THE EFFECT OF PIANO ACCOMPANIMENT TYPE AND HARMONIC CONTEXT
ON THE TUNING PERFORMANCE OF COLLEGE-LEVEL CHORAL MUSICIANS

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ABSTRACT

This study was designed to evaluate the effect of piano accompaniment style on the intonation performance of college-level choral musicians. It was hypothesized that using a piano accompaniment comprised solely of referential tones (RT), as opposed to having all voice parts doubled by the piano (PD), would encourage more desirable intonation performance. Participants ($N = 34$) sang a researcher-composed melody harmonized with traditional Western functional harmony under both accompaniment conditions. Accompaniment type was not found to have a significant effect on the tuning performance of target intervals, but harmonic context did significantly affect the singers' intonation. Most notably, intonation of major 3rds in the I and IV chords closely approximated just intonation, regardless of accompaniment type. In the context of the V chord, performances more closely approximated the high Pythagorean 3rd, which was attributed to a tendency to heighten the leading tone. When comparing intonation performance to the just intonation, equal temperament, and Pythagorean tuning systems, results indicated that performances did not conform perfectly to any one tuning system, supporting the conclusion that the singers' intonation performance was dependent on harmonic context.

CHAPTER ONE

Introduction

Intonation is frequently cited as one of the most important indicators for rating solo and ensemble performance (Ganschow, 2012; Latimer, Bergee, & Cohen, 2010; Stutheit, 1994). If intonation is truly a critical factor in determining performance quality, then one would have to believe that the ability to produce accurate intonation is one of the characteristics of superior musicians. In unaccompanied solo literature, accurate intonation, or tuning performance, would refer to the relationship between melodic intervals, whereas in ensemble performance it would be dependent on the relationship between simultaneously sounding harmonies. Vocalists are often part of the second category, whether singing with other vocalists in an ensemble setting, or as a soloist, given that much of the solo vocal literature is performed with a collaborative pianist or other instrumental compliments. Hypothetically, the ability to sing with accurate intonation should be influenced by the other simultaneously sounding tones, as individual musicians must listen and adjust their tuning in order to achieve intonation accuracy. It is clearly in the best interest of both pedagogues and performers to strive for superior intonation in music performance. How, then, do we instill this ability in student and aspiring professional musicians? One answer to this question is through practice. Many researchers have shown that intonation accuracy increases with experience (Duke, 1985; Madsen & Geringer, 1981; Morrison, 2000; Yarbrough, Karrick, & Morrison, 1995). While this confirmation is encouraging, it does not necessarily provide information as to how one would approach teaching this skill.

In order to approach the teaching of proper intonation, it is first important to have a basic understanding of some mathematical tuning systems as points of reference (for a detailed explanation of historical tuning systems, see Barbour, 2004). Many musicians are familiar with equal temperament, in which the octave is broken up into 12 equal parts, meaning that the distance between each half step is the same. This system is very functional when used for fixed-pitch instruments like the piano, as it allows the musician to change keys at will without the need to retune the instrument. But in order to achieve this, a compromise is made in which pitches are mistuned with respect to the naturally occurring overtone series upon which pure tuning systems are based, anywhere from 2-16 cents (1 cent being equivalent to 1% of an equally tempered half step). While equal temperament is a very practical system, particularly when performing with keyboard instruments, it may not be ideal for non-fixed-pitch instruments performing without keyboard accompaniment, such as human voices. If intonation is considered an important indicator of the quality of one's performance, then why would it be considered acceptable to be 16 cents sharp?

The more mathematically accurate tuning system is that of just intonation, in which these purposeful mistunings do not exist, yielding perfectly tuned harmonies that should be more pleasing to the listener. In an interview I conducted with Peter Phillips, award-winning conductor of the renowned vocal ensemble the Tallis Scholars, he eluded to the importance of striving toward just intonation in choral singing, stating that, "the major thirds [need to be] lower [in comparison] to the piano. [It is] received historical thinking that the chords will ring better if the major thirds are low" (personal communication, April 13, 2012). Phillips then expressed concern:

Because we're trained in equal temperament in so many other departments of what we do, the instinct is to go to the piano tuning. And so what tends to happen is that [the musicians] hit the note sharp, and then they remember, and come down on it.

He also noted that “you need very clean fifths and octaves to support that third. There was a reason for that: in order to get this ringing effect.” The ringing effect that Phillips referred to is the effect produced when the fundamental frequencies and corresponding overtones of the individual chord tones line up, which minimizes any roughness or beating caused by mistuning and increases the amplitude of the overtones, ultimately producing a more aesthetically pleasing sound. Vocalists, who are not restricted by fixed pitch, have the potential to adjust their intonation to produce these ringing effects. So if this is a more desirable performance practice, how then do we instill these tuning tendencies in our students when the piano is heavily relied upon in the choral rehearsal setting?

One way to address the aforementioned question is to adjust how we use the piano in vocal ensemble rehearsals. In a book entitled *Choral Intonation*, musician and professor Per-Gunnar Alldahl (2008) highlighted Phillips’ concern regarding singers being constantly exposed to the equally tempered piano, and outlined a method for encouraging good tuning practices in singers. While Alldahl acknowledged that, depending on the scenario and type of music, there may be a need or desire to err on the side of equal temperament, or even Pythagorean tuning—a system based on consecutive pure fifths that have been adjusted to the proper octave—he does advocate for the pure tuning of just intonation. The system works particularly well for a cappella vocal music

that falls within traditional tonal structures of Western music. But the problem of excessive exposure to the equally tempered piano still exists. It is often common practice for vocal ensemble conductors to have the choir's parts doubled on the piano during the learning process. This is an easy way to teach pitch and rhythm content, but does not instill good intonation skills. In addition to playing parts, Alldahl noted other ways in which the piano might be used during choral rehearsals, including the playing of a harmonic reduction, having only some of the voice parts sing at a time while the remaining parts are played on the piano, eliminating the thirds from the chords played on the piano (as there is greater variation of the thirds between equal temperament and just intonation), providing referential tones on the piano, or not providing any piano support. An important aspect of Alldahl's book focuses on the use of referential tones as a method for encouraging proper intonation. In this method, the 1st, 2nd, 4th, and 5th scale degrees are used, as they have the least amount of deviation from just intonation on the piano, thus providing a good foundation while allowing the singers to adjust the remaining pitches toward a more pure intonation. It is this aspect of Alldahl's method that the current study was designed to explore.

Purpose of Study

The primary purpose of this study was to evaluate one aspect of a potential pedagogical technique for encouraging good intonation in vocal musicians. More specifically, this study evaluated whether the use of referential tones provided on a piano had a positive impact on the tuning accuracy of singers when compared to having all parts doubled on the piano. It is important to evaluate potential methods of instruction in this area in order to help ensemble directors and instructors, as well as amateur and

aspiring professional musicians, to improve their skills. This becomes even more pertinent when the methods are practical in their implementation, such as the method currently being evaluated, which suggests a different way to use tools that are currently employed in practice.

A review of pertinent literature revealed that the majority of intonation performance research focused on instrumental musicians, with far fewer studies examining vocal musicians. Although any reasons provided for this disparity would be speculation, one thing is clear: more research is needed in the area of vocal intonation performance. The current study will help to remedy this deficiency by contributing to the body of knowledge, as well as provide pedagogues with tools to identify potential areas of difficulty in the music to be rehearsed prior to working with their students, with a goal of ultimately guiding them on a more successful path.

Research Questions

The purpose of this study was to evaluate whether intonation performance of undergraduate choral ensemble singers was affected when singing a musical exercise with the piano doubling all parts, versus the piano providing referential tones (as advocated by Alldahl, 2008), specifically when singing diatonic triads in traditional Western functional harmony in the context of an authentic musical excerpt. In addition, a secondary purpose for the study was to compare intonation performance to the just intonation, equal temperament, and Pythagorean mathematical tuning systems in order to ascertain whether vocal musicians show a tendency toward any one system. The research questions that guided this investigation are:

1. Does the use of different piano accompaniment styles—specifically the piano doubling (PD) the singers or the piano being used to provide referential tones (RT) as a tuning reference—have an effect singers' intonation performance in standard diatonic harmonic contexts?
 - a. Are there affects attributable to the interval being performed in reference to the tonic pitch of the chord (unison, major 3rd, minor 3rd, and perfect 5th)?
 - b. Are there affects attributable to harmonic context (the chord function on which the music intervals are performed)?
2. How does the intonation performance of singers compare to the just intonation, equal temperament, and Pythagorean tuning systems?

Answers to the research questions, in addition to contributing to the existing body of knowledge, should have benefits to pedagogical approaches. The findings of this study can assist private music teachers, ensemble music educators, and conductors by bringing awareness to the complexity of intonation, as well as enlighten them to the performance tendencies of upper level musicians, thus providing a point of reference for their own efforts and the efforts of their students and musicians.

Definitions of Terms

For the purpose of this study, the following definitions of terms were used:

1. *Tuning* and *intonation* were used interchangeably to indicate the accuracy of the distance between any given pitches, with regard to the Western music tradition. This is often referred to as being *in tune*. The term *tune* can also indicate the act of adjusting one's performed pitch (higher or lower), or adjusting the pitch of an instrument, such as string tension on a piano or guitar, for the purpose of achieving accurate intonation. For the purposes of this study, *in tune* will be considered anything within 6 cents of a designated reference point.
2. To designate pitch intervals that are not in tune, the term *mistuned* was used, along with *mistune*, *mistuning*, and *out-of-tune*.
3. The term *pitch* is used to describe a perceived audible frequency. It is also used as a label for notated music, in which specific pitches are designated by the letters A through G, and the octaves, which have a 2:1 ratio, are assigned the same letter or *pitch class*. The term *tone* is used interchangeably with *pitch*.
4. The term *scale degree* refers to the sequence of diatonic, or naturally occurring, pitches in a given Western major or minor scale. It is another system for labelling pitches, such as A-G, but instead using the numbers 1-8, where 1 corresponds to the first pitch in the scale and 8 refers to the final pitch an octave above the starting point.

5. *Cents* are used in music as a measure of the interval between two given pitches. In equal temperament, a half step is 100 cents; there are 1200 cents in an octave. To convert the difference between two frequencies from Hertz (Hz), which is a measure of cycles per second, to cents, the formula $c = 1200 \times \log_2 (f_2 / f_1)$ is used, in which c represents cents, and f represents the frequency (Helmholtz, 1885). It can be difficult to visualize Hz, because each octave increases exponentially (e.g., an octave above A220 (Hz) is A440, and an octave above that is A880), so by converting to cents, the increments between each half step are uniform, creating a linear model that is easier to understand.
6. *Just intonation* is a tuning system, based on the natural overtone series, in which all harmonic intervals are tuned purely.
7. *Equal temperament* is the most prevalent tuning system used in the modern Western music tradition. It is devised by dividing the octave up into 12 equal parts. This facilitates the ability to play in any key on a keyboard instrument without having to retune. As a result, the majority of the pitches are mistuned anywhere from 2 cents to 16 cents when compared with just intonation.
8. *Pythagorean tuning* is a tuning system based on pure fifths that have been adjusted to the correct octave in order to create a usable music scale. The result creates pure fourths and fifths, and thirds and sixths with substantial deviation from just intonation that stretch toward the adjacent diatonic half step, which emphasizes melodic voice leading at the expense of harmonic intonation.

9. The term *melodic interval* was used to describe the interval of pitches performed in succession, whereas *harmonic interval* indicated intervals of simultaneously sounding pitches.
10. The term *a cappella* was used to describe the act of singing without any instrumental accompaniment.
11. *Harmonic context* is used to describe an experimental factor which refers to the chord function (e.g. I, iii, IV, etc.) on which the singers perform the music intervals.

CHAPTER TWO

Literature Review

The current study sought to evaluate one component of a suggested pedagogical technique for improving the intonation accuracy of singers by comparing performances accompanied by referential tones with those accompanied by piano doubling. With the importance placed on intonation in the adjudication of musical performances being highlighted in the previous chapter, it is now essential to delve further into pertinent research in this vein in order to understand the motivation and necessity for the study at hand. Much of the extant research in the area of intonation performance focuses on instrumental music rather than vocal performances. Why there is a lack of vocal performance research in this area is unclear. Until more vocal studies are available, however, it is necessary to review both instrumental and vocal intonation research in order to guide this investigation.

In reviewing literature on intonation research, six categories seem to emerge, which will be discussed in separate sections of the literature review. One is the effect of experience on intonation performance. As expected, with more experience comes better accuracy. Discrimination of frequency changes is another area of research. This encompasses perception of minute changes regarding the degree to which a given tone can be altered while still being considered in tune. Closely related to discrimination is the perception of intonation. There are many studies that report intonation tendencies observed in isolated and music contexts. Comparing music performance with different mathematical tuning systems, such as Pythagorean tuning or just intonation, is another category in intonation research. Studies drawing comparisons between performance and

perception will also be discussed. To conclude the review of literature, writings related to intonation pedagogy will be explored.

Effect of Experience on Intonation

Researchers have been interested in the effects of experience on the intonation of musicians. Studies have been completed with participants ranging from elementary-aged children to professional musicians. In one such study, using a large sample size ranging from second graders through professional music faculty, Madsen, Edmonson, and Madsen (1969) reported that experience had a positive effect in terms of sensitivity to intonation. In this case, perception of frequency changes was studied. Participants were presented with stimulus tones in 30-second durations. The tones either remained consistent with no deviation, or remained consistent for the first 5 seconds, then either ascended or descended for the remaining time at a rate of 2 cents per second, for a maximum deviation of 50 cents. A total of fifteen stimuli were presented in a randomized order to the participants. The findings indicated that, for individuals with more musical training, perception of intonation deviation occurred more quickly, with the most accurate discrimination occurring within the 5- to 10-second interval, or the initial 2- to 10-cent deviation. There was also a significant increase in correct responses observed when comparing older, more musically experienced participants with the younger, less experienced ones, a finding which was corroborated in studies by Yarbrough, Karrick, and Morrison (1995) and Morrison (2000).

Yarbrough, Karrick, and Morrison (1995) researched the effect that knowledge of the mistuning had on the perceptual and performance tuning accuracy of wind players. Participants ($N=197$), comprising beginning elementary and middle school

instrumentalists, were assigned to one of three different groups, the first being told that they would begin each task in the sharp direction, the second told they would begin in the flat direction, and the third given no knowledge of the direction of mistuning. For the perception task, the participants adjusted a pitch control knob to match the presented stimulus tone. The knob was preset by the researchers to be either sharper or flatter than the stimulus tone. A similar procedure was used for the performance task, in which the researchers preset the length of the wind instrument of each participant to begin the task either sharp or flat. Results indicated that there was no significant difference between the treatment groups. However, years of experience again was shown to have a positive effect on tuning accuracy.

Similar results were found by Morrison (2000) in a two-experiment study focusing on how the intonation of wind instrumentalists was affected by melodic context, tuning procedure, and experience. In the first experiment, participants, who were elementary, middle, and junior high school band students in their first, second, or fourth year of participation, were presented with a prerecorded tuning pitch and asked to tune to said pitch. Following this task, participants played a brief melody along with a recording. With regards to melodic context, Morrison reported that both more- and less-experienced wind instrumentalists performed pitches with similar accuracy, regardless of whether the pitches were approached from above, below, or were repeated or sustained. Therefore, melodic context of pitches did not affect the accuracy of performance. The second experiment was similar to the first, however, the primary focus consisted of three conditions, including (1) behavioral, in which participants tuned to a prerecorded pitch prior to performance, (2) verbal, in which participants were instructed to play as in tune

as possible, and (3) a control group, in which no additional information was given to the participants and no opportunity to tune their instrument was provided. After being randomly assigned to one of three conditions, participants again played the same melody along with a recording. For both the three experimental conditions and the pitch contexts, no significant differences were found. However, for both the first experiment and the behavioral group in the second experiment, performance of the isolated tuning pitch was significantly more accurate than the performances in the melodic contexts. A tendency toward sharp performance was observed, particularly among the more experienced students, and experience was again shown to have a positive effect on the accuracy of intonation.

In comparing the abilities of music majors to non-music majors with no musical training, college students' ($N=36$) accuracy in perceiving intonational changes was studied (Peterson & Smith, 1930). Participants were presented with the tonic note, in the key of C major, which was played simultaneously with the 2nd, 3rd, 4th, 5th, 6th, and 7th scale degrees, in ascending order, and were asked to identify which of the four consonant intervals were "changed or unnatural" (p. 562). The results indicated that the participants with music experience were significantly better at identifying mistunings than the participants without music experience.

Another study comparing musicians to non-musicians was conducted by Madsen and Geringer (1981), using a much larger sample size ($N=480$). In this case, the primary goal was to study the participants' discrimination ability with regards to tone quality and intonation. Participants were asked to indicate whether anything was wrong with given duets performed by a flautist and oboist, and, if there was something wrong, to indicate if

it was bad tone quality, bad intonation in the sharp direction, bad intonation in the flat direction, or a combination of problems. Stimuli consisted of performances with bad tone, with pitches sharpened by 50 cents, or with nothing wrong. Mistuning in the flat direction was intentionally omitted by the researchers. A chi-square test was performed based on the seven possible categories, which included bad tone, sharp, and flat for both the flute and oboe separately, with a seventh category indicating that nothing was wrong with the stimulus example. Results indicated that there was a significant difference between music and non-music majors, with music majors' responses significantly more accurate than responses of non-majors.

Researchers have found repeatedly that experience is positively related to intonation accuracy in both performance and perception. Given that information, one should strive to select appropriate participants with significant experience when conducting research related to intonation accuracy of musicians. Because intonation performance is an important topic for musicians, conductors, and pedagogues, it is encouraging to know that, with practice, intonation does improve.

Discrimination of Frequency Changes

It has been established that musicians with more experience have a greater propensity towards intonation accuracy. Also important when considering intonation research is both the point at which one recognizes a frequency change, as well as how much flexibility exists while still being able to label tuning performance as accurate. These two measures are often referred to as Just Noticeable Difference (JND) and Range of Acceptable Tuning (RAT).

The JND reported in any given study can vary substantially. In a session on psychological acoustics during the seventy-fifth annual meeting of the Acoustical Society of America, Houtsma (1968) presented research in which a paired comparison design was used to determine JND. Participants were presented with two melodic intervals and were asked to decide which was larger. Ultimately, the JND was estimated between 13 and 26 cents (Burns, 1999). This is a moderate estimate when compared to other studies.

While the purpose was not exactly to ascertain a JND, Peterson and Smith (1930) investigated how far major 3rds, perfect 4ths, perfect 5ths, and major 6ths can be mistuned from just intonation before the mistuning would be noticed by subjects with and without musical training. Participants heard the tonic note C4 (256 Hz) played simultaneously with D4, E4, F4, G4, A4, and B4, and were asked to identify which of the aforementioned consonant intervals were "changed or unnatural." Results indicated that the range of changes that went unnoticed were 29, 31, 32, and 36 cents, respectively, for the musically trained group, and 39 cents to over 50 cents for all of the intervals for the non-musically trained group. This is a staggering rate of change, as some of these frequency modulations are approaching a quarter step, especially when recalling the aforementioned results of Madsen et al. (1969), which indicated that the most accurate perception occurred in the initial 2- to 10-cent frequency shift.

Samolov (2010) used church bells as stimuli to determine JND because, as the researcher noted, there can be significant inharmoniousness between different partials. Therefore, the frequency of the partials were altered for this study, changing in increments of ± 5 cents, up to 50 cents. In the first experiment, participants, who all had at least eight years of music experience, heard an ideal bell with ideal partials, followed

by a randomized series of bell tones with altered partials. Participants were charged with the task of identifying when the bell tones became unpleasant due to the frequency alteration. In a second experiment, a paired comparison design was used, with the first bell tone being ideal and the second one altered or repeated for a control. Participants were asked to indicate if they heard any change. Ultimately, Salomov found the JND for the frequency alterations to be between 10-15 cents. These findings are similar to those observed by Madsen et al. (1969), in which participants with more music experience were most accurate in detecting changes in intonation between 2 to 10 cents.

Of course, determining intonation in a musical context, such as intervals, can be very different from comparing single, isolated pitches. Vos (1982) proposed that the perception of beats, the roughness created by nearly coinciding harmonics, may contribute to "out-of-tuneness" that one can experience in music performance. The goal of his study was to examine the perception of major 3rds and perfect 5ths, focusing on pure and mistuned intervals, beat sensitivity, and awareness of the mistuning direction. It was not surprising that Vos found the discrimination thresholds for major 3rds to be higher than for 5ths, as an equally tempered major 3rd is considerably more mistuned, at 14 cents, than an equally tempered 5th, which is only slightly mistuned at a 2-cent deviation. Both interval size and sensitivity to beats were found to affect perception of interval size. In cases where mistunings were not too great, there was a lower tolerance for sustained tones than for shorter tones.

Also in the vein of musical context, Fyk (1982) sought to determine the tolerance zone, or range of acceptable tuning (RAT), for various music intervals. Participants comprised two groups, the first being music education students with seven years of

instruction in music, and the second consisting of expert music recording engineers. The stimuli consisted of repeated pairs of melodies, all two measures in length, which were composed for the experiment to avoid strong harmonic implications. The first melody was presented with accurate tuning as a point of reference. To avoid participants being able to compare between the melodic pairs, the second melody was presented a major 2nd higher than the first, with the last note mistuned either upwards or downwards between 5 to 50 cents. Results for both groups indicated that unisons, octaves and perfect 4ths were best perceived with a tolerance zone ranging from 6 to 20 cents, followed by augmented 4ths, diminished 5ths, and major 2nds with an increase of tolerance to 12 to 24 cents, and finally the minor 2nd and major 7th with a tolerance zone from 15 to 37 cents.

Another aspect that can affect the perception of intonation is vibrato. Besouw, Brereton, and Howard (2008) investigated the effect of vibrato on the range of acceptable tuning (RAT). Using a repeating arpeggiated sequence of three tones consisting of the first, fifth, and eighth scale degrees, the middle of which increased or decreased by 3 cents for each repetition, participants identified the points at which the middle tone was perceived to be in tune and out of tune. The RAT for tones without vibrato was found to be 24 cents. A 10-cent increase was observed for tones with vibrato, for a RAT of 34 cents. Besouw et al. noted that this increase may be explained by a finding in a previous study by Fletcher and Sanders (1967) in which the uppermost frequency of a tone played with vibrato on a violin was, in fact, the pitch originally intended. Yet, this finding is contrary to what Geringer, MacLeod, and Allen (2010) found when they investigated the

way college string players and music majors without a string background perceived the pitch of string tones with vibrato.

In order to study the perceived pitch of tones with vibrato, Geringer et al. (2010) had music majors use a Continuous Response Digital Interface (CRDI) to adjust violin and cello tones without vibrato to match the perceived pitch of stimulus tones played with and without vibrato. Results indicated that the perceived pitch was the mean, or center, of tones played with vibrato. Although vibrato has the ability to mask the perception of intonation, Geringer concluded that it does not necessarily change the intended intonation of the performance.

Clearly there are many factors at work when considering the discrimination of frequency changes. Vibrato has been shown to effect perception, ultimately increasing the acceptability of mistuned intervals. The importance of knowing what one can perceive with regards to the JND is undeniable. Reports of large JNDs, such as the ones found in the studies by Houtsma (1968) and Peterson and Smith (1930), could be believable for participants with no musical experience, but these unnoticed frequency modulations seem too large for musically-trained participants, especially when considering that Madsen et al. (1969), in a very compelling study, reported that the most accurate discrimination of JND for their participants occurred between 2 to 10 cents. The wide discrepancy of reports on this topic is concerning. Yet, it seems that it can be agreed upon that discernment of minute frequency changes is positively influenced by level of experience.

Intonation Perception

Perception of intonation can be affected by many factors. Some more predominant considerations include harmonic context, direction of mistunings, and timbre. With context being important, it is not surprising to find that, as the name of Schellenberg's article states, "Going Out-of-Tune Is More Noticeable Than Going In-Tune" (2002). But it is, perhaps, surprising to find out just how much of an effect context has. The interval of an equally tempered perfect 5th (700 cents) was focused on for the purposes of the study. The interval was mistuned, both sharp and flat, by increments of 20 cents. Listeners were significantly more successful in identifying the mistuning when the first interval presented was more accurately tuned than the interval to which it was being compared. For example, if the standard interval was 700 cents and the comparison interval 680 cents, it was more noticeable than if the order of the standard and comparison intervals in question had been reversed. This indicates that listeners had difficulty discriminating between mistunings of 20%—a rather large discrepancy—when moving from mistuned intervals to correctly tuned ones.

Another method for observing intonation perception is to allow participants to freely tune one pitch to another, creating a music interval which they perceive as perfectly tuned. Nordmark and Ternström (1996) isolated the major 3rd interval in a synthesized, non-beating context so as to ascertain the perceptual intonation preference of expert musicians. Given that one method of tuning is to use beats, or the absence thereof, to attain accurate intonation, the use of a non-beating, synthesized ensemble sound for the stimuli essentially eliminated this variable. Participants used a multi-turn dial to tune a major 3rd above the given reference tone until satisfied with the intonation. This

procedure was repeated twice for ten different reference tones, totaling twenty repetitions per participant. Results indicated that the preferred interval size for the major 3rd was 395.4 cents, slightly lower than the modern equally tempered major 3rd, with participant responses ranging from 388 to 407 cents.

Similarly, Rakowski (1985), focusing on isolated music intervals, had music students adjust the frequency of a variable pure tone to create a given harmonic interval with a fixed pure tone. But instead of focusing solely on the major 3rd, this task was performed multiple times for every interval in a chromatic scale. The resulting frequencies were converted into cents, and ultimately cent deviation from equal temperament. While some deviations were as small as 7 cents, there were other cases that were over 40 cents, particularly for the intervals of a tritone and major 6th, significantly larger than the deviations found by Nordmark and Ternström. Contrary to expectations, deviations for minor 2nds were rather low, whereas deviations for perfect 5ths were larger. A general tendency to compress smaller intervals and stretch larger intervals was observed. Although it is important to observe how musicians perceive the intonation of various intervals, the stimuli used in both of the aforementioned studies created a rather sterile environment in which to tune the intervals, especially when considering that harmonic contexts and timbre play such an important role.

One such example of how timbre can affect perception is found in a study by Warrier and Zatorre (2002). Tone pairs were prepared, the second of which was either the same, 17 cents, 35 cents, or 52 cents higher. In addition to the mistunings, a timbral element was added, presenting the pairs to participants either with the same timbre, a small difference, or a large difference. These different timbres were created in the

computer-generated recordings by artificially emphasizing different harmonic overtones to generate tones ranging from “darker” to “brighter” in quality. Further experiments were performed using a similar procedure, presenting the tones in question as a tone series and in a melodic context. Warrier and Zatorre found that the more that pairs of tones differed in timbre, the more participants perceived the pitches of the two tones to be different, regardless of whether they truly differed. When given a stronger harmonic context, however, participants were able to be more accurate with pitch perception despite the effect of timbre. These findings corroborate a study by Geringer and Worthy (1999), in which college level instrumentalists, both music majors and non-majors, as well as high school level instrumentalists, were presented with paired listening excerpts and asked to rate the change in tone quality and the intonation for each of the pairs. The tones for the stimulus examples were excerpted from recordings of concert trumpet, trombone, and clarinet performers, and presented either unaltered, darkened, or brightened, in different pair combinations. It was found that brighter tones were rated as more sharp, and darker tones more flat.

Having found that timbre can effect perception of intonation, one might wonder to what extent this effect can influence a listener. Using four different experiments, Russo and Thompson (2005) found that timbre can influence the perception of interval size. An extreme example from the first experiment showed that musically untrained participants perceived a tritone, in which the interval began with a dull timbre, then shifted to a bright timbre when ascending to the tritone, as larger than a perfect 5th that shifted from a bright to dull timbre. This "interval illusion" effect held true for both musically trained and untrained participants in the remaining three experiments.

Clearly, timbre is an important element in music, and should have implications in rehearsal and performance. Citing concerns regarding traditional wind ensemble mass tuning practices, Byo, Schlegel and Clark (2011) explored the effect of octave and timbre on the tuning accuracy of wind instrument players. Participants were presented with various recorded tuning notes and asked to tune their instruments, holding their pitch for approximately 3 seconds when they felt their tuning was accurate. The recorded tuning notes consisted of tones produced at the pitch level of B-flat 4, using flute, clarinet, and oboe, as well as a tone at the pitch level of B-flat 2 produced on a tuba. They were arranged into three randomized orders in which the participants would tune. The stimuli were produced using professional musicians, who performed the given pitches consistently for approximately 10 seconds, using a tuner as a visual cue for intonation accuracy. The tones were then reviewed by two of the researchers, who selected the ones they felt were the highest quality in terms of pitch and evenness. It is important to note that this is one of the few studies that created stimulus tones using live musicians. Following the tuning task, participants were asked which tones were easiest and hardest with which to tune, if they felt it mattered at all. They were also asked how they typically tuned in their own wind ensembles. For the performance task, the frequency of the middle portions of the recorded participant responses were analyzed, thus eliminating any onset or offset effect, and converted to cent deviation scores for analysis. Results of a repeated measures ANOVA of the absolute cent deviations indicated that there was no significant difference with regards to the three tuning groups (the instruments which sounded either B-flat 2, 3, or 4), however, there was a significant difference found in terms of stimulus timbre. The absolute cent deviation when participants tuned to the tuba

was significantly larger than for the other three instruments, indicating that mass tuning to the tuba in wind ensembles may not be the best choice for good intonation. Data were also categorized as sharp, flat, or in tune (within ± 5 cents) for all of the stimuli timbres, and no significant differences were found among the three groups. As for the perceptual questions asked of the participants, a large percentage indicated that it was easiest to tune to the tuba, and a majority said that they normally tune to the tuba in their own bands. This perception is clearly not in alignment with the performance of the participants, which indicated that tuning deviated the most when the tuba was used as a reference tone.

The effect that timbre can have on music perception is important to consider in both performance and research. In vocal music, text and pronunciation becomes an additional variable that affects timbre. Bloothoof and Plomp (1984) conducted spectral analyses of various vowel sounds to investigate the source of variability of timbre in vocal production. Recordings were made of 14 professional singers, half of which were women, and half men, in which they were asked to sing nine different vowel sounds in nine different styles, including light, dark, neutral, free, pressed, soft, loud, with and without vibrato. This was repeated at various pitch levels. Style of singing only showed a slight effect on the spectral variation of sung vowels. Vowel sound was the most significant factor, with findings indicating that the back vowels contained a greater amount of variability of timbre in vocal production than the higher front vowels. These findings provide guidance for research design when testing in the area of vocal performance, as the use of higher front vowels, like [i], can serve as an additional control, since there is evidence that there is less variability in performance of these vowels.

Intonation Tendencies

As discussed previously, intonation accuracy appears to increase with experience (Madsen et al., 1969; Madsen & Geringer, 1981; Morrison, 2000; Peterson & Smith, 1930; Yarbrough, Karrick, & Morrison, 1995). A general tendency for erring on the side of sharpness is frequently observed as musicians gain more experience. Exploring the intonation tendencies of instrumentalists in woodwind quintets, Mason (1960) recorded solo and ensemble performances of two such quintets, one made up of students and the other professionals, and compared them to various tuning systems to see if woodwind players tended towards one over the others. For both the solo and ensemble conditions instrumentalists did not conform to any one tuning system, however, the professional musicians tended most towards equal temperament while the students were closest to Pythagorean tuning. Both groups were furthest from just intonation. A general tendency towards playing sharp was observed.

Geringer (1978) also found a proclivity for sharpness when he studied the relationship between the intonation perception and performance of ascending scales. Participants were 96 undergraduate and graduate music students enrolled in applied lessons, and consisted of an equally balanced number of randomly selected string players, wind players, pianists, and vocalists. Vocalists and pianists were asked to sing the ascending scale, while the string and wind instrumentalists performed the task using their own instruments. Participants performed the ascending scale both unaccompanied and with recorded piano accompaniment. Half of the participants were then given feedback indicating that musicians tend to perceive flatness more accurately than sharpness, that there is a tendency to perform sharp, and that they exhibited this tendency. They were

told that their playing was sharp regardless of whether it actually had been. Then they were asked to either perform again, with particular focus on intonation accuracy, or to retune their original recording using a variable speed tape player. The other half of the participants, serving as a control group, only received the instruction to perform as accurately as possible, and not given the information regarding the tendency toward sharpness. They, too, were asked to either perform a second time or to retune their original recording. The frequency for each pitch in both the performance tasks and the perceptual readjustment tasks were analyzed and converted into cents. Perception of the unaccompanied ascending scale was less accurate than the performance of the same, however, the difference was not significant. There was no significant difference between the verbal inducement group and the control group, suggesting that verbal feedback may not have a considerable impact on tuning accuracy. A tendency toward sharpness, when compared to equal temperament, was observed. The vocalists had a greater propensity toward sharpness than the instrumentalists.

Further evidence of sharp performance has been provided by Kantorski (1986), who examined the effect of accompaniment and register on the intonation of collegiate string players. Participants, presented with a prerecorded, computer generated accompaniment that approximated the sound of a flute, played ascending and descending tetrachords composed of whole steps. The pitch level of the accompaniment was lower than that of the participants when the participants played in the upper register of their instruments, and above that of the participants when the participants played in their lower register. Using equal temperament as a point of reference, it was found that performances in the upper register were significantly more sharp than those in the lower

register, although performances in the lower register still tended toward sharp when compared to equal temperament. Descending tetrachords were performed significantly more sharp than ascending tetrachords.

Similar findings were reported by Sogin (1989) when studying the intonation performance of undergraduate, graduate, and professional string players. With the reasoning that it is an infrequently used scalar pattern, the participants played E-flat, F, G-sharp, and A-sharp in both ascending and descending directions, with and without vibrato. Frequency ratios were converted into cents for analysis. The results indicated that the string players tended to play sharp regardless of scale direction or vibrato.

Yet again, this tendency towards sharpness was observed by Karrick (1998) as he explored how wind instrumentalists tuned harmonic intervals. Two groups, the first consisting of professional instrumentalists and the second made up of advanced students, were recorded playing both a melody line along with a synthesized harmony, and the harmony with the synthesized melody. In comparing targeted intervals, no significant difference was found between performances above or below the synthesized stimuli when compared to deviation from equal temperament, however, there was less consistency when participants played below the stimulus. Location did, however, have a significant effect when considering direction of mistuning, as there were significantly more sharp responses when performing below the stimulus. The professional group was found to perform more sharp than the student group when playing below the stimulus. Overall results did indicate a propensity towards playing sharp.

Yarbrough, Karrick, and Morrison (1995) found a slightly different result linked to experience, yet the overall results still held true to the proclivity for sharpness. The

initial direction of mistuning had a significant effect on both the perception and performance task, with players showing a tendency toward sharpness when approaching from above, and flatness when approaching from below. In terms of experience, it is interesting to note that there was a significant difference found for the direction of tuning error for the performance task only, with less experienced players tending toward flat responses and more experienced tending toward sharp. A closer look at the aforementioned studies revealed that professionals and advanced music students were used as participants in all of the studies that reported a penchant for sharpness (Geringer, 1978; Kantorski, 1986; Karrick, 1998; Madsen et al., 1969; Mason, 1960). It has also been demonstrated that years of experience had a positive effect on tuning accuracy (Madsen et al., 1969; Madsen & Geringer, 1981; Peterson & Smith, 1930; Yarbrough et al., 1995). Ultimately, it seems that this tendency towards sharpness, which is associated with experience, somehow translates into more accurate intonation practices, as interpreted by professional musicians.

Comparison of Different Tuning Systems

Many researchers who have studied aspects of intonation compare performed frequencies with various mathematically defined tuning systems. Equal temperament, having been predominantly used for the past few hundred years, particularly on fixed pitch instruments such as the piano, does seem to have an advantage over other tuning systems. This predisposition to equal temperament is highlighted by many studies, but said predisposition may be related to the instrument or instrument family.

One such example is a study by Karrick (1998), who studied how harmonic intervals were tuned by wind instrumentalists, particularly with regard to tuning system,

location of performed pitches, and deviation from equal temperament. Two groups were used for the purpose of the study, one made up of advanced students and the other consisting of professional instrumentalists. Participants were recorded playing a duet along with a synthesized stimulus in two different contexts, either playing the melody above the stimulus or playing the harmonic line below the stimulus. The target intervals, which included major and minor 3rds and 6ths, perfect 4ths and 5ths, unisons, and octaves, were compared after calculating the mean frequency and converting the frequency ratios into cents. The greatest variability was found in 3rds and 6ths. There was no significant difference found between performances above or below the stimuli when compared to deviation from equal temperament, but less consistency was found when participants played below the stimulus. When compared to three different tuning systems, Pythagorean tuning, just intonation, and equal temperament, the intonation of the selected harmonic intervals performed by the participants most closely conformed to equal temperament, and was furthest from just intonation.

Similar tendencies have been found for woodwind players (Mason, 1960). Mason recorded unaccompanied solo performances and ensemble performances of one student and one professional quintet. Pitches from every scale degree of the major scale, along with the addition of the augmented 4th, or tritone, were analyzed and converted to cents. Cent deviations for both solo and ensemble performances were calculated in comparison to Pythagorean tuning, just intonation, and equal temperament. Results indicated that the musicians did not conform to any specific tuning system, but, in general, the professional players tended more towards equal temperament and students tended towards Pythagorean tuning. Both groups were furthest from just intonation.

In another study comparing performance to just intonation, Pythagorean tuning, and equal temperament, Leukel and Stoffer (2004) found results contrary to previous reports of wind player performance when they examined the intonation of professional flautists, focusing specifically on major and minor 3rds. In order to simulate an authentic performance experience, the flautists played in an acoustic similar to a concert hall, performing the intervals in question as duets, with one musician focusing on consistency of intonation, while the other focused on adjusting their own intonation. The intervals were performed in a simultaneously-played isolated condition, and both ascending and descending as part of major, minor, and dominant seventh chords. The flautist performed each task as many times as needed, until, in their professional opinion, they felt that they had two acceptable recordings in terms of intonation. For the isolated context without harmonic reference, the major 3rd tended most toward pure, or just intonation, while the minor 3rd was closest to equal temperament. These tendencies held true for the harmonic context. Flautists were furthest from Pythagorean tuning for both major and minor 3rds.

In the realm of string players, Pythagorean tuning tendencies are predominantly reported in intonation research. This is not surprising, considering the fact that these fretless, bowed, string instruments are tuned to pure perfect 5ths, and that Pythagorean tuning is constructed of pure, perfect 5ths. Nickerson (1949) found this to be true when analyzing the intonation of 24 professional string players from six string quartets. The musicians played an excerpt from Haydn's *Emperor Quartet*, both as an unaccompanied solo line, and as a melody in harmonic context. When frequency ratios were analyzed, results indicated that for both the unaccompanied melodic task and the harmonic task the performances were closest to Pythagorean tuning and furthest from just intonation. There

was, however, a significant difference found between the melodic and harmonic contexts in the performance of 3rds, with solo performances tending toward the sharper, Pythagorean tuning, and harmonic context performances flatter in the direction of equal temperament and just intonation.

Loosen (1993) also studied the intonational tendencies of string players by analyzing the intonation of eight professional violinists playing a three octave major scale. The violinists were instructed to play the scales, using no open strings, slowly and without vibrato, focusing on accuracy. Frequency ratios were analyzed in two different ways. The first followed the assumption that the violinists were basing their intonation on the previously played pitch. The second was assessed on the basis that the violinists were playing in the key of C major, thus using C as a reference point. Following analysis, the intonation of the scales was compared to equal temperament, Pythagorean tuning, and just intonation. When analyzing frequency ratios intervallically, results indicated that the violinists tended to play between Pythagorean tuning and equal temperament. Equal temperament and Pythagorean tuning both fit equally well when analyzing frequency ratios based on the three octave C major scale as a whole.

Utilizing equally tempered and justly tuned accompaniments, Kopiez (2003) studied the intonational adaptability of two professional trumpet players. The participants were given the recorded accompaniments and a score for the solo trumpet part ten days in advance so they would be able to prepare. They were informed that one of the accompaniments was tuned to equal temperament, and the other was tuned to just intonation, and they were asked to adapt accordingly. The subjects were also tested to see if they were able to distinguish between harmonic progressions presented in different

tuning systems, which they both did flawlessly. After the ten days, recording sessions were held in which the participants were asked to play the melody five times for each tuning system in question. Focusing on minor 3rds, major 3rds, perfect 5ths, minor 7ths, and octaves, the frequencies were analyzed for the pitches in question using Praat software, and then converted to cents for analysis. No significant differences were found between the performances over the two different tuning systems. The performances of the participants most closely resembled equal temperament, deviating most from just intonation. Kopiez attributed this finding to a "burn in" effect, in which performers are so used to playing using equal temperament that it comes most naturally regardless of the accompaniment.

For a study designed to observe the relationship between the intonation perception and performance of college level wind instrumentalists, Ballard (2011) used equal temperament, Pythagorean tuning, and just intonation for comparisons. For the performance tasks, the participants, 60 wind instrumentalists from two universities, were instructed to play the first phrase of the *Star Spangled Banner* on their own instrument using accurate intonation. Performances were either unaccompanied, or with computer generated piano accompaniments that were altered to conform to the three tuning systems. This performance task was repeated with the participants singing the melody on a neutral syllable. Overall, no significant differences were found between any of the tasks. There were also no significant differences found in the vocal performance condition with regard to tuning. In fact, intonation was significantly worse for the vocal condition than the instrumental, with deviations up to 23.47 cents. It is odd that one would have instrumentalists sing when studying intonation performance, particularly

when it has been demonstrated that years of study on one's own instrument were associated with improved intonation accuracy. Therefore, it is not surprising that these instrumentalists lacked the vocal control to perform as accurately with their voices as they could with their instruments. Similar research needs to be performed with experienced vocalists in order to ascertain the intonational tendencies of vocal musicians and whether those tendencies deviate from the various instrumental areas. There was, however, a significant difference found in the instrumental performance task, indicating that the players most closely approximated equal temperament and were farthest from Pythagorean tuning and just intonation.

An interesting study of barbershop quartet singing was conducted in which two quartets sang a cadence multiple times for the purposes of analyzing the performed intonation (Hagerman & Sundberg, 1980). Barbershop quartets are renowned for the accuracy of their tuning, and there was an expectation that their tuning would conform most closely to just intonation. However, this expected pure tuning was not observed. With the exception of octaves, 5ths, and 4ths, which were performed close to pure and Pythagorean tunings, music intervals were not found to conform to any specific tuning system. Hagerman and Sundberg did, however, interpret major 3rds performed on the tonic chord to be a “flattened version of a Pythagorean third,” while in the context of a dominant chord they were deemed “a stretched version of a pure third” (1980, p. 42).

It is important to note that, in all of the aforementioned studies, no performances ever matched any one tuning system exactly. There were, however, tendencies observed which conformed more closely to one tuning system over another. Many of these tendencies seem to be connected to instrument family, with woodwind and brass players

tending more towards equal temperament and string players towards Pythagorean tuning. Yet, there are also contrary findings indicating that some woodwind players tend towards Pythagorean tuning, or even just intonation. In the future, it may be valuable to perform research comparing the intonation tendencies of vocalists and woodwind, brass, and string players, to see if there are any significant differences in their performance. At this point, it seems that the only conclusion that may be drawn is that results vary by study and that musicians do not perfectly conform to any one tuning system.

Perception Versus Performance

Many researchers have compared performance with perception of intonation. One would assume that these two aspects are strongly connected, as the ability to perceive accurate intonation must contribute to one's ability to perform with accuracy. Results of the research, however, have been somewhat inconclusive. In studying the effect of tone quality on intonation performance and perception, Worthy (2000) report a low correlation between the two tasks, albeit not statistically significant. For this study, high school and university level wind instrumentalists were charged with two tasks. The first was a perceptual paired comparison task in which the participants were presented with two successive tones in the timbre of their own instrument. While the frequency of these tones did not change, the second of the pair was presented with either a darker timbre, a lighter timbre, or unaltered. Using Likert-type scales, participants rated the tone quality and the intonation of the second tone as compared to the first. This task was completed in a randomized order using four different pitches, for a total of 12 comparisons per participant. Brighter tones were interpreted as sharper, and darker tones were interpreted as flatter. This same trend was observed in the performance task, where

participants matched the same stimulus tones by playing their own instruments.

Participants tended to play sharper when matching a brighter tone, and flatter when matching a darker tone. In this case, there was a small connection observed between intonation performance and perception. These findings are similar to those of Russo and Thompson (2005), who determined that an "interval size illusion" can be created using contrasting timbres.

Ely (1992) also reported a low correlation between performance and perception while studying collegiate wind players' intonation abilities with regard to timbre. Participants consisted of 27 instrumentalists evenly divided among flute, B-flat soprano clarinet, and alto saxophone players. They had been selected by their applied instrument instructors as being able to complete intonation tasks well. Stimuli consisted of a melodic phrase recorded by the applied instrument instructors on their instrument. They were asked to focus on accurate tuning, and were allowed to play the melody as many times as they wished until they felt the performance was accurate. Instructors were able to view an electronic tuner while playing in order to assess their performance and ensure consistency. For the performance task, participants played along with each version of the prerecorded melody, which was heard through headphones, for a total of three recordings. The results of the performance task showed that, while intonation varied significantly between participants, timbre was not found to have a significant effect on the intonation of the performers. This is contrary to most of the research on timbre and intonation, as many have found timbre to have a significant effect on performance and perception (Geringer & Worthy, 1999; Russo & Thompson, 2005; Warrier & Zatorre, 2002; Worthy, 2000). Ely did note, however, that participants had slightly less deviation

when playing along with the timbre of their own instrument. When playing along with other instrument timbres, participants tended to play more flat than sharp. For the listening task, recordings of the performance task were used as stimuli. Participants heard duets between like instruments, as well as flute and saxophone, flute and clarinet, and clarinet and saxophone, totaling six different timbral combinations. As participants listened to each performance, they indicated the placement of out-of-tune pitch pairs on a provided response sheet. Results of the listening task indicated that participants more accurately detected intonation problems in timbral conditions which were dissimilar, for instance, saxophone paired with flute, rather than like timbral combinations, such as two saxophones. Overall, there was only a low correlation found between intonation performance and perception.

Significant interactions were found in another study comparing intonation perception and performance (Geringer, 1978). After performing unaccompanied and accompanied ascending scales, the 96 undergraduate and graduate music student participants were divided into two groups, one performing ascending scales for a second time, either after verbal inducement or as a control, and the other retuning their original performance, again with or without inducement. Results indicated significant differences between intonation perception and performance. The performance task was more accurate than the perceptual task, particularly in the case of the perception of the unaccompanied ascending scale. Accompanied performance and perception tasks were found to be more accurate than unaccompanied tasks.

Also focusing on performance versus perception, Vurma and Ross (2006) had 13 professional singers perform ascending and descending melodic intervals of minor 2nds,

tritones, and perfect 5ths. For the initial perception task, prior to singing the performers were instructed to remember any intonation errors they made while completing the performance task. Immediately following the performance task, the singers identified the notes that they felt were poorly tuned by indicating the direction of error with an arrow next to the note in the music. Another perceptual task was completed in the same fashion, this time with the singers listening to the recording of their own performance and basing their judgments on what they heard rather than what they recalled from their performance. A second group of participants, identified as "expert listeners," also completed the perceptual listening task, evaluating the recorded performances of the singers using the same procedure as the first group. Results of the post-performance recall task indicated that the singers' responses were random at best. The singers were much more accurate evaluating the recordings of their performances. The average deviation of intonation from equal temperament for pitches they judged to be correct was 11 cents, while the average deviation of pitches participants judged to be incorrect was 25 cents. This difference was statistically significant. Similar results were found with the expert listener group, corroborating the listening evaluation of the performers. Results of the performance task indicated that participants had a tendency to compress the smaller, minor 2nd interval, and stretch the larger tritone and perfect 5th intervals. Intonation for the minor 2nds and perfect 5ths was more accurate than that of the tritone. Results indicated that performed intonation could deviate as much as 25 cents and still be perceived as acceptable. While the initial perceptual task of the singers evaluating their own performance was not accurate, in comparing intonation performance with the final

perceptual listening task, results appeared congruent, as demonstrated by a significant Pearson product moment correlation.

In contrast, Ballard (2011) found no correlation between performance and perception when utilizing various tuning systems in order to study intonation performance and perception of musicians. College level wind instrumentalists performed two perceptual tasks and two performance tasks. One perception task involved participants determining whether the second of a pair of tones was sharp, flat, or unaltered. The most either of the sharp or flat tones was altered was 8.6 cents, a relatively small adjustment considering the wide range of intonation discrimination previously discussed. The success rate for this isolated perception task was under 50%, yet still deemed better than chance. For the remaining perception task, as well as for both performance tasks, the initial phrase of the *Star Spangled Banner* was used as the stimulus. Participants were charged with identifying the mistuned pitches for the perceptual task, again indicating whether they were sharp or flat. For the performance tasks, the participants both played the melody on their own instruments and sang the melody, encouraged to focus on accurate intonation. The instrumental and vocal performances were repeated four times, once unaccompanied, and the remaining times with a computer generated piano accompaniment altered to conform to either equal temperament, Pythagorean tuning, or just intonation. The tuning system had no significant effect on perception. Likewise, there was no significant effect for tuning system on the vocal performance task. The vocal performances were, however, significantly more out of tune than the instrumental performances, with pitch deviations as great as 23.47 cents. There was, however, a significant difference for tuning condition

for the instrumental performance task, indicating that the instrumental performances were closest to equal temperament and furthest from Pythagorean tuning and just intonation. Overall, there were not any significant correlations found between any of the tasks, both between perception and performance and within perception and performance. The instrumental performance task was found to be quite accurate, much more so than the vocal performance or perceptual tasks.

Researching the performance and perception of intonation in two-part vocal exercises, Vurma (2010) also found that performance was significantly more accurate than perception. For the performance task, 15 professional singers sang a brief vocal exercise along with a synthesized accompaniment. The exercise consisted of a melodic minor 2nd and a melodic perfect 5th, in which the singer returned to the starting pitch each time after singing these intervals, for a total of six sung tones. A two-beat rest was placed between the first three pitches and the last three. The accompaniment began and ended each three note grouping in unison with the singer and played a melodic perfect 4th and a melodic major 3rd, which, when paired with the singer, created a major 3rd and a minor 3rd respectively. The performance task was completed five times, during which the middle tone of the accompaniment was presented, in a randomized order, either in tune, 20 cents flat, 40 cents flat, 20 cents sharp, or 40 cents sharp. The singers were instructed to perform "as they would sing in a real concert situation and to try to stay in tune" (p. 26). Results indicated that the singers' performances were significantly affected by the frequency modulations. In fact, the 40-cent modifications created major 3rds as large as 452 cents and minor 3rds as small as 252 cents. These are relatively large differences when compared to the equally tempered major 3rd of 400 cents and minor 3rd

of 300 cents. For the perceptual task, recordings from the performance task were used as stimuli. A separate group of expert musicians was employed for the evaluation of the recordings. They were asked to identify, both in the sung parts and the synthesized accompaniment parts, whether the note(s) in the middle harmonic interval were in tune, or should have been produced higher or lower. There was a strong correlation found for identification of mistuning in the accompaniment, but not for the sung parts. Expert listeners correctly identified mistunings, and the direction thereof, 58% of the time when the frequency of the accompaniment was shifted 40 cents, but only 34% of the time when it was shifted 20 cents. When comparing performance to perception, the singers were far more accurate in terms of holding true to equal temperament, in which they were in the realm of ± 20 cents 80% of the time, significantly better than the accuracy of the expert listeners' responses.

It is interesting that, because one must be able to perceive in order to perform accurately, results relating performance to perception are so mixed. In the cases of low or statistically insignificant correlations between these two aspects, such as the studies by Ely (1992) and Worthy (2000), there do seem to be similar trends when comparing performance and perception of intonation with timbre as a variable. Although researchers have found a statistically significant difference between performance and perception, with performance being more accurate than perception (Geringer, 1978; Vurma, 2010), Vurma and Ross (2006) found a significantly positive relationship between the intonation performance of singers and their perception of intonation, when they evaluated recordings of their performances. However, the same study indicated that evaluation of one's performance using recall immediately following the performance task

was inaccurate (Vuma & Ross, 2006), and Ballard (2011) found no correlation between performance and perception. These discrepancies raise the question of why there do not seem to be consistent findings in terms of intonation performance and perception. These discrepancies may be a result of the studies' differing designs and tasks. At this point, there seems to be a need determine why there may be little or no connection between these two very important aspects of music performance, rather than additional investigations based on comparisons or correlations.

Intonation Pedagogy

With accurate intonation performance being an important aspect of music performance, one would reason that many studies on the topic of intonation pedagogy must exist, which could be used to inform our practices in classroom and rehearsal settings. But, at present, there is only one study that I have come across that attempts to assess the effectiveness of an intonation pedagogy program. With the lack of empirical research in this area, we must then turn to expert opinion in order to identify pedagogical techniques that will promote accurate intonation. But before exploring pedagogical opinion, it is important to understand what exactly constitutes “good” intonation.

Logic dictates that research on the Range of Acceptable Tuning (RAT) be considered when establishing what is considered good intonation. But the RAT reported has spanned from as little as 6 to as great as 37 cents deviation from a given standard, depending on the music interval (Fyk, 1982), and the RAT increases with the addition of vibrato (Besouw et al., 2008; Geringer et al., 2010). Less deviation from an established baseline for “perfect” intonation should be more desirable, but establishing a baseline is not as easy as it may seem. There are many mathematical tuning systems that have been

devised. The three that are most often used for comparison in intonation research are Pythagorean tuning, equal temperament, and just intonation. So is any one of these more or less ideal than the others? Yes...and no. Musicians do not consistently conform to any one of these tuning systems (Hagerman & Sundberg, 1980; Karrick, 1998; Leukel & Stoffer, 2004; Mason, 1960; Nickerson, 1949). Alldahl (2008) suggested that all three of these systems can be most suitable, depending on the musical context and accompaniment type, with just intonation being most desirable in a cappella music that is tonal and harmonically conceived, equal temperament being most effective when performing highly chromatic music or when performing with a fixed pitch instrument like the piano, and Pythagorean tuning when performing expressive melodic lines. It would even be conceivable that a combination of all of these tunings would be most desirable in any given piece of music. Further, good intonation can be subjective, ultimately falling under the purview of experienced musicians to make judgements on what is accurate and how we might teach this accuracy.

Although there is a lack of research in this areas, many music professionals have written about the topic of intonation pedagogy. It is a subject that comes up regularly in sources such as the *Music Educators Journal* and the *Choral Journal*. Jordan (1987) discussed audiation—a term, coined by Edwin Gordon, indicating the process in which one silently, and consciously, perceives music internally—as an efficient pedagogical method for improving choral intonation. Audiation was also addressed in an article in which strategies for teaching the technique to instrumental ensembles were recommended (Dalby, 1992). While the use of audiation is likely beneficial in teaching music and improving intonation, it is extremely difficult to empirically test. Because audiation by

definition occurs in the minds of individual music students, it proves troublesome to observe. While we could potentially identify improvement of audiation in a pretest-posttest design, it would be difficult to rule out the effect of other variables, which may be the reason for the lack of empirical studies on this topic.

Inner hearing, a process similar to audition, has been identified as an important step in vocal production that may not be completed by less experienced singers (Grant, 1987). In addition to instilling the habit of “Listen-Think-Sing” in vocal students, Grant also emphasized the effect of using proper vocal production techniques on good intonation. He also noted that imagery and metaphor, pedagogical strategies often in rehearsals, may not be the best approach to achieving good intonation, particularly when the students have nothing with which to connect the imagery being used.

Other individuals have highlighted observations on causes of poor intonation and recommended potential pedagogical solutions. Wine (2004) noted that problems with intonation could generally be attributed to either physiological or psychological factors. Physiological factors pertain to vocal production and technique. Many others also have indicated that intonation can be influenced by such physiological factors as posture, breath support, and tessitura or range issues (Doscher, 1991; Grant, 1987; Jordan, 1987; Powell, 1991; Skelton, 2005; Wine, 2004). Vocal fatigue has also been cited as a cause of poor intonation (Doscher, 1991; Wine, 2004). Psychological factors that can influence intonation relate to how singers perceive pitch, which can be effected by musical factors, such as direction of line or awkward intervals, physical factors that influence how singers hear themselves and others, such as the acoustics of the rehearsal/performance space and seating formation, and confidence that comes with knowledge of one’s vocal line (Wine,

2004). Some individuals advocate for awareness of vertical harmonies (Jordan, 1987; Powell, 1991) and horizontal melodic line (Powell, 1991) as means for improving intonation, with some going as far as advocating for just intonation over equal temperament (Alldahl, 2008; Frampton, 2010; Skelton, 2005).

Several books about choral and vocal technique also address the topic of intonation from a pedagogical standpoint. The tendency is to address probable causes of intonation issues and recommend solutions. Brinson and Demorest (2014) indicated that poor vocal production was the most prevalent culprit, including improper breath support, breathing, posture, vowel resonance, head/chest mix, and muscular tension. The solution given is to focus efforts on these issues, putting extra emphasis on breath support and relaxation. Similar causes and solutions were suggested in a book by Davids and LaTour (2012).

As previously mentioned, there is one instance in which a researcher evaluated a pedagogical approach for promoting accurate intonation. Dalby (1992) evaluated a computer-based program designed to help improve intonation perception. He found that participants in the program showed a statistically significant improvement in their ability to discriminate harmonic intonation. If this is the case, why aren't programs such as these more mainstream? This is an example of an empirically studied program that showed promise, yet never reached the public. Perhaps the cost of implementation would be prohibitive. This is why it is important to identify empirically tested, easy, inexpensive, and effective pedagogical techniques that can readily be used in the classroom. One such example of this may be the methods identified and explained by Per-Gunnar Alldahl (2008), in his book *Choral Intonation*.

Alldahl (2008) outlined the finer points of intonation performance practice in varying contexts and complexities, providing a method for teaching these skills to choirs. Consistent with the ideas of the previously-mentioned professionals, Alldahl addressed the identification of potential problem areas in the music, including characteristics such as tempo, direction of line, and vowel, but he goes beyond these concerns to encourage the incorporation of actual theoretical tuning systems into choral rehearsal strategies. More specifically, he compared and contrasted the uses of just intonation, Pythagorean tuning, and equal temperament in musical performance practice.

Just intonation is built on pure, beatless intervals. While this yields brilliant sounding harmonies, it is limited in that musicians playing fixed-pitch instruments are unable to change keys at will, given that the half steps aren't all equidistant. But, this is not a limitation for a cappella choral music. Alldahl pointed out that many Renaissance madrigals and motets sound much better using this system. However, the more complex the music gets—for example music containing a great deal of chromaticism and/or key changes, or atonal music—the more difficult it is to use just intonation. In these instances, equal temperament is extremely useful. Equal temperament also allows musicians playing fixed-pitch instruments to change keys without the need to retune their instrument. In order to achieve this, intervals are mistuned anywhere from 2% to 16% from pure. As can be seen in Figure 1, this compromise is negligible for some intervals, such as the 4th and the 5th, but rather large for others, such as the 3rd and 6th. This leads to less brilliantly-sounding harmonies, as it introduces mistuning that results in beats, which are generally considered undesirable, particularly at resolutions and cadences. This deviation from pure intonation is noticeable to an even greater extent in Pythagorean

tuning, however this system can be a musically expressive tuning for solo melodies; thus, Alldahl referred to it as *melodic intonation*. This is similar to what virtuoso cellist Pablo Casals called *expressive intonation*, in which major intervals would be widened, minor intervals would be compressed, and leading tones heightened, a practice exactly opposite to the logic of just intonation, but far more emotive from a virtuoso soloist's perspective (Blum, Tortelier, & Hopkins, 1980).

Figure 1. Comparison of tuning systems in cents (Alldahl, 2008).

Three different tuning systems have been presented here, all with strengths and weaknesses in different musical contexts and situations. Equal temperament is well-suited to fixed-pitch instruments and chromatic music and Pythagorean tuning can promote expressive intonation that emphasizes leading tones and half step motion, yet both of these sacrifice purely tuned intervals. Just intonation retains the pure intervals, but is only effective when performing without fixed-pitch instruments in music that is generally diatonic. The fact that there is no consistency in reported tuning tendencies of musicians from extent research—aside from musicians not conforming precisely to any mathematical tuning system—combined with this situational nature of tuning, makes it clear that there is no one correct answer regarding what constitutes perfect tuning. But there are more desirable tunings to approximate, which change based on the type of music one performs. So are there pedagogical approaches that would help student

musicians better learn how to develop these fine tuning skills? And is it possible to empirically test these approaches?

One such pedagogical approach is provided by Alldahl (2008), who noted various ways the piano may be used as a rehearsal tool when choirs learn a cappella music, the extremes of which being using the piano to double what the choir members are singing, versus not using the piano at all. One particular use of the piano Alldahl advocated is for “referential tones,” pitches carefully selected to be played on the piano that are designed to give the singers a point of reference without imposing equal temperament on them, but instead allowing them to rely on their ears to detect beats (or the absence thereof). Through this process, the piano is used to support good intonation rather than impress a less desirable intonation performance. In order to select appropriate referential tones, Alldahl recommended the following guidelines: “keep the same referential tone as long as possible; change referential tone preferably through leaps of fifths/fourths; whole-tone steps in the “referential part” will also work; use tritone or semitones only if absolutely necessary; avoid thirds and sixths” (2008). Ultimately, it is the both the reference tone and its overtones to which the singer tunes. For example, in the key of C major, if the singer is singing on the 5th scale degree (G) on the tonic chord (C), the tonic would be played an octave and a 5th below the sung pitch, as the second overtone (or third partial) would then line up with the singers pitch. The tonic pitch an octave up can be included to help with audibility (see Figure 2 for an illustration of this process). This method provides a practical approach to piano usage in the rehearsal process that shifts more of the responsibility for performing with good intonation to the singers through both education

about intonation options and the refinement of listening skills, one with concrete concepts that can easily be tried and tested in a classroom or research setting.

Figure 2. Referential tone partials (Alldahl, 2008).

Conclusion

Throughout this review of literature, research and topics providing information regarding the effect of experience on intonation, tendencies in intonation performance, intonation perception, comparison of intonation performance of different mathematical tuning systems, and intonation pedagogy have been explored. All of this material helps to illustrate the current state of music intonation research and practice. It is well established that experience has a positive effect on the accuracy of intonation performance (Madsen et al., 1969; Madsen & Geringer, 1981; Morrison, 2000; Peterson & Smith, 1930; Yarbrough, Karrick, & Morrison, 1995), and there appears to be a tendency toward sharp intonation with increased experience (Geringer, 1978; Kantorski, 1986; Karrick, 1998; Madsen et al., 1969; Mason, 1960). But these are the only variables for which any true consistency is observed in the literature.

In the area of intonation perception, there has been discrepancy among study findings with regard to the Just Noticeable Difference (JND) of fine tuning changes, ranging from as little as 2 cents (Madsen et al. 1969) to as great as approximately 30 cents for musically trained individuals and greater than 50 cents for musically untrained

individuals (Peterson & Smith, 1930). The Range of Acceptable Tuning (RAT) reported has also spanned anywhere from 6 to 37 cents, depending on the music interval (Fyk, 1982), and the RAT increases with the addition of vibrato (Besouw et al., 2008; Geringer et al., 2010). Additional factors that have been shown to influence intonation perception include timbre (Geringer & Worthy, 1999; Russo & Thompson, 2005; Warrier & Zatorre, 2002) and musical context (Hagerman & Sundberg, 1980; Nickerson, 1949; Warrier & Zatorre, 2002). Without some sort of harmonic context or reference tone, perception and performance of intonation can be affected. It is extremely important to be aware of these facts when designing research, performing music, and teaching in the classroom.

Three mathematical tuning systems—Pythagorean tuning, equal temperament, and just intonation—are commonly used as models for comparison in the area of intonation performance research (Hagerman & Sundberg, 1980; Karrick, 1998; Leukel & Stoffer, 2004; Mason, 1960; Nickerson, 1949). Some researchers reported musicians performing closest to equal temperament and furthest from just intonation (Ballard, 2011; Karrick, 1998; Mason, 1960), while others found that performances were closest to Pythagorean tuning (Loosen, 1993; Nickerson, 1949). Still others found that intonation changed based on the music interval (Leukel & Stoffer, 2004) or the harmonic context (Hagerman & Sundberg, 1980). From a practical performance standpoint, deciding which tuning system to approximate is influenced by the style of music and the type of accompaniment (Alldahl, 2008). To implement these performance practices with their students and musicians, however, a teacher must be equipped with pedagogical approaches to teaching intonation.

Many different obstacles to good intonation have been identified by professional music educators, along with possible solutions to these obstacles. Issues with technique or production are commonly cited as having a negative influence on intonation (Doscher, 1991; Grant, 1987; Jordan, 1987; Powell, 1991; Skelton, 2005; Wine, 2004). Some authors have suggested strategies such as audiation for improving intonation (Dalby, 1992; Grant, 1987; Jordan, 1987). Many of the remedies recommended are difficult to test empirically, as there are too many variables for which to control. That is why it is important to conduct studies designed to evaluate tangible and practical pedagogical strategies, such as Alldahl's use of referential tones, as the current study sought to do.

CHAPTER THREE

Method

The purpose of this study was to evaluate how piano usage effects the intonation of vocal musicians—specifically, whether the use of a referential tone (RT) piano accompaniment, as advocated by Per-Gunnar Alldahl in his book *Choral Intonation*, encourages more accurate tuning than when the singers are accompanied by the piano doubling (PD) all of the voice parts. In order to evaluate this pedagogical approach, a stimulus melody representative of a 4-part chorale-like musical composition was developed using specific rules to target all diatonic pitches in the major scale set in appropriate diatonic functional harmonies. Carefully-determined criteria were also used in the targeted selection of appropriate participants. It was determined that a crossover design was the best way to evaluate the tuning accuracy of singers with regards to the PD and RT accompaniments, as it allows for the participants to serve as their own control, and is effective in cases of small sample sizes (Wellek & Blettner, 2012). Note that for the purposes of this study, the most desirable intonation is considered to be that which approximates just intonation when singing with the RT accompaniment, as advocated by Alldahl (2008) and Phillips (2012), and equal temperament when singing with the PD accompaniment, given that this is how the piano is tuned. In addition to just intonation and equal temperament, comparisons to the more melodic Pythagorean tuning were also included.

Independent Variables and Stimulus Melody

In order to test the effects of piano usage on intonation, two different accompaniment contexts were used as the independent variable for the current study: (1)

piano doubling (PD), in which participants performed along with a computer-generated piano recording playing a 4-part music composition that included the singer's melody line, and (2) referential tone (RT), in which the piano provided only foundational tones specifically selected to encourage the desired intonation performance.

The stimulus melody was created to simulate an authentic musical experience, while still enabling the tuning of specific pitches to be analyzed. The following criteria were used to guide development of the stimulus melody:

- The melody must be entirely stepwise in order to facilitate ease of sight-reading.
- The melody must not go beyond an octave in range so as to avoid any technique issues that may arise from the singers performing extreme vocal registers.
- The melody must be diatonic, not containing any accidentals outside of the specified key signature, thus ensuring simple, standard harmonic progressions.
- Target pitches must be preceded by the same note in order to give the participant additional time to listen and adjust their tuning, as well as to avoid any influence of direction of approach (e.g., ascending or descending lines).
- The pitches targeted for analysis must all be a half note in duration, which will give the singers enough time to accurately tune, as well as provide a sufficient length of tone to be analyzed.
- The melody must include target pitches with major 3^{rds} from the I, IV, and V chords, minor 3^{rds} from the iii and vi chords, and perfect 5^{ths} from the I, IV, and V chords. The minor 3rd from the ii chord was excluded due to that chord not conforming well to just intonation (see Barbour, 2004).

Using these criteria, I created the melody shown in Figure 3. The target pitches for analysis are indicated by a box around the notes.

Figure 3. Stimulus melody; boxes around notes indicate target pitches.

For the PD context, a simple, 4-part, hymn-like texture was adhered to in the creation of the accompaniment. In this context, all four parts were heard in the piano accompaniment, with the melody in the uppermost line (see Figure 4).

Introduction:

Sing top line:

Figure 4. Piano Doubling (PD) context in 4-part chorale style with 4-bar introduction.

A foundational line was created to serve as the experimental RT context, which was based on the guidelines set forth by Alldahl (2008). He recommend using the 1st, 5th, and 4th for the key of the piece whenever possible, while attempting to maintain the RT for as long as possible, moving by leaps of a 4th or 5th, and avoiding the use of a 3rd or 6th. Given the stimulus melody, it was necessary to use some stepwise motion in the accompaniment in order to achieve the desired vertical harmonies. It should also be noted that, while Alldahl illustrated the use of referential tones in a variety of octaves in relation to the vocal parts, playing an octave below the singers provides the benefit of having the piano overtones present in the same range as their vocal part. Although I would have preferred to provide referential tones an octave below the stimulus melody, it proved impractical for the tenor and bass arrangements due to the extremely low range. Thus, to maintain consistency for all voice parts, I decided to place the referential tones in the same octave as the vocal parts. In the RT condition, only the referential tones were heard by the participants while they sang the melody, as illustrated in Figure 5. For both the PD and RT contexts, a 4-bar introduction was played, from which the singers obtained the starting pitch.

Figure 5. Referential Tone (RT) context with 4-bar introduction.

The key of D Major was chosen for sopranos and tenors, because the stimulus melody should fall comfortably in their vocal ranges without reaching into extreme ranges or going through major register shifts that might affect intonation due to technical reasons. For the same reasons, the stimuli were presented to altos and basses in the key of B-flat Major. To view full scores, see Appendix B.

Finale 2014 music notation software, using the Garritan Instruments for Finale sampled Steinway piano sound and standard human playback, was used to create the piano accompaniment for the two contexts (PD and RT). Audio files were exported from Finale, then edited in Reaper, v. 5.50c, a digital audio workstation, through which the recordings were normalized to ensure proper and consistent volume between recordings of the two contexts. A second independent variable, harmonic context, is present due to

the use of an authentic musical example, as opposed to intervals in isolated (non-musical) contexts. The target intervals were embedded within the various chords that comprised the functional harmonic structure of the musical example. Because both major 3rds and perfect 5ths were performed within I, IV, and V chords, and minor 3rds were performed within iii and vi chords (see Figure 3), including harmonic context as an independent variable allows for comparison of intonation performances between the different chords within which the target intervals were performed.

Dependent Variables

Where accompaniment type (PD and RT) served as the independent variable, the vocal performance of the participants served as the dependent variable. Recordings of the vocal performances were made, from which the frequencies of the target pitches (see Figure 3) were analyzed to assess whether the intonation of the participants was different between the two different accompaniment contexts.

Subsequent comparisons to just intonation, equal temperament, and Pythagorean tuning could then be made in order to determine whether intonation performance was more closely aligned to any of the tuning systems under either of the context conditions. The purpose for this comparison is twofold. There is a historical precedent in that musical performances have often been compared to these three tuning systems in intonation research (Ballard, 2011; Hagerman & Sundberg, 1980; Karrick, 1998; Kopiez, 2003; Leukel and Stoffer, 2004; Loosen, 1993; Mason, 1960). And, more importantly, these are the tuning systems thoroughly discussed by Alldahl (2008), for which he provided both sound reasoning for using each tuning system depending on the musical situation, as well as pedagogical approaches for reinforcing their use.

Research Design

Participants were asked to sing a melody specifically composed for this study; once in the PD context and again in the RT context. The study was performed under the assumption that using the piano to double the vocal parts of singers is a fairly common practice in the choral rehearsal setting. Therefore, the PD context was designed as an authentic control, serving as a point of reference to the experimental RT context. A crossover design was used to compare the effect the two contexts had on the tuning accuracy of the singers. In a crossover design, participants cross from one treatment period (or, in this case, context) to another, as illustrated in Figure 6.

Figure 6. Visual representation of research design.

There are two aspects of the crossover design that made it particularly suitable for the present study, which Wellek & Blettner (2012) summarized clearly:

The essential feature distinguishing a crossover trial from a conventional parallel-group trial is that each proband or patient serves as his/her own control. . . .

Moreover, the crossover design is advantageous regarding the power of the statistical test carried out to confirm the existence of a treatment effect:

Crossover trials require lower sample sizes than parallel-group trials to meet the same criteria in terms of type I and type II error risks. (p. 276)

Because the current study examined the effect piano accompaniment had on the tuning accuracy of singers, it was logical to have the participants serve as their own control. To

control for possible order effects, participants were randomly assigned to one of two sequences, with half of the participants presented with the PD context first, followed by the RT context, and the other half presented with RT, then PD.

One of the difficulties with crossover design studies is the need for participants to complete a second trial without possible interference from the initial experience. For the purposes of this study, I decided to have participants listen to a 1.5-minute excerpt from a recording of Arnold Schönberg's String Quartet No. 3 to serve as a washout period/palate cleanser. Given that it is a 12-tone composition, the lack of functional harmony and tonal center should washout any residual pitch memory the participant may develop while singing the stimulus melody in the initial context, thus enabling an uninfluenced performance in the second context. Duke (1985) and Edmonson (1972) used 15-second and 30-second excerpts of recorded orchestral music, respectively, to serve the same function between participants' performances of selected intervals. Given that their participants were performing several intervals in succession, shorter excerpts were effective. Because participants in the present study were performing a longer melody, I reasoned that a longer excerpt was warranted, the length of which was explored in a pilot study, which will be addressed later in this chapter. To serve as a further distraction, participants completed a music-themed word search (see Appendix H) during this washout period.

Participants

Undergraduate students in auditioned choral ensembles with at least 3 years of ensemble singing experience served as participants. Ensemble experience was favored over private lesson experience based on my belief that ensemble experience would

provide more practice opportunities in tuning outside of the confines of equal temperament (private lesson students generally perform with piano). Singers with absolute pitch, or perfect pitch, were excluded from the study, because this particular skill may influence their performance with regards to tuning. Participants were recruited from three different auditioned choral ensembles, two of which were from a large Midwestern university and one from a small Midwestern university. These participant criteria were decided upon because previous research has shown that level of experience has an influence on intonation performance (Yarbrough et al., 1995; Fyk, 1982; Peterson & Smith, 1930; Madsen et al., 1969). The 39 volunteers from these ensembles easily met the selection criteria, with the average number of semesters participating in an ensemble being 11.71 semesters ($SD = 3.83$). An exception was made for one participant who only had 1 year of ensemble singing experience, because the participant was a music major with 5 years of private vocal instruction.

To recruit the participants, I addressed the singers during a regular rehearsal session in three different collegiate-level auditioned choral ensembles, reading from a prepared recruitment script that detailed the information provided in the informed consent form, both of which were approved by the Institutional Review Board (see Appendix D and Appendix E). During the recruitment address, it was verbally indicated that graduate students and singers with perfect pitch need not fill out the questionnaires or sign up for recording session times. Potential participants were encouraged to read the informed consent form and to ask any clarifying questions. If the singers consented to participate in the study, they were asked to indicate their intent to participate by filling out a brief questionnaire, which, in addition to confirming that they did not have perfect pitch, asked

questions about gender, age, year in school, major, voice part, and number of semesters of choral ensemble participation and private voice lessons (see Appendix A). They could either sign up for a recording session time, or simply attend one of the designated open recording session times.

Of the 39 volunteers who completed the recordings, five showed extreme difficulty in completing the task. Because of their inability to accurately sing the pitches indicated in the written music, I ultimately excluded them from inclusion in the study, leaving a sample size of 34 participants: 9 sopranos, 9 altos, 7 tenors and 9 basses. . Music majors comprised 82.4% of the sample population. The mean age was 20.47 years old ($SD = 1.71$). The mean number of semesters of private voice lessons was 7.09 ($SD = 3.97$).

To control for possible order effects, half of the participants were presented with the sequence PD first, then RT, with the other half being administered the RT followed by the PD. The procedure for assigning presentation order will be described in detail in the Procedures section of this chapter.

Procedure

Participants individually attended recording sessions that I facilitated. Prior to beginning, I asked each singer verbally whether he/she still consented to participate in the study (for full recording session script see Appendix F). At this time the participant's completed questionnaire, which had been filled out during the recruitment session, was checked to verify that the participant did not have perfect pitch, thus indicating eligibility to participate in the study.

First, the participants were asked to sing a brief accompanied melody as a sound check, during which they would be able to hear both their own voice, as well as a recorded piano accompaniment, through the headphones. The first half of the accompaniment was similar to the PD context and the second half similar to the RT context (see Figure 7). This task was completed as many times as needed in order to set a comfortable volume level and balance between voice and piano accompaniment.

The musical score is written in D major (two sharps) and 4/4 time. It consists of three systems of music. The first system, labeled "Introduction:", shows a piano accompaniment with chords in the right hand and single notes in the left hand. The second system, labeled "Sing top line:", shows a vocal line in the right hand with chords in the left hand. The third system shows a piano accompaniment with a single melodic line in the right hand and a bass line in the left hand.

Figure 7. Calibration exercise used as sound check.

Once the calibration task was complete, the singers moved on to the experimental portion of the recording session. Participants were randomly assigned to one of two sequences, either PD-RT or RT-PD, based on voice part (soprano, alto, tenor, bass) and the order in which they attended the recording sessions, so that the number in each subgroup would be as equal as possible. Prior to beginning data collection, four slips of

paper, two with PD-RT and two with RT-PD written on them, were placed into a small cloth bag. The slips were drawn at random when the first person from each respective voice part came to their recording session. Once the starting sequence was established for each voice part, participants were administered the sequences in an alternating pattern, so as to attain a well-balanced data set. That process, plus the fact that the singers had signed up or showed up for recording session times as available, resulted in sufficient randomization.

After being given an opportunity to study the music to be sung prior to performance, the participants sang through the melody twice in each context. The first time through gave the participants a chance to practice and assess their tuning accuracy before making the recording used for the study. The second performance of each context was recorded and retained for analysis. Between the performances of the stimulus melody in the different contexts, participants listened to the Schönberg excerpt and worked on the word search puzzle that served as the aural and mental washout period.

For both the sound check and the PD and RT contexts, singers were asked to sing using the syllable [ti] (with the “i” pronounced like a long “ee”). I decided to use this syllable after consulting with a professional choral/vocal pedagogue. There were concerns regarding the [a] and [u] vowels because a great deal of variation exists between singers, an observation supported in a study by Bloothoof and Plomp (1984), which showed that [u] had the greatest amount of variance between different singers. The [i] vowel serves best for empirical research on tuning because, as the aforementioned study showed, the [i] vowel was among the vowel sounds with the least amount of variation, both overall and of the frontal vowels, which helps to control for extraneous variables

related to the variation in vowel production of the participants. Using the [t] consonant encouraged healthy airflow while maintaining consistent resonance, and provided a strong attack for the participants, thus assisting with their rhythmic accuracy. An added benefit of this consonant was that, when analyzing the vocal performances, it visually helped to delineate between pitches in the spectrograph, making it easier to identify the target pitches.

Data Collection and Analysis

Recording sessions took place in venues of convenience in which singers would be accustomed to performing, including small classrooms, a small performance hall, and a voice studio. While it would have been ideal to have more consistency in terms of facilities used, this was made difficult due to class schedules and room availability. It did not, however, appear to bother the singers, and the quality of the performances and recordings were all sufficient for analysis.

For the recordings, a Zoom H2n Handy Recorder was used because of its functionality as a USB audio interface with zero-latency direct monitoring, which allowed the singers to hear themselves in real time, as well as its ease of portability. Two sets of Seinheiser HD 280 Pro Headphones connected to the 1/8-inch headphone output jack on the Zoom H2n were used for monitoring, which, because of the over-ear, closed-back design, helps limit any sound generated through the headphones from being picked up by the microphone. The output was split so that a second pair of Seinheiser HD 280 Pro Headphones could be used by the researcher to monitor the recording. The Zoom H2n was connected to the micro USB port of a Samsung Galaxy Tab A 9.7 tablet running an Android 6.0.1 operating system. Audio Evolution Mobile Studio version 4.5.8 was the

digital audio workstation (DAW) used to send the piano accompaniment signal to the singer while recording the performance via the built-in microphone on the Zoom H2n. This setup was advantageous, as it was compact and highly portable, making setup and teardown very efficient.

Once the recordings had been made, solo audio files were analyzed using Praat version 6.0.40 (Boersma & Weenink, 2018), a phonetics analysis software program that, among many other things, is able to analyze the mean pitch, in Hertz (Hz), of a selected duration of audio. Similar to the method Ballard (2011) used, onsets and offsets were omitted and, in cases where the participant made a tuning adjustment following onset, the latter portion of the sample was analyzed. This was done by using a simple visual appraisal of the pitch consistency. An average frequency, in Hertz (Hz) for each target pitch was determined, then compared to the frequency of the tonic pitch of the chord for the purposes of obtaining the interval data, which was ultimately converted to cents using the formula $c = 1200 \times \log_2 (f_2 / f_1)$ (for further explanation, see Helmholtz, 1885 or Patel, 2010). When considering pitch in terms of frequency, one can get a precise measurement of the cycles per second of the fundamental frequency (e.g., A = 440 Hz), but the difference in Hz from A1 to A2 is not the same as that of A5 to A6. This is because pitch height increases exponentially. If A4 = 440 Hz, then A5 = 880, and A6 = 1760. This 2:1 ratio holds true for all octaves. The difficulty in working with frequencies from a statistical standpoint is that the distance between any two given pitches is not equidistant. The logarithmic conversion yields continuous data, which is much more conducive to statistical analysis (see Figure 8 and Figure 9 for a comparison of Hz and cents). Therefore, the data points used for statistical analysis were the cents obtained from the

conversion of the average Hz of the target pitches. Using cents allowed for easy understanding of descriptive statistics, including the mean, standard deviation, and graphical representation of the 95% confidence intervals, as well as the comparison of means from both contexts.

Figure 8. Line graph of the frequencies of each octave of A on the piano.

Figure 9. Line graph of the cents between each octave of A on the piano.

Pilot Study Procedure and Modifications to the Study

Prior to gathering data, I conducted a pilot study, the primary purpose of which was to ensure that all planned procedures were operating optimally. Four participants, one from each voice part (soprano, alto, tenor, bass) were recruited to participate. Two of the four participants held music degrees. All participants actively sang regularly in music ensembles at the time that the pilot study was conducted, and had extensive ensemble experience in school ($M = 11.2$ semesters, $SD = 7.37$). Following the recording sessions, the participants were asked to fill out an additional questionnaire (see Appendix G) designed to gauge the clarity of the instructions, the volume levels in the headphones, the participant's general comfort level during the procedure, the ease of singing the stimulus

melody in their vocal range, and the perceived effectiveness of the washout/palate cleanser length, as well as seek any specific feedback regarding how any part of the process might be improved. It should be noted that questions pertaining to the vocal range of the stimulus melody and the length of the washout activity were asked verbally, while the other questions were addressed on the questionnaire.

All pilot study participants indicated that the instructions were clear, that they were able to set the volume levels in the headphones to a comfortable listening level that allowed them to focus on tuning accurately with the piano recording, and that they were comfortable with everything that they were asked to do. All singers felt that the range of the stimulus melody, specific to their voice part, fit comfortably in their vocal ranges. One participant recommended that the instructions could be clarified by separating out the instructions for the washout activity from the instructions for the recording session. As a result, instructions regarding the washout activity were supplied immediately before its occurrence.

When asked about the length of the washout activity, the two participants who were administered the 2-minute string quartet excerpt indicated that they felt the length was effective for eliminating tonal memory, effectively cleansing their palate prior to the second period. For the participants who were administered the 1-minute excerpt, one indicated that the length was sufficient, while the other thought that the excerpt could have been a bit longer. I decided to split the difference, making the excerpt 1.5-minutes for the final experiment, which worked well as there was a cadential point at that mark in the music.

The procedure was very similar to the one used in the main study with some slight variations. One such variation pertains to how the headphones were used. The first three participants had the headphones completely covering both ears, relying solely on the zero-latency headphone monitoring to hear themselves. Feedback from these three participants indicated that, while singing in this manner was not something with which they were familiar, they found no difficulty in successfully completing the task. The fourth participant had more experience with recording sessions and, following the procedure, discussed alternative headphone usage. Specifically, flipping one of the ear pads out so as to facilitate hearing one's self in the room. This modification was tried with the participant, but the playback of the piano accompaniment was picked up by the microphone, making analysis of the fundamental frequency less reliable. Also, the ability to hear the accompaniment in stereo was lost, which was not ideal. A compromise was attempted in which the participant pushed one of the ear pads back and slightly off of the ear, facilitating the ability to still hear the accompaniment in stereo, while at the same time being able to hear one's self more naturally in the room. We decided that this would yield the most authentic experience for participants. A side effect of this alteration was that the volume of the piano recordings was perceived as lower when both ears were not fully covered by the headphones. To correct for this, the recordings were normalized and the amplitudes adjusted so that the perceived volume was greater. Participants could then adjust the volume of the piano recording to a more comfortable accompaniment level.

CHAPTER FOUR

Results

The present study was designed to assess the effects of different piano accompaniments on the tuning performance of college-level choral musicians. This chapter includes the analysis of data collected, the purpose of which was to address the following research questions:

3. Does the use of different piano accompaniment styles—specifically the piano doubling (PD) the singers or the piano being used to provide referential tones (RT) as a tuning reference—have an effect singers’ intonation performance in standard diatonic harmonic contexts?
 - a. Are there affects attributable to the interval being performed in reference to the tonic pitch of the chord (unison, major 3rd, minor 3rd, and perfect 5th)?
 - b. Are there affects attributable to harmonic context (the chord function on which the music intervals are performed)?
4. How does the intonation performance of singers compare to the just intonation, equal temperament, and Pythagorean tuning systems?

Based on the research questions, the following null hypotheses were tested:

- There will be no significant differences between PD and RT accompaniments on singers’ intonation performance of unisons, major 3rds, minor 3rds, or perfect 5ths.
- There will be no significant differences in intonation performance between harmonic contexts.

- There will be no significant interactions in intonation between accompaniment type and harmonic context.
- There will be no significant cent deviations from just intonation, equal temperament, or Pythagorean tuning in the singers' performances of the reference pitches.

In addition, because sequence of treatments was included in the design as a control variable, the following null hypothesis was tested:

- There will be no significant effects attributable to accompaniment sequence on intonation responses.

In order to address the first research question, a two-factor Repeated Measures Analysis of Variance (RM-ANOVA) was performed for each of the targeted music intervals, in which piano accompaniment type (PD and RT) and harmonic context served as the within-subjects factors. The dependent variables were the performances of the targeted pitch intervals (in cents). It should be noted that, in the case of the performance of the root of the I chord, accompaniment was the sole factor used, because the singer was singing in unison with the stimulus pitch.

Because a crossover design was used for this study, sequence (PD-RT and RT-PD) was used as the between-subjects factor in order to test for any carryover effect (Dallal, 2012). As will be seen in the RM-ANOVA tables throughout this chapter, no statistically significant interaction between accompaniment type and sequence was found in any of the music interval conditions ($p > .05$), which indicated that no carryover effect was present.

The results are presented in separate sections, arranged by targeted music interval. For ease of reference, Table 4.1 provides a summary of the means and standard deviations (in cents) for the intonation performance of each targeted music interval in the harmonic context in which each was performed. These were calculated using the fundamental frequency of the root of each chord as the starting point for each interval. Means and standard deviations are given separately for the piano doubling and referential tone accompaniment types, allowing for a side-by-side comparison. Mathematical tuning system interval values (in cents) for just intonation, equal temperament, and Pythagorean tuning are also included in Table 1 for reference.

Table 1

Tuning System Reference with Means and Standard Deviations of Intonation Performances (in cents) of Music Intervals in Harmonic Contexts by Piano Doubling and Referential Tone Accompaniment Types.

Music Interval and Harmonic Context	Tuning System Reference (cents)			Piano Doubling		Referential Tone	
	JI	ET	PT	Mean	SD	Mean	SD
Unison (Root of I)	0	0	0	-.24	11.59	-4.23	7.15
Major 3rd of I	386	400	408	385.73	14.82	388.35	12.16
Major 3rd of IV	386	400	408	390.42	14.78	389.71	13.52
Major 3rd of V	386	400	408	403.91	14.17	412.43	17.48
Minor 3rd of iii	316	300	294	296.95	14.94	298.85	14.91
Minor 3rd of vi	316	300	294	304.99	15.27	310.54	19.55
Perfect 5th of I	702	700	702	689.32	13.11	691.15	10.64
Perfect 5th of IV	702	700	702	700.21	11.85	706.04	14.93
Perfect 5th of V	702	700	702	698.01	13.24	697.95	11.94

When interpreting results of intonation performance, discrepancies may occasionally arise between what may be statistically significant versus what is musically important. For this study, I decided to designate any intonation performance within 6 cents of a comparison point, either alternate piano accompaniments or targeted tuning

system, as being *in tune*. This window was selected based on prior intonation research, particularly with regard to just noticeable difference (JND), range of acceptable tuning (RAT), and comparison to tuning systems. Discrimination of JND of tuning for musicians has been reported as most accurate between 2-10 cents (Madsen et al., 1969), and RAT was found to be within a tolerance zone ranging from 6-20 cents (Fyk, 1982). Karrick (1998) also designated intonation performances within 6 cents of a target as an *in tune* performance.

Unison

Results of a RM-ANOVA, found in Table 2, indicate that piano accompaniment type had a statistically significant effect on the intonation performance of the unison interval that is formed by performing the root of the I chord, $F(1, 32) = 4.20, p = .05, \eta^2 = .12$. The mean performance in the PD context was more accurate ($M = -.24, SD = 11.59$) than in the RT context ($M = -4.23, SD = 7.15$).

Table 2

Repeated Measures Analysis of Variance of Intonation Performance of the Unison Interval with the Root of the I Chord by Accompaniment Type

Source	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>p</i>	η^2
Accompaniment Type	1	270.55	270.55	4.20	.05*	.12
Accompaniment*Sequence	1	51.09	51.09	.79	.38	.02
Error	32	2061.97	64.44			

* $p \leq .05$

This is illustrated in Figure 10. The 4-cent difference between these two means, while statistically significant, was small. Even though this fits within my operational definition of *in tune*, the statistical decision is to reject the null hypothesis that there will be no

significant difference in singers' intonation performance given different piano accompaniment types for the unison pitch.

Figure 10. Mean intonation performance of unison with the root of the I chord in PD and RT contexts (95% confidence intervals) with horizontal reference line indicating the just intonation (JI), equal temperament (ET), and Pythagorean tuning (PT) systems.

Major 3rd

For major 3rds performed in the I, IV, and V chords, a statistically significant interaction was found between accompaniment type and harmonic context, $F(2, 64) = 3.77, p = .03, \eta^2 = .11$. Significant main effects were found for both accompaniment, $F(1, 32) = 5.05, p = .03, \eta^2 = .14$, and harmonic context, $F(2, 64) = 35.52, p < .001, \eta^2 = .53$. The results of this RM-ANOVA can be seen in Table 3. Because there was a significant interaction between accompaniment type and harmonic context, and significant main effects were observed for both, *post hoc* analyses using the Bonferroni adjustment were completed in order to observe the simple effects.

Table 3

Repeated Measures Analysis of Variance of Intonation Performance of the Major 3rd Interval in Various Harmonic Contexts by Accompaniment Type

Source	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>p</i>	η^2
Accompaniment Type	1	616.24	616.24	5.05	.03*	.14
Accompaniment*Sequence	1	179.23	179.23	1.47	.23	.04
Error	32	3902.75	121.96			
Harmonic Context	2	17752.82	8876.41	35.52	<.001*	.53
Harmonic Context*Sequence	2	335.84	167.92	.67	.51	.02
Error	64	15992.44	249.88			
Accompaniment*Harmonic Context	2	742.85	371.43	3.77	.03*	.11
Accompaniment*Harmonic Context*Sequence	2	37.65	18.83	.19	.83	.01
Error	64	6307.89	98.56			

* $p \leq .05$

While the effect of accompaniment type was not found to be significantly different for mean intonation performances of major 3rds in either the I or IV chords ($p > .05$), there was a significant difference observed for the V chord ($p = .01$). In the PD context, the mean performance was 403.91 cents ($SD = 14.17$), while mean performance in the RT context was 412.43 cents ($SD = 17.48$), significantly higher than the PD context. Therefore, the null hypothesis is rejected only for intonation performance of the major 3rd in the V chord. The differences in intonation performances of all major 3rds is illustrated in Figure 11, which allows for both the comparison of PD and RT accompaniments in each of the three harmonic contexts.

Figure 11. Mean intonation performances of major 3rds in the I, IV, and V chords in PD and RT contexts (95% confidence intervals) with horizontal reference lines indicating the just intonation (JI), equal temperament (ET), and Pythagorean tuning (PT) systems.

From the perspective of harmonic context, while there were no significant differences found between the mean intonation performance of major 3rds in the I and IV chords in either accompaniment type ($p > .05$), there was a significant difference between intonation performances between the I chord and the V chord in both the PD context ($p < .001$) and the RT context ($p < .001$), and between the IV chord and the V chord in the PD context ($p < .001$) and the RT context ($p < .001$). Mean intonation performance of major 3rds in the V chord was 403.91 cents ($SD = 14.17$) for the PD context and 412.43 cents ($SD = 17.48$) for the RT context, significantly higher when compared to performance on the I chord in the PD context ($M = 385.73$ cents, $SD = 14.82$) and the RT context ($M = 388.35$, $SD = 12.16$), and the IV chord in the PD context ($M = 390.42$, $SD = 14.78$) and the RT context ($M = 389.71$, $SD = 13.52$), all of which is again illustrated in the aforementioned Figure 4.2. Therefore, the null hypotheses for both harmonic context and its interaction with accompaniment type were rejected. Intonation performance of major 3rds was affected by accompaniment type in certain harmonic contexts.

Minor 3rd

For minor 3rds performed in the iii and vi chords, no significant main effect for accompaniment type was observed ($p > .05$), nor was there a significant interaction between accompaniment type and harmonic context ($p > .05$). There was, however, a significant main effect observed for harmonic context, $F(1, 32) = 8.69, p = .01, \eta^2 = .21$. The results of the RM-ANOVA can be seen in Table 4.

Table 4

Repeated Measures Analysis of Variance of Intonation Performance of the Minor 3rd Interval in Various Harmonic Contexts by Accompaniment Type

Source	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>p</i>	η^2
Accompaniment Type	1	473.42	473.42	3.08	.09	.09
Accompaniment*Sequence	1	105.06	105.06	.68	.42	.02
Error	32	4925.72	153.93			
Harmonic Context	1	3309.28	3309.28	8.69	.01*	.21
Harmonic Context*Sequence	1	331.50	331.50	.87	.36	.03
Error	32	12185.93	380.81			
Accompaniment*Harmonic Context	1	113.19	113.19	1.31	.26	.04
Accompaniment*Harmonic Context*Sequence	1	60.17	60.17	.70	.41	.02
Error	32	2767.08	86.47			

* $p \leq .05$

Because there was a significant main effect for harmonic context, *post hoc* analyses using the Bonferroni adjustment were performed. With no significant main effect for accompaniment type, data from the PD and RT contexts were collapsed for the iii and vi chords, respectively, for the purposes of exploring the main effect of harmonic context. The mean intonation performance of minor 3rds for the iii chord was 297.90 cents ($SD = 12.84$), significantly lower than when performed in the vi chord ($M = 307.77$,

$SD = 15.70$). Thus, the null hypothesis that harmonic context does not affect intonation performance was rejected. For minor 3rds, intonation performance was significantly different, as illustrated in Figure 12.

Figure 12. Mean intonation performances of minor 3rds in the iii and vi chords (95% confidence intervals) with horizontal reference lines indicating the just intonation (JI), equal temperament (ET), and Pythagorean tuning (PT) systems.

Perfect 5th

For perfect 5ths performed in the I, IV and V chords, there was no significant main effect for accompaniment type was observed ($p > .05$), nor was there a significant interaction found between accompaniment type and harmonic context. There was, however, a significant main effect of harmonic context, $F(1, 32) = 17.85, p < .001, \eta^2 = .36$. Results of the RM-ANOVA are shown in Table 5.

Table 5

Repeated Measures Analysis of Variance of Intonation Performance of the Perfect 5th Interval in Various Harmonic Contexts by Accompaniment Type

Source	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>p</i>	η^2
Accompaniment Type	1	327.24	327.24	2.33	.14	.07
Accompaniment*Sequence	1	422.28	422.28	3.01	.09	.09
Error	32	4486.01	140.19			
Harmonic Context	2	5724.33	2862.17	17.85	<.001*	.36
Harmonic Context*Sequence	2	152.08	76.04	.47	.63	.02
Error	64	10262.19	160.35			
Accompaniment*Harmonic Context	2	307.04	153.52	2.10	.13	.06
Accompaniment*Harmonic Context*Sequence	2	58.84	29.42	.40	.67	.01
Error	64	4683.61	73.18			

* $p \leq .05$

Post hoc analyses using the Bonferroni adjustment were performed to examine the significant main effect for harmonic context. With no significant main effect for accompaniment type, data from the PD and RT contexts were collapsed for the I, IV and V chords, respectively, for the purposes of exploring the main effect of harmonic context. The mean intonation performances in each harmonic context were all statistically significantly different from one another. Mean performance of the perfect 5th in the I chord was 690.23 cents ($SD = 10.43$), significantly lower than performance in both the IV chord ($M = 703.12$ cents, $SD = 10.83$, $p < .001$) and the V chord ($M = 697.98$ cents, $SD = 10.53$, $p = .002$). Performances between the IV and V chords were also significantly different ($p = .02$), although the performances were only 5 cents apart. Overall, the null hypothesis regarding harmonic context was rejected. Intonation performances of perfect

5ths differed from one another based on harmonic context. Figure 13 illustrates these findings.

Figure 13. Mean intonation performances of major 3rds in the I, IV, and V chords (95% confidence intervals) with horizontal reference lines indicating the just intonation (JI), equal temperament (ET), and Pythagorean tuning (PT) systems.

Comparison to Tuning Systems

In order to ascertain the results of the second research question, pertaining to how the intonation performance of the aforementioned music intervals compares to the just intonation, equal temperament, and Pythagorean tuning systems, one-sample *t*-tests were used. Means were compared to determine whether directional cent deviation of each performed pitch was significantly different from the target pitch for each tuning system. The results of these analyses are summarized in Table 6. Due to the multiple comparisons, a more conservative alpha level of .01 was used in an effort to avoid Type I statistical errors. Because the main effect of accompaniment type was statistically insignificant for the majority of performed music intervals, I decided to collapse the PD and RT contexts for the purpose of the tuning system comparisons. Intonation performance of the unison, as well as the major 3rds in the V chord, in both the PD and

Table 6

t-Tests for Deviation from Tuning Systems by Interval in Harmonic Context.

		Test Value = 0					
Interval	Tuning System	<i>t</i>	<i>df</i>	<i>p</i>	Mean Cent Difference	95% Confidence Interval	
						Lower Limit	Upper Limit
Unison (Root of I)	Just Intonation	-1.67	33	.10	-2.23	-4.95	.49
	Equal Temperament	-1.67	33	.10	-2.23	-4.95	.49
	Pythagorean Tuning	-1.67	33	.10	-2.23	-4.95	.49
Major 3rd of I	Just Intonation	.52	33	.61	1.04	-3.02	5.10
	Equal Temperament	-6.49	33	<.001*	-12.96	-17.02	-8.90
	Pythagorean Tuning	-10.50	33	<.001*	-20.96	-25.02	-16.90
Major 3rd of IV	Just Intonation	1.80	33	.08	4.06	-.54	8.67
	Equal Temperament	-4.39	33	<.001*	-9.94	-14.54	-5.33
	Pythagorean Tuning	-7.92	33	<.001*	-17.94	-22.54	-13.33
Major 3rd of V	Just Intonation	9.92	33	<.001*	22.17	17.62	26.71
	Equal Temperament	3.66	33	.001*	8.17	3.62	12.71
	Pythagorean Tuning	.08	33	.94	.17	-4.38	4.71
Minor 3rd of iii	Just Intonation	-8.22	33	<.001*	-18.10	-22.58	-13.62
	Equal Temperament	-.95	33	.35	-2.10	-6.58	2.38
	Pythagorean Tuning	1.77	33	.09	3.90	-.58	8.38
Minor 3rd of vi	Just Intonation	-3.06	33	.004*	-8.23	-13.71	-2.75
	Equal Temperament	2.88	33	.01	7.77	2.29	13.25
	Pythagorean Tuning	5.11	33	<.001*	13.77	8.29	19.25
Perfect 5th of I	Just Intonation	-6.58	33	<.001*	-11.77	-15.41	-8.13
	Equal Temperament	-5.46	33	<.001*	-9.77	-13.41	-6.13
	Pythagorean Tuning	-6.58	33	<.001*	-11.77	-15.41	-8.13
Perfect 5th of IV	Just Intonation	.60	33	.55	1.12	-2.66	4.90
	Equal Temperament	1.68	33	.10	3.12	-.66	6.90
	Pythagorean Tuning	.60	33	.55	1.12	-2.66	4.90
Perfect 5th of V	Just Intonation	-2.23	33	.03	-4.02	-7.69	-.35
	Equal Temperament	-1.12	33	.27	-2.02	-5.69	1.65
	Pythagorean Tuning	-2.23	33	.03	-4.02	-7.69	-.35

* $p \leq .01$

RT contexts were analyzed separately, however, because there were significant differences attributable to accompaniment found for these intervals.

The directional cent deviation from the just intonation, equal temperament, and Pythagorean tuning systems is illustrated in Figure 14. For the unison on the root of the I chord, intonation performance was not significantly different from any of the three tuning systems ($M = -2.23$ cents, $p > .01$). It should be noted that all of the mathematical tuning systems have the same starting point.

Figure 14. Directional cent deviation from just intonation, equal temperament, and Pythagorean tuning systems for performed music intervals in each harmonic context (*denotes significant difference from tuning system).

Intonation performance of major 3rds in the context of the I and IV chords conformed most closely to just intonation. However, intonation performances significantly deviated from both equal temperament and Pythagorean tuning ($p < .001$). Results differed for performances of the major 3rd in the V chord. In this harmonic

context, the tuning conformed most closely to Pythagorean tuning, deviating significantly from just intonation ($p < .001$) and equal temperament ($p = .001$).

A difference between harmonic contexts was also observed between intonation performances of minor 3rds. The minor 3rd in the iii chord conformed most closely to equal temperament ($M = -2.10$ cents), followed by Pythagorean tuning ($M = 3.90$ cents). But intonation performance was significantly different from just intonation ($M = -18.10$ cents, $p = .00$), and so the null hypothesis was rejected. For intonation performance of minor 3rds on the vi chord, the null hypotheses were rejected for all tuning systems. Mean intonation performance deviated significantly from just intonation ($M = -8.23$, $p = .004$), equal temperament ($M = 7.77$, $p = .01$), and Pythagorean tuning ($M = 13.77$, $p < .001$).

For the perfect 5th intervals, in the context of the IV chord the mean intonation performance was slightly sharp, but conformed equally well to all of the tuning systems ($p > .01$), thus failing to reject the null hypotheses. Similar results were observed for performances on the V chord, with no significant difference from any of the tuning systems ($p > .01$), although the mean intonation performance was slightly flat. Performances on the I chord, however, yielded very different results. The null hypotheses was rejected for all tuning systems in this harmonic context ($p < .001$), with all performances significantly flat, deviating from equal temperament by -9.77 cents and from just intonation and Pythagorean tuning by -11.77 cents.

Because the mean intonation performance of unison with the root of the I chord and major 3rds in the V chord were the only contexts in which accompaniment type (PD or RT) had a statistically significant effect, it is important to highlight these intervals in

their original form prior to the collapsing of the data. One-sample *t*-tests were performed to determine whether directional cent deviation from each of the mathematical tuning systems was statistically significant for these intervals in both the PD and RT accompaniment contexts.

All of the mathematical tuning systems all have the same starting point. As such, the resulting *t*-tests of the deviation of performances of unison with the root of the I chord from each tuning system are identical within each accompaniment type. In the PD context, there is no significant difference from any of the tuning systems ($p > .01$). There was, however, a statistically significant difference from all of the tuning systems in the RT context ($p = .002$). Mean cent deviation from the root of the I chord was 4.28 cents in the flat direction. It should be noted that, while statistically significant, the mean intonation performance falls within the predetermined 6-cent threshold for in tune performance. The results of these *t*-tests are summarized in Table 7.

Table 7

t-Tests for Deviation from Tuning Systems for Unison with Root of I chord by Accompaniment Type.

		Test Value = 0					
Accompaniment	Tuning System	<i>t</i>	<i>df</i>	<i>p</i>	Mean Cent Difference	95% Confidence Interval	
						Lower Limit	Upper Limit
Piano Doubling (PD)	Just Intonation	-.12	33	.91	-.24	-4.28	3.81
	Equal Temperament	-.12	33	.91	-.24	-4.28	3.81
	Pythagorean Tuning	-.12	33	.91	-.24	-4.28	3.81
Referential Tone (RT)	Just Intonation	-3.45	33	.002*	-4.23	-6.72	-1.73
	Equal Temperament	-3.45	33	.002*	-4.23	-6.72	-1.73
	Pythagorean Tuning	-3.45	33	.002*	-4.23	-6.72	-1.73

* $p \leq .01$

For major 3rds on the V chord, intonation performance in the PD context did not deviate significantly from both equal temperament and Pythagorean tuning ($p > .01$), having been performed approximately 4 cents from each tuning system and falling equidistant between them. There was a significant and large deviation from just intonation, however ($M = 17.91$, $p < .001$). Alternatively, in the RT context, intonation performance conformed most closely to Pythagorean tuning ($p = .15$), overshooting it, in fact, by 4.43 cents. This indicates that the mean performances were significantly different from both equal temperament ($M = 12.43$, $p < .001$) and just intonation ($M = 26.43$, $p < .001$). The statistical analyses are summarized in Table 8, and the results are graphically illustrated in Figure 15.

Table 8

t-Tests for Deviation from Tuning Systems for Major 3rds in V Chord by Accompaniment Type.

		Test Value = 0					
Accompaniment	Tuning System	<i>t</i>	<i>df</i>	<i>p</i>	Mean Cent Difference	95% Confidence Interval	
						Lower Limit	Upper Limit
Piano Doubling (PD)	Just Intonation	7.37	33	<.001*	17.91	12.96	22.85
	Equal Temperament	1.61	33	.12	3.91	-1.04	8.85
	Pythagorean Tuning	-1.68	33	.10	-4.09	-9.04	.85
Referential Tone (RT)	Just Intonation	8.82	33	<.001*	26.43	20.33	32.52
	Equal Temperament	4.15	33	<.001*	12.43	6.33	18.52
	Pythagorean Tuning	1.48	33	.15	4.43	-1.67	10.52

* $p \leq .01$

Figure 15. Directional cent deviation from just intonation, equal temperament, and Pythagorean tuning systems for intonation performance of major 3rds on the V chord (*denotes significant difference from tuning system).

Summation

Accompaniment context (PD and RT) was not shown to have a significant effect on the intonation performance of singers, with the exception of the unison with the root of the I chord and the major 3rd performed in the V chord. It was instead the main effect of harmonic context that resulted in statistically significant findings for a majority of the performed intervals.

Because there was only one harmonic context for performances of unison with the root of the I chord, harmonic context was not included in the statistical analysis for that interval. The difference in mean intonation performance was statistically significant between the PD context (-.24 cents) and the RT context (-4.23 cents), thus the null

hypothesis was rejected. When comparing these performances to the just intonation, equal temperament, and Pythagorean tuning systems, intonation was not significantly different from any of the tuning systems in the PD context, but was significantly different from all of the tuning systems in the RT context. It should be noted, however, that these intonation performances fall within the determined 6-cent threshold for being considered in tune from a practical musical perspective.

For intonation performance of major 3rds, there was a significant interaction between accompaniment type and harmonic context. After examining the simple effects, this interaction was traced back to major 3rds in the V chord. While intonation was not significantly different for performances in the I and IV chord harmonic contexts, intonation performances in both of these chords were significantly different from those in the V chord. The same held true for accompaniment type, with no significant differences when the major 3rd was sung in the I and IV chords, yet a significant difference observed in the V chord. For major 3rds in the V chord in the PD context, mean intonation performance was 403.91 cents, which was not significantly different from equal temperament, yet deviated significantly from both Pythagorean tuning and just intonation. In the RT context, however, mean intonation performance was an additional 8.52 cents in the sharp direction, totalling 412.43 cents. Performance in this accompaniment context was not significantly different from Pythagorean tuning, but did deviate significantly from both equal temperament and just intonation, exceeding both in the sharp direction by 12.43 cents and 26.43 cents, respectively.

Intonation performance of minor 3rds was significantly different given different harmonic contexts. Mean intonation performance in the iii chord was 297.90 cents,

which was not significantly different from both equal temperament and Pythagorean tuning. It was, however, significantly sharp when compared to just intonation. Mean intonation performance in the vi chord was significantly higher (307.77 cents) than performances in the iii chord, as well as significantly different from all mathematical tuning systems, falling equidistant between equal temperament and just intonation, while being farthest from Pythagorean tuning.

A significant difference between different harmonic contexts was also observed for intonation of perfect 5ths. Intonation performance was not significantly different from any of the tuning systems for performances on the IV and V chords. Intonation performance on the IV chord was closest to just intonation and Pythagorean tuning (703.12 cents), and intonation performance on the V chord was closest to equal temperament (697.98 cents). Intonation performance on the I chord, however, was significantly flat (690.23 cents) when compared to all of the mathematical tuning systems. All of these results are thoroughly discussed in the following chapter.

CHAPTER FIVE

Discussion

The primary research question that guided the present study pertained to whether different piano accompaniments would have an effect on the intonation performance of college-level choral musicians. The specific accompaniment strategies of interest included the piano doubling (PD) all voice parts, versus the use of referential tones (RT) as advocated for by Alldahl (2008). Intonation was assessed by having participants sing a researcher-designed melody in an authentic musical context, characterized by traditional Western functional diatonic harmony, along with both types of accompaniments. Because triads are of particular importance to a vast body of choral repertoire, the principal focus was on the intervals of 3rds and 5ths. For each of the 34 participants, the tuning of major 3rds performed in I, IV, and V chords, minor 3rds performed in iii and a vi chords, and perfect 5ths performed in I, IV, and V chords were analyzed. A unison performance with the root of the I chord was also analyzed.

Overall, based on the study's findings, it may be concluded that accompaniment type did not significantly affect the intonation performance of the college-level choral musicians who participated in this study. The significant main effect observed for the unison performance was negligible, and while there was a significant main effect for accompaniment type for the performance of major 3rds, it was attributed to the interaction with harmonic context, specifically the influence of the leading tone in the V chord. It was, instead, the harmonic context that had the greatest affect on the intonation performance of singers who participated in this study.

The second research question of the present study pertained to how intonation performance compared to the just intonation, equal temperament, and Pythagorean tuning systems. These three tuning systems have frequently been used for comparison in intonation research (Ballard, 2011; Hagerman & Sundberg, 1980; Karrick, 1998; Kopiez, 2003; Leukel and Stoffer, 2004; Loosen, 1993; Mason, 1960). More importantly for this project, these are the tuning systems thoroughly discussed by Alldahl (2008), who provided both sound reasoning for using each tuning system depending on the musical situation, as well as pedagogical approaches for reinforcing their use. The findings of the present study indicated that intonation performance of these choral musicians did not consistently align with any single tuning system, but instead varied between music interval and harmonic context.

Effect of Piano Accompaniment Type

The conclusion that accompaniment type did not significantly affect the intonation performance of the singers who participated in this study was based on the fact that, for the majority of music intervals performed, the main effect for accompaniment type was not found to be statistically significant. However, there were two notable statistical findings that warrant further discussion. One involves performances of unison with the root of the I chord, for which statistical significance and musical importance yield contrary results. The other pertains to performances of major 3rds in different harmonic contexts, for which a significant interaction between accompaniment type and harmonic context was found.

The only instance in which accompaniment type was found to have a statistically significant effect on intonation performance—without the presence of an interaction

between accompaniment type and harmonic context—was for performances of unison with the root of the I chord. Intonation performance in the PD context was more accurate when compared to performance in the RT context. However, intonation performance in the RT context was only 4 cents lower by comparison. This calls to question the difference between statistical significance and musical importance.

For the purposes of identifying intonation performances as *in tune*, a 6-cent threshold was adopted. This was selected based on prior intonation research into just noticeable difference (JND), range of acceptable tuning (RAT), and comparison to tuning systems. Discrimination of JND of tuning for musicians has been reported as most accurate between 2-10 cents (Madsen et al., 1969), and RAT was found to be within a tolerance zone ranging from 6-20 cents (Fyk, 1982). Karrick (1998) also designated intonation performances within 6 cents of a target as an in tune performance.

Although the effect of accompaniment type was statistically significant for this interval, given that performances in the PD and RT contexts were within the 6-cent tolerance zone, it is safe to conclude that from a practical perspective the difference is not musically meaningful. It is, however, interesting that the mean performance with a greater level of harmonic support (PD context) was more accurate than when the harmonic support was only implied (RT context). This may indicate that having a more prominent harmonic context assisted with unison performance. Regardless, the fact that the difference between performances was not musically important led me to conclude that the practical affect of accompaniment in this case was negligible.

The exception to the findings that accompaniment type was not significant was discovered in intonation performance of major 3rds. In this case there was a significant

interaction between accompaniment type and harmonic context. Intonation performance was not significantly different between performances in the I and IV chords. Nor was there a difference between performances with the PD and RT accompaniments in either of these harmonic contexts. But this was not the case in the context of the V chord.

The mean intonation performance of the major 3rd in the V chord was solely responsible for the statistically significant interaction between accompaniment type and harmonic context. Not only was there a significant difference between performances with PD versus RT accompaniments, the intonation performance was significantly higher than performances of major 3rds in the other harmonic contexts. In the PD context, the major 3rd in the V chord was 11 cents higher than performance in the I chord, and 13 cents higher than performed in the IV chord. Mean intonation was even higher in the RT context, with differences reaching 19 cents and 22 cents for PD and RT contexts, respectively.

A possible explanation for the extremely sharp performance of the major 3rd in the V chord, as compared to performances in the I and IV chords, may be that the pitch was either consciously, or subconsciously, interpreted by the singers as having a leading tone function. The major 3rd in the V chord is the 7th scale degree in the diatonic major scale. And in authentic cadences—phrases concluding with the chord progression of V to I—the movement from the 7th scale degree to the root of the I chord is important due to the half step motion. This helps to create a pull toward the tonic. From this perspective, the observed tendency toward sharpness becomes logical. This finding is similar to what virtuoso cellist Pablo Casals called *expressive intonation*, for which a key aspect was a heightening of the leading tone to further emphasize the pull toward tonic (Blum,

Tortelier, & Hopkins, 1980). The heightening of the leading tone observed in the present study was further amplified in the RT context, which was likely due to the fact that the piano was not doubling the leading tone, ultimately allowing for more flexibility to utilize this expressive intonation performance. However, in this particular musical example, while there was leading tone motion ascending back up to the tonic pitch, the chord it led to was, in fact, a IV chord, and not cadential. I intentionally designed this in order to reduce the effect the leading tone might have on intonation performance. This proved to be irrelevant, as the harmonic function of the V chord implying a leading tone was clearly the most important predictor of intonation performance. This finding is further supported by the evidence that harmonic context had the greatest affect on the participants' intonation performance.

Effect of Harmonic Context

Harmonic context was found to have the greatest affect on intonation performance for every music interval studied (excluding unison performances with the root of the I chord, for which there was only one harmonic context). As discussed in the previous section, harmonic context was determined to be the most important factor in its interaction with accompaniment type for differences between performances of major 3rds. But for minor 3rds and perfect 5ths, the only significant main effect was that of harmonic context.

Minor 3rds performed in the iii chord were 10 cents lower than those performed in the vi chord, a statistically significant difference. This result was unexpected, as intonation performance of minor 3rds should hypothetically be the same regardless of the harmonic function of the minor chord. A possible explanation for the difference between

performances of minor 3rds on the iii and vi chords might be the use of an unconventional chord progression. In striving to avoid the cadential leading tone of the major 3rd in the V chord, I placed the vi chord immediately following a half cadence, which would traditionally be followed by a I chord. While the vi chord is a common replacement for the I chord, in this context it may have aurally confused the singers, leading to a difference in intonation performance.

Another unexpected result was observed in the intonation performance of perfect 5ths across different harmonic contexts. The primary difference between intonation performance of perfect 5ths was found in performances in the I chord. Intonation was as much as 12 cents flat when compared to mathematical tuning systems. Performances on the IV and V chords were much more accurate, not significantly different from any of the tuning systems. It should also be noted that, while performances on the IV and V chords were significantly different from one another statistically, the 4-cent difference is not concerning, since this is at the lowest end of the just noticeable difference (JND; Madsen et al., 1969). From a practical performance standpoint, and based on the operational definition used in this study, a difference of within 6 cents of the targeted tuning systems on the IV and V chords would be considered as accurately tuned (see Karrick, 1998).

Comparison to Mathematical Tuning Systems

I was also interested to learn how the intonation performance of college-level choral musicians compared to the just intonation, equal temperament, and Pythagorean tuning systems. For performances of perfect 5ths, I expected that there would not be a significant deviation from any of the tuning systems. Alternatively, I expected greater differences for performances of major and minor 3rds. The reason for these expectations

is that there is less variation between the different mathematical tuning systems for perfect 5ths, as compared to 3rds. For example, in just intonation, a major 3rd is 386 cents, whereas in Pythagorean tuning it is 408 cents, a difference of 22 cents. But for perfect 5ths, there is only a negligible 2-cent difference between all of the tuning systems. While many of the results conformed to the expected findings, there were some surprises observed in performances of major 3rds, minor 3rds, and perfect 5ths.

Performances of perfect 5ths in the IV and V chords were found to have no significant difference from any of the tuning systems. While performances in the IV chord were slightly closer to just intonation and Pythagorean tuning, and performances in the V chord slightly closer to equal temperament, these differences were negligible. What was unexpected, however, was intonation performance in the I chord, which was 10 cents flat when compared to equal temperament and 12 cents flat when compared to just intonation and Pythagorean tuning. Performance falls outside the 6-cent threshold for being considered in tune, so these results were both statistically significant and musically relevant. These results were surprising, particularly given the consistent accuracy participants demonstrated when singing perfect 5ths in the IV and V chords. In the case of the I chord, it is possible that the flat performance is due to some flaw in the design of the stimulus melody. I attempted to minimize any influence of tessitura and direction of approach in the melody I composed, but perhaps this was not enough. Thus, since I was unable to identify a reason as to why this discrepancy might exist, further research is warranted to determine whether perfect 5ths in the I chord present unique intonation problems, or whether this is just an artifact of the musical example used in this study.

Unlike perfect 5ths, greater differences were expected to be observed when comparing intonation performance of 3rds to the mathematical tuning systems. These expectations were based on two factors. One was the previously-mentioned differences between the mathematical tuning systems, which span 22 cents. Another factor that contributed to the expectation of a greater deviation in performance of 3rds was that there is a great deal of variability between intonation performance tendencies reported in the extent body of research, particularly in the performance of 3rds.

Results of the present study indicated that participants performed major 3rds using either just intonation or, in the case of the V chord where the sung 3rd was perhaps perceived as a leading tone, Pythagorean tuning. Interestingly, the presence of the vocal part being doubled by the piano did not change intonation performance in the I and IV chords. That means intonation was almost 14 cents lower than what was sounded by the equally tempered piano. This may indicate a tendency toward performing the noticeably low major 3rds found in just intonation regardless of the presence of an equally tempered accompaniment. But, when the major 3rd functioned with a perceived leading tone quality, intonation performance was considerably higher. When the piano doubled the singers, mean intonation performance was 4 cents higher than equal temperament, falling equidistant between it and Pythagorean tuning, and not significantly different from either. But, in the absence of the piano doubling, with only the referential tone sounding below the singers, performance was even higher, exceeding Pythagorean tuning by 4 cents, significantly different from equal temperament. When compared to performances in the I and IV chords, the difference in intonation performance is 25 cents—the equivalent of a quarter of a semitone.

The same tendencies toward specific mathematical tuning systems were not observed for performances of minor 3rds, however. Instead of an approximation of just intonation, a tendency toward equal temperament was observed, to some extent. There was no presence of a perceived leading tone to influence intonation performance in the iii and vi chords, so consistency between performances was expected. But instead a difference between performances in these two chords was observed. It was intonation performance in the iii chord that conformed most closely to equal temperament, followed by Pythagorean tuning, while deviating significantly from just intonation. But intonation in the vi chord deviated significantly from all of the tuning systems, falling equidistant between just intonation and equal temperament, and furthest from Pythagorean tuning. The only explanation for this lack of consistency that I have identified was the previously-mentioned use of an unconventional chord progression.

Comparisons to Intonation Research

When comparing the results of the present study to extant intonation research, I noticed some consistencies, as well as some important disparities, particularly in the case of intonation performance of 3rds. But before discussing these observations, it should be noted that, compared to research in the instrumental area, intonation performance research in the vocal area is currently far less developed. Any attempted explanations for this would just be speculation. I do hope that the current study will help contribute to this area and encourage others to explore the topic. Until there is more vocal research in this area, we must rely primarily on instrumental intonation research. There is, however, one notable vocal study that found unexpectedly different results from the present study.

Barbershop quartets are famously known for their use of pure, accurate intonation, which is generally associated with just intonation. Results of the present study found that the singers performed major 3rds using just intonation primarily. Surprisingly, Hagerman and Sundberg (1980) found that barbershop quartets did not, in fact, sing using just intonation. The only similarity between the findings of that study and the present one is that harmonic context had an effect on intonation. Major 3rds performed in the tonic chord were interpreted as a “flattened version of a Pythagorean third,” while in the context of a dominant chord they were deemed “a stretched version of a pure third” (1980, p. 42). This is opposite from what was found in the current study.

The barbershop quartets in question were semi-professional and repeatedly sang one of their standard chord progression exercises, a typical practice for the ensembles. As such, I would expect that tessitura or other vocal production issues did not influence intended intonation performance. In the case of the dominant chord, perhaps the lowered major 3rd had to do with the addition of the minor 7th in the chord, or perhaps the voice leading within the chord progression. But this does not explain the performance of the major 3rd in the tonic chord, which should hypothetically employ pure intonation. While I would expect experienced barbershop quartets to favor just intonation, perhaps the tendency toward stretched intervals is a byproduct of musical experience, as reported in many instrumental intonation studies (Geringer, 1978; Kantorski, 1986; Karrick, 1998; Madsen et al., 1969; Mason, 1960; Sogin, 1989; Yarbrough et al., 1995). But this tendency is not observed in all instrumental studies.

Leukel and Stoffer (2004) found that flautists performed major 3rds closest to just intonation, while their minor 3rds were closest to equal temperament. The results of the

current study are very similar to these findings. But these results are not consistent with all intonation research. For example, Kopiez (2003) found that professional trumpet players performed major 3rds equally tempered, while minor 3rds were sharp by 9-10 cents, more closely approximating just intonation—again, exactly opposite from the findings of Leukel and Stoffer (2004) and the present study. Both Ballard (2011) and Karrick (1998) found that wind instrumentalists conformed most closely to equal temperament, deviating most from just intonation.

For string players, major 3rds were found to be sharp in comparison to equal temperament, tending toward Pythagorean tuning (Mason, 1960; Nickerson, 1949). This tendency toward sharpness was also observed in performances of perfect 5ths, a tendency observed in only one of the three harmonic contexts in the present study. This tendency toward sharp perfect 5ths was also observed for trumpet players, who performed approximately 8 cents sharp relative to equal temperament (Kopiez, 2003).

The disparity observed in intonation performance research is likely due to a great number of factors, not the least of which is instrument type. While there seems to be a trend indicating that string players approximate Pythagorean tuning, wind players approximate equal temperament, and singers oscillate between various tuning systems, there are always exceptions found. It should be noted, however, that, despite sometimes significant deviations from various tuning systems, to the trained musicians these intervals and chords are often still considered to be in tune. Perhaps a unifying factor is that there is a wider range of acceptability for 3rds than there is for unisons and 5ths, as evidence not only by the variability between mathematical tuning systems, but by the results of extant intonation research.

Practical Application of Tuning Systems

Mathematical tuning systems are merely theoretical constructs based on mathematical calculations. Although it is possible to analyze the intonation of post-performance recordings, the process takes a considerable amount of time and effort. This makes it impractical for use in a rehearsal setting. However, an awareness of ideal tuning based on musical considerations, as well as knowledge of how to implement these fine tuning adjustments, can be of particular importance for musicians, conductors, and pedagogues, as it allows for appropriate approximation of the desired intonation performance. But what is ideal tuning?

According to Alldahl (2008), ideal tuning is dependent on musical factors. For example, equal temperament would be most desirable when singing with a fixed-pitch instrument like the piano or in cases where the music is highly chromatic. For diatonic music in which the vertical harmonies are prevalent, or in Renaissance music, just intonation would be most desirable, as it is based on the pure, beatless intervals, yielding brilliant sounding harmonies. Alternatively, in more melodically conceived music, it may be desirable to heighten half step motion or the pull toward the tonic, ultimately stretching the major 3rds, approximating Pythagorean tuning, which Alldahl also referred to as *melodic intonation*. While this last option produces harmonies that are least in tune, it can heighten the natural give and take of tension and resolution in music by creating a slight added dissonance in the dominant chord prior to resolving to the root. Ultimately, depending on the piece of music, it may be desirable to approximate multiple tuning systems within a single composition based on the musical factors present. This practice was, in part, represented in the results of the present study.

Performances of major 3rds appropriately approximated just intonation in the RT accompaniment context. Oddly, the same held true for performances in the PD context, which should have been closest to equal temperament, as that was how the piano was tuned. Instead, the mean intonation performance was 12 cents lower than what was provided in the piano part. Is it possible that singers exhibit a tendency toward justly tuned major 3rds despite equally tempered 3rds being presented by the piano? There was, however, a notable deviation from just intonation for major 3rds in one specific harmonic context in the present study. Further research would be required to determine whether these were merely anomalies in the present study, or represent actual tendencies of choral musicians.

The high major 3rd of the Pythagorean tuning system was most closely approximated by the participants when singing as part of the V chord. The sung pitch was likely perceived as a leading tone, which in terms of this melodic intonation practice would naturally be heightened. While it was expected that singers would favor harmonic purity and perform this major 3rd justly in the RT context, the fact that it was performed 25 cents higher does not necessarily make the tuning inaccurate—instead, it may be considered merely expressive. This would conform with Alldahl’s guidelines for tuning within this musical context.

Similar tuning tendencies did not hold true for performances of minor 3rds. Performances in the iii chord were closest to equal temperament, while performance in the vi chord were significantly different from all of the tuning systems. If the same held true for minor 3rds as did for major 3rds, one would expect just intonation to be approximated consistently, especially in the RT accompaniment context. But this was

not the case. In fact, intonation performance of minor 3rds was the least accurate of all the performed intervals. Any suggested reason for this inaccuracy is speculative, but perhaps choral musicians get less exposure and practice on repertoire in minor keys or with minor cadences. Maybe more time should be spent singing minor music, if not in repertoire, then in vocal warm-ups, with special attention given to pure intonation when appropriate.

The primary purpose of this study was to isolate one very specific aspect of Alldahl's (2008) pedagogical outline: the use of piano-provided referential tones as opposed to the piano doubling all vocal parts. One question of import was whether these two accompaniment contexts would naturally elicit different intonation performances. Unexpectedly, this was not shown to be true in the current study. Accompaniment type did not have a significant effect on the intonation performance of the singers. So, while there was not a natural tendency for the singers to adjust their intonation when presented with referential tones, it would be shortsighted to conclude that Alldahl's method is without merit. Only a single aspect of Alldahl's method was tested, and no training was provided to the singers prior to completion of the performance task. In order to thoroughly evaluate the effectiveness of Alldahl's suggested approach, a training regimen would need to be designed, implemented, and empirically tested. However, preliminary findings that harmonic context can affect singers' intonation do support Alldahl's proposed ideas regarding approximating different tuning systems based on the specific musical situation. Based on this evidence, as well as my own anecdotal experience in implementing some of these concepts with choral ensembles, I fully endorse this approach and encourage pedagogues interested in improving their students' intonation

skills to read Alldahl's book and put his suggested techniques into practice. I see no harm in implementing these techniques, and much potential gain in good and expressive intonation.

Limitations

When designing the present study, I sought to create an authentic performance experience for the participants with the hope of making the results more applicable in practice. While every effort was made to control for extraneous variables, it is difficult to control for everything in a real-world scenario. As discussed in the literature review, poor vocal production can effect intonation performance, which may stem from improper breath support, breathing, posture, vowel resonance, or muscle tension (Brinson & Demorest, 2014; Doscher, 1991; Grant, 1987, Jordan, 1987; Powell, 1991, Skelton, 2005; Wine, 2004). Wine (2004) suggested that psychological factors can also influence tuning performance, which may stem from acoustical factors that influence how singers hear themselves, level of familiarity with the vocal line affecting one's confidence, or even musical factors, such as direction of line.

I did strive to control for direction of approach by preceding each targeted pitch with a note on the same pitch, effectively employing only repeated tones. Even so, there was a sense of contour created by the pitch content preceding the target pitches. Band students were not found to be influenced by direction of approach (Morrison, 2000), and Sogin (1989) found that string players exhibited a tendency toward sharpness regardless of whether playing ascending or descending scales. Unfortunately, the current study is not designed in a way to allow for a comparison of how the pitches were approached, and

this variable will require follow-up studies to ascertain whether this may have an influence on singers' intonation performance.

Another issue with using an authentic musical example was the incorporation of harmonic context into the research design. This ultimately provided interesting results, but an assumption had to be made in interpreting these findings. It could be argued that the singers did not have an explicit awareness of the harmonic context in which they were singing, particularly with regard to the RT context. I did attempt to control for this with the design of the musical examples. Both the melody and the accompaniments were designed to make the harmonic context apparent. The melody was stepwise and diatonic, beginning and ending on the root of the I chord. Further, both accompaniments had introductions that emphasized the I and V chords, providing a solid sense of tonality. But even with these controls in place, can the singers' knowledge of harmonic context be assumed? Perhaps not explicitly. But I would argue that, given the participants' level of experience, they likely had a strong implicit knowledge of tonal relationships and harmonic function. This assumption guided my conclusions.

A further limitation with regard to harmonic context was that the research design did not provide for a great deal of comparison of performed music intervals between the harmonies used. In retrospect, I should have designed a musical example with multiple opportunities to make these comparisons. Or, perhaps more effective would have been to use multiple musical examples, providing more data for comparison. That approach would have required a longer duration of participation from the singers, however, which was a practical concern.

Musical experience may have also affected the results of the present study. It has been established that experience has an effect on the tuning tendencies of instrumental musicians (Yarbrough et al., 1995; Fyk, 1982; Peterson & Smith, 1930; Madsen et al., 1969; Morrison, 2000), although less research has been conducted with singers. The present study employed college-level choral musicians. I assumed that their several years of experience singing in choral ensembles, as well as the ability to earn a position in an auditioned ensemble, would have provided the requisite amount of experience for accurate intonation performance. But the results of the present study could have yielded different findings given a participant pool with a different level of musical expertise. If performances of musicians at different levels were analyzed, such as middle school, high school, collegiate, and professional vocalists, it could provide a means for comparison, illustrating how intonation performance changes with experience. The analysis of professional vocalists could arguably provide a more accurate representation of desirable intonation practices.

Related to musical experience of the choral musicians who participated in the present study is the issue of authentic experience. Although an effort was made to create as authentic a music-making experience for the singers as possible, they were, by nature of the procedure, outside of their natural choral singing environment. Some of the singers undoubtedly had experience with solo literature, but others may have only had experience singing as part of an ensemble. Unfortunately, I did not have the technical means to record and analyze singers simultaneously within a complete ensemble. As a result, the participants were required to sing alone with the piano accompaniments. It is possible that results could have differed if the participants were given the opportunity to

sing together as an ensemble. Studying the tuning tendencies of singers within the ensemble setting could provide a more realistic picture of music making within the choral context.

One other variable not fully controlled for was that of the ensemble directors' pedagogical approaches to addressing intonation performance. Participants were recruited from three different ensembles. While having a diverse sample provided a certain level of control, there may still have been intonation performance tendencies present as a result of ongoing study with their current ensemble directors. Interviews might have been conducted with each ensemble director in order to ascertain what, if any, pedagogical approaches they used in addressing intonation performance, which would have provided an additional means of comparing the musical backgrounds of the participants.

Recommendations for Future Research

Although the type of piano accompaniment did not elicit different intonation performance in singers, the data still told an interesting story that warrants further research. Harmonic context was found to have a significant effect on intonation performance. This, however, was more a byproduct of the stimulus music, rather than an aspect that was carefully controlled. Future research seems warranted with a focus on the effect of harmonic context and harmonic function on the tuning tendencies of singers. It may also be advantageous to explore to what extent—either implicitly or explicitly—choral musicians understand their role in the harmonic context of the music they sing.

With preliminary findings indicating that harmonic context can influence tuning performance, it may also be prudent to revisit the discussion of what constitutes ideal

intonation from an empirical perspective. Authors cited in previous chapters have suggested that ideal tuning is dependent on a variety of musical factors. Although it is possible to mathematically identify what might be considered ideal tuning, and use computer programs to determine to what extent performances line up with these predetermined tunings, there is still the question of actual human perception. How do undergraduate choral musicians' perceptions of what is ideally tuned compare to mathematical definitions? Are these perceptions different for expert listeners? Studies comparing performance and perception of choral musicians could help to answer these questions.

Another possible area of inquiry pertains to the variability observed in intonation performance of 3rds. Mathematically, there is a difference of 22 cents between 3rds in just intonation and Pythagorean tuning, yet they are both hypothetically considered to be in tune. There were significant differences observed between performances of 3rds in the present study, and findings from previous intonation research have yielded differing results (Ballard, 2011; Karrick, 1998; Kopiez, 2003; Leukel and Stoffer, 2004; Hagerman & Sundberg, 1980). It may be beneficial to contribute to a perceptual baseline by testing the range of acceptable tuning for 3rds and 5ths, providing a basis for comparison.

Pedagogical Implications

It is important to return to the concept of what constitutes good intonation. If Alldahl's guidelines for appropriate intonation practice are assumed, which are supported by mathematical fact and musical logic, then good intonation is dependent on musical factors including instrumentation, level of chromaticism, melodic versus harmonic

emphasis, and harmonic function. These factors would inform the musicians whether just intonation, equal temperament, or Pythagorean tuning should be approximated.

In the present study, performance of major 3rds aligned quite well with the idea that just intonation should be approximated to achieve pure harmonies, and Pythagorean tuning can be approximated when the pitch being performed functions as a leading tone. Findings did, however, differ from intonation suggestions based on accompaniment type. While the tendency toward pure intonation is advantageous in the RT context or in a *cappella* choral music, when singing repertoire with piano accompaniment, such as the PD context in the present study, singers should be striving to tune with the piano, in which case they should be approximating equally tempered tuning as best as they can. This was not the case for the major 3rds in the I and IV chords, for which tuning approximated just intonation regardless of accompaniment type. It is recommended that special attention be given to performing forces, particularly whether or not singers are performing with fixed-pitch instruments like the piano, when making decisions about intonation performance.

When tuning triads, it is important to establish a pure 5th on which to build the chord. In the present study, the sample exhibited a tendency toward flat perfect 5ths. This is curious, as the difference between perfect 5ths in the tuning systems referenced is only 2 cents. Perhaps the compression of the 5ths was a result of the compression of the major 3rds toward just intonation. This would be reminiscent of 1/4 comma meantone tuning, a system based on pure 3rds, as opposed to pure 5ths like in the Pythagorean system, that emerged in the Renaissance as 3rds became the most important music interval (see Duffin, 2008). But in order to achieve pure intonation, we should be striving

for the high, 702-cent perfect 5th. Mathematically and aurally, this provides a solid foundation on which to build the rest of the chord, and thus this performance practice should be reinforced in musicians.

Although these fine tuning adjustments sound good in theory, they can be difficult to implement, particularly with less experienced musicians. High school ensembles may or may not have the capacity for awareness and adjustment at this level of refinement. This may even be challenging for college-level vocalists. According to expert musicians, there are many technical factors (e.g. posture, breath support, tone quality) that can have a positive effect on intonation performance (Brinson & Demorest, 2014; Davids & LaTour, 2012; Skelton, 2005; Wine, 2004). These types of factors seem to be far easier to address and assess in the rehearsal setting. Implementing some of the fine-tuning techniques as advocated by Alldahl (2008), however, could have additional benefits that go beyond better intonation. From a pedagogical perspective, in order to develop the skills to make fine-tuning adjustments unaided by a teacher, singers would need to develop the ability to identify how their own vocal part functions harmonically and in relationship to the other voice parts. As pedagogues, we should not focus solely on performance, but spend time teaching our students to become independent musicians who can read music and understand how their individual parts function within chords. Once they can do that, next logical step would be to apply this information toward making informed fine-tuning adjustments. Perhaps these skills can be cultivated in undergraduate music education majors through aural training and ensemble courses, or even as part of the score study process in advanced conducting courses, ultimately helping students gain the requisite knowledge and experience to pass these techniques on to their future

students. However, there is still more to learn about how to approach teaching these difficult skills to less experienced musicians.

One way to begin teaching fine tuning skills is to identify opportunities for positive experiences. When an ensemble happens to tune a chord correctly, the director can bring this to the students' attention, and analyze the chord with them, identifying how and why it was tuned correctly. Students can be encouraged to transfer that tuning practice to similar chords and chord progressions in the same piece of music, as well as to other compositions. Another possibility for teaching tuning may be found in the results of extant empirical research. Timbre has been shown to affect the perception of pitch height (Geringer & Worthy, 1999; Russo & Thompson, 2005; Warrier & Zatorre, 2002). Brighter timbres tend to be perceived as higher and darker timbres as lower. Perhaps directors teaching their students to make fine tuning adjustments can begin with the application of this research. For example, students might be taught to use a slight brightening of the vowel when singing the 5th in the chord, or a darkening when singing the major 3rd. This technique would be easily accessible to less experienced choral musicians, and could help provide the needed experience for them ultimately to start thinking in terms of tuning rather than timbre. Developing the ability to analyze and identify how one functions within performed music, adjusting timbre, and ultimately making fine-tuning adjustments all point towards providing students with the skills required for them to take more personal responsibility for the music-making process. Closely related to this is the use of referential tones in the piano. Because this strategy avoids doubling all of the vocal parts on the piano, the onus of accurate intonation performance is placed on the ensemble members. The use of carefully-planned

referential tones during rehearsals can further support this cognitive task, providing singers with additional experiential practice in making tuning adjustments.

As pedagogues and musicians, we should recognize the importance of accurate intonation in musical performance. It has been frequently cited as one of the most important indicators for rating solo and ensemble performance (Ganschow, 2012; Latimer, Bergee, & Cohen, 2010; Stutheit, 1994). And, anecdotally, it is one of the factors that separates good musicians and ensembles from great ones. But ideal intonation is not just what is found on the piano. Ideal intonation is situational, dependent on the style of music, harmonic context, and performing forces. By developing an awareness of the nuances of intonation performance practice, one can develop a better understanding of the music they are performing and strive for a higher level of music-making.

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APPENDIX A

Questionnaire

Please complete the following to the best of your ability.

Name: _____ Email: _____

Phone #: _____ Preferred mode of contact: ☐ Email ☐ Call ☐ Text

Do you have perfect pitch (also referred to as absolute pitch)? ☐ Yes ☐ No
(If yes, you do not need to complete the rest of the questionnaire)

Gender (check one): ☐ Female ☐ Male ☐ Other _____ ☐ Prefer not to say

Age: _____ Year in School: _____ Major: _____

What voice part do you typically sing in choral ensembles? _____

How many semesters of private voice lessons did you take in high school? _____

How many semesters of collegiate-level private voice lessons have you taken, including this semester? _____

How many semesters did you sing in high school choral ensembles (please only count 1 semester, even if you sang in multiple ensembles)? _____

How many semesters have you sung in collegiate-level vocal music ensembles, including this semester (please only count 1 semester, even if you sang in multiple ensembles)?

APPENDIX B

Soprano/Alto Sound Check

Introduction:

Sing top line:

Tenor/Bass Sound Check

Introduction:

Soprano PD

Introduction:

Sing top line:

Soprano RT

Introduction:

Sing top line:

Alto PD

Introduction:

Musical notation for the Introduction of Alto PD. The piece is in 3/4 time, indicated by a treble clef and a 3/4 time signature. The melody is written in the treble staff, and the bass line is in the bass staff. The introduction consists of four measures. The first measure has a half note G4 and a half note E4. The second measure has a half note G4 and a half note E4. The third measure has a half note G4 and a half note E4. The fourth measure has a half note G4 and a half note E4.

Sing top line:

Musical notation for the Sing top line of Alto PD. The piece is in 3/4 time, indicated by a treble clef and a 3/4 time signature. The melody is written in the treble staff, and the bass line is in the bass staff. The melody consists of eight measures. The first measure has a half note G4 and a half note E4. The second measure has a half note G4 and a half note E4. The third measure has a half note G4 and a half note E4. The fourth measure has a half note G4 and a half note E4. The fifth measure has a half note G4 and a half note E4. The sixth measure has a half note G4 and a half note E4. The seventh measure has a half note G4 and a half note E4. The eighth measure has a half note G4 and a half note E4.

Musical notation for the end of the Sing top line of Alto PD. The piece is in 3/4 time, indicated by a treble clef and a 3/4 time signature. The melody is written in the treble staff, and the bass line is in the bass staff. The melody consists of eight measures. The first measure has a half note G4 and a half note E4. The second measure has a half note G4 and a half note E4. The third measure has a half note G4 and a half note E4. The fourth measure has a half note G4 and a half note E4. The fifth measure has a half note G4 and a half note E4. The sixth measure has a half note G4 and a half note E4. The seventh measure has a half note G4 and a half note E4. The eighth measure has a half note G4 and a half note E4.

Alto RT

Introduction:

The introduction consists of two staves in 3/4 time. The upper staff contains four whole rests. The lower staff contains a descending eighth-note scale: G4, F4, E4, D4, C4, B3, A3, G3.

Sing top line:

A musical score for the song 'The Rose Tree'. It features two staves, a treble clef and a bass clef, with a key signature of one flat (B-flat). The melody is written in the treble staff, and the accompaniment is in the bass staff. The music is in 4/4 time. The melody consists of a series of eighth and quarter notes, with some rests. The accompaniment consists of a steady eighth-note pattern in the bass line.

[illegible]

Tenor PD

Introduction:

Sing top line in your own octave (one octave down):

Tenor RT

Introduction:

Introduction:

8

3/4

Key signature: three sharps (F#, C#, G#). The introduction consists of four measures. The treble clef staff contains whole rests in all four measures. The bass clef staff contains a descending eighth-note scale: F#4, E4, D4, C#4, B3, A3, G#3, F#3.

Sing top line:

8

3/4

Key signature: three sharps (F#, C#, G#). The "Sing top line" section consists of eight measures. The treble clef staff contains the melody: F#4 (quarter), E4 (quarter), D4 (quarter), C#4 (quarter), B3 (quarter), A3 (quarter), G#3 (quarter), F#3 (quarter). The bass clef staff contains a descending eighth-note scale: F#4, E4, D4, C#4, B3, A3, G#3, F#3.

8

3/4

Key signature: three sharps (F#, C#, G#). This section continues the melody from the previous system. The treble clef staff contains: F#4 (quarter), E4 (quarter), D4 (quarter), C#4 (quarter), B3 (quarter), A3 (quarter), G#3 (quarter), F#3 (quarter). The bass clef staff contains a descending eighth-note scale: F#4, E4, D4, C#4, B3, A3, G#3, F#3.

Bass PD

Introduction:

Sing top line in your own octave (one octave down):

Bass RT

Introduction:

[illegible]

Sing top line:

A musical score for the song 'The Rose Tree'. It features a treble and bass staff. The treble staff has a key signature of one flat (B-flat) and a common time signature (C). The melody is written in a simple, folk-like style. The bass staff provides a harmonic accompaniment. The score is divided into two systems, each containing four measures. The first system ends with a double bar line, and the second system also ends with a double bar line. The music is written in a clear, legible font.

[illegible]

APPENDIX C

Institutional Review Board
University of Missouri-Columbia

190 Galena Hall
Columbia, MO 65201
573-882-3181
irb@missouri.edu

February 16, 2018

Principal Investigator: Tristan T Frampton
Department: Curriculum & Instruction-PHD

Your IRB Application to project entitled The Effect of Piano Accompaniment Style on the Tuning Accuracy of College Singers was reviewed and approved by the MU Institutional Review Board according to the terms and conditions described below:

IRB Project Number	2009599
IRB Review Number	230751
Initial Application Approval Date	February 16, 2018
IRB Expiration Date	February 16, 2019
Level of Review	Exempt
Project Status	Active - Open to Enrollment
Exempt Categories	45 CFR 46.101b(2)
Risk Level	Minimal Risk
Internal Funding	Personal funds

The principal investigator (PI) is responsible for all aspects and conduct of this study. The PI must comply with the following conditions of the approval:

1. No subjects may be involved in any study procedure prior to the IRB approval date or after the expiration date.
2. All unanticipated problems and deviations must be reported to the IRB within 5 business days.
3. All changes must be IRB approved prior to implementation unless they are intended to reduce immediate risk.
4. All recruitment materials and methods must be approved by the IRB prior to being used.
5. The Annual Exempt Form must be submitted to the IRB for review and approval at least 30 days prior to the project expiration date. If the study is complete, the Completion/Withdrawal Form may be submitted in lieu of the Annual Exempt Form
6. Maintain all research records for a period of seven years from the project completion date.
7. Utilize all approved research documents located within the attached files section of eCompliance. These documents are highlighted green.

If you are offering subject payments and would like more information about research participant payments, please click here to view the MU Business Policy and Procedure:

http://bppm.missouri.edu/chapter2/2_250.html

If you have any questions, please contact the IRB at 573-882-3181 or irb@missouri.edu.

Thank you,
MU Institutional Review Board

DOCTOR OF EDUCATION

4/2/2018

Tristan Frampton
7044 Holly Hills Avenue
Saint Louis, MO 63123

Dear Researcher Tristan Frampton,

This is to notify you the Institutional Review Board (IRB) has approved your application and granted permission to use subjects for the study entitled, "The Effect of Piano Accompaniment Style on the Tuning Accuracy of College Singers."

Your approval number is #000200. You will need to reference this number in the appendix of your study and any future funding or publication submissions. Your IRB approval expires on 4/2/2019.

In order to maintain such approval, you must adhere to the exact procedures of data collection as described in your original application. In order to modify your processes or procedures, you must obtain IRB approval in writing from the IRB review board.

Missouri Baptist University does not accept responsibility or liability for research activities conducted without the IRB's approval, and the University will not accept or grant credit for any work failing to comply with the policies and procedures related to ethical standards in research.

You are expected to keep detailed records of all research activities, and maintain them for a period of ten years.

If you have any questions, please contact the Institutional Research program at 314-392-2335.
Congratulations on completing this milestone.

Sincerely,
Missouri Baptist University IRB Committee

Missouri Baptist University
One College Park Drive
St. Louis, MO 63141

APPENDIX D

Informed Consent Form

Effect of Piano Accompaniment Style on the Tuning Accuracy of College Singers

Researcher: Tristan Frampton

PhD Candidate in Learning, Teaching, & Curriculum, University of Missouri

Director of Music Activities, Assistant Professor of Music, St. Louis College of Pharmacy

Telephone: xxx-xxx-xxxx

Email: xxxxxx@missouri.edu

You have been asked to take part in a research study. Below are the details of the study, which will also be verbally described to you by the researcher. Please review the following information—asking questions about anything you do not understand—before deciding whether or not to participate. Your participation in this study is completely voluntary. Refusing to participate will not result in any penalty. You may remove yourself from the research study at any point without penalty.

The purpose of this research study is to observe the tuning tendencies of undergraduate vocal music majors during performance of a melody under different accompaniment conditions.

If you consent to participating in this study, you will be asked to fill out a brief informational questionnaire, and perform melodies along with pre-recorded piano accompaniments while wearing headphones and singing into a microphone, which will be recorded, much like a studio recording session.

The estimated time to complete your participation in the study is approximately 15 minutes.

Risks and Benefits: There are no risks associated with this study outside those experience in daily life. Benefits may include additional experience in evaluating your personal tuning/intonation skills required for performing well as a soloist or ensemble member, as well as contributing to research on music education and choral rehearsal techniques.

Compensation: There is no compensation for participating in this study. Your grade in voice lessons or choir will not be affected in any way.

Confidentiality: All forms and audio recordings from this study will be securely stored and kept confidential. No one will have access except for the researchers involved with this study. Forms and recordings will be retained by the researcher for a period of 7 years after the study has been complete, per MU policy. Any resulting publications will exclude personally identifying information. During the course of the study, if any new information becomes available that may affect your decision to remain in the study, the researcher will contact you.

Questions and Contact Information: Please ask any questions you may have at this time. If you think of questions later and would like additional information, or wish to withdraw your participation, contact the researcher using the information provided at the top of the page.

If you have any questions regarding your rights as a research participant, you may contact the University of Missouri Institutional Review Board at xxx-xxx-xxxx, or my doctoral advisor, Dr. Wendy Sims, at xxx-xxx-xxxx.

Informed Consent Form

Effect of Piano Accompaniment Style on the Tuning Accuracy of College Singers

Researcher: Tristan Frampton

PhD Candidate in Learning, Teaching, & Curriculum, University of Missouri

Director of Music Activities, Assistant Professor of Music, St. Louis College of Pharmacy

Telephone: xxx-xxx-xxxx

Email: xxxxxx@missouri.edu

You have been asked to take part in a research study. Below are the details of the study, which will also be verbally described to you by the researcher. Please review the following information—asking questions about anything you do not understand—before deciding whether or not to participate. Your participation in this study is completely voluntary. Refusing to participate will not result in any penalty. You may remove yourself from the research study at any point without penalty.

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Risks and Benefits: There are no risks associated with this study outside those experience in daily life. Benefits may include additional experience in evaluating your personal tuning/intonation skills required for performing well as a soloist or ensemble member, as well as contributing to research on music education and choral rehearsal techniques.

Compensation: There is no compensation for participating in this study. Your grade in voice lessons or choir will not be affected in any way.

Confidentiality: All forms and audio recordings from this study will be securely stored and kept confidential. No one will have access except for the researchers involved with this study. Forms and recordings will be retained by the researcher for a period of 7 years after the study has been complete, per MU policy. Any resulting publications will exclude personally identifying information. During the course of the study, if any new information becomes available that may affect your decision to remain in the study, the researcher will contact you.

Questions and Contact Information: Please ask any questions you may have at this time. If you think of questions later and would like additional information, or wish to withdraw your participation, contact the researcher using the information provided at the top of the page.

If you have any questions regarding your rights as a research participant, you may contact the Missouri Baptist University Institutional Review Board by phone at xxx-xxx-xxxx, or by mail at Missouri Baptist University, Xxx XXXXXXXX Xxxx XXXXX, Saint Louis, MO, xxxxx.

APPENDIX E

Recruiting Session Script

My name is Tristan Frampton and I am a doctoral candidate in music education at the University of Missouri-Columbia. I am currently conducting research on how piano accompaniment affects the tuning accuracy of ensemble singers. This is very exciting, as it can potentially provide us with knowledge about readily-available alternative teaching methods that can be used to improve ensemble intonation performance, ultimately making your choir sound better than it already does! In order to do this, I am looking for undergraduate students currently singing in auditioned vocal ensembles to volunteer to participate in private recording sessions—similar to a studio recording session—in which you will sing a melody along with two different piano accompaniments.

Your participation in this study would be very minimal, consisting of filling out a brief questionnaire and participating in one recording session lasting approximately 15 minutes. There are no risks associated with participating in this study. Any personally identifying information will be kept confidential and recordings will not be made publicly available. Benefits to participating in this study may include additional experience in evaluating your personal tuning skills required for performing well as a soloist or ensemble member, as well as contributing to research on music education and choral rehearsal techniques.

While it would be of great benefit to me, and to the music teaching community, for you to participate in this study, you are in no way required to do so. Your grade in this class will not be affected in any way whether you do or do not participate. Even if you choose to participate, you may withdraw from the study at any time.

Informed consent forms have already been distributed. If you have not yet done so, please read the informed consent form and ask me any questions that you may have. Please note that all undergraduate students currently singing in this ensemble are eligible to participate; sorry graduate students, you are not eligible, so you do not need to fill out the questionnaire. Also, if you have absolute pitch, also known as perfect pitch, you are not eligible for the study either.

Undergraduates, if you agree to participate in this study, please indicate your willingness to do so by filling out the questionnaire that I am about to distribute. Once you complete the questionnaire, please return it to me. The informed consent form is yours to keep. I will also be passing around a sign-up sheet on which you can indicate your preferred time to do the recording session. Thank you very much for your time and consideration.

APPENDIX F

Recording Session Script

You are about to participate in a research study about the intonation of singers when presented with different piano accompaniments. You have already seen the informed consent form for participating in this study. Do you still consent to participation? If, at any time, you have questions, or wish to withdraw from the study, please let me know.

Before we begin, please make sure that your cell phone is on silent.

This will be similar to a professional recording session, in which you will be able to hear yourself, as well as a backing track, through studio headphones. First, you will put on the headphones like this [demonstrate]; I would recommend that you move one of the earpads off of the ear to the back slightly so you can hear yourself better when you sing. You will then sing a practice melody—on the syllable [ti]—along with a pre-recorded piano accompaniment. You can use the volume buttons on the right of the microphone by holding up or down to adjust the volume of the piano accompaniment. You may complete the practice example as many times as needed in order to set the volume level. Please note that, for the experiment, you will be asked to tune as accurately as you can with the piano accompaniment, so please set the volume level with this in mind. Once you are comfortable with the volume level, we will proceed with the experimental portion of the recording session. Do you have any questions? ... Are you ready for the practice melody?

[Proceed following stimulus/volume calibration]

You will now sing the following melody—using the syllable [ti]—with two different accompaniments. You will be given as much time as you need to study the melody prior to performance. Once you are ready, you will sing the melody twice with the first accompaniment, then, following a short activity, sing the same melody twice with the second accompaniment. Please focus on accurate intonation, singing as in-tune as possible with the piano accompaniment, particularly on the half notes. Do you have any questions at this time? ... Let me know when you are ready to sing.

[Proceed following first recording]

You will now listen to a brief excerpt of string quartet music while working on a music-themed word search, after which we will continue with the next recording.

[Following washout activity, proceed with second recording]

Are you ready to sing again?

[Proceed with second recording]

APPENDIX G

Pilot Study Questionnaire

Please complete the following to the best of your ability.

Name: _____ Email: _____

Phone #: _____ Preferred mode of contact: ☐ Email ☐ Call ☐ Text

Do you have perfect pitch (also referred to as absolute pitch)? ☐ Yes ☐ No
(If yes, you do not need to complete the rest of the questionnaire)

Gender (check one): ☐ Female ☐ Male ☐ Other _____ ☐ Prefer not to say

Age: _____ Year in School: _____ Major: _____

What voice part do you typically sing in choral ensembles? _____

How many semesters of private voice lessons did you take in high school? _____

How many semesters of collegiate-level private voice lessons have you taken, including this semester? _____

How many semesters did you sing in high school choral ensembles (please only count 1 semester, even if you sang in multiple ensembles)? _____

How many semesters have you sung in collegiate-level vocal music ensembles, including this semester (please only count 1 semester, even if you sang in multiple ensembles)?

Feedback on Procedures and Equipment

Were all of the instructions clear? ☐ Yes ☐ No (If no, please explain)

Were you able to set the volume levels in the headphones so that it was comfortable to sing and focus on tuning with the piano recording? ☐ Yes ☐ No (If no, please explain)

Did you feel comfortable with everything you were asked to do? ☐ Yes ☐ No
(If no, please explain)

Do you have any specific, concrete suggestions for ways in which the procedure can be improved?

APPENDIX H

Composer Word Search
<http://musiced.about.com/>

A	I	D	R	E	V	V	A	Z	T	I	S	Z	H	P	B	P	A
Z	B	J	Q	L	M	G	F	Z	F	H	B	I	H	K	R	D	L
M	E	N	D	E	L	S	S	O	H	N	O	K	U	O	A	I	E
Y	S	X	L	H	C	F	Q	Z	G	H	A	Y	D	N	H	W	D
M	O	N	T	E	V	E	R	D	I	H	C	A	B	N	M	K	N
L	W	K	D	U	L	J	J	B	A	H	G	R	A	I	S	B	A
P	R	A	C	H	M	A	N	I	N	O	F	F	J	W	C	E	H
H	P	C	H	O	P	I	N	M	O	T	F	G	H	H	U	E	A
T	C	H	A	I	K	O	V	S	K	Y	D	X	S	S	E	T	E
A	R	Q	D	P	X	K	F	B	S	P	S	B	N	R	W	H	P
J	V	E	D	R	A	V	E	L	Y	K	K	I	Y	E	A	O	A
W	I	I	B	Y	K	S	N	I	V	A	R	T	S	G	G	V	D
U	M	N	V	U	A	Y	D	M	N	O	M	P	Z	L	N	E	L
V	O	Y	L	E	H	X	T	Z	S	I	L	J	U	M	E	N	B
Y	Z	Q	E	E	S	C	S	J	H	R	R	Q	B	W	R	P	W
U	A	Q	O	V	V	N	S	D	A	C	F	W	R	X	N	Q	U
E	R	M	J	H	O	B	C	J	P	N	T	E	G	D	L	K	S
V	T	D	A	C	P	C	S	Z	S	C	H	U	M	A	N	N	J

BACH
 BEETHOVEN
 BRAHMS
 CHOPIN
 GERSHWIN
 HANDEL
 HAYDN

IVES
 LISZT
 MENDELSSOHN
 MONTEVERDI
 MOZART
 RACHMANINOFF
 RAVEL

SCHUBERT
 SCHUMANN
 STRAVINSKY
 TCHAIKOVSKY
 VERDI
 WAGNER

VITA

Growing up surrounded by music and musicians, Tristan Frampton developed a passion for the art form, with a particular interest in choral music. He went on to attend Truman State University, where he studied vocal performance with Dr. Jacqueline Collett and choral conducting with Dr. Paul Crabb, earning a Bachelor of Arts in Music with a Vocal Emphasis in 2003. He then went on to earn a Master of Music in Choral Conducting in 2005 from the University of Arizona, where he studied conducting with Dr. Bruce Chamberlain. After teaching high school choral music for a few years, he returned to his studies to earn a Doctor of Philosophy in Music Education from the University of Missouri, under the guidance of Dr. Wendy Sims. While there, Dr. Frampton also studied vocal performance and pedagogy with Prof. Ann Harrell, and advanced choral conducting and literature with Dr. Paul Crabb. Dr. Frampton is currently an Assistant Professor of Music and Director of Music Activities at St. Louis College of Pharmacy where, in addition to directing ensembles and teaching music-related courses, he has begun focusing on composing new choral music, which is beginning to be premiered by outside ensembles. He plans to continue composing and actively engaging in music teaching and scholarship at the collegiate level.