

Emma Lindsey

2016639

BMPF7013F:

Independent Study Module

*A potential use of formant tuning to
enhance intonation within a choral setting*

A POTENTIAL USE OF FORMANT TUNING TO ENHANCE INTONATION WITHIN A CHORAL SETTING
--

CONTENTS

ASSESSMENT 1 - PORTFOLIO	4
INTRODUCTION	4
PLANNED PROGRAMME OF STUDY	5
CRITICAL REFLECTION	10
ASSESSMENT 2 – WRITTEN ASSIGNMENT	14
Introduction	14
Harmonics.....	14
Intonation	15
Choral intonation.....	16
Formants.....	16
Vowel Formants	17
Formant Tuning.....	21
Formant Tuning Within Choirs	23
Application	24
Conclusion	28
References	29
Appendix A.....	34

Figures

Figure 1, Assignment timescale – p. 6

Figure 2, Intervals of the harmonic series – p. 14

Figure 3, Glottal flow waveforms and the corresponding harmonic spectra for varying levels of vocal fold adduction – p. 15

Figure 4, SATB D major open spacing chord and harmonics of each chord member – p. 16

Figure 5, Spectrographic model of the first two vocal tract formants, the vowel formants – p. 18

Figure 6, Frequency of second formant versus first formant for ten vowels by 76 – p. 18

Figure 7, Traditional representation of relative position of the highest point of the tongue in American English vowels (right), corresponding acoustic data (left) - p. 19

Figure 8, IPA vowel quadrilateral – p. 20

Figure 9, Approximate First Formant Locations – p. 22

Figure 10, SATB D major open spacing chord, harmonics of each chord member, and approximate pitch locations of first and second formants of the vowel /e/ - p. 24

ASSESSMENT 1 - PORTFOLIO

INTRODUCTION

Although Cooksey (1977) formulated an approach to choral adjudication over 50 years ago, a standardised method remains notably absent in contemporary competitive settings (Hensley, 2021). Hensley did indicate that one of the most important aspects adjudicators listen for is intonation. In this study, I am proposing that the use of formant tuning could be helpful in achieving this objective. As the choral director of an amateur choir founded in 2021 with a focus on competitive singing, I am actively seeking strategies to improve the choir's performance capabilities. Prior to embarking on the MA course, I harboured a belief, based on experience, that vowels played a pivotal role in achieving excellence in choral work, especially in the realm of intonation,

I was further compelled to research this area after reading 'Vowel and Consonant Modification for Choirs' (Nix, 2010). Vowel modification, which is also referred to as formant tuning, is a technique for aligning formants with harmonics to boost acoustic output (Sundberg, 1987, p. 126). This will be more fully explained below in the literature review. I was particularly struck by Nix's discussion of the potential use of vowel modification for the sopranos in the loud and high-pitched recurring main theme of 'Dies Irae' from Verdi's Requiem – a work I had sung at the First Night of the BBC Proms in 2022. Despite the prominence of this concert and the number and precise nature of rehearsals, a shading of the /e/ vowel to a blended /ɛ/ and /æ/ and further alterations as the line descends was not a concept that was discussed (Nix, 2010, p. 20). I had gained a foundational understanding of harmonics and formants during my time on the MA course and I recognise, from that and from experience, that singing as a choral soprano, particularly above the stave, often presents challenges with regards to clear diction. As singers reach G5, the pitch has surpassed the first formant of all vowels except /a/. Consequently, regardless of the intended vowel, the resulting sound is most likely to be perceived as an /a/, even without deliberate modification (McCoy, 2011, p. 299). Whilst performing Beethoven's Ninth Symphony at the Royal Festival Hall and again at the Royal Albert Hall in 2022, considerable effort was invested in refining German diction, but some additional understanding in terms of first formants by all would have been invaluable given the high-pitched nature of this piece. McCoy suggests modifying the text "die ganza Welt" to "Da ganza Walt" arguing that singers risk vocal injury if they attempt to preserve the original vowel sounds and the audience do not benefit more (McCoy, 2011, p. 299).

I believe that formant tuning has an important role to play in choral music and in this project, I would specifically like to address the use of this technique to enhance intonation in a homophonic choral chord. For every note in the chord, there are a series of harmonics. If this technique is able to accentuate or de-emphasise certain harmonics, there is the potential opportunity for fine tuning a chord. McCoy provides anecdotal evidence of this strategy working where he modified the vowel for the basses in order to avoid dissonance with the upper voices (2013, p. 48), and Nix provides a method for tuning a D major chord on an /e/ vowel (2010, p. e468) which will be fully discussed below.

Miller and Schutte stated in 1990 that “conscious application of formant tuning to the practice of training singers has been slow in developing” (p. 232) and although this was 33 years ago this appears to still be true of its use chorally. In my four decades of choral singing within the UK, I have never encountered discussions on formant tuning within a choral context. This omission might stem from factors such as limited awareness among choral directors, time constraints or apprehensions about poor diction, but I have no evidence of that. Nonetheless, I speculate that certain choirs might be harnessing these techniques, giving them a competitive advantage over other choirs, which might explain the reluctance to discuss them openly.

I am motivated to understand these concepts and introduce them more widely to choirs. I recognise that my knowledge of formant tuning is limited. In this assignment, I intend to critically analyse existing research on intonation, formant tuning and its application within a choral setting to improve my understanding and refine my choral leadership. I intend to develop a reference guide for use by choirs that incorporates essential elements needed to guide choral directors and singers in the implementation of this strategy. In addition, I aim to identify areas that require further research.

PLANNED PROGRAMME OF STUDY

Aim

I aim to develop a pedagogical resource to support the implementation of formant tuning in choirs specifically with reference to enhancing intonation in homophonic chords.

Objectives

I intend to examine the available data and produce a narrative literature review to:

- a) Define harmonics, formants, vowel formants and formant tuning.
- b) Define intonation as relevant to choirs.
- c) Investigate the use of formant tuning and its potential impact on intonation within a choral setting.
- d) Identify methods to incorporate the use of formant tuning.
- e) Produce a reference guide for use by choral directors and singers.
- f) Understand deficiencies within the current body of research and the possibilities for further research.

Expected Learning Outcomes

I anticipate that by the end of this module, I will have a deeper understanding of the potential use of formant tuning within my own choir and a practical strategy for adopting this method to enhance intonation. In addition, I believe that I will have identified research ideas for Module 6.

Timescale

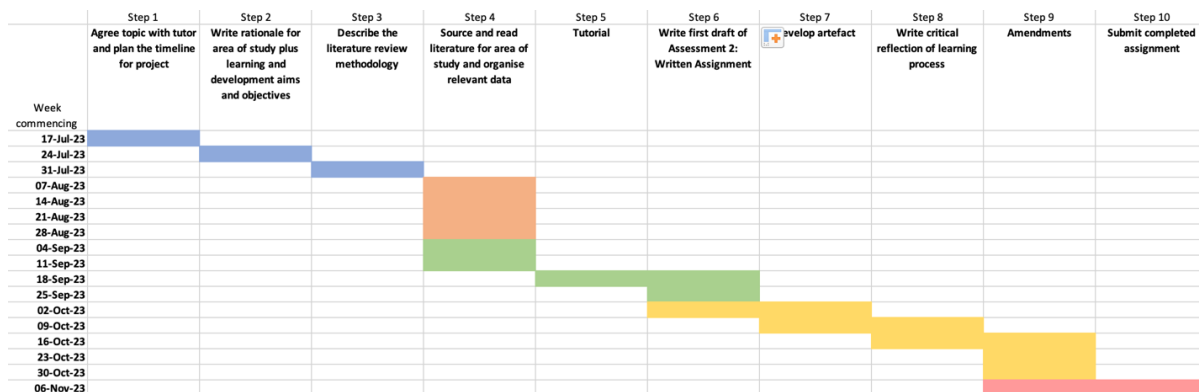


Figure 1, Assignment timescale

Contextualisation of Study

This study was guided by the social constructivism paradigm, which acknowledges the existence of multiple realities (ontology), considers knowledge as co-constructed and subjective (epistemology) and places importance on values (axiology) as outlined by Guba and Lincoln (1994). The literature review was more specifically informed by a heuristic approach, characterised by discovery and problem-solving that prioritises utility over certainty. Heuristics offer no assurance of delivering a correct solution to a problem, but instead focus on delivering judgments and decisions that are good enough to meet urgent needs in situations of uncertainty,

where information is incomplete. This process combines reasonable search methods together with one's intuition. In my role navigating the path between theory and practice, this paradigm enables harmonious co-existence of researcher and practitioner within a single individual, as it allows for the integration of data from both sides if it contributes to valuable knowledge (Heineman Pieper, 1989). The reference guide was generated using a pragmatic approach, which recognises the interplay between experience, knowledge and action (Kelly and Cordeiro, 2020). This also aligns with my dual role as both a practitioner and researcher, bridging the gap between theory and application. This pragmatic stance allows for a flexible integration of various methods to yield practical and actionable insights, moving beyond the limitations of a single philosophical viewpoint (Rossman and Wilson, 1985; Feilzer, 2010).

It is important to clarify that this study revolves solely around a literature review; it does not involve testing on subjects in choirs as ethical clearance has not been secured for such investigations. My goal is to provide an honest and comprehensive representation of the data without bias towards any particular outcome. In scoping the project on Mendeley Online, I found that there was a limited amount of white literature that precisely addressed the subject, as discussed below in the Methodology. Consequently, this study draws upon data from foundational subjects, such as acoustics and phonetics, and data from formant tuning in solo singing. Given my role as a part-time researcher, I have made judicious decisions about which sources to include or omit, factoring in the constraints of time and resources available to me.

The intonation of a choir can be influenced by the tuning system they employ. Two prominent systems are Equal Temperament Tuning (ETT) and Just Intonation or Tuning (JI). ETT divides the octave into 12 equal parts and is commonly used in choirs, especially in contexts where instruments accompany voices or when compositions have complex harmonies (Howard and Angus, 2017, pp. 166–170). Just Intonation is based on the natural harmonic series and can result in purer intervals without beats (Withington, 2020). Research by Howard (2007) provides insight into this phenomenon of pitch drift where unaccompanied singers unconsciously adjust their pitch to the harmonic series, thereby slightly deviating from the expected Equal Temperament Tuning pitch. The harmonics that derive from each singer's fundamental frequency clearly follow the harmonic series, as does JI. However, there is the possibility for variance if using ETT. For example, in figure 10, if ETT is being used the alto's A4 will be slightly different in frequency to the bass's third harmonic A4. This is a further consideration of the use of formant tuning once it is

established that there is validity to the strategy using JI. Assessment 2 below does not discuss tuning systems.

In English, dialectal variations are primarily marked by differences in vowel sounds (Ladefoged and Disner, 2012, p. 45). Many of the studies referred to within this project are based on American English rather than British English. In the reference guide, I have tried to refer to British English where possible as I believe that will more useful for British choirs like mine. The existence of a standard form of English in Britain is a subject of considerable debate and this study refers to BBC English as a standardised form (Ladefoged and Disner, 2012, p. 45). This is based on the pronunciation of newsreaders and is similar to Received Pronunciation (RP) (Deterding, 1997). In more recent times, the accent adopted by British newsreaders has evolved, reflecting a shift towards a more diverse and representative range of accents including regional variations (Cruttenden, 2014, p. 6), which is not reflected in this study nor is there specific information on singing in foreign languages.

Methodology

This narrative literature review will primarily examine peer-reviewed publications. An initial scoping search was conducted on Mendeley Online on 9 September 2023 using 'vowel modification choir', 'vowel modification choral', 'formant tuning choir' and 'formant tuning choral', which produced seven articles. Consequently, I expanded my search to encompass 'vowel choir' and 'vowel choral'. After removing duplicates and articles that were clearly irrelevant such as papers on Parkinson's Disease, aerosol dispersion and the ageing voice, 34 articles remained which required closer examination to assess their relevance to this study. I also searched 'choir intonation' and 'choral intonation'. In total, this resulted in 269 articles of which 13 had the potential to be relevant but needed further investigation.

At this point, I used the search terms above as the basis for searching Google Scholar, Science Direct, Journal of Singing and the Choral Journal. The searches on Google Scholar and Science Direct produced a large number of results, so they were organised for relevance before the top 97 articles from Google Scholar and 86 from Science Direct were downloaded. My last search was on 10 September 2023. The data retrieved was organised in Mendeley, facilitating the screening process to eliminate duplicates and further filter out non-relevant studies by reviewing abstracts and skimming articles where necessary. The exclusion criteria were defined to omit articles that:

1. Did not pertain the singing voice
2. Did not discuss Western classical or choral music
3. Were not written in English or available as a translation in English

Following a tutorial on 28 September 2023, where the definition of intonation was discussed, as mentioned in the Critical Reflection below, I completed further searches on pitch perception OR pitch-matching AND cepstral peak OR harmonics. This led to an additional eight articles. In addition, I have also made use of some grey literature, when it was deemed reliable, valuable, and useful and where the required information did not seem to exist within white literature. This included books by experts in vocal pedagogy and research and some website resources particularly for completion of the reference guide. I have critically assessed the literature for its applicability, summarised it and examined the frequently cited references to identify further research. I have categorised my notes into themes and have summarised my findings in Assessment 2 below. To create the reference guide for formant tuning, I identified the essential elements necessary for practical application for the choral director and for the development of singers following the review of the literature.

CRITICAL REFLECTION

In this project, I aimed to create a tool to enhance intonation in choirs through formant tuning. I maintained a journal to track and reflect on this educational journey. For my analysis, I used a slightly modified version of Greenway's Active Reviewing framework, as presented by the University of Edinburgh (2018). This framework, designed for educators to reflect on their teaching, includes four stages: Facts (an unbiased account of events), Feelings (emotional responses), Findings (lessons learnt) and Future (applying these lessons ahead). The straightforward structure and its basis in education worked well for a critical assessment of my learning experience.

Facts

I investigated the potential application of formant tuning to improve the perception of intonation within choral homophonic chords by conducting a narrative literature review. Given the paucity of research on this specific subject, I examined the impact of harmonics on intonation and the general tuning of vowel formants in solo and ensemble singing to gather more relevant data. As a practical outcome of this project, I developed a reference guide for choral directors and singers. This tool includes the use of the International Phonetic Alphabet (IPA) for targeting specific vowels, techniques for further modifying vowel quality and guidance on handling diphthongs. Additionally, it offers essential information to choral directors to inform strategic planning for formant tuning. I recognise the potential benefits of this technique, but having completed this study acknowledge that its effectiveness warrants further investigation.

Feelings

This assignment has been both intellectually stimulating and emotionally taxing. Through the MA course, I have explored a range of subjects which have all been in response to specific questions that I had. While each project has been beneficial, I have struggled to find a specialism for continued growth in a topic. Entering this project, I was uncertain about what to study and this feeling of doubt was compounded by a change in my circumstances this year. I have been working full-time in asset management in addition to teaching singing on a part-time basis, running a choir and singing in a busy London symphonic chorus. I had planned to transition from Finance to a full-time role in teaching this year, but due to health issues, I have had to suspend that plan in addition to my teaching and my own singing. The introduction above provides a sense of how I selected a subject. Despite the challenges, my project has unexpectedly ignited a passion for phonetics within me presenting a clearer path for future research. Nonetheless, the scarcity of

conclusive evidence confirming the efficacy of formant tuning has been disconcerting at times and a very different experience from previous projects where I have perhaps had too much information. The lack of evidence has at time threatened to 'derail' the project and lead me to doubt its value. However, having completed the study, I remain cautiously optimistic about the efficacy of formant in choral practice.

Findings

The study was initially inspired by a book chapter by Nix (2010). In my last project on vibrato, I found his articles to be reliable and informative (2013, 2014) and I have felt that he is a trustworthy source. In an informal scoping of the project, I came across two articles by McCoy (2011, 2013), a dissertation (Strychacz, 2021) and an article by Saus (2012). The ease of these discoveries made me naively anticipate that there would be a number of peer-reviewed articles on this precise subject comparing the use versus non-use of formant tuning in homophonic chords. The absence of such comparative research marked the first significant challenge in my study. I had briefly read the dissertation, but I had wanted to find my own evidence from white literature and build my own conclusions, rather than on the grey literature of a dissertation and therefore had not thoroughly digested his work. To overcome this lack of specific research, I instead investigated the separate topics of harmonics, formants, formant tuning and phonetics in the hope of finding evidence from peer-reviewed journals that I could compile to suggest this technique would work in choirs.

While I knew that I was trying to find evidence that formant tuning could assist with the perception of consonance or dissonance (if desired) in a homophonic chord, I questioned my use of the term 'intonation' to reflect this. My understanding of intonation had been the precision of the interval between two notes. As the knowledge that harmonics cannot be modified and thus formant tuning has no impact on the value of the fundamental frequency registered for me, I realised that if I used my definition of intonation this would not make sense. On my tutor's advice, I explored the concepts of cepstral peaks and pitch-matching, searching for evidence that individuals might pitch-match more effectively with complex tones than with pure tones. It was during this phase that I encountered the concept of the missing fundamental in an article by Oxenham (2012, p. 13335), which was a turning point in my project. This refers to a phenomenon in the perception of sound where the brain perceives the pitch of the fundamental frequency even when that harmonic is absent. This shows that our perception of pitch is influenced by harmonics. From this I took hope that if certain harmonics were boosted through the use of formant tuning it could have an impact on our perception.

In trying to write the first draft, I experienced a wave of self-doubt due to the lack of critical evidence to specifically support or not support this theory. As I drafted, the idea of shifting topic to formant tuning within solo singing started to appear as a more viable alternative. Yet, after a tutorial, I began to reconcile with the notion that the potential significance of formant tuning in choral settings indeed warranted further investigation, even if my current findings were inconclusive. I began reading a chapter on Choral Voice in Sundberg's book (1987, pp. 136–145) even though it was grey literature and it was the exploration of Sundberg's summary of experiments conducted with Ternström that was a further turning point in my study. While familiar with some of their work, I had not fully explored the breadth of evidence they provided, partly because some of it seems inaccessible, but it ultimately lent more specific support to my study.

The effectiveness of formant tuning in enhancing the intonation of homophonic chords remains inconclusive; however, the research conducted has been valuable particularly in advancing my understanding of harmonics, formants and phonetics. This knowledge will be useful in my future teaching practice and the guide created as a result of this project has its own merits outside of the effectiveness of formant tuning, as discussed below. A significant insight from this project is the realisation that a perfect outcome is not a prerequisite for value.

I found the basis of the International Phonetic Alphabet (IPA) vowel chart particularly memorable, as described in the literature review. Despite technological advancements that have proven variations in tongue positions, phoneticians continue to rely on Bell's foundational research for the vowel chart (Nicholson, 2017). This has led to a deeper awareness of the importance of critically evaluating commonly accepted statements and the necessity to investigate the evidence that supports widespread beliefs. However, even if the articulatory accuracy of such a tool is debatable, it does not detract from its utility. Bell's phonetic transcriptions were notably meticulous allowing us to infer precision in his perception of tongue placement (Ladefoged and Disner, 2012, pp. 148–149). For a learner requiring a visual aid, the IPA chart is a beneficial starting point for grasping the approximate tongue positions.

Future

The project was initiated with the intention of seeking evidence for a competitive advantage by using formant tuning. It remains unclear if this goal has been fully achieved and I would like to continue this line of inquiry in the next module. In the meantime, I am eager to apply the knowledge I have gained on formants in my future teaching practice and I am keen to use the

reference guide in the current work with my choir. The development of the guide is intended to enhance my choir's ability to accurately interpret and transcribe vowels sounds and to offer insights on the handling of diphthongs, whether for the purposes of formant tuning or vowel uniformity. I am hopeful that it can help other choirs refine vowel articulation too and potentially formulate strategies for formant tuning. This educational experience has been profoundly beneficial in my development. I have evolved from having minimal knowledge of acoustics and phonetics to a state of competence and an eagerness to implement what I have learned theoretically into my teaching methods. Most importantly, I have learnt to find value in ambiguity.

A POTENTIAL USE OF FORMANT TUNING TO ENHANCE INTONATION WITHIN A CHORAL SETTING

ASSESSMENT 2 – WRITTEN ASSIGNMENT

Introduction

Intonation is of paramount importance for choirs, consistently emerging as a principal focus during daily rehearsals as documented by Ganschow (2014) and further highlighted by Hensley in his article on festival adjudication (2021). This study examines the evidence for employing formant tuning to accentuate or diminish specific harmonics within sung homophonic chords with the intention of improving the perception of intonation. This narrative literature review aims to define harmonics, intonation, formants, vowels and formant tuning before outlining a strategy for using these concepts within the choral environment together with a pedagogical reference guide for choral directors and singers. Finally, avenues for future research will be identified.

Harmonics

The human voice generates complex periodic tones, consisting of a series of harmonics. Each harmonic is an integer multiple of the first harmonic, also known as the fundamental frequency (f_0). For example, the second harmonic is two times the fundamental frequency, the third harmonic is three times the fundamental frequency, and so on (Plack and Oxenham, 2006, p. 13). In theory, there can be an infinite number of harmonics, but the range of human hearing and a decrease of 12 decibels per octave mean that only a limited number are significant (Sundberg, 1977, p. 82; Titze, 2009, p. 575). Musical notes plot frequency on a logarithmic scale resulting in the following intervals for the first six harmonics (Howard and Angus, 2017, pp. 132–133):

Second harmonic	2:1	An octave higher than the fundamental frequency
Third harmonic	3:2	A perfect fifth higher than the second harmonic
Fourth harmonic	4:3	A perfect fourth higher than the third harmonic
Fifth harmonic	5:4	A major third higher than the fourth harmonic
Sixth harmonic	6:5	A minor third higher than the fifth harmonic

Figure 2, Intervals of the harmonic series

Harmonics originate at the voice source mainly due to two phenomena: the oscillating collisions of the vocal folds and the feedback of acoustic energy from the vocal tract to the glottis altering glottal flow (Titze, 2009). Regarding the former, figure 3 demonstrates three glottal waveform scenarios (shown on the left) and their corresponding harmonics (displayed on the right). As the glottal adduction increases from 20% in the top graph to 80% in the bottom graph, there is a noticeable increase in the number of harmonics. This indicates that a greater level of vocal glottal adduction results in a richer harmonic spectrum (Titze, 2009).

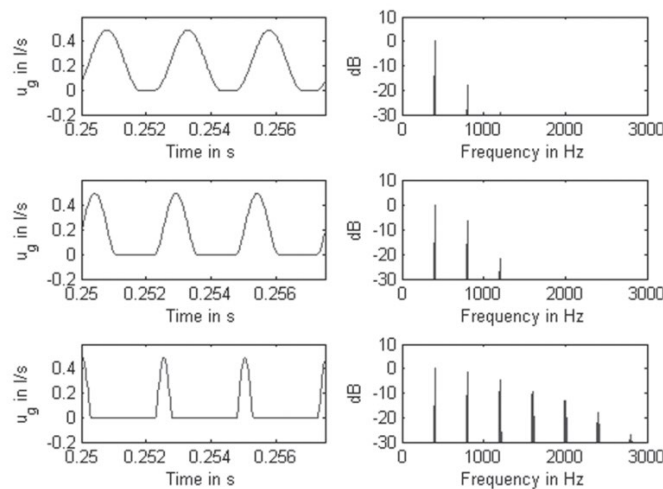


Figure 3, Glottal flow waveforms and the corresponding harmonic spectra for varying levels of vocal fold adduction (Titze, 2009, p. 576)

Intonation

Intonation refers to the precision with which a musician matches pitch with the intended musical note (Swannell, 1992, p. 560). Bendor and Wang explain that while frequency is an objective measurement of sound, pitch is how we perceive that sound (2006, p. 391). Ternström further refines intonation as the purposeful alteration of the fundamental frequency to align the perceived pitch with a target pitch (1991, p. 136). The challenge arises when considering the voice's complex tones, which include a blend of frequencies or harmonics (Bendor and Wang, 2006, p. 391). These harmonics enrich auditory cues and enhance pitch discrimination as evidenced by Moore, Glasberg and Peters (1985). An interesting aspect is the "pitch of the missing fundamental" phenomenon. In situations where the fundamental frequency is absent from a complex tone, listeners still perceive the pitch of the missing fundamental based on the relationships between the existing harmonics (Plack and Oxenham, 2006, p. 13). This suggests that pitch perception is

closely linked to harmonics, though the debate continues over which harmonic predominantly influences this perception. It is generally agreed that the first to the fifth harmonics are most influential, and as the fundamental frequency rises, the perception of pitch may increasingly depend on higher harmonics (Plack and Oxenham, 2006, p. 16). This implies that our understanding of pitch should acknowledge the influence of the entire spectrum of harmonics, not just the fundamental frequency, underscoring the complexity of pitch perception in the context of intonation.

Choral intonation

Harmonics are important in the pitch perception of a single voice, but what happens when multiple voices sing together? Figure 4 illustrates a D major chord sung by soprano, alto, tenor and bass (SATB) voices. The second bar reveals the harmonics of each voice's note, highlighting the common partials or overlaps between these harmonics.



Figure 4, SATB D major open spacing chord and harmonics of each chord member (amended from Nix, 2012, p. e468)

In a study on barbershop quartets, it was found that intervals that share a higher number of partial tones tend to be sung more accurately in tune compared with intervals with fewer shared harmonics (Hagerman and Sundberg, 1980). In a later experiment on the impact of spectral properties it was found that intonation was further improved if the lowest common partial was “enhanced by a formant.” (Ternström and Sundberg, 1988, p. 69)

Formants

Formants can be defined as frequency peaks in the radiated spectrum (Bozeman, 2017, p. 86). Imagine a vocal tract shaped as a perfect cylinder, closed at the glottis and open at the lips,

measuring 17.5cm long (which is typical of an adult male), the first four formants would be at 500Hz, 1500Hz, 2500Hz and 3500Hz (Sundberg, 1977, p. 83). The vocal tract, however, is a flexible tube with multiple resonating cavities, all of which are adjustable (Bozeman, 2013b, p. 37). These include variations in larynx height, pharyngeal constriction, tongue position, velum position, jaw opening and lip configuration (Sundberg, 1977, p. 93; Titze, 2000, pp. 164–168). With regards to men, women and children their vocal tracts typically differ in length (Sundberg, 1987, p. 102). It is interesting to note that the average female vocal tract is not simply a smaller version of the male vocal tract. The average length of an adult female's mouth is approximately 85% of the male average, but the length of the female pharynx is only 77% of the male equivalent. This would also account for differences in formant frequencies (Nordström, 1977).

Each formant corresponds to a standing wave within the vocal tract, which is a fixed pattern of pressure fluctuations that have their highest amplitude at the glottis and approach their lowest at the lips. The length of the vocal tract is a quarter of the wavelength of the lowest formant (Sundberg, 1977, p. 83). Therefore, the length of the vocal tract determines the maximum possible value for the first formant frequency (Sundberg, 1975, p. 95). Alteration to the vocal tract's length or its cross-section will modify the specific frequencies of the formants; the exact nature of these shifts depends on where along the length of the vocal tract the change in size occurs in relation to the standing wave pattern (Sundberg, 1977, p. 83). Changes to the formant frequencies will be discussed further in the formant tuning section below.

A harmonic located near a formant is intensified, typically raising the overall emitted sound level (Carlsson and Sundberg, 1992, p. 256). A typical voice contains multiple formants, but only approximately three to five formants have a “low enough frequency and strong enough in intensity” to be aurally significant (Bozeman, 2013b, p. 38). Basses usually have five formants decreasing to sopranos at the other end of the spectrum, who usually only have three. In addition to having fewer formants, female voices have fewer audible harmonics as their voices are higher. (Bozeman, 2013b, p. 38) This could mean there is less opportunity for resonance.

Vowel Formants

The first two formants, F_1 and F_2 , play a significant role in vowel differentiation (Peterson and Barney, 1952). For example, as shown in Figure 5, a high second formant frequency and a low first formant is interpreted as an /i/ vowel.

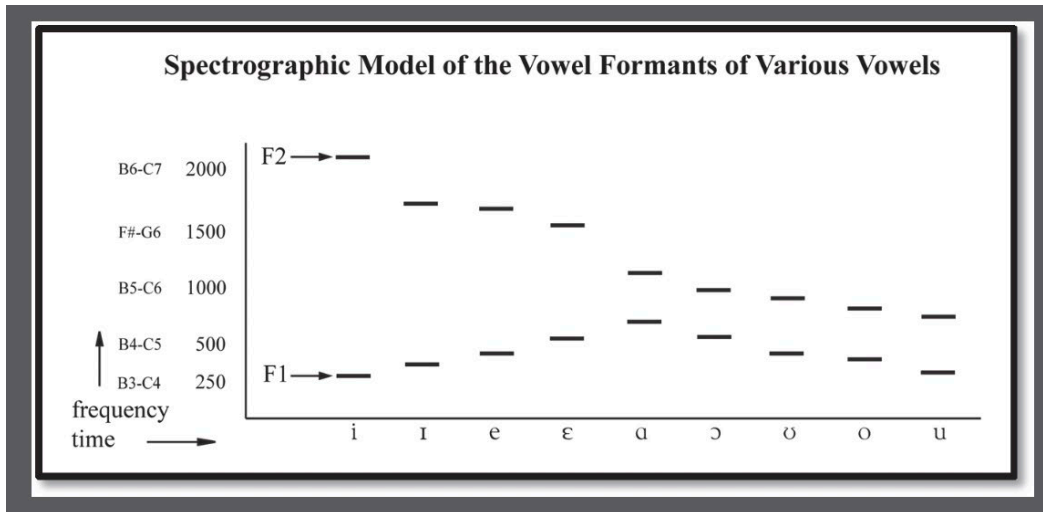


Figure 5, Spectrographic model of the first two vocal tract formants, the vowel formants (Bozeman, 2013, p. 27)

Peterson and Barney (1952) demonstrated that the first and second formant frequencies are not fixed values; rather, they vary within a certain range as depicted in Figure 6. This variation is due to differences in individual speakers, including factors such as age, gender and the specific articulation of vowels. Generally, the formant frequencies are highest in children, intermediate in women and lowest in men. Furthermore, if the analysis were to include sing vowels, there would be an even broader range of formant frequencies for each vowel (Sundberg, 1970, pp. 88–89; Titze, 2000, p. 162).

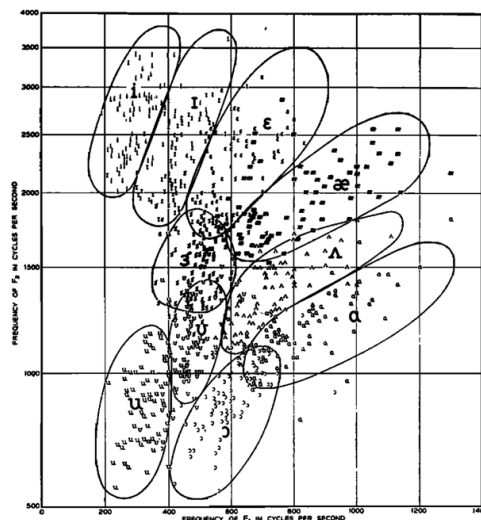


Figure 6, Frequency of second formant versus first formant for ten vowels by 76 speakers

(Peterson and Barney, 1952, p. 182)

Vowels are characterised acoustically by their formant frequencies, articulatorily by tongue and lip positions and symbolically using the International Phonetic Alphabet (IPA), which documents tongue height and frontness and lip rounding and is designed to encompass a comprehensive set of symbols to represent the world's languages (Ladefoged and Halle, 1988, p. 578; International Phonetic Association, 1999, p. 3; Titze, 2000, pp. 162–163). The traditional articulatory approach, originating from Alexander Melville Bell, describes vowels based on the vertical (high-low) and horizontal (front-back) positioning of the tongue, combined with lip opening. While Bell's observations were significant, his assessments of tongue positions were limited by the subjective nature of only what could be seen and felt. Subsequent phoneticians used Bell's concepts of tongue height and backness to create vowel charts, despite X-ray studies showing that actual tongue shapes during speech differ from Bell's initial conceptions and it is still the basis for the IPA vowel chart (Ladefoged and Disner, 2012, pp. 149–151). Comparing a representation of traditional tongue positioning with acoustic data reveals that they are surprisingly similar (see Figure 7).

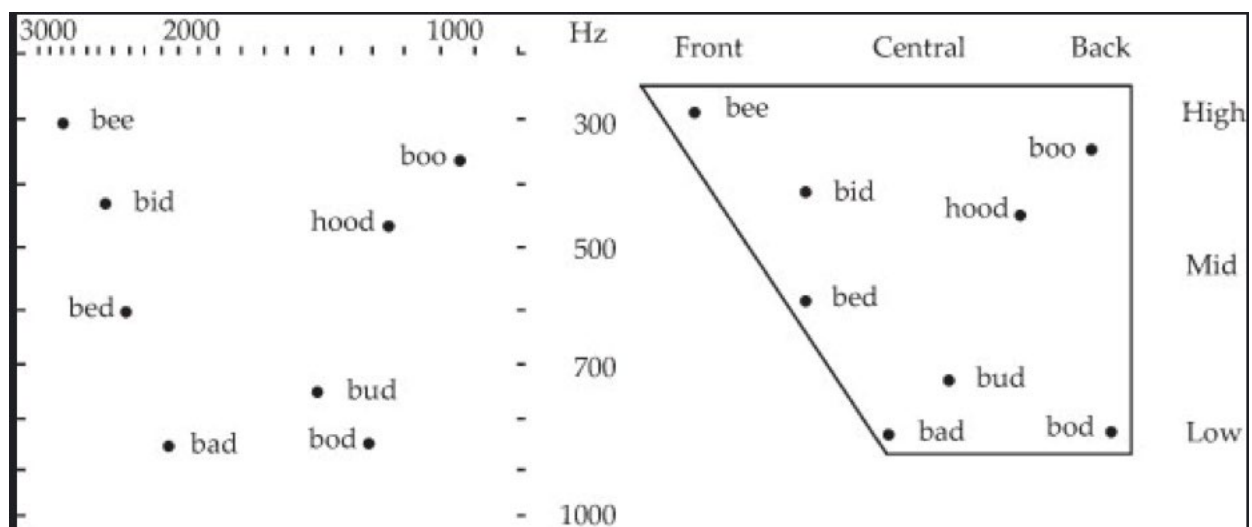


Figure 7, Traditional representation of relative position of the highest point of the tongue in American English vowels (right), corresponding acoustic data (left) (Ladefoged and Disner, 2012, p. 151)

Phoneticians were in essence interpreting variations in formant frequencies through tongue positions – using the first formant to infer tongue height and the second formant to deduce a combination to lip rounding and tongue backness (Ladefoged and Disner, 2012, p. 151). Advancements in technology, such as X-rays, ultrasound and MRI, have provided phoneticians with tools to verify that there are no fixed articulatory positions for vowels (Nicholson, 2017, p.

124). The International Phonetic Association clarified that their vowel chart tongue positions are approximate in the following statement in the accompanying handbook (Figure 8):

The use of auditory spacing in the definition of these vowels means vowel description is not based purely on articulation, and is one reason why the vowel quadrilateral must be regarded as an abstraction and not a direct mapping of tongue position. (International Phonetic Association, 1999, pp. 11–12)

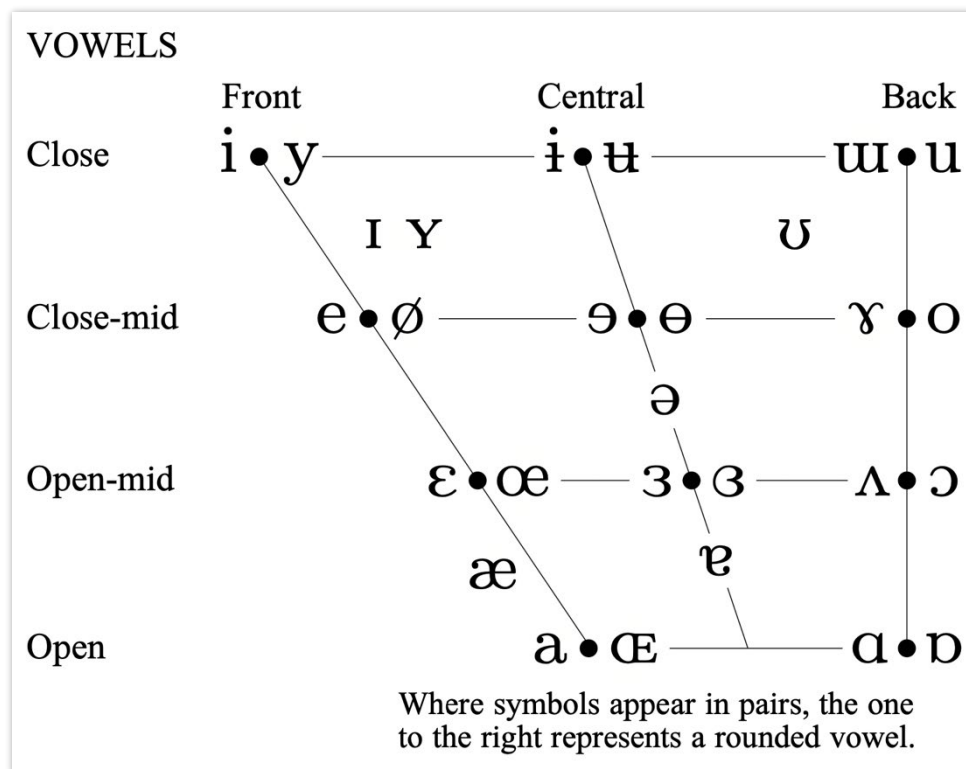


Figure 8, IPA vowel quadrilateral (International Phonetic Association, 2020)

Articulation of vowels involves two primary tongue movements: first, elevation mainly due to the genioglossus and mylohyoid muscles in concert with muscles that regulate jaw height; second, retraction, predominantly controlled by the styloglossus and hyoglossus muscles. However, various muscular combinations can achieve comparable tongue configurations. For front vowels in English, the lips are unrounded and for back vowels they are increasingly rounded as they become higher (Ladefoged and Disner, 2012, pp. 152–153).

Formant Tuning

The alignment of a harmonic with a formant causes it to experience a gain in sound pressure level (SPL), without requiring additional vocal effort at the vocal folds or from breath pressure, which is potentially beneficial for singers (Miller, 1987, p. 12). While harmonics cannot be modified, it is possible for singers to adjust formant frequencies to coincide with a harmonic (Carlsson and Sundberg, 1992, p. 256). Formant tuning, a term coined by Miller and Schutte (1990, p. 231), can be defined as “the tuning of one or both of the first two formants in order to find a better formant/harmonic match for greater resonance.” (Bozeman, 2013b, p. 172) Formant tuning can also be referred to as vowel modification, which Nix (2004, p. 173) more specifically defines as:

shading vowels with respect to the [frequency] location of vowel formants, so that the sung pitch or one of its harmonics receives an acoustical boost by being near a formant.

The first formant (F_1), which is the lowest formant, can range from middle C (C4) to the G above the treble clef (G5) depending predominantly on the vowel being sung. Figure 9 illustrates the estimated position of the first formant for seven different vowel sounds across different voice types. While the pattern for these vowel sounds remain relatively consistent, there is a slight shift in their placement on the staff for each category of voice. For female singers in particular, the fundamental frequency is often higher than the first formant, which is acoustically unbeneficial (Titze, 2004; Sundberg, 2008, p. 546). A potential solution is to increase the frequency of the first formant above the fundamental frequency (Sundberg, 1977, p. 90; Titze, 2004). Sundberg (1975) found that the formant frequencies of a single soprano were found to resemble normal speech patterns when the fundamental frequency was lower than the first formant. However, at higher pitches, the first formant aligned closely with the fundamental. Sundberg (1987) suggest that formant tuning may be an intuitive technique, while Miller and Schutte show that the singer makes a conscious decision to modify without necessarily understanding underlying principles.

When the fundamental frequency reaches or surpasses F_1 it becomes harder to identify the vowel being sung (Benolken and Swanson, 1990; Hollien, Mendes-Schwartz and Nielsen, 2000). Composers are aware of this limitation in vowel recognition at high pitches and tend to avoid placing critical text exclusively in the uppermost range of a soprano (Sundberg, 1977, p. 90). Research also indicates that there is flexibility in the frequencies of vowels and that a singer can modify the vowel to a certain extent without loss of intelligibility (Miller, 1987, p. 12; Benolken and Swanson, 1990) and in addition it is dependent on context, for example, surrounding consonants

(Smith and Scott, 1980; Hollien, Mendes-Schwartz and Nielsen, 2000). In addition, Carlsson and Sundberg's research (1992) suggests that formant tuning should be used judiciously. Their experimental findings indicated listeners preferred performances where formant tuning was not applied to every note in a scale.

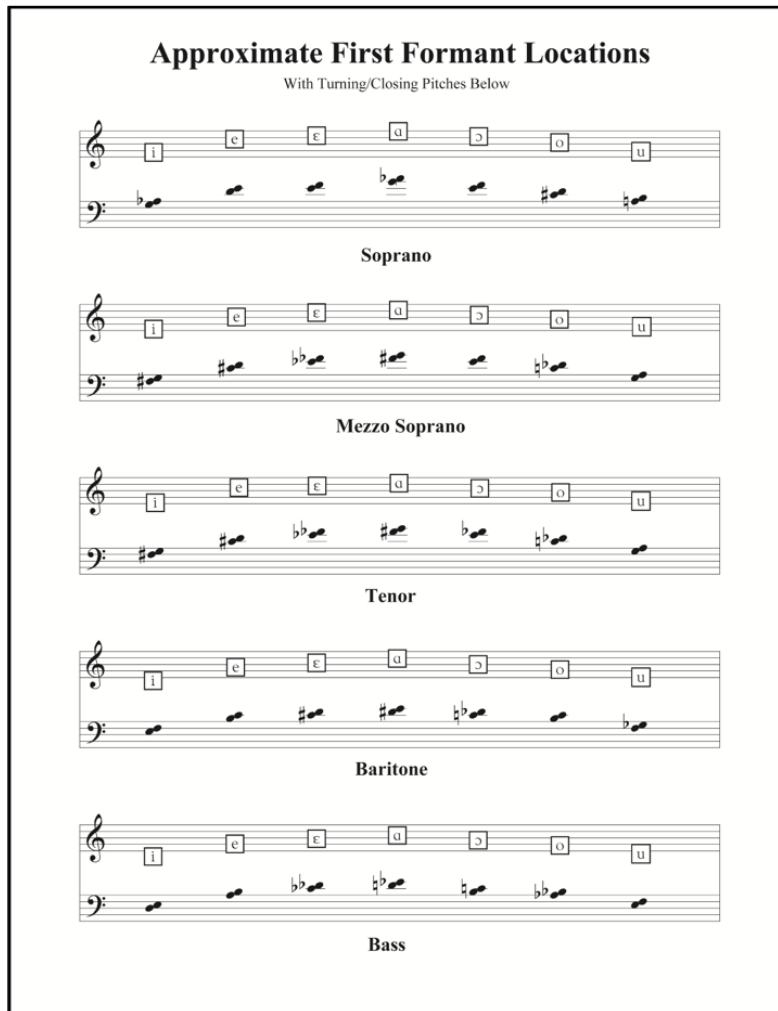


Figure 9, Approximate First Formant Locations (Bozeman, 2013a)

Titze states the following rules for the modification of vowels (2000, pp. 179–180):

1. All formant frequencies decrease uniformly as the length of the vocal tract increases.
2. All formant frequencies decrease uniformly with lip rounding and increase with lip spreading.
3. A mouth constriction lowers the first formant and raises the second formant.
4. A pharyngeal constriction raises the first formant and lowers the second formant.

Ways to implement these frequency changes are discussed in the Application section below.

Before moving further into the specifics of formant tuning within choral contexts, it is important to note one principle as researched by Titze: the principle of maintaining the harmonic below the formant peak. Enhancement of vocal output can be achieved through non-linear interactions between the vocal folds and the vocal tract, with significant amplification occurring when the vocal tract exhibits inertive resistance. However, as the fundamental frequency approaches the first formant, the reactance of the vocal tract shifts to compliant. The effects of this shift are noticeable just above the frequency where inertive and compliant reactances crossover. According to Titze's finding, it is not ideal to precisely tune the first formant to a lower harmonic such as the fundamental frequency, the second or third harmonic. Rather keeping F1 slightly higher than F₀ or a lower harmonic can be beneficial and may result in a significant boost in the acoustic power of the voice. Nonetheless, this strategy may be less effective for very high pitches in female voices where impedance matching is more difficult (Titze, 2004)

Formant Tuning Within Choirs

As discussed above, harmonics can influence the perception of pitch, which makes them integral to any discussion about intonation in choral settings. For an example of how formant tuning can be used to further amplify or diminish particular harmonics within a chord see figure 10, in which Nix has notated a chord for an SATB choir to sing (2010, p. e468). In the second bar, he has written out the harmonic series that is created by each of the notes that the choir sings in bar 1 as above in figure 4. In the third bar, he has indicated the approximate range of pitches for the vowel formants for /e/, which is the vowel that the choir will sing. In this example, Nix uses formant location ranges as stated by Baken and Orlikoff (2000, p. 260) with the lower note being the average for male voice and the upper note being the average for female voice.

Nix suggests that the bass continues to target the original /e/ vowel, as the third harmonic is on A₄ which lies just beneath the first formant. The tenor requires a small modification of vowel. The second harmonic is on D₅ and therefore the tenor will modify the vowel towards /ɛ/, which has a higher first formant location (see figure 9) but is articulatorily quite similar (see figure 8). The alto's fundamental frequency is an A₄ and, similarly to the bass, the alto will continue to sing an /e/. For the soprano, the fundamental frequency of F₅ (739.99Hz (Titze, 2000, p. 387)) lies above the first formant of /e/ (476-536Hz (Baken and Orlikoff, 2000, p. 260)). Nix suggests blending an /ɛ/

with an /ʌ/, perhaps to preserve some integrity of diction by using /ɛ/ which has a somewhat higher first formant at approximately 610Hz (Peterson and Barney, 1952, p. 183) combined with utilising an even higher first formant location of approximately 760Hz for /ʌ/ (Peterson and Barney, 1952, p. 183). The change of reference for formant values to Peterson and Barney in this example is due to a lack of access to Baken and Orlikoff's measurements, which were cited by Nix.



Figure 10, SATB D major open spacing chord, harmonics of each chord member, and approximate pitch locations of first and second formants of the vowel /e/ (Nix, 2012, p. e468)

Application

Appendix A presents a reference guide designed for choral directors and singers, aimed at facilitating the implementation of formant tuning strategies. The initial four sections are intended as exercises and discussion points led by a choral director in order to equip singers with the skills necessary to execute these strategies effectively. Research by Dromey, Heaton and Hopkin (2011) demonstrates that a small amount of training can have an impact when a group of young adults with amateur singing experience could significantly alter the acoustic properties of vowels following just 15 minutes of instruction. Additionally, the guide's information on the IPA, vowels and diphthongs is beneficial for overall choral development, independent of this specific strategy. The final section is intended solely for the use of choral directors and serves as a pre-rehearsal preparatory tool to be used in conjunction with the theoretical knowledge from this literature review. The section provides the reference materials required to plan an initial formant tuning

strategy for key homophonic chordal moments. The strategy can then be tested within a rehearsal. The sections of the guide are as follows:

Using IPA Symbols

It is easy for English singers to have an “almost cavalier” attitude to singing in their own language as opposed to the care that is taken with sounds in a foreign language (LaBouff, 2008, p. 25). In addition, there are inconsistencies in pronunciation between different singers such as the second syllable of heaven (LaBouff, 2008, p. 25; Karna and Goodenow, 2010, p. e466). It would seem reasonable to find a method for singers to be able to target and notate the same sounds more accurately. Therefore, the reference guide contains various information on phonetic symbols. Firstly, it contains the IPA vowel quadrilateral (International Phonetic Association, 2020) to introduce the phonetic symbols, their approximate articulatory positions and their sounds. Nicholson argues that despite the IPA vowel chart being only approximate guide from articulatory perspective, it still holds value as a teaching tool (2017, pp. 124–125). This is followed by a list of the standardised British English vowels and their pronunciations. The phonetic guidance offered here, while initially tailored to BBC English, holds the potential for future expansion to encompass additional phonetic elements not currently addressed in addition to sets of vowels and more specific elements of further languages such as nasalised vowels (Collins, Mees and Carley, 2019, p. 87). The guide also contains an exercise for further familiarising singers with phonetic symbols. It is suggested that singers make use of the British English vowels in addition to the ones illustrated, if it is perhaps more relevant to the choir’s repertoire (Westerman Gregg, 1997).

In choral settings, it has been observed that choral singers default to using the schwa vowel, which is known for its neutral timbral quality (Ternström and Sundberg, 1989). These observations underscore the importance of equipping choirs with an International Phonetic Alphabet (IPA) chart and ensuring a comprehensive understanding of vowel production, especially in light of formant tuning.

Exploring the vowels

This section makes use of three exercises to explore the tongue and lip movement of vowels from primarily a tactile perspective (Collins, Mees and Carley, 2019, pp. 79–80), as opposed to the visual and auditory aids of the pages focusing on the IPA vowel chart and English vowels.

Modification

This section provides some simple strategies for adjusting the formant frequency without having to target specific vowels:

Frequencies adjust higher or lower if the vocal tract length changes, becoming lower for a longer vocal tract and higher for a shorter one (Sundberg, 1977, p. 83). One way to change the length of the vocal tract is to raise or lower the larynx: a lower larynx increases the length of the vocal tract, lowering the formant frequencies and therefore creating a darker sound. Conversely, a raised larynx creates a brighter sound as a result of a shorter vocal tract and higher frequencies (Titze, 1993). In Western classical singing, a low larynx is generally preferred (Sundberg, 1977, p. 84) and the reference guide includes a 'pre-yawn' exercise by Chapman for achieving this (2006, p. 288). In addition, the vocal tract naturally becomes smaller at the top of a singer's range (Bozeman, 2013b, p. 38), resulting in changes to vowel formant frequencies that may need to be taken into consideration when formulating a strategy. A second method for changing the length of the vocal tract involves the lips. Retracting the corners of the mouth effectively shortens the vocal tract, while lip rounding lengthens the vocal tract (Sundberg, 1977, p. 82 and p.90).

The first formant appears especially responsive to movements of the jaw in all voice parts from soprano to bass (Sundberg, 1975; Sundberg and Skoog, 1997). A wide opening of the jaw can also constrict the pharynx (which as mentioned above also raises the first formant) in addition to a reduction in constriction at the mouth end of the vocal tract (Sundberg and Skoog, 1997, p. 305). The 1997 experiment also indicated that on certain vowels /i e u o/ another articulatory method may be used prior to the jaw. This was tested by Sundberg (2008) on a single soprano which showed use of the jaw opening on all vowels at higher pitches, but at 4 to 5 semitones below the F0/F1 crossover, there were multiple strategies including a reduction in height of the tongue dorsum relative to the jaw on /i e u/ contrasting with a wider lip opening for /o/ in addition to a jaw opening for /a/.

Austin (2007) found use of the jaw on the vowels /a i u/ at higher pitches with a greater degree of opening for /a/ in his study of 12 singers (voice types ranged from soprano to bass-baritone). This research compared the degree of opening of jaw opening in two groups of singers: one group with less than four years of college training and one with eight to 20 years of training and professional experience. No significant difference was found in the amount of jaw opening between novice and experienced singers. This could suggest that wider jaw opening for high

notes is instinctive, not requiring formal training. Alternatively, it may indicate that jaw opening is a basic skill taught early in a singer's education, such as in general music classes or choir practice during their formative years. This is a consideration for choral directors that their formant tuning strategy has the potential to be enhanced or diminished by modifications that singers make intuitively. The guide contains a page to highlight the effect of jaw opening, which can be discussed further.

Titze (1998) found that a wider pharynx configuration consistently led to a darker and stronger sound quality. This is attributed to the lowering of the first formant frequency (F_1), which results in greater emphasis on the lower partials of the vocal tract resonance. The study confirms the fourth rule: a tube exhibits a lower F_1 when it is wider near the closed end (larynx side) and narrower towards the open end (mouth). A widened pharynx can alter vowel perception unless compensatory articulatory adjustments are made. For accurate vowel representation, the location and degree of constriction in the vocal tract must remain consistent relative to the mouth configuration. The reference guide includes an exercise for widening the pharynx (Kayes, 2004, p. 12).

Diphthongs

A diphthong is a sound “that has a change in vowel quality during the course of the syllable” (Ladefoged and Disner, 2012, p. 48). Ladefoged and Disner distinguish nine diphthongs in BBC English: /eɪ/, /əʊ/, /aɪ/, /aʊ/, /ɔɪ/, /ɪə/, /eə/, /aə/ and /ʊə/. Emmons and Chase state that “the second vowel should be articulated as clear as the first” (2006, p. 70) and prefer the vowel sound proportions to be two-thirds to one-third or three-quarters to one-quarter depending on tempo and the time signature. An alternative suggestion is that the initial vowel sound occupies about 90 to 95 per cent of the note length, while the remaining five to ten per cent is taken up by the second vowel sound (Nair, Howard and Welch, 2019, p. 1065). The transition between the two sounds can be clearly seen on a spectrogram and in addition this tool helps singers to understand and correct any unintended diphthongs (Nair, Howard and Welch, 2019, pp. 1066–1067). The reference guide includes a list of BBC English diphthongs, their sounds and an exercise that I created for practising the transition between the two vowel sounds. It does not suggest a precise formula for the timing of all transitions going forward – that is at the discretion of the choral director and is influenced by the genre, tempo and underlying rhythmic structure. In addition, the exercise is not focused on formant tuning the specific vowels to get the best acoustic output, it is simply an exercise with regards to transitioning effectively between two sounds.

References for choral directors

While the theoretical concept of formant tuning every note for every part might seem beneficial, in practice, it is neither feasible nor necessarily acoustically advantageous (Carlsson and Sundberg, 1992). The following strategy should be reserved for homophonic chords particularly in pivotal moments or cadences. It is important to note that formant frequencies vary on an individual basis (Nix, 2004, p. 173). Therefore, choir members may need to target slightly different vowel sounds. The guide provides the following reference tools: the intervals of the first six to eight to harmonics, three sets of vowel formant frequencies, frequencies of notes in the Equal Temperament Tuning system and the general principles of formant tuning. Three sets of formant frequencies are included as one is the result of a large-scale study in American English, one is a small-scale study but it is in BBC English and one is a clear illustration of how F_1 locations change through the different voice parts. It is anticipated that there is a trial-and-error element to the strategy with the final plan only being fully realised in the rehearsal with singers present.

Conclusion

In conclusion, the effectiveness of formant tuning as a method to improve intonation in homophonic chords within choral settings remains an open question. It is hard to state that this strategy works without evidence that compares choirs or ensembles singing with and without formant tuning and the resulting perception of intonation. While current research does not provide definitive answers, there is sufficient potential in the concept to merit further, more targeted testing. The 'pitch of the missing fundamental' phenomenon particularly underscores the significance of harmonics in pitch perception (Plack and Oxenham, 2006, p. 13). This insight highlights the intricacies involved in the perception of pitch and intonation and compels a broader consideration of the entire harmonic spectrum rather than focusing solely on the fundamental frequency. Empirical studies reinforce the importance of harmonics in choral singing. Research by Hagerman and Sundberg (1980) on barbershop quartets demonstrates that intervals sharing a greater number of partial tones are more likely to be sung in tune than those with fewer common harmonics. Subsequent work by Ternström and Sundberg (1988) further reveals that enhancing the lowest common partial with a formant can lead to even more precise intonation. These findings collectively suggest that a nuanced understanding harmonics and formants is crucial for advancing choral intonation practices, an area where formant tuning might play a key role. The exploration of these relationships, therefore, remains an essential avenue for future research in choral music studies. Furthermore, the broader exploration of acoustics and phonetics undertaken in this study promised to be of great benefit to my choir and my future teaching practice and the

reference guide developed as a result of this research has the potential to be a valuable asset for choirs in general.

References

- Austin, S.F. (2007) 'Jaw Opening in Novice and Experienced Classically Trained Singers', *Journal of Voice*, 21(1), pp. 72–79. Available at: <https://doi.org/10.1016/j.jvoice.2005.08.013>.
- Baken, R. and Orlikoff, F. (2000) *Clinical Measurement of Speech and Voice*. 2nd Ed. San Diego, CA: Singular Publishing.
- Bendor, D. and Wang, X. (2006) 'Cortical representations of pitch in monkeys and humans', *Current Opinion in Neurobiology*, 16(4), pp. 391–399. Available at: <https://doi.org/10.1016/j.conb.2006.07.001>.
- Benolken, M.S. and Swanson, C.E. (1990) 'The effect of pitch-related changes on the perception of sung vowels', *The Journal of the Acoustical Society of America*, 87(4), pp. 1781–1785. Available at: <https://doi.org/10.1121/1.399426>.
- Bozeman, K. (2013a) *Approximate first formant locations*, Available at: <http://www.kenbozeman.com/resources/1stFormantLocationsImage.jpg>.
- Bozeman, K. (2013b) *Practical Vocal Acoustics*. Hillsdale, NY: Pendragon Press.
- Bozeman, K. (2017) *Kinesthetic Voice Pedagogy: Motivating Acoustic Efficiency*. Inside View Press.
- Carlsson, G. and Sundberg, J. (1992) 'Formant Frequency Tuning in Singing', *Journal of Voice*, 6(3), pp. 256–260.
- Chapman, J. (2006) *Singing and Teaching Singing: A Holistic Approach to Classical Voice*. 1st Ed. San Diego, CA: Plural Publishing.
- Collins, B., Mees, I. and Carley, P. (2019) *Practical English Phonetics and Phonology*. 4th Ed. Abingdon: Routledge.
- Cooksey, J.M. (1977) 'A facet-factorial approach to rating high school choral music performance', *Journal of Research in Music Education*, 25(2), pp. 100–114.
- Cruttenden, A. (2014) *Gimson's Pronunciation of English*. 8th Ed. Abingdon: Routledge.
- Deterding, D. (1997) 'The Formants of Monophthong Vowels in Standard Southern British English Pronunciation', *Journal of the International Phonetic Association*, 27(1–2), pp. 47–55. Available at: <https://doi.org/10.1017/S0025100300005417>.
- Dromey, C., Heaton, E. and Hopkin, J.A. (2011) 'The Acoustic Effects of Vowel Equalization Training in Singers', *Journal of Voice*, 25(6), pp. 678–682. Available at: <https://doi.org/10.1016/j.jvoice.2010.09.003>.

- Emmons, S. and Chase, C. (2006) *Prescriptions for choral excellence*. New York: Oxford University Press.
- Feilzer, M.Y. (2010) 'Doing mixed methods research pragmatically: Implications for the rediscovery of pragmatism as a research paradigm', *Journal of Mixed Methods Research*, 4(1), pp. 6–16. Available at: <https://doi.org/10.1177/1558689809349691>.
- Ganschow, C.M. (2014) 'Secondary School Choral Conductors' Self-Reported Beliefs and Behaviors Related to Fundamental Choral Elements and Rehearsal Approaches', *Journal of Music Teacher Education*, 23(2), pp. 52–63. Available at: <https://doi.org/10.1177/1057083713485587>.
- Guba, E. and Lincoln, Y. (1994) 'Competing paradigms in qualitative research', in N. Denzin and Y. Lincoln (eds) *Handbook of qualitative research*. Thousand Oaks, CA: Sage, pp. 105–117.
- Hagerman, B. and Sundberg, J. (1980) 'Fundamental frequency adjustment in barbershop singing', *STL-QPSR*, 21(1), pp. 28–42. Available at: <http://www.speech.kth.se/qpsr> (Accessed: 1 November 2023).
- Heineman Pieper, M. (1989) 'The heuristic paradigm: A unifying and comprehensive approach to social work research', *Smith College Studies in Social Work*, 60(1), pp. 8–34. Available at: <https://doi.org/10.1080/00377318909516663>.
- Hensley, D. (2021) 'How Will Your Choir be Judged?', *The Choral Journal*, 62(2), pp. 30–41.
- Hollien, H., Mendes-Schwartz, A.R. and Nielsen, K. (2000) 'Perceptual Confusions of High-pitched Sung Vowels', *Journal of Voice*, 14(2), pp. 287–298.
- Howard, D. and Angus, J. (2017) *Acoustics and psychoacoustics*. Fifth edn. Abingdon: Routledge.
- Howard, D.M. (2007) 'Intonation Drift in A Capella Soprano, Alto, Tenor, Bass Quartet Singing With Key Modulation', *Journal of Voice*, 21(3), pp. 300–315. Available at: <https://doi.org/10.1016/j.jvoice.2005.12.005>.
- International Phonetic Association (1999) *Handbook of the International Phonetic Association: A guide to the use of the International Phonetic Alphabet*. Cambridge: Cambridge University Press.
- International Phonetic Association (2020) *IPA Vowel Chart*, <http://www.internationalphoneticassociation.org/content/ipa-chart>.
- Karna, D. and Goodenow, S. (2010) 'The Use of the IPA in the Choral Rehearsal', in D.R. Karna (ed.) *The Use of the International Phonetic Alphabet in the Choral Rehearsal*. Lanham, Maryland: Scarecrow Press, pp. e83–e307.
- Kayes, G. (2004) *Singing and the Actor*. 2nd Ed. London: Bloomsbury.

- Kelly, L. and Cordeiro, M. (2020) 'Three principles of pragmatism for research on organisational processes', *Methodological Innovations*, 13(2), pp. 1–10. Available at: <https://doi.org/10.1177/2059799120937242>.
- LaBouff (2008) *Singing and Communicating in English*. New York, NY: Oxford University Press.
- Ladefoged, P. and Disner, F. (2012) *Vowels and Consonants*. 3rd Ed. Chichester: Wiley-Blackwell.
- Ladefoged, P. and Halle, M. (1988) 'Some Major Features of the International Phonetic Alphabet', *Source: Language*, 64(3), pp. 577–582.
- McCoy, S. (2011) 'The Choir Issue, Part 1', *Journal of Singing*, 67(3), pp. 297–301.
- McCoy, S. (2013) 'Formantology', *Journal of Singing*, 70(1), pp. 43–48.
- Miller, D. (1987) 'Some Observations on the Soprano Voice', *Journal of singing*, 43(5), pp. 12–15.
- Miller, D. and Schutte, H. (1990) 'Formant Tuning in a Professional Baritone', *Journal of Voice*, 4(3), pp. 231–237.
- Moore, B.C.J., Glasberg, B.R. and Peters, R.W. (1985) 'Relative dominance of individual partials in determining the pitch of complex tones', *The Journal of the Acoustical Society of America*, 77(5), pp. 1853–1860. Available at: <https://doi.org/10.1121/1.391936>.
- Nair, G., Howard, D. and Welch, G. (2019) 'Practical voice analyses and their application in the studio', in G. Welch, D. Howard, and J. Nix (eds) *The Oxford Handbook of Singing*. Oxford: Oxford University Press, pp. 1049–1070.
- Nicholson, L. (2017) 'Teaching vowels physically', *Voice and Speech Review*, 11(2), pp. 121–131. Available at: <https://doi.org/10.1080/23268263.2017.1383551>.
- Nix, J. (2004) 'Vowel Modification Revisited', *Journal of Singing*, 61(2), pp. 173–176.
- Nix, J. (2010) 'Vowel and Consonant Modification for Choirs', in D. Karna (ed.) *The Use of the International Phonetic Alphabet in the Choral Rehearsal*. Lanham, Maryland: Scarecrow Press, pp. e308–e616.
- Nix, J. (2013) 'Vibrato and Non-Vibrato Singing: Who teaches it? How do they teach it? Does it make a difference?', *Choral Journal*, 53(9).
- Nix, J. (2014) 'Shaken, not stirred: Practical ideas for addressing vibrato and nonvibrato singing in the studio and the choral rehearsal', *Journal of Singing*, 70(4), pp. 411–418.
- Nordström, E. (1977) 'Female and infant vocal tracts simulated from male area functions', *Journal of Phonetics*, 5, pp. 81–92.
- Oxenham, A.J. (2012) 'Mini-Review Pitch Perception'. Available at: <https://doi.org/10.1523/JNEUROSCI.3815-12.2012>.

Peterson, G.E. and Barney, H.L. (1952) 'Control Methods Used in a Study of the Vowels', *The Journal of the Acoustical Society of America*, 24(2), pp. 175–184. Available at: <http://asadl.org/terms>.

Plack, C. and Oxenham, A. (2006) 'The Psychophysics of Pitch', in C. Plack et al. (eds) *Pitch: Neural Coding and Perception*. New York: Springer, pp. 7–55.

Rossman, G.B. and Wilson, B.L. (1985) 'Numbers and Words: Combining Quantitative and Qualitative Methods in a Single Large-Scale Evaluation Study', *Evaluation Review*, 9(5), pp. 627–643. Available at: <https://doi.org/10.1177/0193841X8500900505>.

Saus, W. (2012) 'Choral Phonetics-when vowels control the intonation'.

Smith, L.A. and Scott, B.L. (1980) 'Increasing the intelligibility of sung vowels', *The Journal of the Acoustical Society of America*, 67(5), pp. 1795–1797. Available at: <https://doi.org/10.1121/1.384308>.

Strychacz, D. (2021) *THE ACOUSTICS OF VOWEL FORMANTS IN CHORAL BLEND, BALANCE, AND HOMOPHONIC INTONATION*.

Sundberg, J. (1970) 'Formant Structure and Articulation of Spoken and Sung Vowels', *Folia Phoniatri Logop*, 22(1), pp. 28–48. Available at: <http://karger.com/fpl/article-pdf/22/1/28/2796656/000263365.pdf>.

Sundberg, J. (1975) 'Formant Technique in a Professional Female Singer', *Acustica*, 32, pp. 89–96.

Sundberg, J. (1977) 'The acoustics of the singing voice', *Scientific American*, 236(3), pp. 82–91.

Sundberg, J. (1987) *The Science of the Singing Voice*. Northern Illinois University Press.

Sundberg, J. (2008) 'Articulatory Configuration and Pitch in a Classically Trained Soprano Singer', *Journal of voice*, 23(5), pp. 546–551. Available at: <https://doi.org/10.1016/j.jvoice.2008.02.003>.

Sundberg, J. and Skoog, J. (1997) 'Dependence of Jaw Opening on Pitch and Vowel in Singers', *Journal of voice*, 11(3), pp. 301–306.

Swannell, J. (1992) *The Oxford Modern English Dictionary*. New York: Oxford University Press.

Ternström, S. (1991) 'Physical and Acoustic Factors that Interact With the Singer to Produce the Choral Sound', *Journal of Voice*, 5(2), pp. 128–143.

Ternström, S. and Sundberg, J. (1988) 'Intonation precision of choir singers', *The Journal of the Acoustical Society of America*, 84(1), pp. 59–69.

Ternström, S. and Sundberg, J. (1989) 'Formant frequencies of choir singers', *The Journal of the Acoustical Society of America*, 86(2), pp. 517–522.

The University of Edinburgh (2018) *The Four Fs of Active Reviewing*, Available at: <https://www.ed.ac.uk/reflection/reflectors-toolkit/reflecting-on-experience/four->

ff::~:text=This%20framework%20is%20designed%20by,have%20learned%20in%20the%20future.

Titze, I. (1993) 'Raised Versus Lowered Larynx Singing', *Journal of singing*, 50(2), pp. 37–37.

Titze, I. (1998) 'The Wide Pharynx', *Journal of singing*, 55(1), pp. 27–28.

Titze, I. (2000) *Principles of Voice Production*. 2nd Ed. Iowa City: National Center for Voice and Speech.

Titze, I. (2009) 'How are harmonics produced at the voice source?', *Journal of singing*, 65(5), pp. 575–576.

Titze, I.R. (2004) 'A theoretical study of f0-f1 interaction with application to resonant speaking and singing voice', *Journal of Voice*, 18(3), pp. 292–298. Available at: <https://doi.org/10.1016/j.jvoice.2003.12.010>.

Westerman Gregg, J. (1997) 'On Singing in English', *Journal of singing*, 53(4), pp. 49–50.

Withington, A. (2020) 'Just Intonation: A basis for enhancing choral intonation', *The Choral Journal*, 60(7), pp. 26–41. Available at: <https://www.jstor.org/stable/26870192>.

Appendix A

Using formant tuning to enhance intonation in choirs

For choral directors and singers

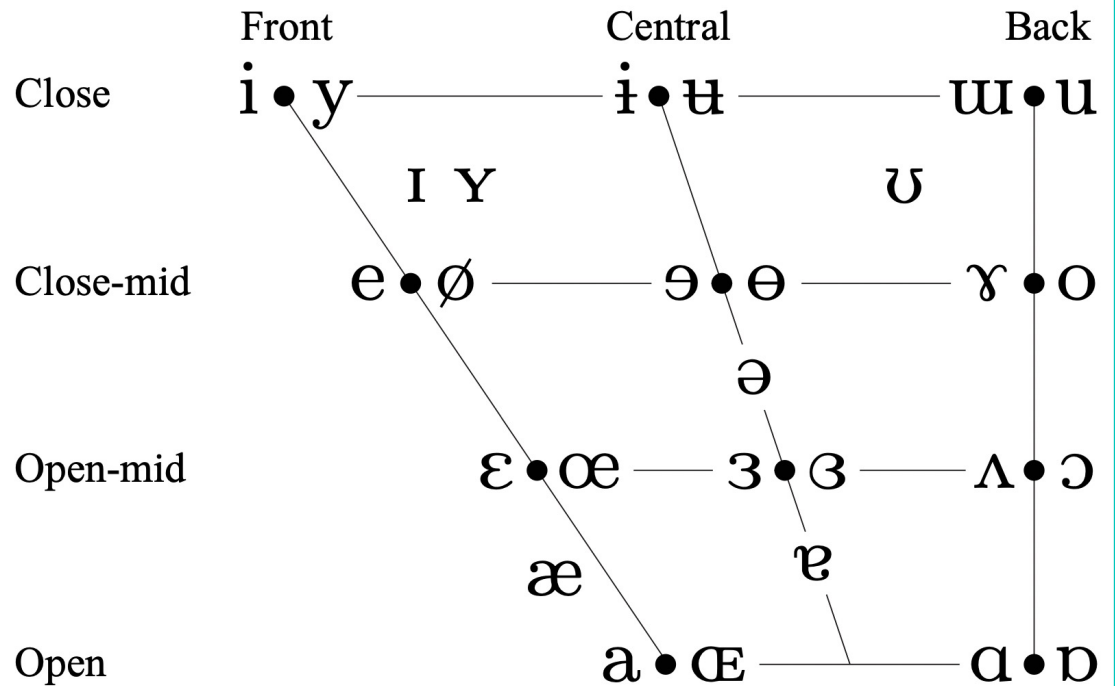
Using IPA symbols

IPA vowel quadrilateral



http://www.vowelsandconsonants3e.com/chapter_1.html#
(Ladefoged and Disner, 2012)

VOWELS



(International Phonetic Association, 2020)

English vowels

⚡ Long

e⚡

	b__d	b__t	h__d	k__t	<i>IPA symbols</i>
1	bead	beat	heed		i:
2	bid	bit	hid	kit	ɪ
3	bayed	bait	hayed	Kate	eɪ
4	bed	bet	head		ɛ
5	bad	bat	had	cat	æ
6	bard	Bart	hard	cart	ɑ:
7	bod(y)	bot(tom)	hod	cot	ɒ
8	bawd	bought	hawed	caught	ɔ:
9	bud(dhist)		hood		ʊ
10	bode	boat	hoed	coat	əʊ
11	booed	boot	who'd	coot	u:
12	bud	but	Hudd	cut	ʌ
13	bird	Bert	heard	curt	ɜ:
14	bide	bite	hide	kite	aɪ
15	bowed	bout	howd(y)		aʊ
16	Boyd		(a)hoy	quoit	ɔɪ
	b__	p__	h__	k__	
17	beer	peer	here		ɪə
18	bare	pear	hair	care	eə
19	byre	pyre	hire		aə
20	boor	poor			ʊə

(Ladefoged and Disner, 2012, p. 49)



Exercise using IPA symbols

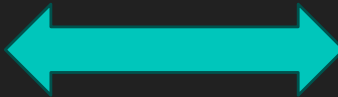
Karna and Goodenow (2010, p. e163)

Either use the above vowels or replace them with vowels from the English vowel table

Exploring the vowels

Vowel articulation: exercise 1

(Collins, Mees and Carley, 2019, p. 79)

/ɑ:/ as in palm  */i:/ as in fleece*

1. Say the vowel /ɑ:/
2. Put your finger in your mouth.
3. Say the vowel /i:/
4. Remove your finger.
5. Look in a mirror and repeat the vowel sounds.

Vowel articulation: exercise 2

(Collins, Mees and Carley, 2019, p. 80)

/i:/ as in fleece ↔ /ɛ:/ as in square ↔ /æ/ as in trap

1. Say these vowels.
2. Can you feel the tongue moving down?
3. Say them in reverse order.
4. Can you feel the tongue moving up?

Vowel articulation: exercise 3

(Collins, Mees and Carley, 2019, p. 80)

/ɑ:/ as in palm ↔ /ɔ:/ as in thought ↔ /u:/ as in goose

1. Say these vowels a number of times.
2. Focus on what is happening to the lips.
3. Focus on what is happening to the tongue.

Modification

Exercise: lowering the larynx

(Chapman, 2006, p. 288)

1

Stand in alignment with head and neck well positioned.

2

Place thumb and index finger either side of the larynx.

3

Place tongue in an /i/ position in the mouth.

4

Inhale as though about to yawn.

5

Stop there! Do not complete the yawn.

6

Notice that the larynx has dropped (and the soft palate has lifted).

7

Remove fingers and practice five times.

Lowering the larynx = darker sound
Raising the larynx = brighter sound



round



neutral
unrounded



spread
unrounded

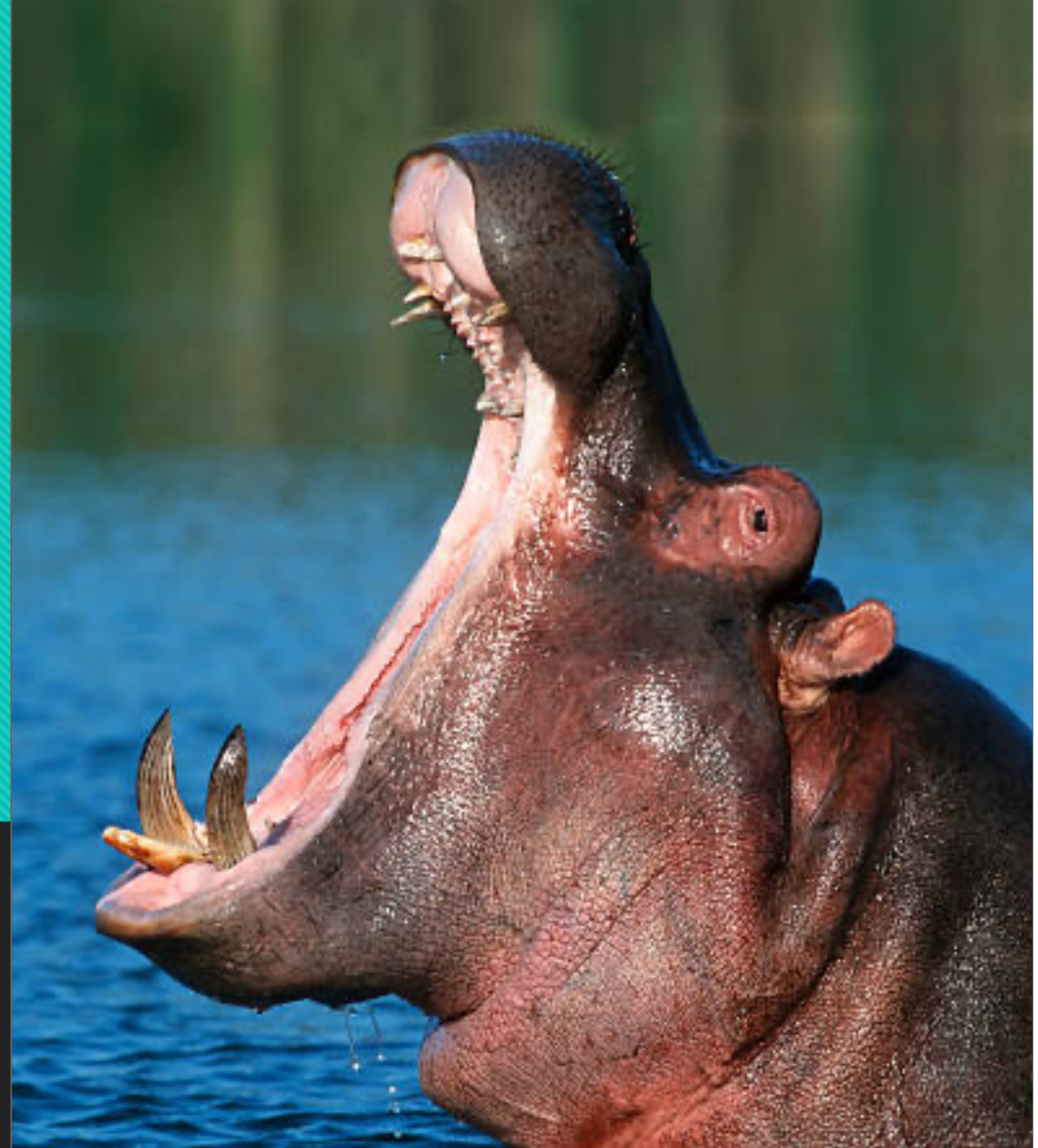
Lip positions

(Anderson et al, 2022, chapter 3.5)

Lip rounding = darker sound
Lip spreading = brighter sound

Jaw opening

Open the jaw to a greater degree
as the pitch rises



Think of a funny situation that makes you want to smile inside. Hold the feeling of that inner smile.

Allow the sensation to develop further down in your vocal tract.

Allow yourself to giggle or chuckle.

Let the sensation grow into laughing out loud.

Visualise being in a silent movie. Laugh silently, working just as hard as you did before.

As you continue to laugh silently, notice the physical work involved.

Suppressed Laughter

(Kayes, 2004, p. 12)

Wider pharynx = darker sound

Diphthongs

Diphthong

from the Greek word for two sounds

a sound with a change in vowel quality during the course of the syllable

- e + I as in train
- ə + ʊ as in phone
- a + I as in bike
- a + ʊ as in owl
- ɔ + I as in boy
- I + ə as in ear
- e + ə as in chair
- ʊ + ə as in tourist
- a + ə as in fire

Pictogram amended from English File, Oxford University Press (2023)



Diphthong Exercise

GUIDELINES

- This exercise practises moving from the first vowel sound to the second vowel sound as a choir.
- The first vowel sound should blend into the second with no break.
- It also shows singers a possible way of notating vowels in order to collectively target the same precise sound at the same time.
- In general when singing a diphthong, sustain the first vowel sound and introduce the second vowel sound with less emphasis at the very end or as instructed by the choral director.
- If the diphthong is sung over multiple notes, the first vowel sound is used for all the notes except the last one or part of the last one, as directed.



References for choral directors





First eight harmonics of C3
(Bozeman, 2013b, p. 19)

Harmonic	Interval
Second harmonic	An octave higher than the fundamental frequency
Third harmonic	A perfect fifth higher than the second harmonic
Fourth harmonic	A perfect fourth higher than the third harmonic
Fifth harmonic	A major third higher than the fourth harmonic
Sixth harmonic	A minor third higher than the fifth harmonic

Harmonic series

Table 3 — Frequencies in hertz (Hz) and frequency levels in semitones counted (sc) up from C₀ for the usual equal-tempered scale. Subscripts by octaves above C₀. C₀ approximately equals 16.352 Hz so that A₄ = 440 Hz exactly

Frequency			Frequency			Frequency		
Note	Level sc	Frequency Hz	Note	Level sc	Frequency Hz	Note	Level sc	Frequency Hz
B ₂	35	123.47	B ₅	71	987.77	B ₈	107	7902.1
A#/Bb	34	116.54	A#/Bb	70	932.33	A#/Bb	106	7458.6
A ₂	33	110.00	A ₅	69	880.00	A ₈	105	7040.0
G#/Ab	32	103.83	G#/Ab	68	830.61	G#/Ab	104	6644.9
G ₂	31	97.999	G ₅	67	783.99	G ₈	103	6271.9
F#/Gb	30	92.499	F#/Gb	66	739.99	F#/Gb	102	5919.9
F ₂	29	87.307	F ₅	65	698.46	F ₈	101	5587.7
E ₂	28	82.407	E ₅	64	659.26	E ₈	100	5274.0
D#/Eb	27	77.782	D#/Eb	63	622.25	D#/Eb	99	4978.0
D ₂	26	73.416	D ₅	62	587.33	D ₈	98	4698.6
C#/Db	25	69.296	C#/Db	61	554.37	C#/Db	97	4434.9
C ₂	24	65.406	C ₅	60	523.25	C ₈	96	4186.0
B ₁	23	61.735	B ₄	59	493.88	B ₇	95	3951.1
A#/Bb	22	58.270	A#/Bb	58	466.16	A#/Bb	94	3729.3
A ₁	21	55.000	A ₄	57	440.00	A ₇	93	3520.0
G#/Ab	20	51.913	G#/Ab	56	415.30	G#/Ab	92	3322.4
G ₁	19	48.999	G ₄	55	392.00	G ₇	91	3136.0
F#/Gb	18	46.249	F#/Gb	54	369.99	F#/Gb	90	2960.0
F ₁	17	43.654	F ₄	53	349.23	F ₇	89	2793.8
E ₁	16	41.203	E ₄	52	329.63	E ₇	88	2637.0
D#/Eb	15	38.891	D#/Eb	51	311.13	D#/Eb	87	2489.0
D ₁	14	36.708	D ₄	50	293.66	D ₇	86	2349.3
C#/Db	13	34.648	C#/Db	49	277.18	C#/Db	85	2217.5
C ₁	12	32.703	C ₄	48	261.63	C ₇	84	2093.0
B ₀	11	30.868	B ₃	47	246.94	B ₆	83	1975.5
A#/Bb	10	29.135	A#/Bb	46	233.08	A#/Bb	82	1864.7
A ₀	9	27.500	A ₃	45	220.00	A ₆	81	1760.0
G#/Ab	8	25.957	G#/Ab	44	207.65	G#/Ab	80	1661.2
G ₀	7	24.500	G ₃	43	196.00	G ₆	79	1568.0
F#/Gb	6	23.125	F#/Gb	42	185.00	F#/Gb	78	1480.0
F ₀	5	21.827	F ₃	41	174.61	F ₆	77	1396.9
E ₀	4	20.602	E ₃	40	164.81	E ₆	76	1318.5
D#/Eb	3	19.445	D#/Eb	39	155.56	D#/Eb	75	1244.5
D ₀	2	18.354	D ₃	38	146.83	D ₆	74	1174.7
C#/Db	1	17.324	C#/Db	37	138.59	C#/Db	73	1108.7
C ₀	0	16.352	C ₃	36	130.81	C ₆	72	1046.5

(Acoustical Society of America, 2023)

Frequencies of notes on the Equally Tempered Scale

		i	ɪ	ɛ	æ	ɑ	ɔ	ʊ	u	ʌ	ɜ
Fundamental frequencies (cps)	<i>M</i>	136	135	130	127	124	129	137	141	130	133
	<i>W</i>	235	232	223	210	212	216	232	231	221	218
	<i>Ch</i>	272	269	260	251	256	263	276	274	261	261
Formant frequencies (cps)											
F_1	<i>M</i>	270	390	530	660	730	570	440	300	640	490
	<i>W</i>	310	430	610	860	850	590	470	370	760	500
	<i>Ch</i>	370	530	690	1010	1030	680	560	430	850	560
F_2	<i>M</i>	2290	1990	1840	1720	1090	840	1020	870	1190	1350
	<i>W</i>	2790	2480	2330	2050	1220	920	1160	950	1400	1640
	<i>Ch</i>	3200	2730	2610	2320	1370	1060	1410	1170	1590	1820

Formant values (American English)

Peterson and Barney (1952, p. 183)

Formant values (BBC English)

(Deterding, 1992, p. 52)

	connected		citation	
	F ₁	F ₂	F ₁	F ₂
i:	280	2249	275	2221
ɪ	367	1757	382	1958
e	494	1650	560	1797
æ	690	1550	732	1527
ʌ	644	1259	695	1224
ɑ:	646	1155	687	1077
ɒ	558	1047	593	866
ɔ:	415	828	453	642
ʊ	379	1173	414	1051
u:	316	1191	302	1131
ɜ:	478	1436	513	1377

Men

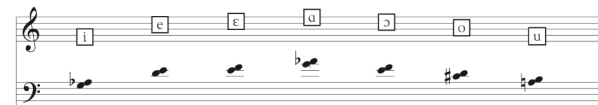
	connected		citation	
	F ₁	F ₂	F ₁	F ₂
i:	303	2654	319	2723
ɪ	384	2174	432	2296
e	719	2063	645	2287
æ	1018	1799	1011	1759
ʌ	914	1459	813	1422
ɑ:	910	1316	779	1181
ɒ	751	1215	602	994
ɔ:	389	888	431	799
ʊ	410	1340	414	1203
u:	328	1437	339	1396
ɜ:	606	1695	650	1593

Women

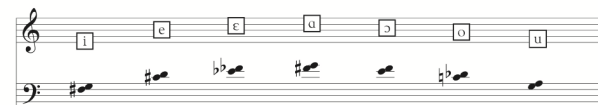
F1 locations by voice type

Approximate First Formant Locations

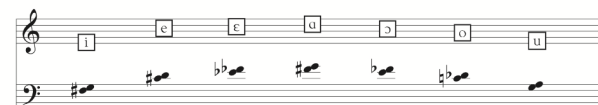
With Turning/Closing Pitches Below



Soprano



Mezzo Soprano



Tenor



Baritone



Bass

(Bozeman, 2013a)

- All formant frequencies decrease uniformly as the length of the vocal tract increases.
- All formant frequencies decrease uniformly with lip rounding and increase with lip spreading.
- A mouth constriction lowers the first formant and raises the second formant.
- A pharyngeal constriction raises the first formant and lowers the second formant.

(Titze, 2000, pp. 179–180)

Formant tuning principles

References

- Acoustical Society of America (2023) *Frequencies in hertz (Hz) and frequency levels in semitones counted (sc) up from C0 for the usual equal-tempered scale*. Available at: <https://asastandards.org/terms/table-3-frequencies-in-hertz-hz-and-frequency-levels-in-semitones-counted-sc-up-from-c0-for-the-usual-equal-tempered-scale-subscripts-by-octaves-above-c0-c0-approximately-equals-16-352/>
- Anderson, C. *et al.* (2022) *Essentials of Linguistics*. Available at: <https://ecampusontario.pressbooks.pub/essentialsoflinguistics2>.
- Bozeman, K. (2013b) *Practical Vocal Acoustics*. Hillsdale, NY: Pendragon Press.
- Bozeman, K. (2013a) *Approximate first formant locations*. Available at: <http://www.kenbozeman.com/resources/1stFormantLocationsImage.jpg>
- Chapman, J. (2006) *Singing and Teaching Singing: A Holistic Approach to Classical Voice*. 1st Ed. San Diego, CA: Plural Publishing.
- Collins, B., Mees, I. and Carley, P. (2019) *Practical English Phonetics and Phonology*. 4th Ed. Abingdon: Routledge.
- Deterding, D. (1997) 'The Formants of Monophthong Vowels in Standard Southern British English Pronunciation', *Journal of the International Phonetic Association*, 27(1–2), pp. 47–55.
- International Phonetic Association (2020) *IPA Vowel Chart*. Available at <http://www.internationalphoneticassociation.org/content/ipa-chart>.
- Karna, D. and Goodenow, S. (2010) 'The Use of the IPA in the Choral Rehearsal', in D.R. Karna (ed.) *The Use of the International Phonetic Alphabet in the Choral Rehearsal*. Lanham, Maryland: Scarecrow Press, pp. e83–e307.
- Kayes, G. (2004) *Singing and the Actor*. 2nd Ed. London: Bloomsbury.
- Ladefoged, P. and Disner, F. (2012) *Vowels and Consonants*. 3rd Ed. Chichester: Wiley-Blackwell.
- Oxford University Press (2023) *English File*. Available at: <https://elt.oup.com/student/englishfile>
- Peterson, G.E. and Barney, H.L. (1952) 'Control Methods Used in a Study of the Vowels', *The Journal of the Acoustical Society of America*, 24(2), pp. 175–184.
- Titze, I. (2000) *Principles of Voice Production*. 2nd Ed. Iowa City: National Center for Voice and Speech.