Influences on pitching variation in a cappella choral singing

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Abstract

One of the most important aspects of choral singing is the ability to sing in tune with the other members of the choir. Singing in tune within a choir does require each singer engaging in careful and focussed listening to the other parts to establish the placement of the pitches of their individual notes within their own part. Simply singing in tune with, for example, notes played on a piano will not result the most 'settled', 'beautiful' or 'consonant' tuning due to the use of equal tempered tuning - twelve equal semitones in each octave on a piano. It is the use of 'just intonation' during a cappella or unaccompanied singing that has the potential to result in more settled, beautiful or consonant tuning, which results from focussed and careful listening to pitch. However, there are other complicating factors when striving to sing in tune. It turns out that the human hearing system additionally uses other aspects of acoustic signals when it is engaged in pitch perception, most notably, timbre (note 'quality') perception. These matters are described along with their implications for overall individual and choral tuning.

Key words pitch drift, equal temperament, just intonation, *a capella*, timbre, tuning.

Introduction

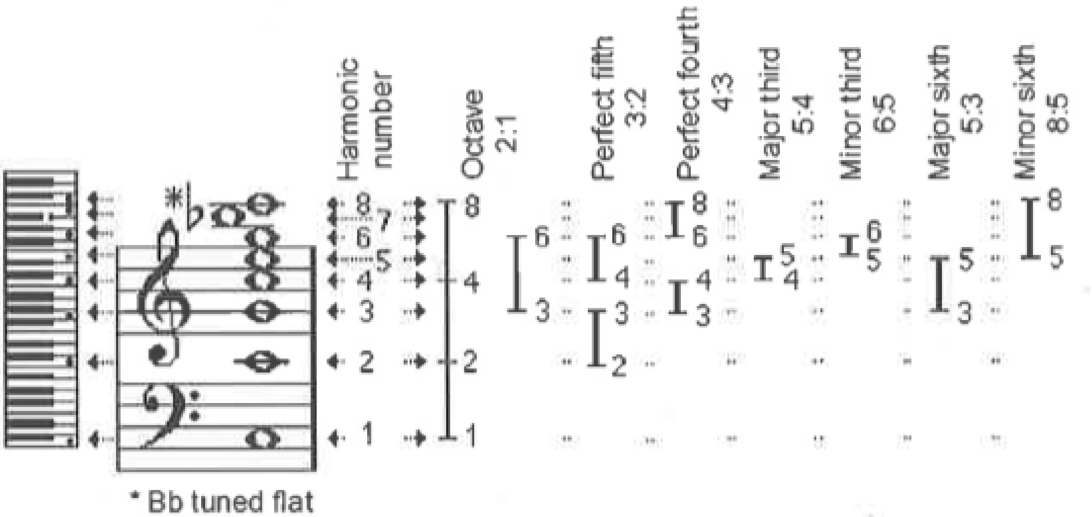
A key element in *a cappella* or unaccompanied choral singing is the ability to sing in tune, but what exactly does that mean? The tuning of notes on a modern piano relies on the notion of each semitone being essentially the same musical interval which in turn enables music to be played in any of the twelve major and minor keys thereby allowing modulation to any key. The drawback is that all intervals except the octave are not exactly in tune and therefore not as musically 'consonant' as they could be.

If a choir wants to sing *a cappella* properly in tune, then it should be striving to make use of musically consonant intervals. This can be done through careful listening between the parts (without the notes being played on a piano!) by altering the pitch of individual notes until the chord is most 'settled' in terms of what is described as its tuning consonance. This process is far easier to achieve with sounds that are not varying or undulating in some way such as when vibrato is present. Sung vocals are always undulating even in the context of what might be described as a vocally 'straight' sound (taken here to mean with no vibrato – if indeed no vibrato is possible), as there will always be small variations from human larynx vocal fold vibration during singing known as 'flutter' – variations above about 5 per second (e.g. Ternström, 2002). Couple this with two other facets of pitch perception: (1) we do not hear our own voice as others hear it due to our ears being behind our mouths, and the presence of bone conduction (Pörschmann, 2000) which causes us to hear a bass heavy version of our own voices and (2) when the timbre (dullness/brightness) of a sound varies the pitch also varies. The issue of practical pitch perception when singing then becomes rather complex. In practice, minimising beats is not a viable strategy; basically, a singer has to listen to the pitches of the individual notes and make a judgement about their pitches in real time when singing.

Tuning of musical intervals

Modern keyboard instruments, such as the piano, are nominally (by ear) tuned in equal temperament which means that every semitone is an equal musical interval (this is why the tuning system used is known as '*equal* temperament'). The underlying fundamental frequency of any two notes that are one semitone apart is exactly one twelfth of an octave (there being twelve semitones in one octave). The fundamental frequency change for one octave is doubling (*2) to go up an octave or halving (*0.5) to go down by an octave. The fundamental frequency change for one semitone involves multiplying by a number that equals 2 (an octave) when multiplied by itself 12 times. Mathematically, this is the 12th root of 2, or $\sqrt[12]{2} = 1.0595$. In practical tuning experimental work, a semitone is rather large and the usual unit used is the 'cent', where one cent is one hundredth of a semitone. The tuning plots included herein make use of cents. Therefore there are 1200 cents in an octave and one cent is the 1,200th root of 2, or $\sqrt[1200]{2} = 1.000578$. (Formulae for converting between cents, and frequency ratios can be found in Appendix 3 of Howard and Angus, 2017.)

Figure I
The first 8 members of the natural harmonic series for the note C3 (C one octave below middle C) set out against a keyboard and stave (Adapted from Howard and Angus, 2017).



Every note from a musical instrument or human voice consists acoustically of a set of harmonics and these form the natural harmonics series (see Figure I). Notice that the first 6 members of the harmonic series contain intervals between individual harmonics that are related to major and minor chords (octave, fifth, major third and minor third). This means that if other members of the choir are singing notes of these chords, then various harmonics from individual singers may well line up (for example, if the bass sings the tonic and the tenor sings a note that is a fifth higher, the 3rd harmonic of the bass note should exactly match the second harmonic of the tenor note). Lined up harmonics provide a strong basis for tuning by listening. This is excellent and very helpful but tuning by lining up harmonics does not work in equal-tempered tuning and presents a major choral tuning dilemma.

The dilemma is this – properly in-tune intervals are not available on a keyboard instrument tuned in equal temperament, so no amount of asking singers to tune, for example, to a piano will achieve accurate tuning (except in the case of octaves). For a musical fifth this is because the frequency ratio in equal temperament is based on seven equal tempered semitones (mathematically this frequency ratio is that for one semitone multiplied by itself 7 times or $\sqrt[12]{2}^{7} = 1.4983$). However, the frequency ratio for a just tuned fifth is the ratio (3/2), or that of the third harmonic divided by the second harmonic, and (3/2 = 1.5). Although the difference between 1.5 and 1.4983 looks small, it is audible. Do not be misled as to its significance in musical tuning, any discrepancy, however small between two steady notes causes undulations or 'beats' which are clearly audible.

Table1
Frequency ratios for common musical intervals in equal temperament and just intonation

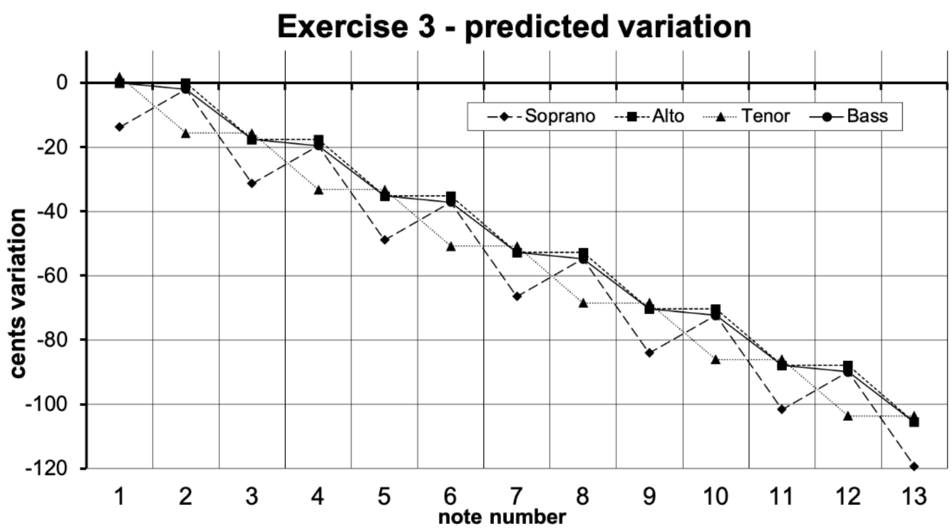
	Frequency Ratio Multiplier	
Musical Interval	**Equal Tempered**	**Just temperament (harmonic ratio)**
Unison	1.0000	1.0000 (1/1)
Major second		1.1250 (9/8)
Minor third	1.1892	1.2000 (6/5)
Major third	1.2599	1.2500 (5/4)
Fourth	1.3348	1.3333 (4/3)
Fifth	1.4983	1.5000 (3/2)
Minor sixth	1.5874	1.6000 (8/5)
Major sixth	1.6818	1.6667 (5/3)
Minor seventh		1.7500 (7/4)
Octave	2.0000	2.0000 (2/1)

This difference between tuning in equal temperament and just intonation can be calculated for other intervals commonly encountered in choral musical compositions. A selection of the most common musical intervals and their tuning ratios in equal temperament and just intonation is shown in Table 1. Note that the equal and just tempered ratios are different for all the musical intervals provided except for the unison and the octave; this is the mathematical realisation of the choral tuning dilemma.

Figure II
***Exercise 3* by David Howard (tempo: crotchet = 50 bpm)** (from Howard (2007)

A way of exploring any tendency of a choir to drift in pitch is to try singing *Exercise 3* shown in figure 2, with those singing the alto and tenor parts being asked to take care to observe the tied single notes between alternate chords. Based on just intonation and assuming the tied notes are observed and that singers do tune the chords carefully in just intonation (please note that this SHOULD NOT be performed with keyboard accompaniment!), the overall pitch drift should involve the final C major chord being around a semitone flat compared to the starting chord plus an octave as shown in Figure III. The chords in these exercises are based on triads which have a number of overlapping harmonics to aid tuning; Hagerman and Sundberg (1980) found that pitching accuracy for Barbershop singers was more accurate when there were increased numbers of common harmonics between singers' notes.

Figure III
Predicted just intonation pitch drift analysis in cents variation from equal temperament for *Exercise 3* shown in Figure II - (from Howard, 2007a)

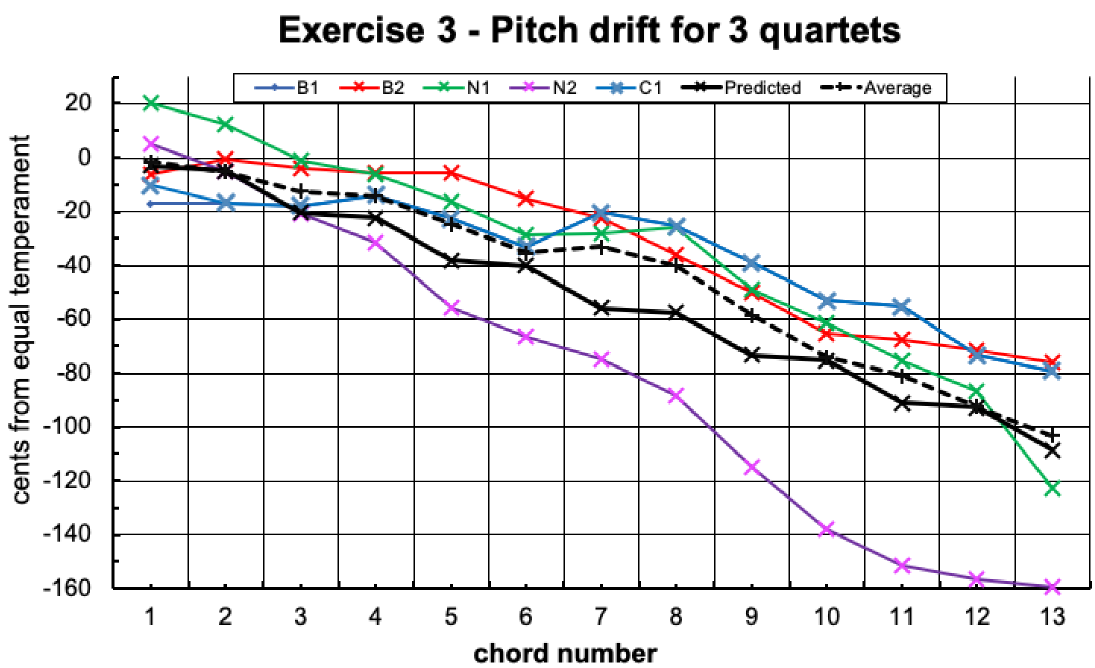


The predicted pitch drift on a chord by chord basis assuming tuning in just intonation for *Exercise* 3 (see Figure II) can be observed in Figure III. Here, the average fundamental frequency of each sung note within an individual chord has been calculated in just intonation relative to the tonic of the chord. Calculation for the next chord is based on finding a note between subsequent chords that are in the simplest harmonic ratio (e.g. same note or octave, perfect fifth, perfect fourth, major third, minor third . . .) and then repeating this process until the end of the piece is reached. The ratios are converted to cents relative to one note in the piece, usually a tonic in the first chord as here (the alto starting note, middle C). This is what is plotted in figure three for each of the four parts.

If the piece remained in exact equal temperament throughout, the plots for all the individual notes of each part would be horizontal lines at 0 cents. Observation of Figure III immediately shows that there is a continuing flattening pitch drift away from equal temperament from the start of the piece. Notice also that by definition as described above, the tuning of the first chord cannot have all notes in equal temperament.

It can be seen that the tenor part drops in pitch by about 18 cents on each new note, but as one would expect, retains that note's pitch when it is tied. The alto part similarly retains its pitch on tied notes, but also drops in pitch by about 18 cents on each note change. The bass part also exhibits a note-by-note pitch drop of about 18 cents which is to be expected, since each time the alto part changes note, the bass part, having sung another note in between, remains an octave below it. The soprano part alternately has a pitch rise followed by a larger fall throughout the piece. This exercise can, and arguably really should as an informative experience, be used with choirs (or indeed choral director conference audiences!) to demonstrate this pitch drift effect.

Figure IV
Measured pitch drift variation from equal temperament in cents averaged across all four (SATB) parts for *Exercise 3* (score shown in Figure II)



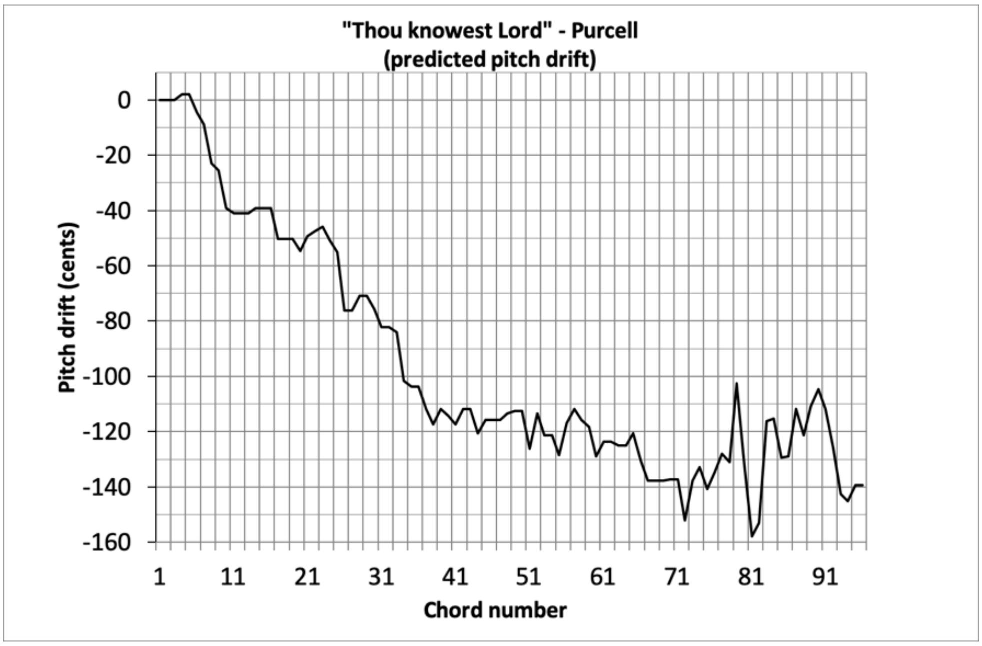
It is performed by three semi-professional vocal quartets, two of whom sang it twice (B1, B2 and N1 and N2), alongside the predicted pitch drift described in Howard (2007a) and the overall average from all 5 quartet renderings. Consistency in performance pitch drift for *Exercise 3* (see figure 3) can be seen in this figure. In all cases, the pitch drift exhibited follows the predicted pitch drift (solid black line in Figure IV) closely but not exactly. The average drift plot over the five performances (dashed black line in Figure IV) is a reasonable overall match to the prediction, especially in terms of the endpoint where the flattening by a semitone is almost exactly matching the prediction. Note that for all recordings, there was no priming at the start of the experiment as to the effect under investigation.

There are a number of reasons why the drift observed is not always consistent between performances or necessarily close to the prediction. For example, it is clear from Figure IV that for the 'N2' plot, the group went flat to a much greater degree than in their first attempt. In addition, distractions during a performance, lapses in concentration, concentrating on other aspects than pitching, the presence of local background acoustic noise or non-optimal local acoustic properties of the performance space could all either individually or severally directly affect sung pitch. In addition, one should bear in mind secondary perceptual aspects, such as timbre and volume, that can have a direct effect on pitch perception thereby affecting the observed variation.

Exercise 3 presented here was specifically contrived to illustrate the potential for pitch drift to take place during a cappella choral singing. It could quite understandably be suggested that this has nothing to do with the real world of *a cappella* choral composition performance. In practice, this is not the case. Any music that modulates and later returns to the starting home key (a basic musical feature of essentially all music) has both the potential to and is very likely to exhibit overall pitch drift. It is perfectly possible to analyse the score of any individual piece of *a cappella* choral music to determine the nature of the implied pitch drift required to keep the piece in maximally harmonically consonant tuning. By way of an example, Figure 5 overleaf shows the predicted average pitch drift, based on a just intonation analysis of the score, for *Thou knowest Lord the secrets of our hearts* by Henry Purcell. Overall, this piece drifts flat by just over a semitone according to this model.

In performance, a choral director must decide whether any pitch drift is acceptable in *a cappella* singing since for many members of choirs, audiences and their conductors it is not. Pitch drift is a necessary consequence of consonant just tuning between individual parts. There is a need both for education as well as advice for singers as to what is expected. If settled, harmonically tuned consonant chords are desired then the rehearsal use of a keyboard must be very carefully considered. The choir should be given opportunities to experience consonant tuning for themselves, but this must be weighed against the support required to learn the notes so that the singing becomes confident enough to hold the harmony together. To achieve excellent tuning, it is vital that singers can hear each other appropriately - an important but often ignored aspect of choral singing (Howard, 2015). Muddling parts up so that singers do not perform in individual part blocks but have a member of two different parts, one on each side, can dramatically improve tuning (as well as dynamic range and timbre) simply because singers can hear their own contribution with direct reference to that of other parts.

Figure V
Predicted pitch drift in cents based on just intonation against chord number for *Thou knowest Lord the secrets of our hearts* by Henry Purcell.



Singers do of course take responsibility for their own pitching but, for many, the notion that pitch drift is a necessary consequence of consonant tuning is not an easy concept to take in. One could allow pitch drift to occur and not worry about it, which in many ways is arguably the true manifestation of a musical performance since it is a 'real' effect. Pitch drift, though, is so often viewed as a malaise that needs to be conquered because it is so often considered to be a fundamentally bad performance practice. It should be noted, though, that it is perfectly possible to stay in pitch and still have excellent consonant tuning. The following advice from The British Association of Barbershop Singers sums up their approach where the harmony notes are sung relative to the lead's melody:

> The melody is consistently sung by the lead, with the tenor harmonising above the melody, the bass singing the lowest harmonising notes, and the baritone completing the chord. Barbershop singers adjust pitches to achieve perfectly tuned chords in just intonation while remaining true to the established tonal centre. (https://www.singbarbershop.com)

Conclusions

Good vocal technique, overall choral blend and tuning and musicianship are primary skills that can enhance a choral performance. Choral singing brings great joy, pleasure and social support to many people; humans have a basic need to work in groups to a common aim and achieving a laudable musical performance together is a most worthy venture. If one or two goals can be developed to gently stretch a choir in its music making over time, the satisfaction will be heightened for all concerned in making the music as well as for those in the audience. Pitch control is an often neglected aspect of choral singing and understanding why the use of a modern keyboard tuning in equal temperament is not a good pitch model for singers whilst finding other ways to encourage consonant tuning is a vital starting point. The ability of a choir to achieve good consonant harmonic tuning makes a massive difference to the overall performance as well as the degree of enjoyment offered to the audience.

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