by notes 12 and 13, whereas note 14 does not clarify a tendency towards meantone temperament or a very much lowered Pythagorean intonation. The latter is best defined in pitch than in direction in the last two notes, which alternatively points to a raised meantone temperament strategy.

Alto

This is one of the clearest Pythagorean intonation strategies of the motet.

Notes	Intonational strategies
1-2	These notes are performed with a slight lowering in relation to the model, which is nevertheless the source for the adopted intonational strategy.
5	The note presents a small deviation upward, perfectly understandable due to the articulatory speed and the fact that the note is a bit more stressed than the following one.
7	This note presents a special result already commented upon in the alto's note 11.
7-12	These notes portrayed the same behaviour as the alto section of the choir, which is a meaningful feature of the results. Here, notes 7 to 9 present a small sharpening in relation to the model, while the remaining notes agree with the Pythagorean leading note procedure. Note 11 is a bit sharpened in relation to note 10, probably due to the consonantal articulation [m] together with the [i] vowel followed by consonantal articulation [n] which prepares the next syllable. The last note is sharpened in relation to the model, but still agrees with it much more than with any of the other models. Perhaps the singer tension at the end of the motet, together with the need of sustaining the sound at the end of the air supply, causes this pitch-sharpening. Naturally, further research would be needed to clarify this issue.

Tenor

The quartet's tenor, with the exception of notes 6 and 7, present the same shape in relation to the directionality of the notes. These are meaningful results in relation to strategies that may be shared by different groups. The same applies almost in the same way to the alto and bass results.

Notes	Intonational strategies
1-4	There seems to be a lowered meantone temperament strategy in the first half of the passage, together with a lowered Pythagorean intonation strategy in the second half. This behaviour is roughly the same as takes place with the tenor section of the choir.
4-9	In this second 'third' of the phrase, the intonational strategy takes a plunge into pure intonation and meantone temperament values. It must be noted that note 9 is the one that goes upward in all of the singers of the quartet and sections of the choir. However, it would be normally expected that this note would remain within the confinements of meantone temperament. The fact that it does not so requires further research, most probably on the 'intrinsic pitch of vowels', as well as on the effect on intonation of strong consonantal articulation.
10-14	It must be said that here the intonational strategy is undefined between Pythagorean and pure intonations. The first note of this last passage of the phrase starts with a result that is lower than expected, then it goes until note 12 in the direction of pure intonation, just to get to the heights of Pythagorean intonation again in the last two notes. However, it also must be said that note 13 has consonantal articulation together with vocalic [i] followed by consonantal [n] articulation in preparation for the last syllable of the motet. This could cause pitch-sharpening, causing the overall result to point to pure intonation.

Bass

Pythagorean intonation is mainly utilised in the last phrase of the bass, with a few interesting remarks.

Notes	Intonational strategies
1-6	Beginning with a low first value in relation to the Pythagorean model, it assumes its general shape and approximate level of deviation. Note 4 clearly denotes a procedure based on temperament, while note 6 shares

the comments with the soprano's note 11.

7 This note's value indicates the adoption of meantone temperament/pure intonation.

8-10 The models hold values that are placed very close to each other. However, considering the possibility of pitch-flattening on note 9 due to articulation issues, it could be concluded that meantone temperament is the most likely strategy adopted in this passage.

4.3.3 - The BBC Singers

- Sopranos: Jennifer Adams-Barbaro, Pamela Priestley-Smith, Alison Smart, Margaret Feaviour
- Altos: Judith Harris, Lynette Alcantara, Jackie Fox, Penny Vickers
- Tenors: Eugene Ginty, Andrew Murgatroyd, Neil Mackenzie, Ian Kennedy
- Basses: Stuart Macintyre, Stephen Charlesworth, Brindley Sherrat, Richard Bourne

- Manager: Stephen Ashley-King

- Date and venue: July the 7th, 1997, in the Performance area in the Music Department of City University, London.
- Duration: about three hours. The BBC manager allowed the whole working day for the experiment.
- Number of takes: twenty-one takes were performed. Two of them were not taken into account, because of a technical problem with one singer's electrodes. It turned out that the laryngograph connected to the singer was turned off on these occasions. Nineteen takes were then utilised for measurements and results .

This was the only recording session that would allow the investigation of the relationship between simultaneous performances of the same melodic line. This is a meaningful addition to the analytical possibilities of the experiments: the evaluation of personal variations in pitch within the limits of a choral section. It was very useful investigating the interplay between individual intonational strategies and pitch perception within the limits of a choir section. A quartet performance would bring forth beats at the level of harmonics, mainly. There are only a few occasions in which unison between adjacent voices of a quartet would present the opportunity for beat detection at the level of the fundamental frequencies in the *Ave Verum Corpus* motet. So, in the case of a choral experiment, the presence of beats is expected to be much more evident than with solo ensemble singing, since it is equally manifested at both levels—fundamental frequency and harmonics. All of these phenomena would occur, of course, in the presence of nearly non-vibrato singing during performance. This was not the case with The BBC Singers, which may have been an important cause for the kind of results obtained in the experiment.

An important feature of ensemble performance, which will be stressed again in the next chapter as one of the most important and usually overlooked characteristics of ensemble singing perception, is related to pitch perception within the section of a choir. It is *not* perceived as a narrow band of frequencies (the resultant of the summation of individual pitches), but as a *new single pitch line* determined by the average of all of the singers' results. This fact may be of utmost importance in the delineation of this work's theoretical propositions when considered from a practical perspective. It could happen that the interaction of individual melodic lines would determine each singer's strategy, as if an overall balanced melodic line was looked for by the singers as a group, not as individuals. This would happen, of course, with groups that have experienced a long time singing together, as The BBC Singers have. This issue was described as *pitch equalisation.*

Appendix 11 shows The BBC Singers' tables and charts, which are the basis for the following discussion. "The BBC Singers sections' results" table and its related charts show the results for each phrase/section of the choir in relation to reference frequencies *as determined by the singers*, each phrase being considered as a discrete unit in terms of representation of results (appendix 11.1). As with the Royal Academy of Music vocal quartet analytical comments, appendix 7.2 presents the *Ave Verum Corpus* motet's numbered score, which act as a guide to the comments. As it happened with the former group, the acoustic CD provides the relevant sound examples. Tracks 31-32 present the acoustic and larynx excitation signals taken from the recording session. Tracks 38-42 present the replications of the choir's average results by phrase, each section of the choir providing a single melodic line as the result; this means that the perceived beats are the result of interaction between the choir's sections only, for this replication. Tracks 43-62 present the replications for each of the choir's sections, by phrase. The perceived beats are the result of interaction between the singers of each section. Finally, tracks 63-67 provide the full picture (also by phrase) in terms of beat interaction between all singers of the choir. It must be remembered that the perceived melodic line is exactly the same as in sound examples of tracks 38-42, where beats pertaining to each of the choir's sections were not present. As before, it must be taken into account that the source signal is an organ-like sound with total absence of vibrato; consequently, beats will be easily perceived as a result of pitch deviations from pure intonation.

First phrase

Soprano section

Note	Strategy
1-4	A pure intonation procedure was adopted in this passage with a slight deviation upwards, as happens with the quartet's soprano. It must be said that after the third note, breathing was asked for, regarding the comma in the text.
4-6	Pythagorean intonation, as if to counterbalance the strategy of the former notes.
7-10	Probably a musically stressed note caused the pitch-sharpening in note 7. The whole passage agrees with a raised pure intonation.
11-13	The passage may convey a double-meaning strategy. Firstly and according to what happened with the other sections of the choir and the quartet's singers, it seems that note 12 presented pitch-flattening due to an unstressed vocalic articulation, followed by pitch-sharpening caused by a consonantal plus vocalic [u] articulation on the next (target) note. In this case, the overall strategy would be temperament. Secondly, it could be tempting to consider note 13 as Pythagorean, and in that case only the pitch-flattening on the former note would be considered. This hypothesis is less likely to correspond to the real intonational strategy of the note, due to the values presented by the other singers.
14-19	Note 15 suffers from the 'consonantal plus vocalic articulation' uncertainty syndrome shared by the quartet's soprano and all of the other singers and sections. What follows is an uncommon tendency to either equal temperament or an undefined temperament procedure, until note 19 (or perhaps 20). Note 19 displays a small pitch-flattening by virtue of unstressed vocalic articulation.
20-23	Finally, a typical Pythagorean intonation strategy that bears only a slight deviation in the penultimate note, most probably due to the unstressed syllable.

Soprano singers

Note	Strategy
1-4	Soprano I is the only singer to utilise a flattening approach to this passage, in opposition to the other sopranos. Sopranos II and III follow the most common strategy used in this passage, with pitch-sharpening on notes 2 and 4, which coincides with the melodic leaps upwards. In soprano IV, this only happens in note 4.
4-6	Pythagorean intonation in sopranos I, III and IV. Soprano II adopts a temperament strategy.
7-10	Sopranos II and IV opt for pure intonation in note 8, soprano I tends to Pythagorean intonation, while soprano II makes an option for temperament. Note 10 again shows different strategies, with sopranos I to III going sharp (in the case of soprano III, just slightly up because of note 9 raised result), while soprano IV shows pitch-flattening.
11-13	Sopranos I and II define a flattened note 12 and a decidedly sharpened note 13 (consonantal and vocalic [u] articulation may have caused the pitch-sharpening, together with the shortening of the vowel due to the syllable ending with consonant [s]). Soprano III utilises a very well controlled tempered approach to the passage. Soprano IV, again, proceeds in the same fashion she did in notes 9-10. This strategy brings consistency to the singer's musical approach; probably, her musical thinking indicates a different conception in relation to the others.
14-23	In the second half of the phrase, soprano I adopts definitely a Pythagorean intonation with some pitch-sharpening on notes 15 (with consonantal and vocalic [u] articulation that may cause pitch sharpening, together with the shortening of the vowel due to the syllable ending with consonant [m]), 18 and 20 (stressed vocalic [i] syllables). Soprano II makes an option for pure intonation in notes 15-18 and for Pythagorean intonation from note 18 to the end. Pitch-sharpening is displayed in note 15 (see soprano I comment). Note 22, as also happens with soprano IV, is flattened probably due to the unstressed syllable. This also happens with soprano III, whose last note accompanies the flattening of the deviation. Sopranos III and IV are more contained in terms of deviation results, presenting a general tendency to adopting temperament, as notes 16 and 17 of both singers will show. It is interesting to note that the last two notes denote different strategies for

sopranos I and III in relation to sopranos II and IV.

Alto section

Note	Strategy
1-4	Probably a temperament based procedure, with notes 2 and 4 displaying pitch-flattening due to unstressed syllable articulation.
5-11	Beginning at the same pitch as the previous note, the alto section adopts a Pythagorean intonation strategy in this passage, with pitch-flattening on note 9, in an opposite fashion than what happened to the quartet's alto singer. This kind of disagreement, which happens in some places in spite of many of the agreements that equally happen in many others, points to the *real necessity of a thorough experimental research regarding text articulation and pitch-related issues.* The price to be paid for the lack of research on this and other subjects (as for pitch-related vibrato in musical performance contexts) is the maintenance of subjective and sometimes biased ideas and concepts on what should constitute an intonational strategy or – even worse – a tuning model.
12-21	This second half-phrase encapsulates several double-meaning procedures. The first one comes right at the beginning of the passage, indicating either a slight tendency to pure intonation with note 13 defining a pitch sharpening strategy due to an unstressed consonantal and vocalic [u] articulation together with the shortening of the vowel caused by the consonantal [m] ending articulation. Another possible interpretation of notes 12-13 is linked to equal temperament. The descent of note 17 agrees with the quartet's alto singer ('unstressed vocalic syllable'). Note 20 shows pitch-sharpening. Again, it could be caused by the unstressed articulation with shortening of the vowel of the syllable by the consonantal [n] articulation in preparation for the last note, which points to pure intonation.

Alto Singers

Note	Strategy
1-4	The singers have adopted mixed strategies at the beginning of this phrase. Altos I and IV start with a tuning strategy based perhaps on equal temperament in the first two notes, than changing to Pythagorean intonation and meantone temperament, respectively. Alto III utilises Pythagorean intonation with some variation regarding the deviation

results (this certainly has become a common procedure, as can be seen in the analyses). Alto II follows meantone temperament with pitch-sharpening on the first note.

5-11 Alto I seems to adopt Pythagorean intonation from note 5 to note 8, then changing to meantone temperament from note 9 to 11. The latter presents pitch-sharpening (consonantal plus vocalic articulation shortened by consonantal articulation at the end of the syllable). Alto II follows Pythagorean intonation close enough to indicate that the only big deviation to the model occurs in note 11, with pitch-flattening disagreeing with altos I and IV. Alto III's strategy can be defined as the most eccentric one, as if she was trying to balance altos II and IV, by going all the way with great deviations upwards to counterbalance their downward tendency. This procedure (pitch equalisation – see 5.3.4) is extended to the end of the phrase. The alto section results tend to stay very much in the line of equal temperament.

12-21 Different intonational strategies are employed in the second half of the phrase. Alto I goes from Pythagorean intonation to meantone temperament, with some pitch deviations as stated: a sharpened note 15, a flattened note 17 , and sharpened notes 18 and 20. The last note may be taken as a clue to Pythagorean intonation from note 19 onwards. Alto II begins with pure intonation (notes 12-14, with pitch-sharpening on note 13), continues with Pythagorean intonation (notes 15-18, with pitch-flattening on note 17) returning to pure intonation or meantone temperament at the end (notes 18-21). Alto III follows a general Pythagorean line, with an increased deviation upward at notes 18-20. Finally, alto IV adopts the opposite strategy than alto III, with an almost constant deviation downwards. It can be said that notes 12-13 tend to pure intonation, while notes 16 and 18 show pitch-sharpening (the vowel [i] is present in both stressed notes). Furthermore, notes 14, 15 and 19 are lowered with no clear reasoning to uphold the results. This is another argument reinforcing the need for further research.

Tenor section

It seems that pure intonation is prevalent in the first phrase of the tenor section. A few amendments will help in the understanding of some musical and technical issues.

Note **Strategy**

3-4 Clearly, pure intonation is the defined intonational strategy.

8 This note shares with the correspondent values of all of the other performers the same strategy – pitch-sharpening caused by a consonantal plus vocalic [u] articulation (the text syllable also demands a consonantal [s] ending articulation, which shortens the vowel even more). This fact definitely indicates a general proclivity in relation to this kind of phenomenon.

13-14 The pitch raising strategy revealed by note 13 is shared with the bass but not with the female sections of the choir. This is another one of the kind of results that may depend on the singers' musical conception. Again, further research would help to clarify the issue. Note 14 displays pitch-flattening on an unstressed vocalic syllable. Would this be another confirmation of that kind of strategy?

15-16 The tenor section fully agrees with the bass section of the choir and also partially does so with the female sections. However, results are not much alike to the quartet's results.

Tenor singers

Note	Strategy
3-4	All tenors agree with respect to pure intonation for notes 3 and 4.
Overall comments	Tenors I and III seem to counterbalance each other by displaying pitch-sharpening and pitch-flattening, respectively. Tenor I attacks the musically stressed syllables always higher than the unstressed ones in pitch; this attitude differs from what seems to be the intonational strategies presented by the other tenors regarding text articulation. For instance, tenor II is heavily influenced by the pitch-sharpening on (unstressed) syllables that bear consonantal articulation plus [u] or [i] vocalic articulations (always shortened by further consonantal articulation – the only exception being note 13). However, tenor II presents only slight deviations in relation to the models, being the most regular singer of the section. Tenor III begins extremely low by any standards, brings the pitch up to the level of pure intonation in notes 3 and 4, and then lowers it again until note 8 (pitch-sharpening). Notes 13 and 15 are also sharpened. In spite of the pitch-flattening strategy of tenor III, the performer agrees with tenors II and IV regarding unstressed syllables with consonantal plus shortened vocalic articulation.

Tenor IV distributes the results evenly in relation to the models, except, of course, for the pitch-sharpening in notes 8, 13 and 15.

Bass Section

Generally, the bass section seems to develop an intonational strategy that stresses text-related issues much more than the tenor section does.

Note	Strategy
1-4	As happens with the quartet's bass, notes 3 and 4 are lowered in pitch in relation the first two notes of the phrase. This may be caused by the harmonic change or by the onset of note 3 after the comma-related *caesura*.
5-6	Probably this is a temperament-based procedure with pitch sharpening on note 6 due to consonantal plus vocalic [u] articulation together with consonantal [m] ending articulation that shortens the vowel segment of the syllable. Another possible interpretation could be related to Pythagorean intonation with pitch-flattening on note 5; this is not the best option to adopt considering the individual singers' strategies, since the Pythagorean intonation biased results indicate note 6 with higher deviation values. It must be noted that is no clear indication of a flattening influence over note 5 from either vocalic or consonantal articulation.
7-8	A clear case of intonation influenced by text articulation. Note 7 has a stressed consonantal articulation, while in note 8 there is an unstressed consonantal articulation alongside an [u] vowel.
9-10	Repeats the procedure of notes 7-8. All of the singers except one emphasise the shortening of note 10's syllable by further sharpening the note. This is another example of text-related influence on pitch control.
11-12	The musically stressed syllable 'DE' seems to follow a Pythagorean intonation, while the next syllable presents pitch-flattening. The first note effect happens thanks to the bass IV behaviour that strongly emphasises the stressed syllable. The lowering of the second note is common to all basses.
13-14	Pythagorean intonation is clearly the adopted intonational strategy in this passage. Note 13, being a musically stressed note and bearing a consonantal plus vocalic [i] articulation, exhibits pitch-sharpening. The

unstressed and 'all-vocalic' note 14 shows pitch-flattening that may almost be considered as a 'natural law' at this point of the analytical considerations, due to the regularity that notes in a similar situation seem to produce comparable results.

15-17 Pitch-sharpening on the first two notes, in spite of being more pronounced in the first one, guarantees that the last note would give the impression of bearing a distinct pitch-flattening, which may not be entirely true. Note 17 is, in fact, very near to the expected pitch shared by all of the analytical values within a narrow variation range.

Bass singers

Note	Strategy
1-4	Bass I differs from the others in two ways: by assuming a much lower profile and by adopting an opposite direction for the pairs of notes 1 and 2 as well as 3 and 4.
5-6	The results for these notes are discordant between the singers. While basses III and IV point to Pythagorean intonation with a generous pitch-sharpening on note 6, bass I tends to pure intonation with the same pitch-sharpening on the second note. These three basses agree with each other in relation to the (probably) text-related pitch-sharpening. However, bass II seems to choose either equal temperament for *both* notes, or even Pythagorean intonation, without fully achieving the target, nevertheless.
7-8	All the basses fully agree with each other in direction (from and to). The actual result would then depend on how high or low each singer was at the beginning. The explanation for note 8 is the very same found in similar circumstances – unstressed consonantal plus vocalic [u] articulation together with consonantal ending articulation. Basses III and IV show inclination towards Pythagorean intonation, in spite of a distortion upwards denoted in note 7 of bass IV. Bass I keeps the pitch-flattening, while bass II seems to indicate that the intonational strategy for notes 5 and 6 may have been a lowered Pythagorean intonation instead of equal temperament, after all.
9-10	Basses I, II and III perfectly agree amongst themselves with what indicates meantone temperament with pitch-sharpening on note 10 (consonantal plus vocalic [u] articulation, followed by an ending

consonantal articulation). However, Bass IV does not adopt this procedure. It seems that with bass IV pitch-sharpening was intended for note 11, which also presents a particular result that is contrary to the other singers' readings. Notes 10 and 11 of bass IV seem to reinforce the perspective regarding the performer's individual conception of the music.

11-12	With the exception of bass IV, they exhibit a lowering strategy in relation to the adjacent notes. Basses II and III remain near the models' values; bass I reassures his tendency to pitch-flattening, while bass IV embarks on a different route, already addressed in the comments for notes 9-10.
13-14	The pitch-sharpening happens due to a resultant of two employed strategies: basses I and II seem to simply target Pythagorean intonation while basses III and IV go off the limits in the same direction. Unstressed vocalic note 14 confirms the inevitable pitch-flattening.
15-17	Generally, the stressed position of the notes together with the kind of articulation that they present dictates the intonational strategy. All basses except bass II further sharpen the pitch in note 15; bass IV does it with more enthusiasm than the others do, as happened in the whole phrase. All basses, according to the section comments, finish near to the models' values, remarkably close to each other.

Second phrase

Soprano section

Note	Strategy
1-5	The overall tendency of the first two notes is towards Pythagorean/pure intonation, not out of a full agreement of the individual singers, but out of a certain balance between the two tendencies revealed: Pythagorean/pure intonation and meantone temperament. Notes 3 to 5 again represent a kind of balance between two opposing strategies, resulting in a tempered or a slightly Pythagorean strategy.
6-11	The overall impression reveals a tendency towards Pythagorean intonation, with unexpected pitch-sharpening on the first note of the passage. Note 9 acts as if displaying pitch-flattening due to unstressed vocalic articulation rather than bending towards temperament. Note 11 should display a more pronounced pitch-sharpening due to consonantal

plus vocalic articulation with consonantal ending articulation, but the effect is avoided by the soprano I strategy. Why has note 6 been 'awarded' pitch-sharpening? The only explanation up to now is related to the pitch-sharpening also present on the former harmony notes for the alto, tenor and bass sections. However, the soprano section itself did not show pitch-sharpening on the former note (note 5)! Consequently, the question remains open to discussion and research.

12-16	Note 12 shows a slight pitch-sharpening probably caused by the preparation for the upward leap to the target note 13. Note 13 is probably sharpened because it is one of the climax notes of the motet, but this is not necessarily true. Note 4 of the last phrase, which is the note that defines the last climax of the motet, does not present pitch-sharpening.
17-20	Straightforward Pythagorean intonation, which agrees with the general tendency exhibited by all the singers.

Soprano singers

Note	Strategy
1-5	The first two notes of sopranos I and II display opposite tendencies than those of sopranos III and IV. This fact probably points out the singers individual differences regarding intonational procedures, since sopranos I and II follow the strategy defined by meantone temperament, while the other two follow a Pythagorean/pure intonation. Note 3 is a point of reference: all sopranos agree and nearly coincide in results, as if establishing a new starting point regarding intonation. From it, sopranos II and III choose pure intonation, while sopranos I and IV opt for Pythagorean intonation, in the last two notes. Sopranos II, III and IV present pitch-flattening on the last note of the passage, while soprano I produces pitch-sharpening on the same note (in agreement with the "consonantal plus vocalic [u] articulation together with ending consonantal articulation" common behaviour). This may be a meaningful departure from what has been seen until now, perhaps the text-and-stress-related effect presented by soprano I does not have to be the norm after all.
6-11	All sopranos agree strategically regarding note 6, in practical terms. It presents pitch-sharpening, which is nevertheless unexpected and unpredictable. Note 7 adjusts the singers' strategies towards

Pythagorean intonation, creating some interesting possibilities for interpretation when seen according to the overall intonational picture of the phrase, as will be described now. Soprano I seems to use note 6 in opposition to Pythagorean intonation, which is the singer's model for the whole phrase; this causes the shape of notes 5 to 7 to behave like an over-deviated pure intonation, which obviously it is not. Soprano II, however, produces results much more near to pure intonation and conveys a confusing impression about the singer's intonational behaviour. The same happens with soprano III. Notes 8 and 9 are perhaps the most important ones of this passage in relation to intonational strategies. Sopranos II and III seem to change from Pythagorean/pure intonation to meantone temperament in these two notes, while soprano IV is already in meantone temperament in note 8. Only soprano I moves on untouched by the other singers' concerns. Note 11 shows in all sopranos' results, except soprano I, the "consonantal plus vocalic [u] articulation together with ending consonantal articulation" behaviour. It must be noted that note 11 is a very short one, due to the need of air intake in preparation for the long note 13. It is needless to mention that the pure intonation analytical value for note 8 was not considered a viable option for any of the singers.

12-16 Note 12 denotes a coherent strategy in relation to the former note, for each of the singers. The fact that note 13 shows pitch-sharpening enhanced by all of the singers may be due to the leap upwards or to the musical importance and stressed position of the note. It is the first climax note of the motet. Note 14 tends to Pythagorean intonation on the whole, with pitch-sharpening on the soprano II value, as if it were the natural continuation of the strategy in relation to the former note. Note 15 behaves according to the Pythagorean model in sopranos I and II results, but tends to meantone temperament or perhaps pure intonation in sopranos III and IV. All singers move to the same target in note 16, with soprano I remaining sharp, as she has done from almost the beginning of the phrase.

17-20 Once more, the departure note is agreed between all (see comment on soprano I above). Pythagorean intonation is adopted by all the sopranos, with two remarks as follows. Soprano I shows pitch-sharpening, and further enhances it in note 19 (consonantal plus vocalic articulation together with ending consonantal articulation); soprano II exhibits an unpredictable pitch-sharpening on the last note.

Alto section

Note	Strategy
1-4	The section results point to somewhat levelled values not very far from any of the models, with pitch-sharpening on the last note of the passage. Individual results show that different procedures are employed to get to a much simpler overall result; this may indicate a kind of compensatory strategy adopted by the singers (pitch equalisation). This cannot be categorically asserted at this point; further research work must be done on this particular issue in order to clarify this striking possibility. Note 4 shows pitch-sharpening probably due to consonantal plus vocalic articulation together with consonantal ending articulation. This is already established as a real issue also demanding specific experimental work on it.
5-9	Note 5 probably shows pitch-sharpening probably because of the presence of the same effect in the former note. From note 6 to note 9, altos seem to fully agree with Pythagorean intonation.
10-16	Pythagorean intonation is the ruler in this last part of the phrase, also. Some remarks are necessary. Note 11 exhibits pitch-sharpening (possibly due to stressed double consonantal articulation). The singers themselves seem to be divided with this respect, altos III and IV being the responsible ones for the pitch-sharpening. Individual attitudes towards music are certainly responsible for the results! Notes 12 and 13 also present results originated in different approaches, apparently producing a tempered/Pythagorean solution for the passage.

Alto singers

Note	Strategy
1-4	Conflicting strategies are presented by the alto section in the first passage of the phrase. While altos I and IV agree – if not in pitch– in relation to the general shape of the deviations results, altos II and III adopt a more steady line. However, they also do not agree with respect to the chosen strategy: Alto II adopts meantone temperament, while alto III opts for a Pythagorean procedure. Generally, it can be said that altos II and IV adopt meantone temperament, with opposite direction

of deviation for the sequence of notes 1 and 2. Altos I and III tend to Pythagorean intonation, with alto I displaying pitch-flattening on note 2 (consonantal plus vocalic articulation). All singers produce pitch-sharpening on note 4.

5-9 Note 5 is unexpectedly sharpened in altos I and III. It is also raised in the other two singers' results, which indicates pitch-sharpening as happened with the soprano section (note 6). Alto I seems to use temperament in note 6, followed by pitch-sharpening on note 7; another possible interpretation would be pitch-flattening on note 6, followed by Pythagorean intonation in note 7. What would be the right option? Upon looking at the alto II results, the situation is not clarified in any way, since the values define a similar melodic contour. As alto III results depict a great pitch-sharpening in relation to the Pythagorean model, a further look at alto IV results would be required. The values of the latter denote a deviation line towards equal temperament with pitch-sharpening on the last note of the passage (again, probably due to consonantal plus vocalic articulation together with ending consonantal articulation). Therefore, the question of the right options for alto I's notes 6 and 7 remain indefinite. The overall results point to Pythagorean intonation, not necessarily meaning that this was the alto I intended strategy.

10-16 Note 10 is tackled in two different ways by the singers: altos I and II define what can be taken as tempered results, while the other two singers greatly deviate upwards, the result of alto III being the greatest of about 30 cents deviation in relation to equal temperament and about 40 cents deviation in relation to pure intonation. Note 11 is sharpened by altos I, III and IV (alto III comes from an even higher note – this must be taken into account!). Note 13 is also sharpened by alto I, which also happens to note 15 by altos I, III and IV. At last, note 16 is flattened by alto IV in a way that disagrees with the other singers, being the only one to stray away from a nearly unison value.

Tenor section

Note	Strategy
1-5	The upward direction of the first three notes denotes a tendency to temperament after the initial carefully tuned chord. Perhaps it exemplifies the interplay between the initial moment of careful

articulation of the first chord of the phrase and its continuation with less careful approach, the following chords being considered as belonging to a lower level of precedence and treated accordingly. Alternatively, it may happen due to text-related issues, once more – note 3 bears a strong consonantal articulation. Anyway, the melodic line goes up in general terms, from the beginning to note 5 (the pitch-sharpening issue, so often mentioned in this chapter). Note 4 deviates slightly to pure intonation or perhaps to Pythagorean intonation, without a clear indication about what the target really is (it is more secure to assume a temperament-based strategy).

6-10 It is reasonable to claim a pure intonation strategy for the whole of the passage, with pitch-sharpening on note 10 probably due to unstressed consonantal plus vocalic articulation with consonantal ending articulation.

11-17 Notes 11 to 13 tend to Pythagorean intonation, being followed by a tempered procedure until note 15. The last two notes, due to pitch-sharpening, go towards Pythagorean intonation and then pure intonation. The question of the sharpening applied to note 16 being just text-related couldn't be answered with certainty before thorough experimental work is carried out on the subject.

Tenor singers

Note	Strategy
1-5	Tenor I starts almost at pure intonation, rising immediately towards equal temperament, and showing pitch-sharpening on the last note (unstressed consonantal plus vocalic articulation with consonantal ending articulation). Tenor II does the same with a slight pitch sharpening on note 3. Tenor III adopts a pure intonation strategy with pitch-sharpening on the last note of the passage. Tenor IV defines equal temperament from the beginning with the mentioned pitch-sharpening on note 5, and also small pitch sharpening on note 3. Generally, text-related issues are present in notes 3 and 5.
6-10	Notes 6 to 10 are differently characterised by singers that, at least in two cases remain in the borderline between two intonational strategies. Tenor I moves according to pure intonation, being accompanied by tenor III, with pitch-flattening on note 9, probably caused by the unstressed vocalic articulation. Tenor II and IV seem to adopt a

Pythagorean intonation strategy, even if tenor IV seems to bounce up and down from note to note, one of the most clear examples of text-related issues in intonation.

11-17 Tenor I tends to equal temperament from note 11 to note 15, then changing towards pure intonation in the last two notes. This is a rare case of an equal temperament strategy. It can be said, of course, that note 16 presents pitch-sharpening due to unstressed [i] vowel articulation (it also presents consonantal articulation), since the effect is present in all of the tenors' results. This may indeed be the case. The last note tendency to pure intonation is a fact, nonetheless. Tenor II is bent on Pythagorean intonation with a temperament procedure in note 14. The final two notes follow the same strategy derived from tenor I. Tenor III behaves as if the pitch-flattening was the rule, with notes 12 and 13 exhibiting unexpected results, while adhering to pure intonation onwards. The singer also exhibits pitch-sharpening on note 17. Tenor IV, as before, utilises substantial pitch-sharpening in notes 12 and 16 in what, with a little imagination, could be characterised as Pythagorean intonation. Note 14 and 17 are exceptions, the first being a tempered one, and the latter bending towards pure intonation, but not quite achieving it, remaining above the level of equal temperament. This probably occurs due to the excess of deviation in note 16.

Bass Section

Note	Strategy
1-5	Generally, the bass section behaves in accordance with temperament, with a big deviation upwards in the last note of the passage (unstressed consonantal plus vocalic articulation with consonantal ending articulation). However, two opposite strategies can be observed in note 4, especially in basses III and IV, as if one was counterbalancing the other. However, total agreement between them all cannot be avoided in the last note.
6-10	The overall tendency to pure intonation (or meantone temperament) is contradicted only by bass IV with its Pythagorean line. As a result, note 8 seems to be a little tempered in relation to the others. The results of each singer seem to indicate their personal conceptions of the music.
11-17	From the general overview of the results for the passage, the tendency is towards Pythagorean intonation. The first note of the passage (note 11),

however, is pitched according to meantone temperament. Note 16 yields pitch-sharpening, probably due to consonantal plus vocalic [i] articulation together with consonantal ending articulation.

Bass singers

Note	Strategy
1-5	The common feature of all basses is the pitch-sharpening on note 5 (unstressed consonantal plus vocalic articulation with consonantal ending articulation). Basses I and IV begin with a small pitch raising in the first two notes, while bass II displays pitch-flattening on the same notes. Bass III follows the models with only a slight pitch-flattening on note 2 due to unstressed articulation. Note 3 corrects the deviation towards the models in basses I and III, while bass IV initiates a big ascending movement for the next three notes. Note 4 tends to Pythagorean/pure intonation in basses I and IV (the latter greatly exaggerating the deviation result), while in basses II and III it bends towards meantone temperament (a bit overstated by bass III).
6-10	Notes 6 to 9 tend to pure intonation in basses I, II and III, changing to Pythagorean intonation in bass IV. Bass I and IV present pitch-flattening on note 7; as each of them go afterwards in a different direction, the most probable reason for the result might be text-related behaviour. Basses II and III present pitch-sharpening on note 7, opting for pure intonation afterwards, but not as low in pitch as bass I, perhaps because the latter was already tending to pure intonation in the former note. Basses II and III go on with pitch-flattening on note 9, as if caused by unstressed vocalic articulation.
11-17	From the individual results, it can be said that basses III and IV are definitely Pythagorean in their intonational strategy. Bass IV's 12th note, as happened earlier, is far too sharpened in relation to any expected result. Bass I defines pure intonation in notes 12 to 15. As note 16 presents the commented upon pitch-sharpening, it can be said that the whole passage yields pure intonation. Notes 13 to 17 exhibit results very near to each other, and all the little variations in pitch could be considered as following any of the models, since the differences between them are very small.

Third phrase

As can be seen from the sections charts, there is a tendency to start the phrase with raised pitch values. There is also a tendency of the last notes to finish with lowered pitch values. It must be noted that the first and last chords were the chosen ones for the calculation of the reference frequency of the phrase, and consequently would determine the higher or lower positioning of the deviations' results. What is implied here is that if just the first chord was chosen for the calculation of the reference frequency, all deviation values would be shown at much higher deviation values, while the opposite would happen if just the last chord would be chosen for the calculations. As it stands from the adopted procedure, the average position is displayed for the deviation values, with higher values being shown at the beginning and lower values being displayed at the end of the phrase.

Soprano section

Note	Strategy
1-5	The descending strategy in note 4 is common to all the sopranos (and to several singers of the other sections). In addition, the ascending value of note 5 (except for soprano IV) is reciprocated in results from singers of other sections, strongly emphasising the text-related articulation issue regarding intonational strategies.
6-12	The most striking feature of this passage is shown in note 9. All sopranos, except soprano IV, exhibit unexpected pitch-sharpening, as the note bears unstressed vocalic articulation. The entire passage seems to agree with Pythagorean intonation as a strategy of the soprano section, but not as individual strategies of the singers. Note 12 shows pitch-sharpening most probably due to consonantal plus vocalic [u] articulation with consonantal ending articulation.
13-17	Soprano singers seem to treat the melodic line differently in relation to the chosen pitch levels.
18-23	Soprano I exhibits raised intonation all through the second half of the phrase, as if acting in response to soprano III and, to some extent, to soprano IV in order to counterbalance the overall pitch of the phrase (pitch equalisation). Soprano II is the voice that acts most regularly around the centre value of the reference frequency during the whole phrase. This role seems to be performed by different singers in different phrases. The overall results lean towards Pythagorean intonation from

notes 18 to 21 and towards pure intonation in the last two notes.

Soprano singers

Note	Strategy
1-5	Soprano I starts with pitch-sharpening on the first two notes, then falling to an expected level on the next note. This may be the cause of the sudden pitch-flattening on note 3. This also seems to happen with soprano II, by means of a gradual flattening from the first high-pitched note. This behaviour is also displayed in all of the other sections. Sopranos III and IV behave as expected for the first three notes, at least. Note 5, with the exception of soprano IV, yields pitch-sharpening probably due to a consonantal plus vocalic articulation with consonantal ending articulation. The behaviour of soprano IV for this note is unique, since it goes downwards in a contrary movement to the other singers. This fact may be understood by the continuation of its melodic line until the half-phrase, being always on the lower side of the models' values.
6-12	Soprano I resembles meantone temperament in this passage, but it could also be Pythagorean intonation. In fact, no model is actually followed, unless some considerable effort is made to explain unexpected deviations in notes 7, 8 or 9 (it depends on the chosen model), 10 (in the case of meantone temperament) and 12. Note 12 is a typical case of consonantal plus vocalic [u] articulation with consonantal ending articulation. Soprano II seems to adopt Pythagorean intonation, with the aforementioned note 9 idiosyncrasy plus pitch-sharpening on the last two notes. Soprano III displays an intriguing succession of values that may resemble pure intonation in notes 10 to 12, but does not clarify anything in relation to notes 6 to 9. Finally, soprano IV decides on Pythagorean intonation with deviations in notes 7 (temperament procedure?) and 12 (previously mentioned).
13-17	Soprano I draws its deviation line always raised if compared with the others. It seems somehow attached to meantone temperament. This first part of the second half of the third phrase evolves regularly for sopranos I, II and III, with the musically stressed notes being more prominently raised than the following ones. This pitch-sharpening is not apparent in note 13 of soprano II, due to the pitch-sharpening that notes 11 and 12 have already presented. It must be noted, however, that

note 13 initiates a new phrase segment. In such cases, harmonic rules on voice (part) movements can be broken; therefore, intonational strategies could also be redefined. In other words, *note 13 defines a new* beginning and as such the descending movement it displays in relation to note 12 is much less important or relevant to the intonational strategy analysis. Soprano II keeps Pythagorean intonation as the most probable model (plus deviations, of course). Soprano III also redefines its intonational strategy in note 13 by raising the pitch deviation in relation to the former note; the same situation pointed out in soprano II is achieved here by the means of an opposite procedure. Soprano IV takes a different path, by raising the pitch of note 14 unexpectedly.

18-23 Sopranos I and II adopt a mixed intonational strategy, beginning with Pythagorean intonation and finishing with pure intonation. (Or perhaps, soprano I finishes with meantone temperament; this hypothesis, though, is not very strong, since soprano I displays sharpened intonation all through the second half-phrase, and the shape of the melodic line supports the first interpretation. Sopranos III and IV show pitch-sharpening on note 19. Afterwards they follow individual strategies – soprano III going along with pure intonation with a hint of Pythagorean procedure in note 20, and soprano IV adopting equal temperament until the end, with a slight deviation towards pure intonation on the last note.

Alto section

Note	Strategy
1-4	All singers present pitch-sharpening on note 4, in accordance with other sections on the corresponding note. The tenor section does not start with 'higher-then-expected' levels, but follows the same downward direction as the others. They also tend to start with a raised deviation and then lowering until note 3 (the only exception is alto II, whose first and second notes share the same deviations).
5-9	Undoubtedly, Pythagorean intonation is the one chosen for this passage by the alto section, with pitch-sharpening on note 9, caused by a text-related deviation (consonantal plus vocalic [u] articulation with consonantal ending articulation). Notes 6 and 8 present pitch-flattening due to musically unstressed syllables.

Note	Strategy
10-14	The passage from note 10 to note 12 is definitely in Pythagorean/pure intonation, changing to a tempered intonation strategy.
15-20	The last part of the phrase is decidedly Pythagorean until the penultimate note, then changing to a meantone temperament strategy.

Alto singers

Note	Strategy
1-4	Altos I, III and IV start with high deviation in relation to the models, closing the distance in the following notes, or even reaching beyond the expected deviation levels in the case of alto IV. Alto III is the only singer of the section that produces results according to the models. Nevertheless, even that singer shows pitch-flattening and pitch-sharpening in notes 3 and 4 respectively (probably due to text-related issues).
5-9	Individual differentiation is the rule in notes 5 to 9. Alto I follows pure intonation in notes 5 and 6, changing to Pythagorean intonation in note 7 onwards, with inevitable pitch-sharpening on note 9 (consonantal plus vocalic [u] articulation with consonantal ending articulation). Alto II begins slightly but steadily downwards to pure intonation, with a hefty (and unexpected) pitch-flattening on note 8, which causes the supposed pitch-sharpening of note 9 to remain lower than the expected value. Alto III fully adopts Pythagorean intonation with a small pitch raising in note 9. Alto IV seems to emphasise musically stressed notes with pitch-sharpening (notes 7 and 9, not forgetting that note 5 is raised in relation to note 6). Consequently, alto IV's behaviour may be interpreted as adopting a temperament-based strategy with the mentioned oscillations in terms of pitch deviation.
10-14	Alto I loosely follows the pure intonation II analytical values, which coincide with Pythagorean intonation until note 12 and then goes in the opposite direction. Alto II unexpectedly applies pitch-sharpening to note 11, probably for a text-related reason (strong consonantal articulation?); yet, Pythagorean strategy has been followed in spite of that deviation. Alto III seems to agree with pure intonation II, which can be perceived from note 13. Alto IV points to pure intonation I until note 12, then opting for a tempered intonation (which could be loosely interpreted as Pythagorean, if desired).

15-20 Altos I, II and III have chosen the same general strategy until note 19, with little variation in relation to pitch-flattening on note 16. Alto IV adopts pitch-sharpening on the same note, together with the maintenance of a lower pitch level for all notes. In spite of this, the general feeling is that Pythagorean intonation rules, as with the other altos. The last note displays two kinds of result: altos I and III tend to maintain the level of the former note, while altos II and IV plunge decidedly into a meantone temperament procedure.

Tenor section

Note	Strategy
1-5	As happens with the other sections, there is a descending strategy for the first notes of the phrase. Upon examining all results, the overall feeling is that the third note determines the 'true' deviation value for them. This fact seems to be true for the tenor section. From this perspective, the tenor section tends to pure intonation in the first three notes. In note 4 pitch-sharpening is utilised (consonantal plus vocalic [u] articulation), followed by a probable pitch-flattening on note five probably due to unstressed vocalic articulation plus consonantal ending articulation otherwise, the upward deviation movement would achieve the pure intonation analytical value. It is, of course, not possible to prove this assumption at this time, due to lack of research on text-related issues.
6-12	Heavily influenced by the results of tenors III and IV, the melodic line brings about pitch deviation results of very low values. This is an interesting situation, in which tenors I and II do not agree with the other two singers.
13-17	The tenor section utilises Pythagorean intonation for this passage of the phrase. Either musically stressed syllables are raised in pitch (notes 13, 15 and 17), or the other notes are being lowered in pitch as unstressed syllables. The second possibility is more plausible because of the general pitch-flattening of the passage.
18-22	After note 17 there is a *caesura* in the phrase. The intonational strategy starts with meantone temperament for the first two notes changing to pure intonation in the last three, with pitch-sharpening on the penultimate note (enough to touch the meantone temperament value).

Tenor singers

Note	Strategy
1-5	Tenor I seems to agree in principle with the section overall intonational strategy, in spite of not showing deviation results lowered enough to justify pure intonation. However, the ascending direction of note 5 supports the hypothesis (of a raised pure intonation I or alternatively meantone temperament). Tenor II's strategy is more difficult to perceive, since the two first notes fail to confirm a decisive descending strategy. Notes 4 and 5 give the impression that temperament is the real strategy here, note 3 being the odd one in relation to the deviation values. Tenor III gravitates around pure intonation, with note 5 slightly flattened preparing the way for the unusual strategy that follows. Tenor IV behaves as the section average values indicate, only a bit clearer in the last two notes' results.
6-12	Tenor I sounds Pythagorean, except for note 7 that appears to be tempered. Tenor II behaves in agreement with pure intonation, with the exception of note 9, which either tends to Pythagorean intonation or expresses the result of a musically unstressed syllable. Tenors III and IV seem to chose an unexpected intonational strategy, with a descending deviation in the order of –30 to –40 cents for most of the passage. Notes 7 and 8 are related to pure intonation, but the singers do not recover from the huge deviation downwards. Note 12 displays pitch-sharpening in relation to the previous notes.
13-17	Tenor I follows Pythagorean intonation in this passage. Equal temperament is not a very sound option here, in spite of what appears to be shown – values around the straight line of *zero* deviation; the way the results line moves points to Pythagorean intonation. Tenor II reveals mixed behaviour: while notes 13 to 16 seem to point to Pythagorean intonation, note 17 goes down to a meantone temperament strategy. Note 14 also touches meantone temperament. Tenor III, as tenor I, adopts Pythagorean intonation, although with a pronounced pitch-flattening on notes 14 and 16. Tenor IV adopts a clear lowered Pythagorean intonation.
18-22	Tenor I uses a meantone temperament strategy for the first two notes, changing to pure intonation for the remaining three notes. Tenor II also changes from meantone temperament to Pythagorean intonation (a bit

lowered, perhaps). Tenor III goes along with the strategy defined for the section (meantone temperament/pure intonation). Tenor IV seems to agree with tenor III, but exhibits irregular results. For instance, note 18 is sharpened in relation to meantone temperament, perhaps even belonging to Pythagorean intonation (this is not a reliable assumption, since the note is very short and bears a consonantal ending articulation). In addition, the last two notes are quite sharpened in relation to pure intonation, at meantone temperament levels, but with a direction following the pure intonation contour.

Bass Section

Note	Strategy
1-5	Note 3, as happens with the other sections, presents pitch-flattening, further enhanced on note 4 (unstressed vocalic articulation). Note 5, as happens with the equivalent notes in the other sections, exhibits pitch-sharpening due to text-related issues (consonantal plus vocalic [u] articulation with consonantal ending articulation).
6-10	The striking result in this passage belongs to note 10. Its value marks text-related issues with a high priority in the list of subjects to be investigated regarding intonational strategies in performance. The other notes show a tendency towards Pythagorean intonation with pronounced pitch-flattening that also deserves special attention. Possible causes for the pitch-flattening: the descending leap; the diminished harmony in the second beat of the former bar, which brings uncertainty to the harmony of the passage; and the tenor's tempered note 5 which conveys an unpredictable meaning to the modulating harmony.
11-15	As a general result, Pythagorean intonation is the intonational strategy followed in this passage. Note 11 displays pitch-sharpening in relation to the others which are slightly lowered if compared to the model.
16-20	A blend of pure and Pythagorean intonations is exhibited here. Pure intonation is prevalent in notes 16 to 18 and Pythagorean intonation in the last two notes. Pure intonation is sharpened while Pythagorean intonation is flattened in relation to the models. An interesting feature present in the four sections of the choir is the up-down direction of the last two notes, which could be caused by a sloppy attitude towards the notes intonation instead of any specific chosen intonational strategy.

This is a supposition based on the apparently followed strategies: pure intonation for the soprano section, meantone temperament for the alto section, and quite lowered Pythagorean intonation for tenor and bass sections. However, unequivocal evidence on this matter would be hard to find at this time.

Bass singers

Note	Strategy
1-5	All basses adopt the same strategy shared by the other sections. The progressively descending deviation results have only one exception: the first note of bass I. Note 5 exhibits pitch-sharpening from all of the basses, as referred to in the section comments.
6-10	Basses II and III choose a lowered Pythagorean intonation with a small degree of pitch-sharpening on note 8. Bass IV sharpens note 7, unexpectedly, since it is a musically unstressed syllable (would consonantal plus vocalic [o] articulation be enough to cause the effect?). However, in note 10 of bass IV, the most unusual behaviour is observed – a huge pitch-sharpening of about 40 cents deviation from equal temperament. A comparable result in the same note is also presented by bass I, and to a lesser extent, by bass III. Bass I, however, matches bass IV by plunging to an almost –40 cents deviation in note 6. If these large deviation procedures turn out to be the result of an intended intonational strategy after specific experimental investigation, it means that *singing together may not only enhance the good qualities of each performer, but it also may develop biased intonational tendenciesif kept unchecked.*
11-15	Bass I shows a deviation line loosely related to Pythagorean intonation, due to the flattened pitch values. Note 14 is too flattened in relation to the model, but even so it does not justify a pure intonation strategy interpretation. It would be wiser to attribute the deviation differences to pitch-flattening for notes 12 and 14. Note 15 changes towards pure intonation. This will be further considered in the comments for notes 16-20. Bass II seems to follow Pythagorean intonation first and then equal temperament (notes 11-13 and 13-15, respectively). Pitch-flattening is displayed in note 12; its value almost touches pure intonation, but that does not seem to be the intention. The best reason might be a 'musically unstressed syllable'. Basses III and IV present the same kind of results: pitch-sharpening on the first note, but generally a

Pythagorean intonation strategy. The pitch-sharpening is easy to understand, from the results exhibited by the former notes.

16-20	Bass I seems to be applying pure intonation II strategy to the short passage from note 15 to 17. Then, suddenly it goes to pure intonation I in note 18, only to rise up to a Pythagorean deviation level in note 19 and turn back to pure intonation I in the last note. The three last notes' behaviour is also repeated in basses II and III and partially replicated in bass IV! Perhaps a viable explanation would account for a Pythagorean intonation largely lowered or distorted. This would help in understanding bass II results from note 17, bass III for all of the notes, but is not convincing for bass IV results. Note 16 of bass II definitely belongs to pure intonation together with note 17. Note 16 of bass IV is greatly deviated to the extent of more than –40 cents (again, as in note 10, this large deviation does not lend itself to an easy explanation!). Finally, note 20 of bass IV is the only last note with a result that matches equal temperament.

Fourth phrase

Soprano section

Note	Strategy
1-6	Soprano section note 5 assumes the same role as the bass section of the third phrase in notes 10 and 16. A greatly deviated result will also be presented by the alto section in this fourth phrase. This kind of unexpected result brings the need of an investigation on the issues relevant to the problem. Generally, it seems that the soprano section starts from a meantone temperament strategy with pitch-sharpening on note 2 due to unstressed strong consonantal plus vocalic articulation. Note 6 belongs to an unstressed vocalic articulation with consonantal ending articulation, which may be the cause of the note's pitch-flattening.
7-11	A Pythagorean intonation is exhibited in this passage, with pitch-sharpening on notes 8 and 11. Note 8 is musically unstressed, while note 11 is a shortened syllable that bears a *caesura;* in addition, the *caesura* must provide time for air intake in preparation for the next long note.
12-15	Pythagorean/pure intonation, with slight pitch-sharpening, is the intonational strategy of this passage.

16-20 Note 17 seems to define a pure intonation strategy, even if slightly raised in relation to the model, while note 19 defines Pythagorean intonation strategy to end the phrase. It must be noted that the results present a slightly raised tendency from note 5 onwards.

Soprano singers

Note	Strategy
1-6	Note 5 was commented upon in the section results. Note 4 exhibits a small degree of pitch-sharpening from all sopranos, probably due to the intended strategy for note 5, as is well exemplified by soprano IV. Note 2 is pitch raised in all sopranos except soprano II, who decides for pitch-flattening. These results are text-related behaviours that depend on the musical and technical standpoints of each singer for their implementation. Regarding the three first notes of the phrase, it works as if soprano I begins from a tempered or slightly lowered Pythagorean deviation, then applying the pitch-sharpening on note 2. This also happens to sopranos III and IV, only from a meantone temperament deviation level. Soprano II does this also from a (raised) meantone temperament procedure, but sharpening notes 1 and 3, instead. Through this procedure, soprano II decides to emphasise the musically stressed notes of the passage.
7-11	Three distinctive strategies are employed in this passage. Sopranos I and IV apply pitch-sharpening on notes 8 and 11, both with consonantal plus vocalic [u] articulations together with consonantal ending articulation. Soprano II presents a slight pitch raising in note 8, but none for note 11. Soprano III decides to emphasise note 9, which is a musically stressed note, and de-emphasising notes 7 and 11. Generally speaking, sopranos II and III follow a typical Pythagorean intonation; soprano IV may also be seen as adopting a Pythagorean intonation with an extravagant pitch raising deviation in note 11; soprano I, however, behaves differently in relation to the overall strategy. As happens in the other phrases, soprano I apparently shows a tendency to sing regularly with a raised deviation. As considered before, this procedure may be part of a pitch equalisation strategy, as will be discussed in 5.3.4.
12-15	Sopranos I, II and III exhibit the same strategy, in principle. Sopranos I and II adopt a raised intonation (for soprano II this is the only passage in which a raised strategy is used), while soprano III follows the model

level except in the sharpened note 12 (stressed by the singer?). Soprano IV adopts a much different strategy, by using pitch-flattening on note 12 and pitch-sharpening on note 14, in opposition to the other sopranos. This fact could mean that a meantone temperament was intended by soprano IV, though greatly deviated in the last two notes.

16-20	Soprano I show a Pythagorean tendency all the way, in spite of the sharply raised value of note 16 and to a lesser extent, of notes 19 and 20. Soprano II confirms the overall tendency of the section. Soprano III begins with equal temperament or a lowered Pythagorean strategy for the first two notes, opting for pure intonation in note 18 followed by a lowered Pythagorean intonation again in the last two notes. Soprano IV seems to opt for a raised pure intonation until the penultimate note, then changing to Pythagorean intonation.

Alto section

Note	Strategy
1-6	Straightforward Pythagorean intonation, with very little deviation.
7-11	Probably a Pythagorean intonation with pitch-flattening on note 9, this passage could also be seen as beginning with Pythagorean intonation, changing to meantone temperament from note 9.
12-15	Again, Pythagorean intonation seems to be the obvious strategy, with pitch-flattening on note 13. This effect is, in fact, the result of an attempt by one of the singers to make it tempered. Note 13 is the long note of the passage.
16-20	Again, the singers display somewhat similar deviation lines, but raised and lowered in deviation results according to their proclivities. The only note that can be viewed as an exception is note 18, which goes downward in alto II.

Alto singers

Note	Strategy
1-6	Alto I adopts a raised intonational strategy for this passage. Pythagorean intonation is the model, in spite of note 5 being raised unexpectedly (see comment on bass singers of phrase three, notes 6-10). Alto II shows a more confusing strategy that begins at the models' level, employing pitch-sharpening on note 2 (strong consonantal articulation) and singing

the third note also raised. As a result, notes 4 and 5 could be considered as a return to the initial level (temperament) or a slightly lowered Pythagorean intonation. Whatever is the case, note 6 is definitely raised in relation to the tempered or Pythagorean model.

7-11 A possible interpretation of the intonational strategies of the passage would be to consider all results as variations of Pythagorean intonation, with the exception perhaps of alto IV. The suggested strategy is quite clear in alto III's results, with pitch-sharpening on notes 8, 10 and 11; the probable causes for deviation of notes 8 and 11 are consonantal plus vocalic [u] articulation with consonantal ending articulation. Note 10 presents different deviation values for the singers: pitch-sharpening on sopranos I and III, and pitch-flattening for sopranos II and IV. The results may be linked to the singers' musical thinking (or training) regarding text-related issues. Alto I's deviation values show a slight pitch-flattening on note 9. Alto II either displays pitch-flattening on notes 7, 9 and 10 (which seems to be the most reasonable option), or then mixes two strategies: meantone temperament and Pythagorean intonation. Alto IV's double-standard behaviour oscillates between meantone temperament and Pythagorean intonation, making it really difficult to clarify what the intended results could be. The seemingly most obvious (meantone) temperament is not necessarily supported all the way by the pitch-lowered shape of the singer's deviation results.

12-15 Altos II, III and IV draw Pythagorean shaped deviation lines that are lowered, raised and slightly lowered, respectively. Alto I is the singer that defines a different strategy for the passage – equal temperament, with pitch-sharpening on the first note (the former note, note 11, is yet further raised, which helps to explain it). Alto II uses lowered deviation values for this and the former passages. This may also apply to alto IV. Alto III draws raised deviation values for the whole phrase. From that viewpoint, it could be said that there is pitch-flattening on note 13. Alto IV shows pitch-flattening on note 12, differently from the others.

16-20 Note 16 is lowered a bit too much in alto I, but the deviation gap from note 15 agrees with altos III and IV. The markedly different result in note 16 belongs to alto II – pitch-sharpening in relation to the former note. Alto I's strategy is Pythagorean, slightly raised on note 18, tending to be lowered in relation to what would normally be expected (as happens in alto II). However, as note 19 seems to be sharpened in all of the section singers, it may be that note 18 is located at the right level, while the deviation should be attributed to note 19.

Tenor section

Note	Strategy
1-6	Note 5 presents pitch-sharpening in relation to the previous note, in all of the singers' results. This effect is opposed to all of the models, so it may be caused by a music or text-related issue. The average deviation values of the passage points to a tempered strategy.
7-11	Whatever the reason would be for the pitch-sharpening on note 8, it affects all singers. Note 11 also presents pitch-sharpening that happens probably due to the causes to be considered below when discussing the singers' individual performances. Otherwise, this passage exhibits a pure intonation strategy.
12-18	The last passage of the phrase presents a Pythagorean/pure intonation, with pitch-sharpening on notes 12 and 14, together with a slight lowering on note 13 (probably all deviations are due to text-related issues).

Tenor singers

Note	Strategy
1-6	Tenor I follows a Pythagorean intonation strategy, with pitch-sharpening on note 5. Tenors II and IV opt for a temperament strategy, near to equal temperament for tenor II and to meantone temperament for tenor IV. Tenor III provides a pure intonation strategy, with pitch-flattening on note 4, which to a lesser extent is shown by the other voices, as well. Note 6 is lowered in tenors I and III, and raised in tenors II and IV. Consequently, it probably depends on the individual singers strategic tendencies.
7-11	Pure intonation strategy, with pitch-sharpening in notes 8 and 11. The effect of note 11 has been very common in the motet's results – consonantal plus vocalic [u] articulation with consonantal ending articulation. Note 8's effect meaning is more elusive, being perhaps caused by the same issues, as is the case for note 11, plus the fact that it is a musically unstressed syllable. It could be said that all tenors except tenor III follow a pure intonation strategy, a bit sharpened in tenor I.

12-18 Notes 12 to 14 yield the same deviation line for all of the singers. It seems that notes 12 and 14 are raised (except note 12 for tenor III) in relation to the models. Tenors I, II and III show pitch-sharpening on note 15. As for the last four notes, the overall impression is that tenor I adopts meantone temperament; tenors II and IV adopt a Pythagorean intonation (with pitch-sharpening on note 17 for tenor IV); finally, tenor III deviates towards meantone temperament with a flattening strategy on the last note (could it be a Pythagorean procedure?).

Bass Section

Note	Strategy
1-6	Notes 1 to 3 draw the same deviation line shape, with pitch-sharpening on note 2 (strong consonantal plus vocalic articulation on a musically unstressed syllable). The overall impression is one of Pythagorean intonation with pitch-flattening on notes 1 and 4 plus a slightly sharpened note 6.
7-11	It seems that the bass section chooses meantone temperament as the intonational strategy for this passage. There is a slight pitch-sharpening on note 8, a more pronounced one in note 11 (strong consonantal plus vocalic [u] articulation with consonantal ending articulation), and a small pitch-flattening on note 9. These deviation effects could point to a lowered Pythagorean intonation, as an option. In that case, the deviation effects would be softened, which does not very often seem to be the case. It could be a double-meaning intonational strategy, as happens with harmonies all the time!
12-18	It can be said that notes 12 to 14 are behaving loosely according to a raised meantone temperament or pure intonation, while the other four notes loosely adopt a lowered Pythagorean intonation, except for note 16.

Bass singers

Note	Strategy
1-6	Note 4, which is also a musically unstressed syllable (but with no consonantal articulation) behaves differently for each singer, ascending in bass III, keeping the line in bass 4 and descending in basses I and II. The same sort of variation also occurs with note 6. Either note 5 or 6 is

raised in this passage (indicating individual strategy variations). According to the singers results, note 4 could also be interpreted as tending to pure intonation in basses I and II, to Pythagorean intonation in bass III and to equal temperament in bass IV. According to the general picture of the passage, bass I could be employing a raised pure intonation and bass II could be using either Pythagorean or pure intonation – this depends on note 4 or 5 being considered lowered or raised. Bass III seems to be undefined by the Pythagorean and meantone temperament deviation values. Bass IV seems to be definitely Pythagorean.

7-11 Bass I presents pitch-flattening on note 11, in opposition to the other singers (could this imply a pure intonation strategy?). This effect, as presented by the other singers, is probably caused by strong consonantal plus vocalic [u] articulation with consonantal ending articulation. Perhaps bass I is sending a message about the possibility of pitch control in text-related issues. However, in note 14, which presents the same situation, all basses agree by adopting a pitch raising strategy. As it stands from direct observation, it seems that basses II, III and IV adopt meantone temperament as the intonational strategy for the present passage. Pitch-sharpening is displayed on note 8 for basses I, II and IV, while there is pitch-flattening on note 9 of bass III.

12-18 Notes 12 to 14 share the same contour in all basses, with the difference that basses I and IV are raised, while basses II and III are lowered, suggesting Pythagorean intonation and pure intonation/meantone temperament, respectively. All of the singers exhibit pitch-sharpening on note 14, as mentioned earlier. The last four notes present a general deviation tendency to pitch-flattening, especially for note 17 (descending octave leap). The general shape is loosely Pythagorean.

Fifth phrase

Soprano section

Because soprano I displays greatly sharpened deviation values in the whole phrase, it can be inferred that her strategy is largely Pythagorean, since Pythagorean values are the highest ones.

Note **Strategy**

1-4 From notes 1 to 3, all sopranos share the same shape in the deviation line, which gives an impression of a pure intonation/meantone temperament strategy. Note 4 is close to the meantone temperament value. However, this up-down direction shown by notes 1 and 2 is also displayed by all of the other sections, and in the case of altos and basses it denotes Pythagorean intonation. As a result, it seems that for the beginning notes the concept of direction is more relevant than the concept of strategy, which is a somewhat unreasonable statement to make. Perhaps the real strategy is shown in the group's result – pure intonation/meantone temperament, thus reinforcing the idea of pitch equalisation within the soprano section.

4-11	The values are very much in accordance with Pythagorean intonation except for notes 4 and 11. The former was just commented upon; the latter shows pitch-sharpening due to consonantal plus vocalic [i] articulation with consonantal ending articulation. It must also be noted that the syllable is further shortened by the need to breathe in preparation for the end of the phrase (and the motet, also).
12-16	It seems that equal temperament rules the last passage of the motet, in spite of the fact that the individual singers' results only supports equal temperament in soprano II.

Soprano singers

Note	Strategy
1-4	Soprano I is greatly raised in relation to the others. Notes 1 and 2 denote a meantone temperament strategy in all of them except, perhaps, in soprano I. Sopranos II and III define pure intonation in note 3, the same happening to soprano I (taking into account the great deviation), in spite of the Pythagorean value of the note. It must be observed that the shape of the values' line is sometimes more important than the values themselves, since it is quite clear that soprano I is utilising a pitch equalisation strategy. Soprano IV adopts a lowered profile, more akin to meantone temperament. Note 4 is flattened in sopranos I and III (could it be a Pythagorean procedure?), while for sopranos II and IV it is sharpened as for a pure intonation/meantone temperament procedure.
4-11	Soprano I adopts a raised Pythagorean intonation, with further deviations in notes 7 (a small one), 10 and 11. Upon observing the deviation line from notes 7 to 11, it can be said that its shape resembles pure intonation, but the results are so greatly deviated that it can hardly

be considered a viable proposition in practical terms. Soprano II would also behave according to Pythagorean intonation, with pitch-flattening on note 5 and a small pitch-sharpening in notes 7 and 8. Note 11 presents the already mentioned text-related deviation issue. Soprano III displays a lowering effect on most of the notes (4, 6 to 9, perhaps note 10 also), and pitch-sharpening on note 5.

12-16 Soprano I is clearly Pythagorean, with pitch-sharpening on note 12, which comes from an elevated note 11, and also in note 15, due to consonantal plus vocalic [i] articulation together with consonantal ending articulation. Note 16 is lowered in relation to the expected value. Soprano II is equal tempered with pitch-sharpening on note 15. Sopranos III and IV apparently opt for a strategy oriented towards pure intonation and meantone temperament, with some variations in deviation, as follows. Note 12 is a bit flattened, note 14 is flattened only for soprano III, while a small degree of pitch-sharpening is applied to the last note of soprano IV.

Alto section

The alto III intonational strategy clearly points to pitch equalisation. General results for the section blends Pythagorean intonation and equal temperament.

Note	Strategy
1-7	The section presents a largely Pythagorean intonation tendency, with pitch-sharpening on the last note of the passage (a text-related issue), and slightly lowered deviation values from notes 2 to 6. An interpretation according to equal temperament is possible but not as probable as Pythagorean intonation.
8-12	Equal temperament is the most probable strategy for this last passage of the phrase. Note 11 presents pitch-sharpening probably caused by a text-related issue, instead of a Pythagorean tendency at the end of the phrase. The singers, however, behave differently as individuals, the section's tuning strategy perhaps being the result of pitch equalisation (see 5.3.4).

Alto singers

Note	Strategy
1-7	Alto I exhibits a lowered Pythagorean intonation with a greatly

sharpened deviation in note 7 (pitch-sharpening probably due to consonantal plus vocalic [i] articulation with consonantal ending articulation). Note 7 is further shortened by the need to breathe in preparation for the end of the phrase. However, the pitch-sharpening on note 7 is repeated only in alto II, while alto III presents pitch-flattening on the same note, and alto IV maintains the level of the former note. Alto II draws the deviation values to a lower-than-expected level that begins with an apparently Pythagorean procedure, going immediately to a meantone temperament strategy in notes 3 and 4, resuming a lowered Pythagorean intonation in note 5. A lower profile is common to all notes, except note 7. Alto III, on the contrary maintains a higher-than-expected Pythagorean profile, *including* note 7, which does not present any pitch-sharpening. Alto IV presents a lower Pythagorean procedure from note 3 onwards.

8-12	Note 8 presents, in each singer, a result that is akin to the behaviour of the former note. Alto I shows a tendency to Pythagorean intonation, with pitch-sharpening on note 9. Alto II, like Alto IV, opt for pure intonation with pitch-sharpening on note 11; this effect determines that the last note should go downwards, which works fine for alto II, but not so well for alto IV (here, the last note should go upwards). Alto III presents a clearly raised Pythagorean intonation all through (a pitch equalisation issue).

Tenor section

Note	Strategy
1-4	The first two notes present a meantone temperament strategy followed by what seems to be equal temperament until the end of the passage.
4-9	A characteristic behaviour is displayed in note 9 – pitch-sharpening due to text-related problems. It is not utilised by one of the singers, but it is, nevertheless, a pressing issue regarding intonation in the performance situation. Generally, the adopted intonational strategy leans towards meantone temperament, with a pure intonation tendency in note 5.
10-14	The last passage of the phrase begins with air intake in preparation for the big *rallentando* and last-note sound holding requirement. The whole passage is Pythagorean, with pitch-sharpening on the penultimate note (most probably a text-related issue).

Tenor singers

Note	Strategy
1-4	Tenor I tends to Pythagorean intonation in principle, which is mainly indicated by note 4, since note 2 apparently shows a tendency to lowered equal temperament. Tenor II begins with meantone temperament followed by Pythagorean intonation. Tenor III, after beginning with meantone temperament, decides to temper until the end of the passage. Tenor 4 exhibits a meantone temperament strategy with a sharpened note 4.
4-9	Tenor I shows a strategy towards meantone temperament, mainly. Note 5 targets pure intonation, though not fully achieving it. Note 8 is slightly sharpened in relation to the model. Tenor II begins at a Pythagorean level in the first note, pure intonation is aimed at in the second note, while slightly lowered equal temperament is pursued in the remaining four notes. Tenor III may be viewed as targeting pure intonation, with a great pitch-flattening on note 8, unexpectedly. Tenor IV seems to aim meantone temperament with deviations all along the way. Note 9 yields a particularly large pitch-sharpening (due to text-related issues, most probably).
10-14	Tenor I displays a Pythagorean strategy with pitch-sharpening on note 10, while notes 12 and 13 are slightly flattened in relation to the model. Tenor II begins with a slightly lowered note 10, following equal temperament with a small pitch-sharpening on note 13. Tenor III opts for pure intonation with a flattened note 11 and a sharpened note 13. Tenor IV is wholly Pythagorean, with a slightly flattened first note and pitch-sharpening on note 13.

Bass Section

Note	Strategy
1-6	Beginning with a Pythagorean intonation for the first two notes, the bass section adopts a lowered equal temperament, with only the already expected pitch-sharpening on note 6, shared by all basses, and most probably caused by a text-related issue.
7-10	In the last passage of the motet, the bass section seems to adopt a flattened meantone temperament, with a slightly sharpened note 7, following a greatly sharpened note 6. It must be noted that breathing is

required after note 6, in preparation for the last passage of the motet, which includes *rallentando* as well as an extended last note.

Bass singers

Note	Strategy
1-6	Bass I behaviour is largely Pythagorean, with one exception: note 4 tends to pure intonation (as the major third of the harmony). Bass III draws a deviation line comparable to bass I's, only much lowered towards the level of pure intonation/meantone temperament. Bass II produces a descendent deviation line that leans towards meantone temperament/pure intonation, with a final pitch-sharpening on the last note. Bass IV clearly indicates Pythagorean intonation with pitch-sharpening on the first two notes.
7-10	It seems that there is a common feature of the singers of the section: the pitch-sharpening on note 7. Only bass III does not emphasise this procedure. According to this point of view, the basses generally present results according to meantone temperament. Bass II displays a slightly flattened note 8, the same happening to bass II for notes 8 to 10, and to bass IV in notes 8 and 9, to a lesser extent. Bass III, however, is further flattened, especially in notes 8 and 9, unexpectedly. The deviation level for the last note is according to expectations, nevertheless.

4.3.4 - Reference frequencies results

The measurement and analysis of acquired data is the backbone of the current research. The main premise is that a meaningful intonational procedure would be exposed in a performance situation instead of one of the innumerable models built by means of theoretical work. The acquired data results would have to be examined in relation to a reference value and in relation to theoretically established models of intonation. The reference value could have been the standard 440 Hz tone, since it was given as a reference tone to the singing groups before each take of the motet. This choice would pose a problem, however. It can be seen from the results that the singers do not necessarily begin singing close enough to the frequency value given to them as a reference frequency. As a result, it is not possible to consider a theoretical (even if practical) given frequency value as being the real reference frequency value according to the performance results. An alternative solution was simply to choose a value looking for a 'best fit' option. This solution was not considered reliable by the researcher – in spite of the fact that the shape of the deviation line of the results would remain the same, the height of the line would vary according to the chosen reference frequency. This would not be useful for the so-called 'pitch-sharpening' and 'pitch-flattening' measurements, amongst others. The researcher, then, devised a procedure by which the singers themselves would provide the reference frequency for each phrase.

It has been historically expected that the reference frequency should remain unchanged throughout performance, as Padgham (1986:28), Pierce (1992:74), and Blackwood (1985:134) point out very clearly (see quotations at 4.3.5). The possibility of this expectancy not to be fulfilled in performance was a very strong one for the researcher. Therefore, there was a need for the implementation of the best possible technical procedure regarding reference frequencies in the analytical work.

It was also decided that the values of the measurements would be pitted against a few of the most important and theoretically reliable models of intonation for analysis purposes. Equal temperament, extended meantone temperament, extended Pythagorean intonation and extended pure intonation were the chosen models against which the singers' results would be pitted. Two analyses were carried out based on extended pure intonation, after an observed variation in the Royal Academy of Music quartet's results. The *zero line* of this devised analytical procedure is given by equal temperament, because it corresponds to round *cent* values, which are the measurement units universally utilised for intervallic evaluation in music (see 3.5: Analysis tools – Analytical instruments objects – Deviation results).

Some of the keynotes of each phrase were chosen to determine the reference frequency. These notes had to fulfil the following requirements:

- They must belong to chords that have strong harmonic meaning in the musical piece. This means that each chosen chord is expected to be either a tonic, dominant or subdominant harmony. This requirement tends to minimise deviation errors in the calculation of the reference frequency.
- They must not present any substantial difficulty in terms of singing technique. This requirement would diminish singer-related errors in the calculation of the reference frequency.

The thirds of the chords could lead to slightly different results for the reference frequency. As the results would depend on the singers' choices, it is best to allow both for the thirds to be included as well as not to be included in the calculations. Consequently, two calculations were performed for the determination of the reference frequencies of each phrase – the first one would include all of the chord notes, the second one would take the thirds out of the calculation. A score was prepared to show the chosen notes for each phrase of the motet, as can be seen in appendix 7.5, which refers to the reference frequencies.

As can be seen from the score, D_3 was chosen as the reference frequency for phrases one, four and five, while A_2 was chosen as the reference frequency for phrases two and three.

Equalised reference frequencies

As an alternative view of the results, an effort was made to clarify the relationship between all of the reference frequencies. The idea behind this procedure is that the sections and singers' results were to be shown according to their absolute deviations from one phrase to another. It works as if the whole motet had the same reference frequency. To accomplish this, the reference frequencies of phrases two and three were transposed a perfect fourth above, to the same value level as the others. This was done according to the Pythagorean/pure intonation procedure, the only one acceptable for scientific research. It must be noted that equal temperament does not bear any justification to be employed in this kind of manipulation, or any other that would imply its use as a standard or legitimate model.

Just for the sake of completeness, a general reference frequency of A=440 Hz. was also implemented, which would clearly show the intonational strategy differences regarding each phrase.

The results are as follows:

Royal Academy quartet

Appendix 10 shows The Royal Academy of Music vocal quartet's tables and charts. Table "RAM voice's table" and charts "RAM Voice's Charts – Phrase 1", as well as "2", "3", "4" and "5" (appendix 10.1) show the results for each phrase/singer in relation to reference frequencies *as determined by the singers*, each phrase being considered as a discrete unit in terms of representation of results. Table "RAM voice's table (equalised reference frequencies)" and charts "RAM Voice's Charts (equalised) – Phrase 1", as well as "2", "3", "4" and "5" (appendix 10.2) show the results according to the equalised reference frequencies calculated from the singers' results. This second set of table and charts is pitted against a reference frequency valid for the whole music piece, *as determined by the singers*. Table "RAM voice's table (reference frequency = 440 Hz.)" and charts "RAM Voice's Charts (reference frequency = 440 Hz.) – Phrase 1", as well as "2", "3", "4" and "5" (appendix 10.3) exhibit the results according to the reference frequency of A=440 Hz. This set of table and charts is, of course, valid for the whole music piece, and is determined by the international tuning reference. This is intended as a means of clarification about the pitch-level variation of the results throughout the various phrases of the motet. Finally, "RAM reference frequencies' results" depicts the intonational strategy of the vocal quartet in all takes of the recording session.

The Royal Academy of Music vocal quartet has defined reference frequencies that show strikingly different results from The BBC Singers. From the "RAM reference frequencies' results" (appendix 10.4) it can be seen that small differences were detected in the Royal Academy quartet's results, according to the two calculation procedures. Results in which the thirds were taken into account were slightly more differentiated than results that did not consider the thirds. For instance, the difference between the reference frequencies of phrases one and two was about –7 cents with thirds and –2 cents without thirds. In addition, the difference between phrase one and four was about –20 and –19 cents, respectively, while the difference between phrases one and five was of about –25 and –20 cents, in the same order.

From the results, it can be seen that the difference between phrases three and four is about –13 cents in the results with thirds, and about –15 cents in the results without thirds. Perhaps it would be preferable to use reference frequency values calculated without thirds, just to be on the safe side. This does not mean that the results with thirds taken into account are less reliable, only that they allow for a wider range of variation in the results. The most important point, though, is that there is an unequivocal lowering of the reference frequencies values from phrase one to phrase four, which should supposedly remain constant. These lowered reference frequency results point to a variation of about *one syntonic comma*. The syntonic comma is the touchstone of Pythagorean and pure intonation differences, as well as temperament procedures. Therefore, it is highly significant that the results derived from the experiment are found to be very near to the syntonic comma value. This is one of the most important facts brought about by this research: that *reference frequency values can be modified during a performance without being taken as mistakes.* As can be seen from the tables and charts, the results are consistent and coherent with the singers' strategies. In the quartet's measurements, results from phrase one are definitely distinct from the ones derived from phrases four and five.

The BBC Singers

Appendix 11 shows The BBC Singers reference frequencies' tables and charts. "The BBC Singers sections' results" table and its related charts (appendix 11.1) show the results for each phrase/section of the choir in relation to reference frequencies *as determined by the singers*, each phrase being considered as a discrete unit in terms of representation of results. Table "The BBC Singers sections' results (equalised reference frequencies)" and its related charts (appendix 11.2) depict the results according to the equalised reference frequencies calculated from the singers' results. This second set of table and charts is pitted against a reference frequency valid for the whole music piece, *as determined by the singers.* Table "The BBC Singers sections' results (reference frequency = 440 Hz) and its related charts (appendix 11.3) exhibit the results according to the reference frequencies based on A=440 Hz. This set of table and related charts is, of course, valid for the whole music piece, and is determined by the international tuning reference. This is intended as a means of clarification about the pitch-level variation of the results throughout the various phrases of the motet. In addition, the following tables and related charts depict the results for the singers, individually: "The BBC Singers sopranos' results" (appendix 11.4), "The BBC Singers altos' results" (appendix 11.5), "The BBC Singers tenors' results" (appendix 11.6), and "The BBC Singers basses' results" (appendix 11.7). Wrapping up appendix 11, "The BBC Singers reference frequencies' results" (appendix 11.8) evaluate the group's tendencies regarding reference frequencies intonational strategies.

As for The BBC Singers, the results indicate a different situation than that of RAM's vocal quartet. Upon examining the pertinent tables and charts, it becomes clear that The BBC Singers' reference frequencies' variations remain on the borderline of practical pitch perception (JND). The reference frequency results of phrases one, four and five, are nearly identical in both procedures – with and without thirds – in the calculation formulae. The same happens to phrases two and three according to both procedures. It seems that for The BBC Singers, differently from the Royal Academy of Music quartet, calculations with or without thirds are somehow equivalent regarding the produced results. However, it must be taken into account that a choir may behave differently to a quartet, since a fundamentally different structural feature could be relevant for the results – in a choir, several performers share the same melodic line. The researcher was led to believe that four of The BBC Singers who were participating in the recording session have absolute pitch. This could have been the main reason for the reference frequency stability of The BBC Singers.

4.3.5 - General evaluation

In textbook idealised results, the reference frequency for phrases one, four and five should remain constant, and the same should happen to the second and third phrases. Musical literature is full of references to pitch stability, definition of intonational models and related issues. A few citations could clarify the established standpoint in relation to this subject.

Parncutt (1989), page 7:

> … If intervals corresponded to specific frequency ratios, one would expect intonation to vary randomly about one of these. In fact, intonation of intervals with different just and Pythagorean versions normally varies over a range which encompasses both ratios, making it impossible to establish experimentally which of these is **"the" frequency ratio of the interval…** (Bold style applied by the present writer).

Padgham (1986), page 28:

> Actually the problem of temperament concerns all musicians and is not restricted to keyboard players. For example if the following sequence of notes is sung or played with just intervals:
>
> C – G up – D down – A up – E down – C down
>
> We finish on the final note which is 1/5 semi-tone sharp to the first note. … The difference is 21.5 cents or just over a fifth of a semitone, **which would be considered poor intonation.** To avoid it the performer must adjust (i.e. temper) one or more of the intervals involved. (Bold style applied by the present writer).

Pierce (1992), page 74:

> Sometimes just intervals are important, as in some passages in early choral music, and in barbershop quartets. Good singers will sing just intervals in such passages, **and maintain the initial key through using unjust intervals where these are acceptable.** (Bold style applied by the present writer).

Blackwood (1985:134-135), after comments on two instances of the same chord after an extended pure intonation analysis of an excerpt of *Ave regina coelorum* by Orlando di Lasso, writes:

> This difference is sufficiently large to be perceived as a modulation, and represents a distortion of the intent, which **is clearly that the initial chord and the final chord should be the same.** (Bold style applied by the present writer).

From these examples it is clear that variations in reference frequencies are generally believed to be unexpected and undesirable. Yet, it seems from the experimental results that they are prone to occur in *a cappella* ensemble singing. The relevant question that remains from the experiments in relation to this 'orthodox' standpoint is:

> *Is it preferable, from the musical point of view, to maintain a reference frequency throughout a musical piece, or allow it to express the (psycho)acoustic tendencies resulting from the musical content?*

Perhaps musicians need to redefine their (pre)conceptions in relation to intonational strategies in performance situations. Perhaps there is a need to ask why the reference frequency should remain stable throughout a work, while everything else in the music is evolving and changing all the time. Perhaps it is time to stop looking at fixed models of intonation and start exploring the possibilities of flexible intonational procedures.

5 - INTONATIONAL STRATEGIES IN PERFORMANCE SITUATION

5.1 - Introduction

This chapter deals with the intonational strategies defined in the experimental work. Important topics related to the subject are considered beforehand, to clarify some of the issues to be approached in the explanation of the strategies. The old issue of a tendency to melodic behaviour and its identification with Pythagorean intonation, as well as the harmonic bias of pure intonation are the first items to be considered. The question of target notes is then discussed, followed by the main difficulties linked to individual notes or to musical passages. Text-related issues, unexpectedly ranking very high amongst the important and influential elements regarding intonation in the research, are introduced. Following from this, other important topics such as aural feedback, live interaction between performers, the perception of melodic lines in a choral environment, and the means for pitch control in performance are examined. The concept of reference frequencies is introduced, and the section is closed with remarks on the topics of singers' musical education and ensemble singing with instrumental accompaniment.

The description of the adopted intonational strategies follows immediately, presented in a way as to clarify the issue under a few different perspectives. It makes use of the already introduced principles that came about in this research, based on the harmonic series and flexible temperament. The adopted strategies regarding reference frequencies are presented and discussed. A new concept of pitch equalisation within a choral section is unveiled. Musical issues related to phrasing and rhythm are then considered, followed by that other newcomer: text-related issues regarding intonation. The latter are examined from the viewpoint of consonantal and vocalic articulations and their possible influence on pitch deviation results in the experiments. The chapter is wrapped up with a brief discussion on the concept of level of precedence in intonational strategies, and the topic of 'double meaning' in music and its relation to intonational strategies.

5.2 - Important topics in intonational strategies

Before any consideration of the intonational strategies adopted by the singers, it would be interesting to look at the most relevant topics regarding the subject of intonational strategies in performance. In practice, some of them are overlooked or even misunderstood, while others are dealt with as if personal taste is all that is required. This may be the case with target notes and some text-related issues, as well as the intonational strategies themselves. A most common explanation for all sorts of deviation from the established intonational models relates to the need or urge for 'expressive intonation', the tendency of the leading note to lean towards its resolution, and so on and so forth. What is implied in this contention is that the intonational model would be followed if those needs did not arise. Consequently, any deviation from the model is taken as an intended one, which is dangerously inexact and misleading.

5.2.1 - Melody versus harmony

The first and probably most knowledgeable fact about intonation in performance is the melodic tendency towards Pythagorean intonation and the harmonic tendency towards pure intonation. Indeed, Pythagorean intonation was dominant throughout the Middle Ages and still is a most influential intonational procedure nowadays, according to several authorities (see, for instance, the article on 'Pythagorean intonation' in the New Grove Dictionary of Music and Musicians, 1980). String players are regarded as followers of Pythagorean intonation most of the time, and soloists of flexible intonation instruments would tend to do the same. Brass instruments, on the other hand, aim to produce sounds according to the harmonic series, consequently showing a tendency towards pure intonation. It must be noted that string and wind instruments always have technical resources for implementing micro-adjustments of pitch. It could be the player's hand inside the horn's bell, the lips' pressure or their angle of articulation (winds in general and flute, respectively), or the fingers' exact position on the string. In relation to the singing voice, however, there is no general agreement on intonational procedures, apart from the interval-stretching tendency that is considered to pervade most of the melodic procedures.

As mentioned earlier, tuning systems present different levels of implementation of the same key procedure – the division of the octave by means of *harmonic proportion*. The *harmonic series* constitutes its physical counterpart. Pythagorean intonation is the lower resolution version of such a procedure, while pure intonation can be implemented to any desired level, in spite of the fact that the resolution based on the prime number five is its only widespread acknowledged rendition. The most striking difference between Pythagorean and pure intonation resides in the so-called *imperfect consonances* (thirds and sixths). The main procedures of temperaments are designed to correct Pythagorean imperfect consonances towards pure (just) intervals. As these procedures spoil the consonance of the fifths when a limited number of pitches per octave is required, a great number of practical solutions were devised, according to specific needs of repertoire, harmonic language, etc., so as to bring minimal problems for the fifth's consonant status. Taking the thirds as an example, it can be said that tempered thirds are sized in between the Pythagorean and just resolutions of the tuning system. Thus, Pythagorean and pure intonation are the two polar resolutions of the basic procedure that defines a tuning system.

The reasoning that supports the above-mentioned intonational polarity tendencies are so strong that, in the analytical work of this research, the inclination to either procedure (Pythagorean or just) was looked for in the first place, and only afterwards the possibility of any temperament strategy was explored. This standpoint agrees with Lloyd (Lloyd & Boyle, 1978), as expounded in his article 'The Myth of Equal Temperament', about the difficulty of following a temperament strategy in performance:

> ...It is easy to play out of tune: it is a superhuman feat to play 'off the note' with exactly the mistuning required for equal temperament, for we may be sure that the player has no physical means of reproducing equal temperament with the accuracy with which a good string quartet can play in tune. Even the piano tuner with an ear trained to measure the desired dissonance, and with ample time to listen to the beats he produces, does not tune the instrument perfectly in equal temperament.
>
> ...If the piano tuner does not succeed in attaining a perfect equal temperament, how can the artist, playing a momentary note on an instrument of free intonation estimate *exactly* a dissonance which, as Helmholtz showed, must lack definition?

5.2.2 - Target notes

Upon analysing a piece of music, some of the notes are regarded as being strategically positioned in relation to other notes from the point of view of performance. They function as reference marks spread along a pathway, and are aimed at during a performance. They are called *target notes*. The definition of the eligible target notes will depend on each performer. A careful study of the piece should minimise the occurrence of personal differences in the process of choosing the most relevant notes as the targeted ones in performance. In addition, an open discussion of the matter would help to minimise opposite points of view related to this issue. This is possibly a matter that would rely ultimately on personal convictions; however, as happens in the performance of big groups that are bound to be conducted, the conductor's leadership would provide a unifying concept related to this as well as other important issues.

The question of target notes was somehow overruled in this research by a more troublesome topic: differences in intonational strategies linked to text articulation. This is quite clear from the reading of the 'Analyses and Results' chapter. The importance of target notes, nevertheless, is paramount for the correct planning and implementation of a sound intonational strategy. Appendix 7.6 shows one possible selection of target notes score.

5.2.3 - Technically difficult notes or passages

There are many especially difficult notes and passages in music practice. Problems of range, long sustained notes, very short notes, text articulation in lesser known languages (perhaps even in the mother tongue), rapidly articulated text, quick melismatic notes (*coloratura*), breathing problems in specific musical situations, notes that belong to complex harmonies, just to mention some of the difficulties that must be faced by the singer while performing, can be found.

Difficult notes or passages are often a cause for uncertainty and lack of precision in musical practice. Some problems are easy to detect but not so easy to resolve, and may bring out more subtle by-products that are difficult to deal with. For instance, the vowel [i] sung at a high pitch brings forth the need for clear identification because it has no clearly defined formants to identify it; it may also brings about other problems, like a slight alteration in pitch due to the 'intrinsic pitch of the vowels', which would easily go unnoticed. Very often, situations that are even more complex arise in a musical performance. As a result, the common reaction of the performer is to focus on the more salient problem, so to speak, the one that is revealed in the foreground, leaving any other difficulty barely touched. This kind of situation – paying attention mostly to the more salient problems – may be more common than expected. There is a strong possibility that some analytical problems encountered in this research are rooted in this fact. This is almost surely the case for text-related issues.

5.2.4 - Text-related issues

Consonantal articulation

Strong consonantal articulation shows the extreme possibility of pitch variation induced by articulatory movements of the larynx muscles and other articulatory devices such as the jaw and tongue. The tones' onset presents transient attacks that bring a lack of pitch definition to the initial part of the note. This rather chaotic beginning may influence somehow the remaining part of the note, causing pitch-sharpening or pitch-flattening.

Vocalic articulation

According to Ternström and Sundberg (1986), in a choir, the feedback (of the singer's own voice) can at times be masked by the reference (the other singers' voices). This phenomenon may cause a pitch variation in vocalic articulation for the same tone. In experimental work, the presence of masking noise caused an increase in pitch shifts, while normal feedback provided a partial correction of the pitch-shifting effect. Bush (1981) proposed an explanation for vocalic pitch variation, based on the upward pull that the larynx suffers during some vocalic articulations, which would cause pitch-sharpening. Pitch shift effects on vowel articulation are described according to the concept of the *intrinsic pitch* of the vowels. According to Ternström et al. (1983), an experiment was performed involving the singing of several pairs of vowels and the measurements of the pitch raising or lowering caused by the articulation from one vowel to the other. They found that changing to the vowels [i] or [y] from any other tried vowel had the effect of raising the pitch, the opposite happening to [ʹ] and [e] vowels. Unfortunately, the experiment did not use the vowel [u] as target. The vowel [a] is known to present the effect of lowering the pitch, also. In the *Ave Verum Corpus* motet, most of the pitch deviation effects happen with the concurrence of the [u] vowel (*'corpus'*, *'natum'*, *'passum'*, *'immolatum'*, *'perforatum'*, and *'praegustatum'*).

5.2.5 - Aural feedback and live interaction between performers

Choir acoustics is a whole research field by itself. Some basic facts related to performance situation may not be entirely thought out by the composer at the time of music writing. Moreover, music practice changes over time, as new artistic tendencies and performance conditions arise, challenging the performer as a re-creator of the (hopefully) original music behind the notes. Room acoustics have changed a lot during the last two hundred years, making very difficult the replication of the ideal acoustic conditions for early music performance. The situation is not necessarily better for modern music. The sheer size of modern concert rooms does not help the performance of most kinds of music. The achievement of a good intonation constitutes a very demanding challenge in performance in this context. For choral singing, acoustic feedback is the most effective way of implementing pitch control, as suggested by several experiments (as shown by Ternström and Sundberg, 1986, and Ternström, 1994, amongst others). Intonation must be one of the most energy-consuming tasks for a choir section, since the singers are supposed to replicate the same melodic line. Fortunately, singing together presents some specific characteristics that may help each singer to fulfil his or her task successfully.

A well-planned spatial disposition of the singers will help to accomplish a good intonational strategy. Aural feedback will assist in singing near unison within the limits of a choir section, in achieving a good sound balance between all singers, in controlling intonation in real time with the application of some useful tools for its implementation, but also will present a few unexpected side effects. An important one is the *pitch equalisation* strategy that seemed to happen with The BBC Singers. This question will be examined in 5.3.4.

Perception of a choir section's melodic line

One of the most important and overlooked facts about choral performance is related to the perception of a section's melodic line. It is a common belief that musicians perceive a rather narrow cluster of frequencies all the time, originated from the performers of each section. Thus, in the case of the *Ave Verum Corpus* motet, four frequency streams related to the four voices would be listened to. The more experienced the singers are, the narrower the band of frequencies would be. This idea may be reinforced by the fact that, for the performer, it may seem that different notes are being heard all the time, as performed by his or her fellow singers (especially if something goes wrong on intonation). In fact, this idea is far from the truth. If all singers are singing near enough to each other in terms of fundamental frequency, *only one melodic line will be perceived.* Beats will be noticed in nearly vibrato-free performance, accounting for differences in pitch amongst the singers. Personal differences in pitch will not be noticed in vibrato singing, because beats are hidden by vibrato.

In the audio CD, tracks 33 to 67, The BBC Singers replications can be heard. Upon listening to the replications of the choir sections, followed by the replications of all singers, it will be noticed that the melodic lines are identical. Beat perception, however, is greatly enhanced in the latter case because individual melodic lines do not coincide.

However, it might be possible to perceive mistakenly sung notes that would be separated enough from the common pitch frequency as to fall outside the required beat rate frequency for perceptual fusion. This fact, of course, is prone to happen within the limits of a choir section. If the singers are positioned too near to each other, a masking effect could contribute to the false impression that the mentioned 'narrow band of frequencies' is actually perceived, in the case of large individual differences in pitch nearby a perceiving singer. In that case, the singer will not perceive him or herself in a balanced way, and may be more sensitive to the pitch differences perceived by each of his or her ears (in a quasi-binaural perception, if it can be described so). In any case, the amount of deviation of the other singers will determine if the perceived pitches can be detected as different than the average pitch of the choir's section.

5.2.6 - Pitch control in performance

From what has been seen so far, there are some important elements to be considered in relation to pitch definition by each singer. They were dealt with more extensively in chapter two (Intonation). If problems related to vocal technique and musicianship are not causing any trouble, the main issues are:

Categorical perception

This is the basic tool for pitch perception. For most, it is considered the only serious option for pitch perception and control.

Beat detection

This tool makes possible an increase in pitch resolution. It has been for centuries, the tool that allows the implementation of temperaments; however, it has not been used for pitch control in performance. A plausible explanation is that a faulty music education and the assumption that vibrato must be learned by singing students as a natural component of the correct voice technique constitute important causes for the demise of beat detection as a valuable tool for improving intonation.

Vibrato singing and pitch perception

Vibrato is present in several vocal styles and techniques all over the world. However, its use in one culture may be completely distinct from other cultures. Vibrato in the singing voice presents some important features that may be linked to intonation directly or indirectly. They are:

- Vibrato helps vowel identification in high-pitched text.
- Vibrato impairs beat perception, according to the same psychoacoustic principle that helps vowel identification at high pitches.
- Vibrato does not help pitch definition, because of its action on beat detection.
- Vibrato, as usually understood nowadays, goes hand in hand with loudness, which meets modern singing voice demands, especially in operatic singing and comparable performing situations. From the psychoacoustical point of view, changing loudness may lead to a pitch shift perception.

A categorical perception problem may be caused by vibrato, when utilised with a great amplitude oscillation. There are plenty of examples in commercial recordings of inaccuracies in pitch, or rather extreme difficulties regarding note discrimination from a perceptual point of view, due to the extent that vibrato has been utilised in the (almost always loud) passages. The major part of the examples comes from operatic recordings or from choral pieces performed by 'operatic' singers (usually choirs from Opera Houses).

There should be a clearer distinction between the various types or instances of vibrato. Sundberg (1987) states that vibrato, as practised by western operatic singers, is similar to two other types of phonation frequency techniques: tremolo and trill. The first is characterised by a somewhat quicker and irregular modulation rate in relation to the common operatic vibrato, while the latter presents a typical modulation amplitude generally exceeding ±2 semitones (the expected limits for 'normal' operatic vibrato). Winckel (1953) shows that the amplitude of the vibrato undulations varies with loudness of phonation. The researcher understands that the only 'natural' vibrato is the one that occurs *unintended* by the singer; it presents very small amplitude (i. e., variation in pitch). At any time the singer *intends* to use vibrato, as seems to be the case in most operatic vibrato, it is greater in amplitude than natural vibrato and should be considered as a musical *embellishment* rather than a natural singing technique. Intended vibrato belongs to stylistic procedures. Style is not something natural – it is cultivated, artificial. It is not common to all types of music, or it would not be a style. Vibrato limits ought to be the limits of categorical perception; every time this limit is surpassed vibrato becomes a trill. Unfortunately, most of the 'vibrato' heard nowadays is actually trill singing that arises as a result of loud singing with *intended* vibrato.

Masking

Masking is an important feature of psychoacoustics that has important implications for pitch perception and control. The masking of weak harmonics may help tempered intervals to be taken as acceptable ones in terms of consonance perception. It will be more or less effective depending on the shape of the formants. If it enhances beating harmonics of a supposedly consonant tempered interval, the interval will give away its impure status as a consonance. If the offended harmonics are masked by lower strong consonant harmonics, the roughness and beats will not be perceived. In a group of soloists, harmonics are the available tool for the implementation of beat perception as a means of pitch fine-tuning. Often, lower harmonics are strong, sometimes even stronger than the fundamental frequency, which helps beat perception between the lower harmonics of lower voices and the fundamental frequencies of higher voices.

In a choir section, sung notes are not usually masked at the fundamental frequency level by other singers. This fact makes the perception of beats originated from fundamental frequencies more effective, since not only masking is avoided at this level but also the loudness of the fundamental frequency is usually stronger than the loudness of harmonics of higher formants. Consequently, a choir has hypothetically better conditions for pitch control than a group of soloists, provided that beat perception is functional.

Absolute pitch

The ability of some musicians to recognise or even to name or produce any note on demand is called *absolute pitch* or *perfect pitch*. This is yet another issue that bears a reasonable amount of misunderstanding and lack of thorough knowledge. It is not known what is the essential characteristic of absolute pitch, since people can make certain kinds of mistake and yet claim to have this coveted musical ability. Some absolute pitch 'owners' may hear a tone that is deviated from the expected model (this is yet another confusing issue!) and still label it correctly, according to the principle of categorical perception. Others have developed a kind of transposed absolute pitch ability, referred to a flat tuned piano with which they grew up, or to the B flat reference of the brass instrument they have studied, and so on. Some people think that absolute pitch is a precious advantage for its owners, while for others *relative pitch* – which is the ability to recognise and replicate intervals from a given reference frequency – is of paramount importance for a musician.

The important point regarding absolute pitch in relation to this research subject is that it is highly probable that absolute pitch may guarantee the reference frequency stability. This is perhaps neither a good nor a bad feature, just a peculiar characteristic of absolute pitch owners. As can be seen from the results of this research, no special accuracy is attained by any of the singers that could be related to absolute pitch capabilities. The subject of absolute pitch has to be explored much further yet in relation to what is known in order to establish any real benefit in relation to its musical usefulness.

5.2.7 - Reference frequency strategies

Music performance presupposes a musical context. There are always references to some source material, musical structure or notes (pitches). References are necessary for musical organisation. In vocal music, the vast majority of the repertoire assumes a reference pitch, to which the whole piece, or at least its minor divisions (phrases, for instance), is related.

In the case of the *Ave Verum Corpus* motet, it was decided that the reference frequency for each of the phrases would be defined from the performance itself, rather than from a theoretical value. This procedure allows us to assess the deviations' results in relation to the *zero* point of equal temperament unambiguously. The option of determining the results in relation to an A=440 Hz was considered artificial and prone to perpetuate the common tendency of expecting results according to fixed models (see comments at 4.3.4). During the course of the laboratory work, an extremely beneficial effect of the idea behind this premise was discovered – the reference frequency results brought about a completely new concept of intonational strategy in performance. Nevertheless, what helped most was the idea of flexibility from the very beginning, leaving to the performers the responsibility of decision, instead of to a standard theoretical value.

5.2.8 - Other important issues on the subject of intonation in performance

Musical education (cultural influences)

It may be that musical training can affect intonation to the level of determining a strategy based on temperament or on the harmonic series principle. It also may be that the musicians supposed preference for equal temperament or Pythagorean intonation in many of the experiments carried out on intonation is due to musical training based on piano tuning – stretched equal temperament. It must not be forgotten, however, that in all of the results of this research there was no detectable learning effect, and the results of one singer did not seem to have suffered any particular influence relevant to the determination of a particular intonational strategy from any other performer. This issue may be linked to the fact that all singers made use of vibrato. It is not implied that singers do not interact with each other while performing. Furthermore, equal temperament does not seem to have scored well as a model in the experiments.

These facts suggest that fixed models of intonation, as happens in musical training with rigidly tuned instruments, do not exercise influence in the determination of intonation at a microtonal level more than categorical perception. On the contrary, some of the intonational strategies delineated in the experiments suggest that singers did intend some of the results, such as the tenors' notes 3 and 4 of the first phrase (pure intonation), differently from what would be expected of a training based on equal temperament. In this sense, most of the values seem not to agree with a 'brain-washing' technique based on piano training, because equal temperament was very seldom followed, if ever.

As a necessary conclusion to the comments aforementioned, Pythagorean intonation should not be just the result of a 'craving for stretching', as Sundberg puts it, as it were a kind of compulsion. It could just be the result of an intended intonational strategy, as if, for instance, the low-resolution implementation of the harmonic series principle might be a most adequate means to express melodic tendencies, while a more advanced resolution would be implemented only when a harmonic context required it (which would be a very common situation in the western music tradition). If it is taken into account that some musical examples cannot be satisfactorily resolved within the environment of the harmonic series principle, and as a result temperament must be called for, the implementation of intonational strategies would cover the entire range of possible tuning solutions. From the low-resolution (Pythagorean intonation) of the harmonic series principle to its high-resolution implementation (extended pure intonation), intonational strategies will make use of a flexible temperament procedure at any required (or even desirable) time. This instance holds each singer as a co-responsible partner for the intonational strategy adopted for a specific piece of music, on a particular occasion. Rather than a chaotic collection of errors and miscalculations, ensemble singing intonational strategies may depict the real condition of musical awareness and education of the performers.

Instrumental accompaniment

Instruments tend to be affected by fixed tuning procedures. In spite of the fact that the vast majority of instruments allow some pitch variation in performance, intonation is most of the time thought out as a given parameter of musical practice. String instruments are the most manageable ones, not counting the singing voice, when it comes to intonation flexibility. They still present a serious limitation in relation to the singing voice: their open strings are fixedly tuned. This characteristic may have helped to institute one of the main prejudices regarding intonational strategies: the idea that reference frequencies must remain constant in performance. After all, even the most flexible musical instruments (apart from the singing voice) define a given pitch (note) as a reference throughout an entire piece of musicl Hardly anyone would dare to think of allowing such a reference to be rightfully changed during a performance. This situation is being contested in this research. Nevertheless, the fact remains that when singing with instrumental accompaniment, singing voice intonational strategies would necessarily maintain a stable reference frequency.

5.3 - Intonational strategies disclosed in the experiments

The results may appear to show a rather chaotic picture of intonation at first sight. However, as seen in chapter four, the singing groups presented results according to some of the predicted tendencies together with unexpected behaviour. Deviations toward Pythagorean and Pure intonations were detectable according to the harmonic series principle. As for the temperament-like procedures, a mixture of meantone temperament and other tendencies (perhaps attempting to follow the 'standard' model of equal temperament) were noticed.

It is worth noting that a value of about seven cents between different pitches fairly represents the smallest micro-interval that can be perceived melodically. This level of perception is congruent with the amounts of deviation usually proposed for most of the temperament procedures in music history. This followed the researcher's experience of sound editing of replications of intonational analyses and the singers results, involving a large number of micro-transpositions of notes from equal temperament to the required pitches. A micro-interval of about the mentioned size coincides with just noticeable difference (JND) in practice. Consequently, in this research, deviations of about a third of a syntonic comma may not be considered meaningful deviations in terms of intonational strategies, because vibrato singing was used almost all the time, thus making beat detection unworkable.

Harmonic differences require less deviation; a difference of one or two cents can be quite easily perceived with sustained sounds when the interval is expected to be consonant. This perception occurs by means of beat detection, of course. As a rule, the greater the number of different parts that are present in the composition, the easier it is to perceive harmonic beats. In replications of the pure intonation analyses, performed by the researcher by means of a Yamaha SY99 synthesizer with a precision of 1.171875 cents, some of the (pure) thirds and a few other intervals still exhibit perceptible beat wavering due to interval inexactness.

From what has been considered in the last two paragraphs, it can be inferred that vibrato singing cannot guarantee a consistent deviation towards a desired 'model' of intonation, because pitch cannot be controlled by means of beat detection. Even so, beat detection would be useful indeed for controlling pure intonation and some intervals of Pythagorean intonation; consequently, *there is no practical way to adhere to any temperament as a model to be followed.* All of these considerations add to the reasoning that reinforces the researcher's explanation that intonational strategies must be centred on the harmonic series principle and the flexible temperament principle. The 'cultural' hypothesis also does not work at this level: if a musician learns a model of intonation, he or she will only be capable of replicating it at the categorical perception level, which puts within the same margin of error every possible intonational model based on temperament (and also on tuning system).

5.3.1 - Intonational strategies derived from the harmonic series

This section refers to appendices 10 and 11 (mainly 10.1 to 10.2, and 11.1 to 11.2): RAM and BBC overview tables and charts (with reference frequencies defined by the singers), as well as to Appendix 7.2: *Ave Verum Corpus* motet's numbered score.

It was noted that the bulk of the intonational strategies were related to the harmonic series principle. It must be said that the lower resolution of its implementation – Pythagorean intonation – seems to have been targeted most of the time. This is not easily noted from an overall look at the results, as musical and problematic text-related procedures permeate both groups' results in all of the phrases. If this fact is continuously taken into account, it is possible to follow tendencies in the intonational strategies according to the harmonic series principle and to the flexible temperament principle.

As for the strategies related to the harmonic series principle, the overall tendency to Pythagorean procedures is indicative of the predominant melodic behaviour of the singers. In vibrato singing, it seems to be easier to think of scales than chords. At some points, though, some of the singers were busy sorting out the best way to deal with harmony. This is very clear in the tenor's first phrase. Not only the quartet singer but also the choir's tenor section decided to implement pure intonation in notes 3 and 4, which refer to the fifth of the E minor chord. There is total agreement about this procedure, even from the tenors of the choir, individually.

Similar behaviour is demonstrated in several other passages of the motet. All sopranos adhere to Pythagorean intonation in the last four notes of phrase 2. In the same phrase, the quartet alto defines pure intonation for the passage from notes 6 to 9, while the alto section of the choir opts for Pythagorean intonation. The vocal quartet's tenor utilises pure intonation at the beginning of phrases two and three (C# as the major third of the chord), while the tenor section of the choir goes up in pitch from pure intonation in the first three notes of the second phrase, and from Pythagorean intonation to pure intonation in the beginning of the third phrase. These different behaviours of the tenor section may be related to rhythm and phrasing. The alto section defines Pythagorean intonation in notes 8 and 18 of the third phrase with total agreement by the singers. The tenors section also defines pure intonation in note 7 of the third phrase, with only one exception (tenor I). For them, note 13 of the third phrase seems to obtain general agreement, being directed to the raised deviation value of Pythagorean intonation.

5.3.2 - Intonational strategies derived from temperament-based procedures

Temperament strategies were outweighed mainly by text-related issues (consonantal and vocalic articulation) and to a lesser extent by music-related topics (phrasing and rhythm). In this research, music and text-related issues may have masked temperament-based procedures, making their correct evaluation practically undetectable. For instance, in the first phrase, altos define equal temperament in the first four notes. The alto section tends to equal temperament throughout the whole phrase, while the individual singers seem to be more 'democratic' in their strategies. This will be commented upon when considering pitch equalisation and text-related issues (5.3.4). The alto singers give another interesting example in the third phrase, from the beginning until note 8. They start with deviation values that are sharpened in relation to the harmonic series, coming then to its level. Afterwards, they take the descending direction towards pure intonation (in notes 5 to 7) without really getting to it, thus defining a temperament strategy. Finally, they choose Pythagorean intonation in note 8. Only alto III of the choir seems to opt for Pythagorean intonation throughout the entire passage.

Intonational strategies regarding thirds clearly indicate the diversity of the singers' viewpoint. The first three notes of the fourth phrase give rise to all sorts of procedures: the vocal quartet's soprano adopts a Pythagorean strategy, while the tenor opts for pure intonation. Both are very clear about their preferences. As for the choir soprano and tenor sections, temperament seems to be the resultant behaviour, but individual options make use of the whole spectrum between Pythagorean and pure intonations.

5.3.3 - Intonational strategies for reference frequencies

This sub-section unveils one of the most striking findings of the whole research – the fact that singing groups can redefine the reference frequency values of a piece while performing. Both groups developed coherent and consistent strategies in relation to the subject. The Royal Academy of Music quartet took the decision to lower the reference frequencies for the last two phrases. Actually, the reference frequency was lowered in the first part of the third phrase, as anticipated in the first intonational analysis according to extended pure intonation and may be easily seen in the associated charts. As for The BBC Singers, all of the variations in relation to the reference frequencies were situated within the perceptual limits of JND. They do not represent, therefore, a departure from the reference frequency established at the beginning of the piece. Again, the relevant charts show the stability of the reference frequency in all of the phrases of the motet.

The approximate values for the reference frequencies' variations for both groups are self-explanatory. The Royal Academy of Music quartet's total variation of about –7 or –4 cents (for averages that take into account the thirds of the chords for their calculation, or not, respectively) between the first and third phrases reveal a relative stability of the reference frequencies until then. A closer look at the values throughout the third phrase reveals the lowering in pitch that originates the fourth and fifth phrases' reference frequency results of nearly a syntonic comma lower. The BBC Singers' results in relation to the reference frequencies bounce down and up and again down and up, regardless of the presence of thirds in the reference frequency calculations. Hence the strong possibility that absolute pitch may have had a role in it. Also, as will be commented upon in the following paragraphs, a long experience of singing together may lead to a compensatory intonational strategy, that may help to maintain the stability of the reference frequencies.

To make the topic of reference frequencies yet clearer, two further sets of tables and charts were implemented. The first one equalises all of the reference frequencies, by transposing the 'A_2' results of phrases two and three by an ascending perfect fourth, and then taking the average result as a reference frequency for the whole piece. As an alternative, a reference frequency is calculated for the whole piece from the standard A=440 Hz frequency. As already commented upon elsewhere, the two mentioned sets (and for that matter, any set) do not modify the results themselves. Instead, the results are moved up or down, their vertical positioning modified according to the models, as if looking for a 'best fit'. It must be noted that equal temperament and the other analytical models do *not* change the actual values of the measurements. These are just moved around in relation to the reference frequency. The stability of The BBC Singers' reference frequencies is very clear, while the Royal Academy of Music vocal quartet showed that reference frequencies are also flexible, by lowering them from the third phrase onwards. The results are shown in appendices 10.2 to 10.3 and 11.2 to 11.3: The BBC Singers and Royal Academy of Music quartet's tables and charts, with equalised reference frequencies and with a general reference frequency based on A=440 Hz.

The document "Reference frequencies, general averages" shows the approximate calculations of the reference frequency variations for all phrases of the motet related to each group (see appendix 12: *reference frequencies general averages* tables and charts).

5.3.4 - Pitch equalisation within a section of the choir

It is important to bear in mind the intrinsic difference between the groups when examining the results. Results from the choir sections seem to be more balanced then the ones from the quartet. Upon looking at individual results within the choir sections, it comes to the eye that the singers' behaviour can actually be even more irregular than the behaviour of the quartet's singers. Some interesting phenomena seem to occur in choral singing that may explain the overall balance that is apparent in the sections' results. (It must be remembered that there is perceptually only one melodic line per section!). Firstly, there may be a tendency to move by inertia – after deviating, melodic lines may tend to go along with a comparable amount of deviation, until re-routed for strategic reasons. Appendices 11.4 to 11.7 bring examples of pitch equalisation ("The BBC Singers sopranos results", etc.).

A most clear example of pitch equalisation within a section of the choir is exhibited by the singers of the tenor section, in the first phrase. If it were not for music and text-related issues, tenor I would continue with the same raised deviation, tenors II and IV would follow the models, and tenor III would present only lowered values. Secondly, there seems to have been manifested a tendency to pitch equalisation within each section – it was present all the time, as can be seen in the next paragraphs. The first three notes of the fourth phrase of the tenor section are a good example of pitch equalisation. There, tenor I exhibits Pythagorean intonation, tenor III opts for pure intonation, while the others decide to temper, the overall result being a temperament-based intonational strategy. The following occurrences that call for the concept of pitch equalisation in order to be better understood can be pointed out:

- Soprano I always presents raised deviation values, and is partially compensated by sopranos III and IV in the third phrase and by soprano IV in the fifth phrase. In the other phrases, there is no clear evidence of compensation that brings the soprano section to slightly raised values most of the time.
- Alto III also presents raised deviation in all phrases except phrase three. In phrase one, it is equalised by altos IV and II; in phrase II there is a small compensation by alto II, while in phrases four and five it is equalised by alto IV. In phrase three, alto IV goes slightly down, with no evident compensation.
- The tenor section presents the following results (by phrase) regarding pitch equalisation:
- First phrase – tenor I presents raised deviations, while tenor III deviations are lowered.
- Second phrase – tenor III deviations are lowered, and tenor IV deviations are slightly raised.
- Third phrase – pitch equalisation happens as in the first phrase.
- Fourth phrase – tenor III goes slightly down, balanced by tenors I and IV.
- Fifth phrase – tenor III deviations are slightly lowered, with no evident equalisation.
- Bass section:
- First phrase – basses I and II deviations are lowered, while bass IV deviations are raised.
- Second phrase – bass II deviations are lowered and bass IV deviations are raised.
- Third phrase – pitch equalisation happens as in the second phrase.
- Fourth phrase – basses II and III deviations are lowered, while basses I and IV deviations are raised.
- Fifth phrase – bass III deviations are lowered, and bass IV deviations are raised.

The overall shape of the deviation values presented by individual singers within the choir sections suggests that *pitch equalisation* may occur in performance as a matter of fact. Speculating whether this phenomenon would only happen with groups that are used to singing together or if a group of singers brought together for the first time would be prone to adopt the same behaviour is a matter for further investigation.

5.3.5 - Music and text in the context of intonational strategies

One of the most striking suggestions that can be taken from this research is that topics such as the musical conception of the singers and, especially, text-related issues, are of paramount importance in relation to intonational strategies in performance. The tenor choir section's results for the first phrase are very clear on this question, as commented upon in the first paragraph of the sub-section '*Pitch equalisation within a section of the choir*', above. In the third phrase, the syllable 'TUS' (note 4 or five, depending on the choir's section) exhibits pitch-sharpening, definitely linked to text-related issues, since the harmonic context is different for the different sections, but the effect on intonation remains the same.

One interesting feature of these issues is that they may lead to different intonational strategies, all depending on the individual singers' musical conceptions and/or musicianship, as well as on technical training. In notes 17 to 20 in the third phrase the quartet's bass and the bass section of the choir mirror each other in terms of intonational strategy, exemplifying this kind of situation. From the point of view of technical training, it becomes clear that text articulation is not dealt with in relation to intonation in singing classes. Professional singers may have additional difficulties if compared with amateur singers, since vibrato singing – which makes pitch control more difficult to achieve – is considered not a stylistic option, but a desirable and constant companion to singing technique. It may also be that text-related variations in pitch are considered as 'expressive intonation', a very common explanation for anything that is not well understood on the subject.

5.3.5.1 - Musical issues related to phrasing and rhythm

The following comments are made according to their importance, when both issues are relevant to the intonational strategy.

The issue of musical phrasing was somewhat masked as an influential factor on intonational strategies due to the overwhelming presence of text-related deviations results. Musical phrasing accounts for syllable underlining in terms of emphasis and dynamics, as well as for changes in speed, which can exercise some degree of influence on intonation. All sopranos except soprano IV of the choir section seem to underline note 15 of the third phrase for no stronger reason than musical phrasing. It would be possible to consider the example as being related to vowel articulation, but it is reasonable to consider phrasing a more adequate motive for the results. Alto II shows an interesting deviation value in note 8 of the third phrase, which is greatly flattened in relation to the other singers of the section (and even the quartet alto). The most plausible explanation is linked to the de-emphasis of the note in the phrase, together with a probable greater dynamic softening. Perhaps the basses give a clearer example of the influence of musical phrasing in the third phrase, notes 11 to 15. All of the underlined notes are sharpened (though the last one with the addition of strong consonantal articulation), while the notes placed in weaker phrasal positions are flattened in relation to the others.

The quartet's alto provides a good example of musical phrasing, in notes 9 to 11 of the first phrase. At first sight, it seems to be a question linked to text articulation. The choir section, however, does not confirm this approach, portraying a different intonational strategy. In this kind of context, the best explanation for the singer's behaviour is related to musical phrasing, with the associated emphasis and de-emphasis of the notes according to their position or status in the phrase.

The duration of the notes may have an influence on pitch in performance. In ensemble singing, the vocalic part of short notes are usually shorter than equivalent notes in instrumental playing due to consonantal articulation. Thus, the onset and very often the release of such notes suffer the influence of transient attacks from consonantal articulation. All of these factors demand more attention and distract from pitch regulation, as well as making it more difficult to control, in practice. What follows is a list of the main circumstances in the motet that favours this kind of situation:

- Second phrase, soprano: note 11.
- Third phrase: notes 17 (soprano), 14 (alto), 17(tenor), and 15 (bass).
- Third phrase: notes 20-22 (soprano), 17-19 (alto).
- Fourth phrase: note 19 (soprano and alto).
- Fifth phrase: notes 9-11 (sop), 5-7 (alto).

As can be seen from the results, there is no meaningful deviation reinforcing rhythmic influences (at least related to sound length) on intonational strategies. As the motet was chosen for the experiments based not only on its virtues, but also on its lack of problematic features, it may be that phrasing and rhythm-related difficulties might be more influential in most of the choral repertoire than it was in the *Ave Verum Corpus* motet. The overall impression is that phrasing and rhythm should exercise a greater influence on intonational strategies than is depicted in the results of this research. Were text-related issues not as relevant as they seem to have been, music-related issues would probably be more clearly detected.

5.3.5.2 - Text articulation issues related to consonantal and vocalic articulations

Bringing forward a massive and unexpected presence in the results, text-related issues in intonational strategy unveil a new work field to be explored. The scope and range of influence that consonantal and vocalic articulations exercise in terms of pitch definition in ensemble singing will be seen in the following paragraphs. In most of the results, both procedures coexist. A list of the relevant occurrences related to pitch deviation, usually causing pitch-sharpening due to consonantal and/or vocalic articulations, follows (this refers to both groups, when not stated otherwise):

Predominantly consonantal articulation

- Sopranos, first phrase – notes 13 and 15.
- Quartet's alto, first phrase – notes 9, 11, and 13.
- Tenors, first phrase – note 8.
- Basses, first phrase – notes 6, 8, and 10.
- Basses, second phrase – notes 5 and 10.
- Sopranos, third phrase – notes 5 (all except soprano IV), 12 and 17 (all except soprano I).
- Altos, third phrase – note 9.
- Tenors, third phrase – note 12.
- Basses, third phrase – notes 5 and 10.
- Basses, third phrase – note 15.
- Sopranos and choir basses, fourth phrase – note 2 (the other singers and sections seem not have been influenced by consonantal articulation).
- Tenors and basses, fourth phrase – notes 8, 11 and 14 (short note with consonantal articulation; the only exception is bass 1, note 11).
- Sopranos, fifth phrase – note 11 (short note).
- Altos, fifth phrase – notes 7 and 11 (short notes).
- Tenors, fifth phrase – notes 9 and 13 (short notes).
- Basses, fifth phrase – note 6 (short note).

Predominantly vocalic articulation

- Choir's tenor section, first phrase – notes 13 and 15.
- Basses, first phrase – notes 13 and 15, both related to vowel articulation.
- Altos, second phrase – notes 4 and 5.
- All voices, second phrase – penultimate note.
- Sopranos, tenors and basses, fourth phrase (surprisingly, the altos do *not* present pitch-sharpening) – note 5.
- Soprano section, fourth phrase – notes 8 and 11.
- Soprano and alto sections, fourth phrase – note 19 (short vocalic articulation — indication of influence of the intrinsic pitch of vowels, in this case accompanied by consonantal articulation). Individual singers of the soprano section are not quite sure about their tendencies, but the overall result agrees with Pythagorean intonation.

It seems that text-related issues are more relevant for intonational strategies than target or musically stressed notes (related to phrasing and rhythmic procedures). In some passages of the motet, a mixed strategy seems to have been shown by the singers in relation to pitch deviation results. In the present research, there may be plenty of evidence that some vowels are treated as if they have an 'intrinsic pitch' independently of vocalic changing articulation on the same note (see 1.2.4). Furthermore, the combination of consonantal plus vocalic articulation may enhance some of the possible pitch-shifting effects. If this were found to be true, it could hardly be called 'intonational strategy'. Perhaps a lack of specific training regarding the relationship between text articulation and pitch is pointed out in the results. This problem might be avoided with appropriate training and constant attention, but only further research might clarify the issue.

5.3.6 - Effect of the level of precedence on intonation

All these deviations seem to constitute, at face value, a larger picture of chaotic results, as mentioned earlier. However, as was seen in this chapter, there is an underlying order in the manifested results. It seems that it is possible to predict intonational strategies, but it also seems extremely difficult to achieve total agreement amongst the singers. Possibly, one of the main factors that may impede the achievement of even more coherent results is related to what is considered more relevant by each performer. It is highly probable that the attention of the singer would be focused on what he or she considers as being more important in the music piece, thus causing intonation to reflect such attitudes. Decisions about intonational strategies would be made according to the *level of precedence* of musical elements. The singer's musical education, training and other personal attributes would determine the *level of precedence*. The singer as a human being would decide what is more important and consequently more likely to receive more prominent attention.

It may be a controversial topic in the subject of intonation, yet it is an important one. Music and text-related issues quite often bring about one or two disagreements in relation to other singers' results, which implies different approaches or, at least, different technical solutions than the one generally agreed upon. For instance, soprano IV of The BBC Singers behaves differently than the others in the third phrase, note 5. All sopranos and the choir's bass section decide to implement a different strategy than the other singers in the fourth phrase, note 2. This phrase brings out other interesting examples. Note 5 presents pitch-sharpening shared by all singers, except altos. Bass I does not agree with the others (together with tenors) in note 11, surprisingly. Finally, the choir's soprano section follows Pythagorean intonation on the last four notes of the phrase, but the singers do not seem to agree amongst themselves. Is the latter example a case of pitch equalisation within the section, a case for the 'level of precedence' issue, or both?

Intonational strategies related to double-meaning issues

It is sometimes difficult to determine what the relevant strategy is, or even if more than one procedure could be adopted concomitantly by different singers of a group, which leads to the issue of double meaning of musical elements regarding intonational strategies. Double-meaning issues are related to the musical construct, usually linked to the harmonic net of the piece.

By recalling the motet's harmonic structure, it can easily be noted that some of the harmonies can be interpreted in more than one way. For instance, in bar 12, the first beat may be considered an extension to the minor ninth dominant chord or simply a harmonic *appoggiatura*; intonational solutions would differ for each of these possibilities. Usually, diminished chords are the messengers of double-meaning harmonies, as happens four times in the third phrase and in the fifth phrase (second beat of bar 34).

It must not be forgotten that double-meaning issues may be related to other musical parameters than harmony. It may be that for many performers text-related issues are often imbued with a double meaning in terms of musical content. This question may be linked to the *level of precedence* issue examined above, if for any reason it is found difficult deciding what is more relevant – phrasing and rhythm or text articulation.

On these occasions, the *flexible temperament principle* can be the great equaliser in terms of intonational strategies.

6 - CONCLUSION

6.1 - Introduction

New concepts on intonational strategy brought about by this research are dealt with in this last chapter, alongside possibilities for future research on the subject and related issues. Section 6.2 considers the new concepts, beginning with principles of intonational strategies regarding the harmonic series and flexible temperament. They may be referred to as principles that are related to the main intonational strategies in performance.

The concept of reference frequency, a most important intonational principle brought forth in this experimental work, is considered according to its possible flexible behaviour, in opposition to the general assumption that a reference frequency must remain stable for the entire piece. Pitch equalisation, unexpected newcomer to the repertoire of intonational strategies is also identified as a pitch balance provider that would work at least for experienced singers who perform together. Intonation is also considered as depending on the level of precedence regarding musical issues relevant to intonation. Individual singers may have different views on these issues.

The intonational strategies adopted in the experiments are described, with an introductory overview on the subject related to the harmonic series and flexible temperament principles. Questions of vibrato singing, absolute pitch and text-related intonational problems are then focused upon, as they present important results and raise unavoidable issues regarding intonation practice.

Future research on the subject is suggested as a necessary procedure to enlarge the view of the new concepts brought about by the research. Firstly, the continuation of experimental work with ensemble singing groups and choirs, together with an expansion of the harmonic language utilised in the experiments, are considered. Then, important issues regarding vibrato, absolute pitch and text-related issues are regarded as being vital to the subject investigation, due to the extent of their influence on intonational strategies. The differing situation created by performances that include instrumental accompaniment is also considered relevant to the widening perspective of the research.

To wrap up the chapter, the central question of training practices aiming at the enhancement of pitch perception and control is touched upon, and its two main fields of work pointed out: extended vocal technique and software-based training practices. Finally, the future of the investigation is examined in relation to the extension of its experimental procedures to include instrumental research on the subject.

6.2 - New concepts on intonation brought about by the research

Important new concepts were developed on the subject of intonational strategies in performance during the course of this research. Some of them were present in music practice throughout western music history, only shrouded by powerful preconceptions with respect to what was considered correct in terms of musical performance. A clear example of this kind of prejudice is related to the question of reference frequencies, with the ongoing assumption that a piece of music must adhere to a given reference frequency for its entirety. This probably happens because musical instruments, which uphold an 'intonational model in residence', are designed to guarantee the maintenance of the same pitch all the way through the piece. The stability of the reference frequency is a given attribute of most instrumental music, but this fact does not entitle that kind of procedure to be considered as *the* truthful criterion regarding intonation.

The new concepts on intonation follow.

6.2.1 - Principles of intonational strategy

Harmonic series principle

The widely acknowledged principle that is supposed to govern musical perception at the interval level is called *categorical perception.* According to its accepted characteristics, it works in a way to provide a kind of labelling for each perceivable music interval that would place them within categories. These categories share intervals with different musical meanings, those that include pitches such as D# and Eb, for instance. They are not easily distinguishable from each other from the psychoacoustical point of view, because of the proximity of their frequencies, in spite of the fact that their musical meanings are diverse. This happens mainly due to musical education imparted since the 19th Century, which assumes that both notes share the same frequency due to a universal acceptance of twelve-tone equal temperament, alongside the constant use of vibrato which does not allow the musician to be aware of them through beat detection. One of the uncertainties about categorical perception is that it can reveal a great degree of variation according to the musical prowess of the perceiver. The end result is a subjective one. In that sense, the borderlines of each musical interval are variable according to the perceiver's perceptual capabilities.

An important feature of categorical perception is that it presupposes quite wide interval windows within which musical pitches can be placed, together with a somewhat narrower bandwidth that cannot define pitch perception categorically. This happens in a contrary fashion than in perception according to the *harmonic series* *principle*. In this, a note is located on a narrow spot that corresponds to a precise frequency, every other value being considered as a deviation from the target pitch. It can be said that *focus* is the striking difference between the two principles of interval perception. As a result, a far greater number of intervals are available to the perceiver upon the utilisation of the harmonic series principle.

The harmonic series principle provides for a most strict guideline on intonation matters. It is the only principle of music intonation that can be regarded as a 'natural' one, because it has a psychoacoustical counterpart. All of the other solutions to the problem of intonation are 'artificially' engineered. Pythagorean intonation constitutes the low-resolution implementation of the harmonic series principle. The scope of its practicality is hindered somehow, however, by the functionality of the harmonic series working principle – beat detection. From this standpoint – the need to meet the requirements of beat detection – Pythagorean intonation is quite limited. It can be said that the efficient functionality of beat perception demands the implementation of the harmonic series principle to the highest level required at any given moment in music performance, which amounts to adherence to extended pure intonation.

Extended pure intonation, however, cannot solve all intonational problems encountered in the western music repertoire. Furthermore, performers do not consider desirable the implementation of extended pure intonation in all possible instances. This is perhaps a good explanation for the continuous exchange between Pythagorean and pure intonations revealed in the results. Even so, (flexible) temperament is often the best, if not the only available intonational strategy that avoids the production of undesirable mutable notes. It is also the strategy to be called for when a micro-transposition is intended while changing reference frequency.

Flexible temperament principle

Pythagorean and pure intonations bring forth the two extreme intonational procedures when it comes to the implementation of consonance. Temperaments represent intermediate ways to bring about procedures that try to minimise Pythagorean problems in relation to thirds and sixths while at the same time providing a practical solution for the usual instrumental limitation of a fixed number of pitches per octave.

An important issue that arises from the results of the research is that a number of intonational strategies is available to the singer. The musician must be responsible for the extent of the implementation of the intonational strategy according to the harmonic series principle, and also for how much temperament he or she would be willing to make use of in performance. The balance of use of the intonational principles should evolve as they are learned and practised.

6.2.2 - Reference frequencies

The concept of reference frequency is an old one. It is not discussed much because it is taken for granted. A reference frequency is the frequency value of a pitch taken as the reference for intonation, being usually the tonic of the main key of the music. In larger pieces there may be more than one reference frequency – for instance, a sonata movement with two contrasting themes will have each of them related to a different tonic, and consequently, to a different reference frequency. Nevertheless, they are expected to agree regarding the issue of pitch stability. This means that the reference frequency would be determined by the pitch of a chosen note, which is assumed to be bound to a given (equally tempered) interval from the standard tuning tone of A=440 Hz (or near frequency).

The minimal unit with a self-contained musical idea should be considered as the natural building block for many of the musical phenomena, including musical excerpts (like phrases) linked to specific reference frequencies. As happens with time-related phenomena, where each phrase presents *tempi* variations (slight *rallentandi*, different durations for stressed and unstressed beats, etc.), pitch-related phenomena should also be allowed to vary according to musical needs. It could be argued that 'expressive intonation' provides for that variation; generally, 'expressive intonation' is a concept that refers to the emotional content of the music being 'expressed', and is regarded as an additional tool for the interpretation of music. Expressive intonation may not be the issue here, because it usually provides random results in terms of pitch deviation from an expected model (which is considered to be, of course, twelve-tone equal temperament). Intonational strategies, on the other hand, are not procedures that happen at random, since the performers agree upon the strategy as the music evolves. It shows a clear intention, since the intonational strategy is repeatedly replicated if the music piece is performed again and again. It would be possible to state that expressive intonation, according to the meaning stated earlier, is yet another kind of issue, related to a different context and therefore to another subject matter. Its investigation is probably outside the scope of this research.

A change of reference frequency during the performance and the applicability of the reference frequency as a stable pitch reference to shorter musical excerpts, such as a music phrase, are generally not considered either practical or right. However, this was indeed the case for the results presented by the Royal Academy of Music vocal quartet. The results gave rise to a concept of *flexible reference frequency*, regarding the utilisation of psychoacoustical principles in performance to determine the reference frequency. It may not only be changed during performance, but also remain stable within the limits of JND. Furthermore, each singer is co-responsible for the outcome of the results, defined by the group in performance.

6.2.3 - Pitch equalisation

Pitch equalisation was a most unexpected behaviour that emerged as a result of this experimental work. It was noted that some of the singers of the choir showed a tendency to compensate, so to speak, for the deviations of other singers. Whether this is an intended intonational strategy, is not possible to determine at this stage. This phenomenon happens independently of other intonational strategies, whereas singers do agree most of the time regarding other issues, such as text-related ones, for instance. An interesting question that arises on this issue is about whom, amongst the singers, tends to adopt the pitch compensation strategy, what the procedure consists of and why they resort to such a procedure. The possible influence of questions like the familiarity of the singer with fellows performers' proclivities, the automatic pitch-correction mechanism developed by some singers in response to aural feedback, alongside other issues, have also to be investigated.

Whatever the answers to these questions , it seems fairly clear that a possible link to the 'single melodic line' perception of a choir's section (see 5.2.5) is an influential factor regarding the phenomenon. If the perceived melodic line does not correspond to what is being expected, an individual singer may activate a pitch compensation mechanism to correct intonation. If this is the case, it makes the way performers judge intonation extremely important.

6.2.4 - Level of precedence

The last of the newcomers regarding intonational strategies is related to the concept of the *level of precedence*, which seems to be rather influential in the way singers act and react in performance. The central issue here is related to the singers' expectations, or perhaps about what their premises are in relation to musical performance. The idea behind this contention is that the performer would take care of the most important intonational problems first, and then pay attention to secondary questions, which may not get the necessary attention if there are too many concurrent intonational issues.

Individual results tend to show that for some of the singers text-related issues take precedence over phrasing and rhythm, while for others it seems to be the other way around. The determination of the levels of precedence for performers may help to clarify discordant intonational strategies, as well as establish common criteria for study and performance.

6.3 - Intonational strategies

6.3.1 - Overview of intonational strategies

As was described in the last chapter, the adopted intonational strategies may be summed up as a balance of tendencies between Pythagorean and pure intonations as a general picture of the idealised intonational strategies, with temperament-based procedures applied to some passages and revealed in many other spots by individual performers. The primary tendency of the singers to somehow tend to the harmonic series principle, in spite of its low-resolution version (Pythagorean intonation) being more sought after than its high-resolution version (extended pure intonation), is an indication of the rightful position of this principle as the proper way of dealing with intonational issues that arise in performance. Furthermore, it seems that the voices located at the extremes of ranges (soprano and bass) are more prone to utilise Pythagorean procedures that enhance melodic behaviour. This is in accordance with the tendency for the use of more melodious lines for sopranos and basses – the first being usually responsible for the leading melodic lines in most of the repertoire, the latter being responsible for the harmonic foundations of the piece. The bass section utilises a more differentiated melodic behaviour than other sections. Sopranos and basses constitute the 'borderline sections', which gives them a sense of relative independence from the internal sections of the choir. Tenors were generally biased towards pure intonation, perhaps because they have to be more aware of the ongoing harmonies. The altos' tendency was predominantly Pythagorean, a surprising result due to their position as middle-voices in the harmonic fabric. The constant presence of vibrato singing must be taken into account, however, which may account for the bias towards Pythagorean intonation (i.e., melodic behaviour to the detriment of harmony).

Temperament-based intonational strategies were also regularly present. They were certainly expected, perhaps even in a more substantial way. One of the first possible projections from the results of the research was that temperament could rule from the beginning to the end, as would be expected from the widely accepted assumptions on the subject of intonation. Even a close resemblance to equal temperament was a likely possibility. In real life, however, the issue of temperament was overwhelmed by another one, much more pressing and unexpected – the influence of text articulation on intonation.

6.3.2 - Problematic topics regarding deviations to the expected intonational strategies

There were three main topics regarded as highly influential in relation to the experimental results: the omnipresent vibrato in both groups, the possible influence of absolute pitch in the case of The BBC Singers, and the massive presence of text-related issues. The ways that each of these topics are thought of as having affected the final results are described in the next paragraphs.

Vibrato

Vibrato seems to be ingrained in the very core of a singers' tone production technique. In several of the recording takes, it was requested that the singers sing without vibrato or with minimal vibrato, to no avail. It appeared that they could not avoid vibrato production. This fact certainly can be compared with tone production on string instruments – vibrato technique or the lack of it must be learned by practising. The researcher regards the possibility of performers learning and perfecting both ways of tone production – vibrato and (nearly) non-vibrato singing – as a desirable improvement over the ruling tendency of singing techniques nowadays. However, this kind of skill will require great flexibility from the performer.

The central problem with the ever-presence of vibrato in singing performance is related to beat concealment. It is a real possibility, since it was established that vibrato singing does not diminish pitch perception accuracy (see 2.2.3), that it might nevertheless create problems for pitch control when it comes to issues that were not explored systematically and consistently during the technical training period of the performer. This might well be the case for music and text-related issues in the presence of vibrato singing. If the singer does not have access to beat detection, he or she cannot control intonation in a totally satisfactory way. At the end, perhaps vibrato does not have to be a problem for intonation in practice if wisely utilised. From the results of this research, however, it seems that vibrato did get in the way of a thoroughly controlled intonational behaviour. Both groups displayed approximately the same level of control over intonation as they did over vibrato – in other words, their pitch control remained at the categorical level of perception, inasmuch as they failed to maintain a nearly vibrato-free performance when asked to do so.

Absolute pitch

Although theoretically many of the topics investigated in this research may have been affected by absolute pitch, reference frequencies are the most affected of all. There is no conclusive evidence about the influence of absolute pitch on the stability of reference frequencies, but it seems probable that the results of The BBC Singers may have been defined to a degree by absolute pitch.

It must not be forgotten that the question of absolute pitch is yet ill understood. From the individual results of The BBC Singers, it cannot be determined who possesses absolute pitch and who does not. There is no greater evidence shown of stability or compliance to any of the intonational models by any of the individual singers. No one seems to have a tighter control on deviations regarding text-related issues or any other unexpected results. There is no clear evidence that any individual intonational strategy could have taken advantage of absolute pitch. It cannot be said with certainty that reference frequencies were the only results to 'benefit' from the absolute pitch capabilities of some of the singers. Nevertheless, it is reasonable to suggest that the influence of absolute pitch could be felt in a categorical perception-like fashion regarding the issue of reference frequencies.

To further consider this question, it is sufficient to recall the lack of definition of categorical perception. This characteristic alone would explain the possibility of maintaining the reference frequency while allowing for great variations in pitch due to categorical perception with no beat detection correction mechanism as a result of vibrato singing.

The remaining question regarding this issue is: *would The BBC Singers have adopted an intonational strategy that would include a meaningful change in the reference frequency if none of the singers possessed absolute pitch capability?* Pitch equalisation results may indicate a positive answer, though the evidence is hardly convincing. There was a small variation between the phrases' reference frequencies, and text-related issues do not lead to the idea of pitch stability.

Issues regarding text articulation

The most poignant illustration of lack of an adequate training technique during the formation period is given by the results pertinent to text articulation. Firstly, it must be fully understood that text articulation *should not interfere with intonational strategies.* Arguments in favour of pitch deviations in text-related issues could be put forward as follows:

- Text articulation may be included in the category of the so-called 'expressive intonation'.

- It may be desirable to relax text intonation to avoid the feel of too strict pitch behaviour. This argument is also subscribed to the idea of 'expressive intonation', according to which the pitch does not need to be fully compliant to a given model (i.e., equal temperament), or it would otherwise be felt as unnecessarily rigid.

- Pitch deviations may constitute a proper characteristic of text articulation; it would sound unnatural if they were avoided in performance.

Each of these arguments does not hold validity. The reasons are, respectively:

- True expressive intonation presupposes a *musical intention* and a definite awareness about it. It is not accidental, as seems to have been the case with most of the text-related issues in the experiments. Differences of intonation by the singers of the same given section of the choir show on several occasions that they seem not have had a clear idea about the phenomenon. If they shared musical intentions regarding 'expressive intonation', they should also share the same deviation tendencies, which was not always the case. It is much more plausible to explain such pitch deviations in terms of text articulation (larynx and muscles movements) and perhaps even perceptual phenomena (as seems to be the case with vowels) rather than from music expression needs.

- The idea of loosening text articulation to avoid rigid intonation does not help in any way to improve intonation; it only provides a feeling of relative freedom in relation to the rigidity of the assumed model of intonation. It is akin to the idea of loosening the music timing just to avoid the feeling of being too rigid about *tempo*, which does not help phrasing at all.

- A comparison with instrumental intonation would help to clarify this argument. Might it be the case that a different bow technique would result in a different pitch in string instrument performance? Would it be the case that any similar situation with any other kind of musical instrument would cause intonation to be relaxed because of an articulation technique? In the case of the singing voice, would a change in text make it also mandatory to change pitch? Should the Bach *chorales*, for instance, that often comprise several verses, be sung with different intonation each time due to change of text?

As can be seen, text-related issues should not be overlooked, as seems to have been the case with text articulation in relation to intonation in singing teaching. This whole situation may have arisen because of lack of understanding in relation to what constitutes a correct tuning procedure, together with the assumption that twelve-tone equal temperament constitutes a reliable and authoritative model. Consequently, a reaction against a rigid and unnatural model would easily pave the road for a volitional search for an equally unnatural behaviour such as being imprecise in intonation just to avoid the rigidity of the established model.

Ideally, the whole picture of the intonational strategies in the experimental work could have been as follows:

- The harmonic series principle should have been implemented in such a way that Pythagorean intonation could control some of the dissonant harmonies, perhaps to avoid unwanted mutable notes. It might also be relevant to some melodic passages. Triadic consonant harmonies would comply with extended pure intonation, which would likewise determine the intonation of more complex harmonies, as desired. Temperament would be used in situations that would bear uncertainties in relation to pitch definition or on the way to defining a new reference frequency.
- There should not have been such a great number of deviation results (to produce pitch-sharpening and pitch-flattening) connected to text articulation.
- There should have been a more defined agreement on questions related to phrasing and rhythm, as well as on the levels of precedence defined by the singers.
- There should not have been issues related to pitch equalisation.

6.4 - Possibilities for future research

As expected from investigations that resort to new working hypotheses, this research has raised as many more questions than it could hope to answer. Some of the issues raised by the experimental work need further investigation not only for the sake of a better understanding, but also for helping the development of learning/teaching techniques to assist singers in the achievement of better intonation.

6.4.1 - Experimental research with ensemble singing groups

New findings need to be made in order to clarify and perhaps correct some of the most important topics of the research. The first need is to provide for an increase in the population for experimental work. This necessity originates in many of the issues raised by the results of the experiments. Ensemble singing groups as well as choirs need to be brought together, as there are some important issues that are specific to each kind of group. All of these questions are dealt with in the following paragraphs.

Experimental work with nearly non-vibrato singing groups is mandatory to clarify outstanding questions on the relationship between beat detection and intonational strategies, as well as possible outcomes regarding text-related issues. It must be recalled here that both groups evaluated in this research utilised vibrato singing. This means that they could not resort to beat detection as a tool to control intonation. Consequently, the results had to be taken as the expression of the singers' learned musical abilities; all of the advantages of the harmonic series principle in terms of intonational control were probably lost. It is likely that groups that make use of a near non-vibrato singing technique can achieve a greater accuracy in relation to their intonational strategies.

Groups with singers that have absolute pitch capabilities as well as groups that do not have such singers are also important for assessing the influence of absolute pitch on important topics such as intonational strategies and reference frequencies.

It is not known yet, due to the limited number of the participant groups, whether quartet or ensemble singing groups would tend to produce different results than choirs. Only after experimental work has been carried out with several singing groups that have the necessary variety as well as similarity of conditions, might a clearer view of the question be formed.

6.4.2 - Expansion of the harmonic language in the experimental work

Having explored the basic procedures of traditional harmony by means of the *Ave Verum Corpus* motet, it would be of consequence to investigate more complex and diverse harmonic textures. Music from early periods to today's choral compositions should be included in experimental work, as needed. The target issue of this procedure would be the evaluation of intonational strategies in different contexts of harmonic writing, such as the intonational behaviour of singers when extended harmonies become available for the implementation of the harmonic series principle. Would the increase in complexity of harmonic writing determine an increase in the utilisation of temperament-based procedures? Such investigation would be very important for expanding and perfecting guidelines on intonation in performance.

The assumption that composers of ancient music wrote music with a specific temperament in mind does not hold validity. What can be said is that a certain kind of music may have been written with a certain kind of temperament in mind. From the same standpoint, it can be said that temperament 'flavours' are of no consequence in determining any intonational procedure. They are mere by-products of the implementation of a particular tuning technique.

6.4.3 - Important issues to be further investigated

Vibrato

Further investigation is needed on the subject of the influence and consequences of vibrato singing on music perception in performance. According to Sundberg (1987 – see 2.2.3), vibrato does not diminish the accuracy of pitch perception; it is not clear from his experimental work, however, if categorical perception corresponds to the maximum possible resolution, or if a finer resolution can be accomplished in vibrato singing. Vibrato singing may not allow for pitch resolution at the level of the harmonic series principle. How precise can intonational strategies be in the presence of vibrato singing? As in many of the research projects carried out on the subject of singing voice technique, there is very little experimental work aimed at practical issues for the performing musician.

Another topic about vibrato that needs clarification is the question of vibrato being either a stylistic or a technical feature of the singing voice. Does it really have to be present all the time in singing voice tone production, as operatic (lyric) singers tend to believe? Is vibrato necessary, even for stylistic reasons, in most ensemble singing performances? Certainly, an attempt to delineate a clear distinction between the various types of vibrato and similar techniques should be carried out experimentally.

Absolute pitch

The problem with the concept of absolute pitch is the lack of agreement on what it is and about its value as a practical tool for the performing musician. In relation to the subject of intonational strategies, absolute pitch needs to be investigated from the following perspectives:

- Its scope regarding pitch perception. It is very important to determine if subtle differences in pitch such as between Pythagorean and pure thirds can be perceived and controlled in performance by singers that have absolute pitch capabilities. What would be the technical possibilities in terms of intonational control if the above question turns out to be workable? Would the singer be able to make a transposition from the original reference frequency to a new one by utilising a micro-interval in accordance with the intonational strategy agreed upon by the group?
- The possibility of controlling text-related issues, especially if absolute pitch is combined with a nearly non-vibrato singing technique. Would it be possible to control pitch deviations linked to consonantal and vocalic articulation problems with the help of absolute pitch? This would be considered a real advantage in terms of pitch control.

Text articulation

Problems related to text articulation and its effects on intonation are amongst the most pressing issues for thorough investigation, if intonation is expected to be implemented unhindered by influences extraneous to the music itself. There is a need to clarify how vowel changes affect intonation and to what extent. The reported experiments (see 5.2.4) were not comprehensive enough, and were carried out in laboratory conditions; they may not necessarily reflect singing facts in performance. Consonantal articulation may present an even stronger deviation than vowel changes, and as such needs special attention.

Experimental work on consonantal and vocalic articulation must take into account the main languages widely utilised in the standard choral repertoire: Latin, Italian, English, French and German, to say the least. Experimental design must follow the same guidelines as was done in this research – the utilisation of a specific piece (or pieces), a performance situation that includes aural feedback and live interaction between performers, *a cappella* singing, etc. Otherwise, any experimental work on the subject will be useful only to enlarge a view on the mechanics of vowel articulation, 'textbook' reactions to external tone stimuli, and other pieces of information that would have minimal practical results.

6.4.4 - Intonational strategies in ensemble singing with instrumental accompaniment

Intonational strategies would be somehow limited in ensemble singing with instrumental accompaniment in comparison to unaccompanied ensemble singing. The first restriction would refer to the reference frequency principle. As there are no musical instruments with absolute freedom of intonation with the exception of the singing voice, in ensemble singing with instrumental accompaniment the reference frequency would tend to remain stable throughout the piece. For instance, string instruments are tied up to their open strings' tuning, making it difficult the adoption of a mutated reference frequency, as the singers of the quartet of the Royal Academy of Music did. Pitch equalisation would probably (and hopefully) be nonexistent, with the exception of perhaps small difficult passages played by instruments that support flexible intonation (as most of the orchestral instruments do). Of course, it is possible that instrumental players that perform together for a long time may develop an intonational behaviour tending to pitch-equalisation, as seems to happen with singers.

The crux of this question is that singers would have to adapt themselves to the other instruments most of the time, as probably happens with string instruments when playing along with fixed pitch instruments. The utilisation of fixed temperaments would be useful, at least in period music, to diminish intonational problems caused by the adoption of equal temperament. It must be remembered that, in many situations, accompanying instruments may also adapt themselves to the singing voice, inasmuch as they allow for some degree of flexibility in intonation.

6.4.5 - Training practices to enhance pitch perception

Pitch perception may be enhanced by means of two main training techniques: extended vocal technique and software-based activities. As they are not the subject matter of this research, pertinent details will not be given here as to how to implement them. However, the researcher's assumption is that training practices are the real purpose of carrying out the research work. Of course, theoretical propositions have value by themselves, but they are mere pieces of information if not put to work. If it is not destined to be useful for performing musicians, why bother to do research on how they behave in performance?

6.4.6 - Experimental research on intonational strategies in instrumental music

As was seen so far, research on intonational strategies for the singing voice has brought about new concepts as to what may constitute a sound intonational strategy. A further logical step would be the extension of the research to intonational strategies in instrumental music.

The obvious choice for starting point is the family of fretted string instruments. They present in principle only one limitation: the open strings are tuned according to Pythagorean intonation, i. e., by perfect fifths. Perhaps here resides one of the main reasons why they tend to avoid open string playing, apart from the usual explanation related to timbre and the impossibility of the use of vibrato. Tuning by consecutive perfect fifths brings about two intonational problems: the bias towards Pythagorean intonation and the difficulty of adjusting pitch to match accompanying fixed pitch instruments such as the piano.

Wind instruments offer enough intonational flexibility as to provide for the implementation of microtonal procedures. How they behave in performance and how intonational strategies could be implemented on wind instruments is a matter to be defined through experimental studies on the subject.

Some basic topics related to instrumental intonation have to be investigated, such as the possibility to enhance the perception of harmonics through playing techniques and beat detection. Again, the question of vibrato playing remains a serious issue to be examined.

As the situation of intonational strategies in performance now stands, it seems clear that a new field for practical research work has been opened under the requirements that such an enterprise demands. In due time, performing musicians may develop a keen relationship with the working principles that foster sound intonational strategies in performance, if research work is supported and sustained long enough to bring about a body of technical and practical knowledge on the matter.