Influences on pitch variation in a cappella choral singing

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Choral Directions Research Journal, **1**, 94-96.

Abstract

Pitch perception is a crucial element of feedback in singing, one which musicians typically learn about in terms of the frequencies on an equally tempered scale. The evidence suggests that spectral differences such as those between tones from different instruments influence their perceived pitch, in some cases, by as much as 20 cents. In a choral context, issues in tuning become more complicated when different voice types and instruments are combined, depending on which is being used as a reference pitch. In order to achieve their aims with respect to tuning, choral directors should consider the voice and instrumental parts which singers may be tuning against and how this impacts their pitch perception. Musicians with more formal training are inclined to view pitch and timbre as separate properties, unlike those who are informally trained or less experienced, and so acknowledging their interactions increase the potential for experimentation. Those with absolute pitch who can accurately name notes are also affected, as absolute pitch is known to be more accurate for piano than for other instruments. In situations where singers move away from equal temperament, this suggests that absolute pitch possessors may struggle less when tuning against different instruments or voice types. As singers change reference pitches during a piece, greater awareness of the effect of voice and instrument type on pitch perception can help improve their intonation throughout performances.

Every musical performance is shaped by a multitude of factors. In the area of choral singing, issues with room acoustics, the bodily awareness of the singers and insufficient attention being paid to the choral conductor or accompanist can all have a noticeable effect. This can make a large musical performance difference between a rehearsal and final performance. It is widely understood that musical training increases the awareness of pitch, timbre, tonality and other vital features in listening, especially in ages seven and younger. As western classical music either assumes the use of equal temperament or treats the differences between tuning systems as irrelevant, more subtle differences in pitch may be treated as errors. In order to stay “in tune”, a quality which may vary depending on musical taste, singers must develop a great deal of control over their voice, breathing and awareness of acoustic information, and yet the process of filtering incoming sounds for useful information is a complex process in its own right. Many speech scientists have published information on the mechanics of the voice to help choral singers improve their art, and so here we shall focus instead on the auditory system – specifically, pitch and timbre perception in singing.

Singers, among other musicians, are generally aware of the acoustics impacting a performance, mostly as it affects the ease in tracking other voice parts and less so with respect to the overall experience of the audience. Yet acoustics is not a matter of perception and involves only the physical properties shaping the spread of soundwaves. Psychoacoustics is the name for how that sound interacts and is received by the human auditory system, and this is a complicated subject because without even considering the Deaf and hard of hearing community, there is considerable individual variance involved.

In order to discuss pitch and timbre perception we first must relate them to the physical properties of soundwaves –pitch is the perception of a sound wave’s fundamental frequency, or the amount of time it takes for it to repeat a cycle of the pattern of vibrations forming the wave. Timbre is more complex, as it relies on further analysis of the wave. Mathematically, any wave can be broken down into a combination of simpler sine waves, or pure tones in the case of a pitched sound. Hence the original soundwave can be found by combining these pure tones, so long as their frequencies and amplitudes are known relative to each other. While on a conscious level this sort of analysis appears to be a difficult task, the human auditory system can extract relevant information, in many parallel streams, which result in the perception of a roaring deep piano or a bright cornet tone. Through psychoacoustic and other psychological studies as well as analyses of different tones, the features of the spectrum responsible for different timbres are identified during the perceptual processes involved in timbre identification.

The reason to consider pitch and timbre together is that while perception may be analogous to the relevant physical properties of sound, it is not completely accurate and in matters of tuning the differences become significant. Measuring in cents (oen cent = one hundredth of a semitone) or thousandths of an octave, the perceived pitch of a tone ranging over notes with the same fundamental frequency for voice, viola, trumpet and piano can vary by as much as 20 cents (Vurma, Raju & Kuuda, 2010). Pitch is also derived using the spectrum of a tone, and in music the process of finding the fundamental frequency often assumes tones to be harmonic, that is each spectral component has a frequency that is an integer multiple of the lowest component which is the ‘fundamental frequency’. Mathematically, the process of finding the fundamental from even an incomplete set of harmonics is quite simple as the fundamental is often the greatest common divisor - however not all musical tones are completely harmonic, and it is those deviations from a harmonic spectrum which add to the interesting timbres found within an orchestra. On the other hand, real world acoustics means that the frequencies and amplitudes constituting a sound change over time, hence the auditory system has an even greater challenge.

Since the main topic we are concerned with here is pitch perception, it is useful to know some details about how the brain derives pitch. The auditory system starts at the ears, which are divided into the outer, middle and inner ears, and within the inner ear an organ called the cochlea separates a tone into its spectral components, due to the ability of the basilar membrane within to resonate maximally with these different frequencies in different places whose vibrations trigger electrical signals. The cochlea is the first point at which the auditory system organises these spectral components in terms of their frequencies, sorting from low to high, and this ‘tonotopic map’ is preserved through much of the auditory cortex in the brain. The entire spectrum contributes to pitch perception, and a second mechanism happens in the analysis of the electrical signals. In music analysis, relationships between notes are used to find Rameau’s fundamental bass, however this is limited to only twelve notes out of an octave and so in the auditory cortex, relationships between the frequencies of synaptic firing corresponding to spectral components are used to derive the fundamental frequency of a harmonic tone. The following diagram illustrates how pitch is derived from the spectrum of a complex tone:

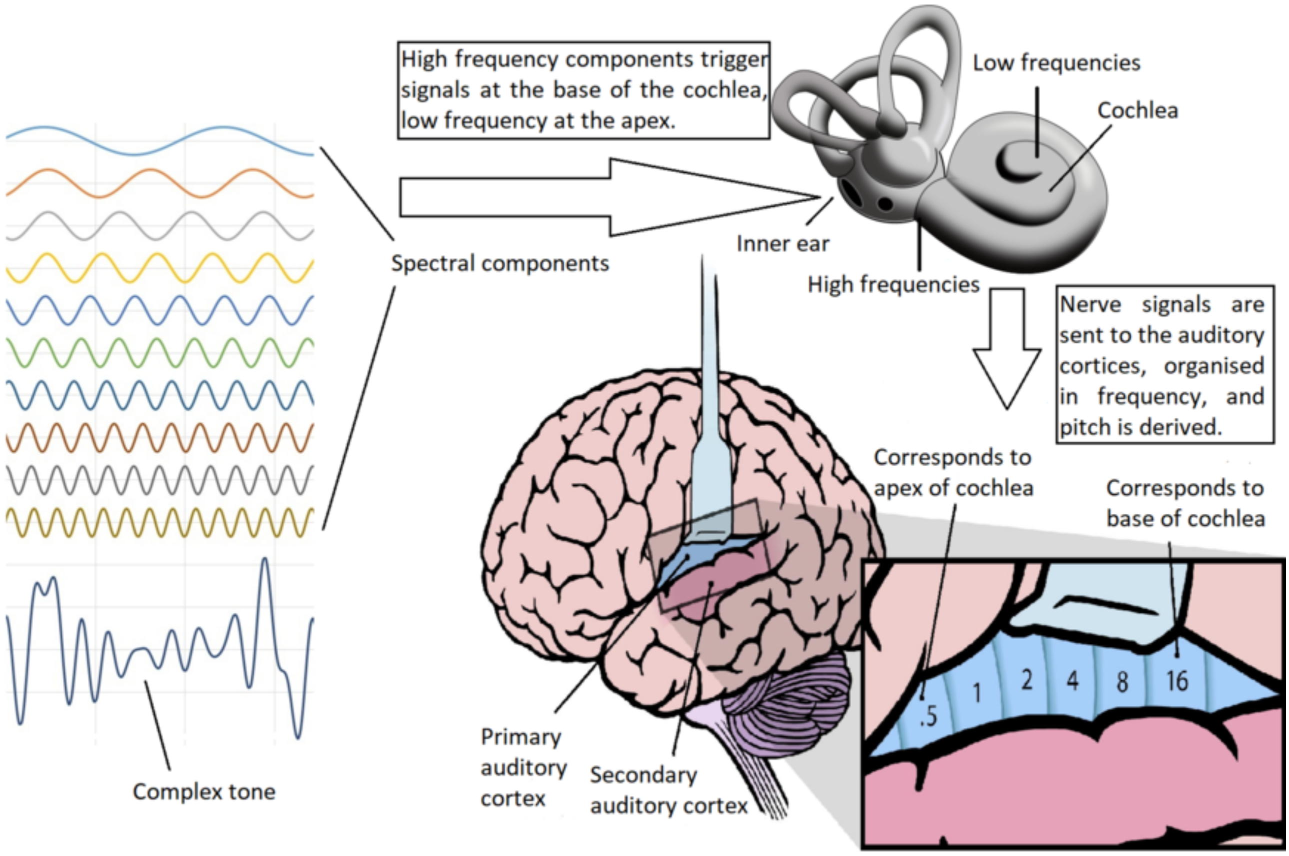


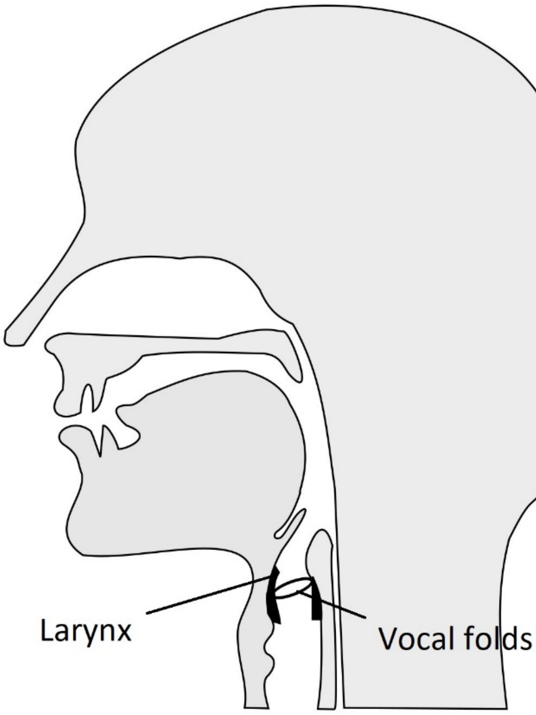
Figure 1: Complex tone represented as the sum of spectral components; Each component leads to auditory nerve signals at different positions on the cochlea depending on frequency; The nerve signals are further processed within the auditory cortex, which keeps the organisation of signals based on frequency (adapted from 'User:BoH – Wikimedia Commons', 2020; Sheldahl, 2018; Brockmann, 2005).

An interesting side effect of how the brain processes harmonic tones is that the pitch perception of pure tones, those with only one spectral component, is unstable and so varies significantly with their amplitude. Tones with more harmonics do not have as obvious pitch shifts with amplitude because there is more information available to derive pitch. There are two factors from the auditory system which result in differences across frequency between the pitches of tones with varying spectra – one involves the tonotopic map produced by the cochlea, and the other relates to neural firing rates. The way in which the cochlea breaks down the spectrum of a tone works best when spectral components are more spaced out in frequency – otherwise, the simpler tones cannot be separated and cause the perception of beats. As complex tones have many components at high multiples of the fundamental, the higher the frequency the more these inseparable components could interfere with pitch perception, hence pure tones with higher fundamental frequencies such as 1000Hz can have a clearer pitch (reference needed). However, our 'auditory learning biography' is another way in which our perception of sounds with different spectra may differ – the experience we accumulate throughout life of listening to and interacting with music, which may aid in the musical processing of people generally considered non-musicians(Altenmüller, 2001). Listeners may process pitch differently with an instrument which is unfamiliar to them than, for example, synth strings from their favourite '80s album.

It is natural for musicians to assume that the auditory processing of non-musicians and amateurs is significantly different, similarly to how their spatial and body awareness would be ill equipped to launch into an aria. Yet evidence shows that they use the tonal context of music in pitch processing similarly to musicians – and this makes sense considering the exposure which most people have to western pop and classical music, harmony and tonality. Krumhansl (1991) found that when asked to identify whether notes in a melody had been altered, listeners used tonality, presence of perfect cadences and a variety of other features to recognise when a note was higher in frequency. In further tests using melodies in unfamiliar styles, participants were found to pick up the new tonalities via statistical distribution of the notes, similarly improving their performance. Other research has found that musicians separate pitch and timbre more (Pitt, 1994), and in singing tasks, community trained singers may more accurately replicate equal tempered pitches in a manner comparable to those with formal training (Mang, 2007). These phenomena could be explained by the treatment of pitch and timbre as separate in classical music training, and the increased attention given to tuning decisions outside of equal temperament by classical choral singers.

The question may also be asked how spectral differences affect the pitch perception of musicians with 'perfect' or 'absolute' pitch. Marvin and Brinkman(2000A) found that pitch perception in general seems to differ between 'absolute' and 'relative' pitch possessors. Absolute pitch possessors based their prediction of isolated notes first on pitch colour i.e. the position of a note in an octave and only then on the octave it is in, whereas relative pitch possessors made more errors on position within the octave than which octave the note was in. More importantly, absolute pitch does vary in accuracy with the spectrum of notes presented. AP possessors excel in identifying the fundamentals of piano tones, compared to both other instruments and synthesised tones, and some people have a form of AP which is exclusive to piano tones. On the other hand, their other results found no difference between accuracy in identifying fundamentals on piano and violin, although violinists showed some differences potentially attributable to their treatment of pitch as a continuous spectrum (2000B). AP possessors are also known to be more accurate in the middle of the frequency range more commonly used by musicians. Choral directors could take advantage of this information when exploring tuning outside of equal temperament, by considering which instruments it would be easier for singers with absolute pitch to tune against.

But how does this apply to choral singing specifically? To understand this, we need to know which features of the voice could affect pitch. First, an explanation of the voice itself is needed. The source filter theory of speech states that the voice can be treated as a combination of a pulsating 'source' which creates pressure waves in the air, and a filter through which the pressure wave passes. For many speech sounds, use of this model where the source is the larynx, and the filter includes the vocal tract from larynx to lips is enough to simulate them. This causes some problems as the model also assumes an independence between the source and filter, which in certain sounds such as the consonants 'v' and 'b' is untrue, but for our purposes the simpler model is enough. It explains the two acoustic features in singing which allow us to talk about pitch perception in the voice – vocal formants, and the harmonics of the note being sung. While a sound is first produced by vibrations of the vocal folds within the larynx, the positions and shapes of different parts of the vocal tract are used to amplify the harmonics in that sound, creating identifiable vowels and shaping the timbre of your voice. We can represent formants as a sort of acoustic filter, which changes the relative amplitudes of the input frequency components leading to a single peak or centre frequency.



From left to bottom right. Figure 2: vocal tract with the position of the vocal folds indicated (adapted from Tavin, 2011); Figure 3: vocal folds from above, shown open during breathing (melvil, 9th November 2016); Figure 4: vocal folds shown closed during speaking (melvil, 19th November 2016).

According to Sundberg (1994), the so-called singer's formant is a major factor in the resulting timbre of a singer's voice – that is, any formants above the second which are developed with training. The centre frequencies of these formants were found by him to vary depending on voice type, with bass singers having the lowest centres compared to the altos with the highest. Sopranos on the other hand have no discernible singer's formant. Thus, the spectra of these voice types vary in a similar way to their overall ranges, and since this has a significant impact on their timbre it may also prove enough to affect the tuning of a choir. Research into pitch and timbre perception has found an influence on the perceived pitch of a tone by its 'centre of gravity' (Vurma, Raju & Kuuda, 2010), which is essentially exactly what the singers' formant does. Within a given voice, that centre is dependent on the shapes and peaks of the formants. This implies that we may hear a bass voice as deeper than a tenor even when they are singing the same note. Tying this within the context of tuning in choirs, studies have also found that singers' intonation drift involves both an adaptation of the intervals being sung based on perceived consonance and a shifting reference note against which to tune (Mauch, Frieler & Dixon, 2014), and so if we consider a choir in which a singer tunes first against bass and later alto parts the resulting complications become apparent. Furthermore, tuning against singers with vibrato may be even less predictable as the range of frequencies considered 'in tune' was found to be broader than for straight singing (Besouw, Brereton & Howard, 2008).

What does this mean for choral singers in practice? For a start, whereas singers with more formal training may need encouragement to think about timbre as a significant part of music, those with informal training and experience may have a conception of pitch and timbre as related but not know how this could lead to tuning decisions outside of equal temperament. Many *a cappela* singers are accustomed to tuning without equal temperament and tuning drift, but the differences in timbre between voice type and their potential effects on pitch could be useful in considering which parts singers choose to tune against. Those with absolute pitch might even find a greater freedom in tuning is more acceptable without instruments such as piano involved, thus showing that while we may want frequency to be the sole defining characteristic of pitch, a scale played on a piano and sung by a baritone is not in fact the same.

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