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USING MIDI TECHNOLOGY TO ENHANCE TUNING SKILLS FOR CHORAL CONDUCTORS

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By

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USING MIDI TECHNOLOGY TO ENHANCE TUNING SKILLS
FOR CHORAL CONDUCTORS

A DOCUMENT APPROVED FOR THE
SCHOOL OF MUSIC

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ABSTRACT

USING MIDI TECHNOLOGY TO ENHANCE TUNING SKILLS
FOR CHORAL CONDUCTORS

BY: PHILIP L. MILLER

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The purpose of this study is to develop and provide software to enhance the tuning skills of conductors. Users of the software will be able to experience and practice tuning within intervals and chord progressions while utilizing a variety of timbres. This is accomplished using MIDI technology and software programmed in "C#" language on the Microsoft.Net Framework for Microsoft Windows. The software uses sampled notes tuned to equal-temperament that can be played back through a pair of computer speakers and then tuned by the user. The user tunes intervals, chords, and chord progressions by moving sliders on the computer screen. For the purpose of this study, just intonation with a moveable "intonation key" is considered to be correct, though tuning to equal-temperament or variations of the two are possible. The computer provides feedback on the accuracy of the tuning as it relates to equal-temperament and just intonation.

Chapter One of this study describes the importance of intonation study for musicians and the need for tools with which to practice tuning. It also provides definitions for technological and tuning terms along with literature related to tuning, MIDI, and education.

Chapter Two provides a background on the development of pitch and temperament along with mathematical calculations for different scales. These

calculations provide the framework for the tuning software included with the document.

Chapter Three includes a brief history of MIDI and the development of software utilizing MIDI technology along with an overview of current music software in education and in the recording industry.

Chapter Four provides the details on the development of the software, *JustTrainer,* included with this document. The procedures for the programming of the software along with instructions for the user are provided.

Chapter Five outlines the tuning exercises for the software and gives instructions on how to access the exercises and the various sounds.

CHAPTER ONE

INTRODUCTION

> The sound of a choir singing in tune is an experience in hearing extraordinarily compelling sound-images produced through changing patterns of timbres, textures, and sonorities. . . . The resultant intonation creates a rich sonority that invites the listener into the music and heightens his or her awareness of the beauty of the choir that is singing it.[1]

THE NEED

When a person attends a concert, one of the most noticeable aspects of the performance is the intonation of the ensemble. Research indicates that intonation is a prime component of a successful performance.[2] Hemholtz states that "correct intonation in singing is so far above all others the first condition of beauty, that a song when sung in correct intonation even by a weak and unpracticed voice always sounds agreeable, whereas the richest and most practiced voice offends the hearer when it sings false, or sharpens."[3] In his book *The Choir and How to Direct It*, Pavel Chesnokov indicates three essential attributes to choral singing: intonation, ensemble, and nuance.[4] Stutheit asked adjudicators to rank the importance of musical elements for high school choirs. Intonation was rated the most important.[5]

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[1] Jameson Marvin, "Choral Singing, In Tune" *Choral Journal* (December, 1991), 27.

[2] See James E. Latten, "Exploration of a Sequence for Teaching Intonation Skills and Concepts to Wind Instrumentalists" (Ph.D. diss., Pennsylvania State University, 2003).

[3] Hermann Hemholtz,,*On the Sensations of Tone* trans. Alexander Ellism (New York: Dover Publications, 1954), 327.

[4] John Christian Rommereim, "The Choir and How to Direct It: Pavel Chesnokov's Magnum Opus" *Choral Journal* 38:7 (February 1998), 29-42.

[5] S. A. Stutheit, "Adjudicators', Choral Directors', and Choral Students' Hierarchies of Musical Elements Used in the Preparation and Evaluation of High School Choral Contest Performance" (Unpublished D.M.A. diss., University of Missouri-Kansas City, 1994).

Although of utmost importance, intonation, unfortunately, can be one of the most elusive goals of choral music, and although there are many factors that affect the intonation of a choral ensemble, most beyond the scope of this paper, one of the most fundamental factors involves listening. Singers must listen to and react properly to the pitches around them. The director, who plays an important role in this process by giving timely and appropriate feedback, can learn how to give the appropriate feedback to an ensemble by consulting the many books that deal with intonation. And while these books are very helpful in dealing with issues about the properties of intonation, conductors are left on their own to hear whether or not satisfactory intonation is achieved. If a conductor cannot make quick judgments on chord tuning or which notes need adjustment, feedback to the ensemble is hindered and rehearsal time is wasted. With this in mind, the understanding and practice of intonation and pitch should be one of the primary goals of conductors.

There are a myriad of books in music education dealing with performance techniques such as breathing, fingering, phrasing, and tone, but there is a gap when dealing with the aspects of playing or singing *in tune*. The books that are available often deal with anecdotes for achieving better choral intonation but do not deal with the subject of a sound *in tune*. As stated before, studies have shown that intonation is the most important factor to the quality of a performance. However, there is a general deficiency in the understanding and training of intonation, and it is often disregarded in academic musical curriculuae. "The weakest link in the entire chain of music excellence is the lack of knowledge and understanding of the simple fact of music acoustics; no phase of music performance has been so sadly neglected as the study and practice of music intonation and harmony."[6] To underscore this, most musicians could readily point out the importance of intonation, but many would have a hard time articulating the definition of performing *in tune*. In addition, most young musicians, especially singers, are not given opportunities for adequately developing auditory skills that aid the training process.

While choral conductors can practice the physical and mental aspects of conducting without an ensemble present, conductors need to be in front of a choir to work on many of the other skills, including developing intonation. Conductors with an ensemble can isolate chords and work with the ensemble to achieve a desired tuning. This is challenging, however. First, in both undergraduate and graduate education, conducting time with ensembles is limited, certainly for the amount of time required for repeated intonation exercises. Second, a conductor must already know the sound of a desired tuning. If one does not know what *in tune* sounds like, it is impossible to give proper instructions to an ensemble. Choral conductors need an environment in which to practice intonation without the use of a live ensemble.

Emerging technology provides outlets for practicing musical skills without either an instructor or an ensemble present. Programs exist to assist students with aural theory skills such as rhythmic and melodic dictation, thus giving students instant feedback on correct or incorrect answers. Students can also get help with composition, arranging, orchestration, and a variety of other advanced theory skills.

Intonation software is now being used to help students learn how to play their instruments in tune. The students play an interval against a sounding tone and receive

[6] W.J. Stegeman, "The Art of Musical Intonation. Part I" *Instrumentalist* 21 (10), 61.

feedback on their intonation. Though this software is helpful to instrumental players in hearing how to make fine intonation adjustments on their instruments, it does not allow the students to hear chords and manipulate individual pitches. No software currently on the market is known to have this feature.

THE PURPOSE AND PROCEDURE

> No amount of information or knowledge can replace the actual training of the ear to perceive the beats of pitch discrepancy.[7]

The purpose of this study is, with the help of software designed specifically for this document, to allow the user to hear various chords and then adjust individual pitches until the desired tuning is achieved. It is the premise of this document that engaging the ear to hear fine adjustments to tuning will allow the conductor to more effectively hear and adjust the intonation of ensembles during rehearsal.

The software accompanying this document contains a series of exercises designed to train a musician to hear and tune chords by manipulating individual pitches. Once the software is installed on a computer, the user will be able to isolate intervals and chords and move the pitch up or down to achieve the desired tuning. The chords appear on the screen and then play through the computer's speakers. The user will decide if the chord is out of tune and then make the changes necessary. The user will then check the answer by clicking on the evaluate button. The computer will display the position for just tuning and show the user if he or she was correct.

One of the major problems when dealing with tuning is that there is no

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[7] S. Colley, *Tuneup* (CD Based Intonation Training System). (Richmond: Tune-Up Systems, 1993), 8.

absolute standard for what is considered to be *in tune*. In a sense, much of tuning is personal preference. However, various systems of tuning have developed and become the most prevalent in western culture. These various tuning systems are discussed in more detail in the following chapter. For the purpose of this document, just intonation is considered to be the desired tuning. This is achieved by tuning the notes in chords to match the overtone series (explained later in the document). "Just intonation has been frequently recommended as the ideal for choral groups and certainly could be adopted in that medium."[8] The exercises in this document are designed with adjustable just intonation as the standard.

This document will not deal with the subject of how a choir tunes when singing with instruments tuned in equal-temperament. The complications and intricacies involved with that subject are beyond the scope of this study.

Another variable beyond the scope of this document is the issue of vibrato. Divergent rates of vibrato in a choral ensemble can affect the tuning and would be very difficult to replicate in the electronic environment. Sounds which include vibrato cloud the tuning and make it difficult for the software to work. This is not to advocate straight-tone, it is simply to provide a practical set of exercises with which to practice tuning. It is the premise of this document that though the electronic environment cannot exactly replicate a choral sound, working with and manipulating pitch in this environment will make the ear more capable of hearing and solving intonation problems within an ensemble. This ear-training should allow the conductor to respond

[8] D.W. Stauffer, *Intonation Deficiencies of Wind Instrument* (Bessemer: Stauffer Press, 1954), 11.

to ensemble intonation problems with better accuracy and greater speed.

The tuning software is on the CD accompanying this document. Installation instructions are included later in the document. In order to utilize the software the following items are needed:

1. A PC Computer (software will not run on Macintosh computers unless they are equipped with Windows software)

2. CD Rom

3. Speakers or headphones connected to the computer

Once installed, the user will follow the instructions in chapter four to practice tuning.

DEFINITIONS

1. Temperament: "tunings of the scale in which some or all of the intervals are made slightly impure in order that few or none will be left distastefully so."[9]

2. Overtone Series: "The term overtone series generally refers to a specific set of frequency components that appear above a musical tone. The related term harmonic series is a more precisely defined mathematical concept. Though musicians often use the two terms interchangeably, the term harmonic series specifically refers to a set of numbers related by whole number ratios. For example, the set of frequencies (in Hz.) 1000, 2000, 3000, 4000, 5000, 6000, etc., forms a harmonic series; so does 500, 1000, 1500, 2000, 2500, 3000, etc. The fundamental, or lowest component of the first series, is 1000 Hz. The fundamental of the second series is 500 Hz. The other frequency components are called harmonics, overtones, or partials."[10]

3. Equal-Temperament: "a tuning of the scale based on a cycle of 12 identical 5ths and with the octave divided into 12 equal semitones, and,

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[9] Mark Lindley, *Temperaments. (Grove Music Online* ed. L. Macy , Accessed [11/01/05]), <http://www.grovemusic.com>

[10] See < http://www.music.sc.edu/fs/bain/atmi98/examples/os/>, June 2006.

consequently, with 3rds and 6ths tempered, uniformly, much more than 5ths and 4ths. Equal temperament is now widely regarded as the normal tuning of the Western, 12-note chromatic scale."[11]

4. Just Intonation: a system of tuning lining up the intervals to match the harmonic series. "The term refers to the consistent use of harmonic intervals tuned so pure that they do not beat, and of melodic intervals derived from such an arrangement, including more than one size of whole tone."[12]

5. Mean-tone: a "system of temperament or a tuning of the scale, particularly on instruments lacking any capacity for flexibility of intonation during performance, which differs from the equal-tempered system normally used on such instruments today. The term refers to a tuning with pure major 3rds (frequency ratio 5:4) divided into two equal whole tones; to achieve this the tuner must temper the 5ths and 4ths, making the 5ths smaller and the 4ths larger than pure by a quarter of the syntonic comma, hence the label 1/4-comma mean-tone, a more specific name for the same kind of tuning."[13]

6. Pythagorean Tuning: "Pythagorean tuning is based on a stack of perfect fifths, each tuned in the ratio 3:2, the next simplest ratio after 2:1, which is the ratio of an octave. The two notes A and D, for example, are tuned so that their frequencies are in the ratio 3:2 — if D is tuned to 200 Hz, then the A is tuned to 300 Hz. The E a fifth above that A is also tuned in the ratio 3:2 with the A at 300 Hz; this puts the E at 450 Hz, 9:4 above the original D. When describing tunings, it is usual to speak of all notes as being within an octave of each other, and as this E is over an octave above the original D, it is usual to halve its frequency to move it down an octave. Therefore, the E is tuned to 225 Hz, a 9:8 ratio above the D. The B a 3:2 above that E is tuned to the ratio 27:16 and so on, until the starting note, D, is arrived at again."[14]

7. Well-Temperament: "any system of tuning in which the twelve notes per octave of the standard keyboard are tuned in such a way that it is

[11] Mark Lindley, *Equal Temperaments. (Grove Music Online* ed. L. Macy , Accessed [06/26/06]), <http://www.grovemusic.com>

[12] Mark Lindley, *Just Intonation. (Grove Music Online* ed. L. Macy , Accessed [06/26/06]), <http://www.grovemusic.com>

[13] Mark Lindley, *Mean-tone. (Grove Music Online* ed. L. Macy , Accessed [06/25/06]), <http://www.grovemusic.com>

[14] Daniel Leech-Wilkinson, *Pythagorean Tuning,* (*Wikipedia, The Free Encyclopedia,* Accessed [06/20/06]), <http://www.wikipedia.org>

possible to play music in any major or minor key without sounding perceptibly out of tune."[15]

8. MIDI: stands for Musical Instrument Digital Interface. A system developed in the early 1980s as protocol from communicating between synthesizers and computers. It is a universal method for transmitting music performance data between keyboards and computers when recording or performing.

9. JustTrainer: the name given to the tuning software that accompanies this document.

10. Sound Forge: an audio editing software program used in this document to set volumes and to create the audio loops.

11. Auto-Tune: a software program designed to "listen" to pitches and adjust them according to the parameters set by the user.

12. Microsoft .Net Framework: a platform for programming developed by the Microsoft Corporation. It is currently one of the most popular programming platforms in the world and was used as the platform for the JustTrainer software accompanying this document.

13. C# Developer Language: a programming language that can be used within the .net framework. The JustTrainer software was programmed in C# language.

RELATED LITERATURE

History of Pitch

A comprehensive list of this literature is beyond the scope of this paper. However, the books below were used in research for this document and provide a thorough history of pitch.

Barbour: *Tuning and Temperament, A Historical Survey*
Hemholtz: *On the Sensations of Tone*

[15] Wikipedia Contributors, *Well Temperament,* (*Wikipedia, The Free Encyclopedia,* Accessed [06/20/06]), <http://www.wikipedia.org>

Backus: *The Acoustical Foundation of Music*
Schoenberg: *Theory of Harmony*
Weyler and Gannon: *Study of Harmony*
Jorgensen: *The Equal Beating Temperament*
Reinhart: *Meantone is Beautiful*
Hall: *The Objective Measurement of Goodness-of-Fit for Tunings and Temperaments*
Leuba: *The Study of Intonation*
Haynes: *A History of Performing Pitch: The Story of "A"*

A general overview on the history of tuning is provided in Barbour's study along with Weyler and Gannon's. Barbour was an important intonation authority in the 1950s, and his book discusses the development of temperament and the controversies surrounding it. [16] Weyler and Gannon focus more on the people influential in the development of pitch, and their book is not overly technical in its discussion.[17] Their study also talks about the emergence of equal-temperament and its dominance in western music. Schoenberg also discusses equal-temperament in his work and explains the reasons behind the temperament compromise. He advocates that temperament provides only a temporary and imperfect solution. [18]

A more scientific approach is provided in Backus' study. He provides an explanation for the mathematical principles of pitch and its related historical development. He advocates that pitch developed based on its naturally occurring acoustical properties.[19] Leuba published a series of charts with overtones and resultant tones which are useful to the understanding of just intonation.[20] These

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[16] See Barbour, *Tuning and Temperament, A Historical Survey.*

[17] See Weyler and Gannon, *Study of Harmony*

[18] See Schoenberg, *Theory of Harmony.*

[19] See Bakus, *The Acoustical Foundation of Music.*

studies can be difficult to comprehend due to the complexity of the mathematical discussion. Nevertheless, they provide a thorough discussion of the overtone series.

Hemholtz contributed to the research on the development of intonation and the importance of correct intonation in performances. He focused on the science behind poor intonation and its effect on performances.[21] His research provides ensemble directors some of the factors that cause intonation.

Jorgenson provides a table and tuning techniques for fifteen different historical tuning preferences. The time tables in his book offer a reference for the development of pitch.[22] Reinhart also develops a chart comparing tuning systems. He advocates the use of meantone for use especially with organs.[23] Hall compares multiple tuning systems and argues that no one system should be classified as *correct*. He states that musicians should use the tuning system that is best suited for the situation.[24]

Haynes discusses the development of the standard of A=440. He moves through various eras and countries and their use of different pitch standards.[25]

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[20] See Christopher Leuba, *The Study of Intonation* (Seattle: Prospect Publications, 1977).

[21] See Hemholtz, *On the Sensations of Tone.*

[22] See Owen Jorgensen, *The Equal Beating Temperament* (Raleigh: The Sunbury Press, 1981).

[23] See Frosch Reinhart, *Meantone is Beautiful* (Bern, Berlin, Bruxelles, Frankfurt am Main, New York, Oxford, Wein: Peter Lang AG, Europaischer Verlag der Wissenschafen, 2002).

[24] See Donald T. Hall, "The Objective Measurement of Goodness-of-Fit for Tunings and Temperaments" *Journal of Music Theory* 17 (Fall 1973).

[25] See Bruce Haynes, *A History of Performing Pitch: The Story of "A"* (Lanham: Scarecrow Press, 2002).

Intonation Preferences

One of the considerations in studies dealing with intonation is that the environment affects the outcome. Many studies, including that of Doscher and Marvin,[26] show that variations in the environment affect the quality of intonation. Placement of musicians in ensembles can also affect intonation as described in a study by Woodruff.[27] While these documents provide environmental factors on tuning they do not provide a way to practice tuning.

Hypothesis that intonation preference has a natural mathematical grounds was put forth by Benade and Meyer and others.[28] These studies state that most musicians should prefer the tunings that line up with the natural overtone series. Redfield states that choirs should prefer just intonation due to the small ratios of the intervals. It is his opinion that no other tuning could possibly be correct. He writes, "It is not too much too say that the sense of harmony is as distinct as the dodo; it has been sunk without a trace. Except for those a cappella choirs which sing and rehearse without the use of any keyboard instrument as a crutch to lean upon, and except for the playing of a few of the very best string quartet organizations, real harmony has disappeared from the earth."[29] Another physical scientist, Jeans, agrees. "It is found to

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[26] See Richard Allen Swann, "An Investigation into the Harmonic Intonation Discrimination and Tuning Preferences of Choral Musicians" (Ph.D. Diss., Florida State University, 1999).

[27] See Neal Wayne Woodruff, "The acoustic interaction of voices in ensemble: An inquiry into the phenomenon of voice matching and the perception of unaltered vocal process" (D.M.A. diss., University of Oklahoma, 2002).

[28] See Swann, "An Investigation into the Harmonic Intonation Discrimination and Tuning Preferences of Choral Musicians."

[29] John Redfield, *Music, A Science and an Art* (New York: Tudor Publishing Co., 1935), 307.

be a quite general law that two tones sound well together when expressed by the use of small numbers, and the smaller the numbers the better is the consonance."[30] Cooper suggests that "since any note sounded as a root already has a harmonic structure above it we tune our major third in the chord with the one already present in the root's overtone structure two octaves higher."[31] This research is valuable to the foundation of the tuning software provided with this document. However, this document will not focus on acoustical research but will provide practical ways of hearing the overtones.

The debate of intonation preferences was put to the test in a variety of experiments. Research has been conducted using different tuning systems and soliciting feedback from study groups. Two of these studies, conducted in 1963, provided a way to test different harmonic configurations and tuning systems and the preferences of the people involved. Richardson's study, which focused on the major third, provided a setting in which thirds could be adjusted to the listener's preference.[32] He then selected a panel of musicians and manipulated organ pipes so they could be tuned easily by the listener. Each musician listened to the third and adjusted the organ pipe until it sounded in tune. The thirds were used in various positions and ranges to provide a broad sampling. His conclusion was that in most cases, the thirds tuned in just intonation are preferable to the others.

Johnson's study in 1963 differed from Richardson's in that Johnson provided

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[30] Sir James Jeans, *Science and Music* (New York: The MacMillan Co., 1937). 37.

[31] Latten. "Exploration of a Sequence for Teaching Intonation Skills and Concepts to Wind Instrumentalists," 35.

[32] See Samuel Louis Richardson, "The Effect of Certain Harmonic Configurations Upon Tuning Preferences for the Major Third" (Ph.D. diss., Indiana University, 1963).

recorded examples of various tunings of chords.[33] He chose a panel of singers to listen to the recordings and select the chords that sounded most in tune. His conclusion differed from Richardson in that the panel preferred the tunings in equal-temperament. The results of this experiment are indeed interesting. It is likely that singers have spent so much time singing with the piano that equal-temperament tuning becomes the *normal* or *correct* sound. It is also possible that using the recordings as opposed to the organ pipes affected the outcome of the experiment.

The study by Sisson also used recordings with various tunings of chords.[34] His results from the panel of musicians stated that just intonation was the preferred tuning for chords. He did find that equal-temperament was acceptable when intervals were played melodically instead of harmonically.

These studies find that most musicians prefer just intonation for triads, but again, do not provide a practical way of practicing tuning. However, these studies provide valuable research, and this research, along with the science that just intonation coincides with the natural overtone series, is the basis for the software provided with this document. In 1987, Bisel had more technology at his disposal for his tuning preference research.[35] He used four theoretically correct tuning systems and had music majors at a university as his panel. His findings also showed that

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[33] See Hugh Bailey Johnson Jr. "An Investigation of the Tuning Preferences of a Selected Group of Singers with Reference to Just Intonation, Pythagorean Tuning, and Equal Temperament." (Mus. Ed.D. diss., Indiana University, 1963).

[34] See Jack Ulness Sisson, "Pitch Preference Determination, A Comparative Study Of Tuning Preferences of Musicians From the Major Performing Areas With Reference to Just Intonation, Pythagorean, and Equal Temperament" (D.M.A. diss., University of Oklahoma, 1969).

[35] See Larry Bisel, "Seeking a Perceptual Preference Among Pythagorean Tuning, Just Intonation, One-Quarter Comma Meantone Tuning, and Equal Temperament" (Ph.D. diss, University of Miami, 1987).

tuning preferences differed depending upon the use. For melodic purposes, Pythagorean was preferred and meantone was found to be preferred for harmonic situations. His conclusion was that more research in this area is warranted. While his technology was much more advanced than earlier studies, it did not provide the ease of tuning practice that today's technology can provide.

Swann also conducted similar research.[36] The purpose of his study was to examine the effect of harmonic tuning and chord inversions on the listening preferences of choral musicians with reference to equal-temperament, just intonation, meantone, and Pythagorean tuning. Swann generated a digital recording of four-note chords with tones from a tunable keyboard. His findings indicated a variety of preferences amongst his test population. The results varied depending on choral experience and the types of choral participation. His study reinforced that no one tuning can be declared as *correct.* While this study used a keyboard just as this document will, the user could not manipulate the pitch in Swann's study. The users could only choose between several chords as to which sounded in tune.

The Education of Intonation

Studies have been conducted on the best ways to teach musicians the skills needed for proper intonation. The difficulty involved with the education of intonation is that it generally has only been practiced in ensemble settings. Several research projects have attempted to design a way to practice intonation in an individual setting.

[36] See Swann, "An Investigation into the Harmonic Intonation Discrimination and Tuning Preferences of Choral Musicians".

Moody designed a way for instrumentalists to practice intonation.[37] His study relied on hearing the overtones and resultant tones (tones created by two or more tones sounding together) and tuning them. The user would use a tuner to generate a consistent and steady tone and then play another steady tone on an instrument. Each note sounding with the generated tone would produce overtones. With practice, Moody states that the user will develop the ability to hear the overtones clearly and tune them to remove the beats. He provides a step by step process to identify the overtones and tune out the beats in the sound. If the steady tone produces the root of a chord and the user plays one octave above the note, the overtone series would sound in the room. The user would then focus on hearing the beats in the sound and adjust the pitch until the beating stopped. This process is difficult and requires an ideal acoustical setting to achieve. If the room does not provide adequate reverberation, the overtones would be difficult to hear. The process also only allows the tuning of up to two notes at a time. Tuning of a triad is not possible.

Marvin describes a method for choral ensembles to work on tuning chords.[38] When a chord does not tune correctly, Marvin first isolates the root of the chord by having the section with the root sing. Once the choir hears the root he adds the fifth and then the third. He asserts that the choir will hear the third and the fifth in the overtones of the root and be able to line them up. Once the singers hear and sing the chord in tune, they will have better success the next time they get to that chord.

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[37] See Moody, "A Practical Method for the Teaching of Intonation".

[38] See Marvin, "Choral Singing, In Tune".

Robert Shaw used this technique also.[39] Shaw began each choral rehearsal the same way; the choir would sing in octave unisons on the syllable "nu" (noo). He then added other pitches by telling the choir to sing within the "sleeve" of the music. In other words, he would have the choir listen to and line up with the overtone series. These techniques would be helpful for intonation when a director is in front of the ensemble. However, the software involved with this document, allows for intonation practice away from the ensemble.

Rommereim studied the choral practices of Pavel Chesnokov and describes his technique for achieving his desired choral intonation.[40] Chesnokov would have every choral singer mark his or her music carefully before singing through a work. Scale steps two, three, six, and seven, would have up arrows marked next to them to indicate singing them high and not allowing them to be flat. Scale step four would have a down arrow, and the tonic and dominant would be neutral. Chesnokov's system was not based on any scientific or acoustical basis, but his choirs were described as having impeccable intonation. Rommereim suggests that by merely marking their music, singers were sensitized to listening for intonation. The arrows helped the choir to always be aware of listening to and adjusting tuning. This reinforces the premise of this document, that listening to and adjusting pitch can help intonation. Rommereim's singers could only do this in rehearsal with others present. The software in this document allows musicians to practice manipulating pitch on their own.

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[39] See Ann Howard Jones, "Shaw: Simply and Clearly the Best" *Choral Journal.* 36:9 (April 1996),19-20.

[40] See Rommereim, "The Choir and How to Direct It: Pavel Chesnokov's Magnum Opus".

A variety of textbooks discuss ensemble intonation and techniques for improvement. Smith's book provides a comprehensive overview of choral pedagogy, including conducting, vocal care, and ensemble techniques.[41] Jordan and Mehaffey provide a set of exercises for choral intonation in their textbook.[42] They use solfege, and have a foundation of listening building blocks for the choral ensemble. Johnson's textbook describes activating the whole body for singing.[43] This activation of body, mind, and voice aids the overall process of choral intonation. Ames and Jordan provide a set of modal exercises sung on neutral syllables.[44] They contend that these exercises push the ear of the singer and heighten awareness of the choral intonation. Jordan and Schenenberger provide another set of solfege exercises for choral ensembles.[45] This set of musical examples and exercises is designed to immerse the choral ensemble in ear-training practice. The premise is again to heighten the singer's sensitivity to tuning. Morris uses a progressive set of choral literature to introduce intonation concepts to the choral ensemble.[46] Wine provides a list of techniques and activities such as changing keys, changing tempos, internal singing, and isolating

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[41] See Brenda Smith, *Choral Pedagogy* (San Diego: Singular, 2000).

[42] See James Mark Jordan and Matthew Mehaffey, *Choral Ensemble Intonation: Method, Procedures and Exercises* (Chicago: GIA Publications, 2001).

[43] See Jeff Johnson, *Ready, Set, Sing! Activating the Mind, Body, and Voice* (Santa Barbara: Santa Barbara Music Pub., 2000).

[44] See Roger Ames and James Mark Jordan, *Choral Ensemble Intonation: Modal Exercises for Choir* (Chicago: GIA Publications, 2001).

[45] See James Mark Jordan and Marilyn Shenenberger, *Ear-Training Immersion Exercises for Choirs: A Companion to Choral Ensemble Intonation* (Chicago: GIA Publications, 2004).

[46] See Steven A Morris, *A Literature Based Pedagogy for Choral Intonation* (St Lucia, Qld., 1996).

chords to improve ensemble intonation.[47]

This is but a sampling of textbooks and articles available on the techniques for improving ensemble intonation. These techniques, however, do not provide basic intonation ear-training exercises for the conductor. The improving technology now offers options for the conductor to train for the intonation problems encountered when dealing with ensembles.

Music Technology, MIDI, and Education

Music technology has greatly advanced over the last decade, thus opening up new possibilities for music software in education. Projects that used to require a room full of expensive equipment can now be done on a home computer. The software, available and being used, offers educators tools to develop music skills. The following literature discusses these opportunities.

Swift developed a study using CODA Music's *Intonation Trainer.*[48] This software, which will be explained in greater detail later in the document, can *listen* to a student playing a note and give feedback on the tuning. The software will give feedback to the user on the direction the note must move to get it in tune. In Swift's study, a group of high school instrumental students were put through a program using this software. All of these students showed improvement in their tuning skills. While this software provides instrumentalists with valuable practice on interval tuning,

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[47] See Thomas Wine, "Check Your Intonation." *Choral Journal.* 44:9 (April 2004), 23-27.

[48] See David Glenn Swift,. "Improving harmonic intonation skills of High School band students using Coda Music Technologies' *Intonation Trainer"* (M.M.E thesis, University of Louisville, 2003).

tuning a triad would be impossible. The user also must be an active participant in the tuning by playing a note on an instrument.

Mager researched the status of MIDI and technology in higher education.[49] A vast majority of teachers responding to his questionnaire indicated that technology was enhancing their student's education. Music theory was listed as one of the highest areas using technology, according to the study. The availability of several fine software programs that develop basic music skills contributes to this. The respondents also felt that music technology will continue to play an increasing role in higher education. Chang also provided a study showing the increase of CAI (computer assisted instruction) in the music classroom.[50] Using many surveys to back his hypothesis, he asserts that the use of CAI will increase the student's learning curve in music fundamentals. This research indicates the need for increasingly functional software for the classroom. This software will be a valuable asset to music education classrooms.

While there is much literature surrounding MIDI, its development, and its growing use in the area of music making and instruction, there is not literature discussing the use of MIDI in the area of intonation instruction. This document adds yet another facet to the ever-growing advantages of music technology.

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[49] See Guillermo Mager, "The Status of MIDI in the Curricula of Higher Education Institutions Offering Degree Programs in Music" (Ph.D. diss., New York University, 1997).

[50] See Kok Chang, "The Effect of Computer Based Music Education Software With MIDI Versus Virtual Keyboard Use on Student Achievement and Opinion" (Ph.D. diss., University of Alabama, 2001).

CHAPTER TWO

PITCH AND THE CHORAL CONDUCTOR

BACKGROUND INFORMATION

Discussion on the topic of intonation requires a basic understanding of the development of pitch. Pitch is defined as "the subjective property of sound that enables it to be compared to other sounds in terms of high or low."[1] Pitch, therefore, is the label given to the perception of the height or depth of frequency. When a sound vibrates in a way that produces a constant cycle, it produces a frequency that can be measured. Hertz (Hz) is the label for that measurement. Intonation is then "the acceptability of performed pitches in comparison with theoretical, conditioned, or otherwise culturally accepted standards of divisions of the octaves."[2]

The perception of pitch is greatly influenced by the overtone or harmonic series. When sounded, each note produces a series of other notes known as the overtones. For example, the pitch A2 sounding at a frequency of 110 Hz has an overtone series as follows:

A2 (110), A3 (220), E3 (330), A4 (440), C#5 (550), E5 (660), G5 (770), …etc.

The overtone, also called partial, sounds one octave above the fundamental A2 at 220 Hz. The ratio between the fundamental and its first overtone is designated 2:1. The third partial at 330 Hz is 3:1 but is reduced to the lower octave for categorization by dividing by two, thus becoming 3:2. The ratio of 3:2 is the perfect

[1] John Bakus, *The Acoustical Foundation of Music* (New York: W.W. Norton, 1969), 110.

[2] See Latten. "Exploration of a Sequence for Teaching Intonation Skills and Concepts to Wind Instrumentalists".

fifth above the fundamental. The fourth partial is another octave, and the major third is the fifth partial at 5:4. The notes become considerably softer as they get higher. However, a good cello can produce up to fourteen audible overtones. Non-harmonic tones exist as well, but only the tuning of the naturally occurring harmonics, i.e., the fundamental and its overtones, will be discussed in this document.

As early as 700 B.C. there is record of the Greeks having developed short songs and scale modes. These were primarily for voice and strings. The Greek scholar Pythagoras (c. 540-510 B.C.) enjoyed and studied musical acoustics and is credited with inventing the monochord, which was a single stringed instrument.[3] This instrument enabled him to experiment with two-note harmonies by dividing the string into different proportions. These experiments form the foundation of musical acoustics. Pythagoras discovered that most musical intervals followed a rational calculation. However, he discovered an "imperfection" in the overtone series which deeply bothered him.[4] He found that seven perfect 2:1 octaves do not arrive at the same note as twelve perfect 3:2 fifths. (Perfect intervals in this case refer to intervals matching the note in the overtone series.) The small but problematic difference of twenty-two cents became known as the Pythagorean comma. The comma also appeared when trying to modulate to different keys. For instance, when based on the natural overtone series, the "F" in the key of C is not exactly the same as the "F" in the key of D. In fact, later mathematicians would prove that "no series of a single

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[3] See Rex Weyler and Bill Gannon, *Study of Harmony* (Vancouver: Justonic Tuning Inc., 1997).

[4] The math involved in his calculations can be quite overwhelming, and this study will not go into depth on the calculations; nonetheless, this study will provide a basic overview of his findings.

pure harmonic interval will precisely match up at any point with another series of a pure harmonic interval. A string of thirds will never land on the same point as a string of fifths, or octaves, or whole tones."[5] This was not acceptable to Pythagoras, so he began work on a system that would make the music *fit*.

> The Pythagorean system is based upon the octave and the fifth, the first two intervals of the harmonic series. Using the ratios 2:1 for the octave and 3:2 of the fifth, it is possible to tune all the notes of the diatonic scale in a succession of fifths and octaves, or, for that matter, all the notes of the chromatic scale. Thus a simple but rigid mathematical principle underlies the Pythagorean tuning. The major thirds are a ditonic comma (about 1/9 tone) sharper than the pure thirds of the harmonic series. When the Pythagorean tuning is extended to more than twelve notes in the octave a sharped note, as G sharp, is higher than the synonymous flatted note, as A flat.[6]

The advantages of this system are that the fourth, fifth, and octave are tuned *pure* (matching the overtone series). However, the third and the sixth are twenty-two cents sharp. This tuning system proved quite adequate for music such as Gregorian chants that primarily used fourths and fifths. When thirds and sixths became more prominent in harmony, however, many became dissatisfied with the Pythagorean system.

Music greatly benefited from the expanded learning and information of the next centuries. Ptolemy (A.D. 90-168), who built upon the traditions of Pythagoras, catalogued all the existing tuning systems including his own. He faulted the Pythagoras system for being too fixated on numbers and not relying on the ear to create a scale which does not "repel the senses."[7] Believing that natural harmonic

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[5] Weyler and Gannon, *Study of Harmony*,5.

[6] James Murray Barbour, *Tuning and Temperament, A Historical Survey* (East Lansing: Michigan State College Press, 1951), 1.

[7] Marin F. Mersenne, *Harmonie Universelle.* (Paris: Sebastien Cramoisy, 1636), 89-90.

ratios create a beautiful order, he was one of the first to classify consonances. In this classification the octave makes up the first category, followed by the fifth and the fourth. Whole tones and thirds follow next. Building upon these pure harmonic ratios, Ptolemy created the modern major scale. This was the first scale to achieve just intonation: an intonation system in which the frequencies of notes are related by whole number ratios and therefore are lined up with the overtone series. For example, Ptolemy's scale has the following ratios:

Unison: 1/1
Second: 9/8
Third: 5/4
Fourth: 4/3
Fifth: 3/2
Sixth: 5/3
Seventh: 15/8
Octave: 2/1[8]

The Middle Ages in Europe saw more discussion in the development of pitch and scales. Polyphony expanded, and parallel organum of the ninth and tenth centuries added harmonic development. The favoring of fourths and fifths in this harmony was due to the pure harmonic sound that could be achieved. It is possible that the major third was avoided because the Pythagorean third is tuned sharp and would cause beats in the sound.[9]

The advancement of harmony in the following centuries brought about the beginning of experiments with temperament. Temperament is "tunings of the scale in which some or all of the intervals are made slightly impure in order that few or none

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[8] See Weyler and Gannon, *Study of Harmony*.

[9] Ibid.

will be left distastefully so."[10] To understand this, one must first understand the advantages and disadvantages of just intonation. Just intonation is based on one simple premise: major thirds are tuned based upon the natural overtone series at the ratio of 5:4. "The justly-intoned chords possess a full and saturated harmoniousness; they flow on, with a full stream, calm and smooth, without tremor or beat. Equally-tempered or Pythagorean chords beside them sound rough, dull, trembling, restless."[11] The "trembling" to which Hemholtz referred is known as acoustical beating. Acoustical beating occurs when two pitches sound together and the overtones interact. Two pitches close together or out of tune with the overtone series will produce audible variations in intensity of sound known as acoustical beats. The mathematical difference between the frequencies of the pitches will determine the frequency of the beats. In the just intonation system, the primary triads (I, IV, V) are all tuned pure and eliminate the beating. The price for this, however, is that the fifth of the supertonic (ii) triad is grossly flat.[12] Another problem with this system is that one cannot modulate to other keys on fretted instruments. To do so would require retuning the instrument. Though a desirable sound in the right situation, the problems make just intonation impractical.

As four-part motets developed in the 14th and 15th centuries, more and more debate about the tuning developed. There was especially dissatisfaction with the

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[10] Mark Lindley, *Temperaments. (Grove Music Online* ed. L. Macy , Accessed [11/01/05]).

[11] Hermann Hemholtz, *On the Sensations of Tone.* trans. Alexander Ellism. (New York: Dover Publications, 1954), 79.

[12] See Swann, "An Investigation into the Harmonic Intonation Discrimination and Tuning Preferences of Choral Musicians".

tuning of the thirds and sixths. Keyboard instruments continued to develop, and though voices could adapt easily, keyboards tuned to be pure in one key would have problems in another. With music gaining complexity and keyboards growing in popularity, temperament became an inevitable development.

Musicians, unsatisfied with the problems of just intonation, began experiments with temperament in the 16th century. The first mathematically precise definition of equal-temperament was given in 1577 by Francisco Salinas.[13] The simple theory behind equal-temperament is the division of the octave into twelve equal parts. This gives complete tonal mobility and makes fixed tuned instruments capable of playing in any key. The disadvantage to this is that no interval except the octave matches the overtone series. "All tempered music is a sacrifice of harmony for a gain in simplicity."[14]

The compromises caused musicians to spend countless hours in search of the best system. Many tuning systems were proposed and used, but only a few made their way into mainstream music. Some instrument makers during the 17th and 18th centuries even experimented with more than 12 notes per octave to try and achieve pure harmonies; some had as many as 53 notes per octave. These obviously proved quite impractical. By 1700, meantone had become a popular system. Meantone was a compromise between Pythagorean and just intonation. This system maintained a pure C-E interval and stretched various other intervals in order to open up some modulations. Well-Temperament was another popular system and was the original

[13] See Barbour, *Tuning and Temperament, A Historical Survey.*

[14] Weyler and Gannon, *Study of Harmony,* 40.

tuning used for Bach's famous work, *The Well-Tempered Clavier.* These systems were more functional for the emerging keyboard music, but they still had limitations. Equal-temperament's ease of transposition enabled it to gain more and more popularity and eventually become the standard that was used extensively in the 19th and 20th centuries.

Although it became the standard for tuning, many musicians have stood in opposition to equal-temperament. Alexander Malcolm in 1685 stated "that tho' the octave may be divided into twelve equal semitones, 'tis impossible that such a scale could express any true Musick."[15] Johann Kimberger stated that "if equal temperament were introduced, as so many insist, the whole wealth of keys would in fact be reduced to only two—namely, C major and A minor—since all major keys would then be mere transpositions of the others, without the slightest individuality of character."[16] "When I go from my justly intoned harmonium to a grand pianoforte," Hemholtz wrote in the mid-nineteenth century, "every note of the latter sounds false and disturbing."[17] Even contemporary composers speak of the limitations of equal temperament. Barbour asserts that "equal temperament does remain the standard, however imperfect the actual accomplishment may be."[18] Hindemith advocated training in both equal temperament and just intonation. He said, "the ear is subject to a certain danger in being exposed only to music constructed of tempered intervals; it

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[15] Weyler and Gannon, *Study of Harmony,* 11.

[16] Johann Kimberger, *The Art of Strict Musical Composition.* trans. David Beach and Jurgen Thym. (New Haven: Yale University Press, 1982), 319.

[17] Hemholtz, *On the Sensations of Tone,* 38.

[18] Barbour, *Tuning and Temperament, A Historical Survey,* 201.

accustoms itself to their clouded qualities, and like a jaded palate loses its sense of natural relations."[19] Schoenberg writes in his treatise on harmony that "we ought never to forget that the tempered system was only a truce, which should not last any longer than the imperfection of our instruments require."[20] Dalby writes, "Even though equal temperament has become the accepted standard of tuning in Western music, many authorities consider just, or pure, intonation to be appropriate for certain musical contexts."[21] Partch comments that the ear hears small number-proportions such as 2:1 or 3:2 as "strong, clear, powerful, and consonant."[22] Comparing the equal-tempered third of 125992:100000 to the just third of 5:4, one can certainly argue that the just third will have the better sound.

Just intonation is not without its own set of critics. Some musicians deem the beatless sound of the just third to be *dull* or *lifeless*. Musicians such as Pablo Casals, Emmanuel Feuermann, Jascha Heifetz, and Fritz Kreisler all favored Pythagorean tuning, deeming it to be more expressive.[23] Kirnberger described this tuning as "less dull and more stimulating" than just intonation.[24] Nonetheless, just intonation remains as a favored sound by many musicians even today.

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[19] Paul Hindemith, *The Craft of Musical Composition.* trans. Arthur Mendel. (London: Schott and Co., 1942), 28.

[20] Arnold Schoenberg, *Theory of Harmony* trans. Roy E. Carter. (Berkeley: University of California Press, 1978), 314.

[21] Bruce Dalby, "A Computer Based Training Program For Developing Harmonic Intonation Discrimination Skill" *Journal of Research in Music Education.* 40 (n2 1992), 139-152.

[22] Gary Edwin Moody, "A Practical Method for the Teaching of Intonation" (D.A. Diss., University of Northern Colorado, 1995), 7.

[23] See Moody, "A Practical Method for the Teaching of Intonation".

[24] Ibid., 4.

String ensembles and a cappella choral groups today use a form of just intonation. Singers and string players are able to adjust tuning on each chord and achieve pure harmonies. Equal-temperament still remains the standard with most choral groups performing with a keyboard instrument. Though beyond the scope of this document, it would be an interesting study to see if there is a mix of just intonation and equal-temperament tuning when choral groups perform with piano. The sound of equal-temperament has become acceptable for choral groups and would not sound incorrect to the listener; nonetheless, the sound of an a cappella choral group with impeccable just intonation still has the ideal sound.

While no tuning system can be conclusively designated as the proper or correct tuning, it is important that conductors understand the history and design of intonation. The awareness of the tuning possibilities will better prepare conductors for work with an ensemble. For the purpose of this document, just intonation will be the standard for tuning.

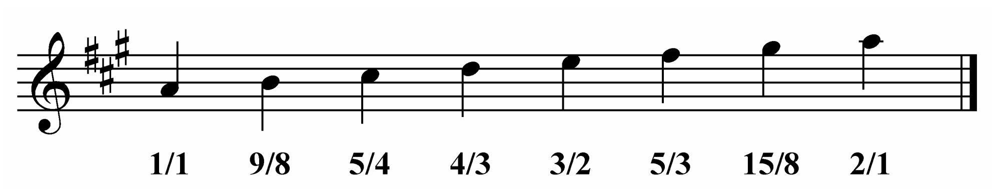
JUST INTONATION AND THE CHORAL ENSEMBLE

Hearing a good barbershop quartet provides one of the best examples of just intonation at work. These and other a cappella groups have the ability to sing in just intonation because there is no piano or other fretted instrument holding them to equal-temperament. The "sweet" sound of a great barbershop group comes primarily from singing the third in just intonation which is 14% flatter than equal-temperament.

This is also true for groups such as a string quartet. Strings, because they do not have frets, have the ability to adjust intonation. In fact, studies show that even large string sections play major triads in just intonation.[25] Even the winds and brass players in orchestras constantly adjust intonation to “fit” in the chord and the chord they strive for is justly tuned.

Just intonation is not a specific scale, but rather a system based upon a set of principles. The basic principle is that all intervals can be represented by whole number ratios of hertz.[26] As an example, the interval of C (264 Hz) to G (396 Hz) has a ratio of 3:2. Though this is close to the equal-tempered fifth, even amateur musicians can hear the difference with a bit of training. A ratio with a smaller number is simply more consonant than one that has a larger number.

Here is a simple chart showing the ratios and frequencies of just intonation when applied to the scale of A Major: [27]



Scale Step	Frequency	Ratio
A	440	1/1
B	495	9/8
C#	550	5/4
D	586.67	4/3
E	660	3/2
F#	733.33	5/3
G#	825	15/8
A	880	2/1

[25] See Slim Golba, <http://www.justintonation.com>, June 2006.

[26] See <http://www.justintonation.net>, June 2006.

[27] *Pitch Palette* Software (Justonic Tuning Inc., Vancouver, B.C., Canada, 2006).

As stated earlier, it is beyond the scope of this paper to investigate the subject of which tuning system is actually used by choirs. In reality, most choirs likely use a mix of many tuning systems, with equal-temperament being the most prominent since pianos are tuned in equal-temperament. The personal preference of the conductor becomes one of primary factors of choral intonation. Though just intonation triads are more consonant and "sweet," many conductors actually prefer the equal-tempered third because it sounds more "active" and "exciting."[28] It is the premise of this document that the practice of hearing and understanding the fine nuances of intonation will provide the ensemble director with an arsenal of color with which to direct a piece.

Compare now the differences between common intervals in just intonation and equal-temperament. The chart below shows the frequencies of notes along with the distances for each interval in C major.

[28] See <http://www.kylegann.com/tuning.html>, June 2006.

JUST INTONATION EQUAL TEMPERAMENT

It is clear that with these interval differences between just intonation and equal-temperament, choirs singing in just intonation will have a noticeably different sound than those using the piano as a tuning model.

TUNING POSSIBILITIES WITH TECHNOLOGY

Existing and emerging technology makes it possible to work with intonation in new ways. Because of the speed of technological advances, the list of software below will be out of date soon after being written. However, the following overview provides a perspective on the technology available at the time of this document's publishing.

With the proper software in hand one does not continually need an instructor standing beside to guide and train the ear in proper intonation. Computers can now "listen" to and provide feedback on intonation. Several interesting software programs have been developed to instruct the users with hearing and adjusting intonation problems.

One of these programs is CODA Music's *Intonation Trainer,* the basic purpose of which is to help students play in tune.[29] The software comes complete with a microphone and a foot pedal that the user depresses while playing a tone against a reference tone sounded by the computer. During the sounding of both tones, the computer "listens" (through the microphone) to the note being played and gives feedback as to the direction the note must move to make the interval just. The user, through practice, should get better at hearing and eliminating the beats in the sound without the computer feedback.

Pitch Palette is a fascinating piece of software developed by Justonic Tuning Incorporation, a company that believes no one tuning method should be accepted as the standard, and that different historical and experimental tuning systems provide a

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[29] See <http://www.coda music.com>, June 2006.

variety of color for compositions.[30] Justonic software works like so:

> To play pure harmony, all notes must be flexible, and they must be precisely retuned, on the fly, in real-time as you play.
>
> The Justonic software makes tuning adjustments to the pitch tables of your microtunable synthesizer. It accomplishes the task in under three milliseconds. This allows pianos and guitars, with MIDI interface, to play and modulate in just, or any other intonation, in real time.
>
> The *Pitch Palette* uses any 12-tone just, or harmonic scale based on whole-number ratios. A default scale is ready to go, other harmonic scales are provided, and the user can create his or her own scales to use with the system.
>
> From this basic scale the system creates a 3-dimensional array of tones based on the parameters of musical key, chord or tonal center, and selected intervals. Rather than twelve tones per octave, the *Pitch Palette* employs - depending on the scale being used - anywhere from 100 to 150 tones per octave.[31]

With so many notes per octave, the user can play pieces on a keyboard directly into the computer and hear it back in any tuning system the user desires. It is fascinating to hear the variety of colors created by the various tuning systems. This would certainly not be possible on acoustic pianos.

A variety of other tuning software exists, including the following titles:

Nonooctave

Lil Miss Scale Oven

Universal Tuning Format Translator

Cupcake Microtonal Synthesizer

FastTrak

Fractal Tune Smithy

Just Intonation Ear Trainer

Pitch Perfect

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[30] See *Pitch Palette* Software.

[31] See *Pitch Palette* Software.

Scala
Tune Lab

These and other tuning software offer alternatives to traditional equal-tempered tuning. However, they do not offer the opportunity to manipulate triads or intervals in real time and thus allow the user to practice hearing the sounds in and out of tune.

CHAPTER THREE

MIDI TECHNOLOGY

History of MIDI

(Musical Instrument Digital Interface)

In January 1983, at the North American Music Manufacturers show in Los Angeles, leading synthesizer manufacturers proposed what was quickly to become known as MIDI (Musical Instrument Digital Interface). KORG, ROLAND, OBERHEIM, and SEQUENTIAL CIRCUITS were several of the companies represented at the conference. This simple idea, introduced at a trade show, completely revolutionized the music industry. In just a few short years MIDI grew from a handful of users into a multi-billion dollar industry. Today, one can hardly go through a day without hearing MIDI at work. MIDI technology is used on recordings heard on the radio, the television, and in theaters.

When dealing with the subject of MIDI, the first and most important thing to understand is that MIDI is not an object. It is not an instrument or something that you play, and you can not walk into a music store and ask for a MIDI. MIDI is merely a method; it is a language that enables communication between two electronic components, and that was designed to unify the electronic music world. "MIDI was conceived as a means for musical instruments (synthesizers and drum machines) to be able to exchange basic performance control information such as "note-on/note-off" (duration), pitch, key pressure (level), program change, etc."[32]

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[32] See Mager, "The Status of MIDI in the Curricula of Higher Education Institutions Offering Degree Programs in Music."

To begin to understand the concept of MIDI, one must understand the sequence of events leading to its creation. Electronic keyboards, in their early development, were large, expensive, and available only to those few able to pay the exorbitant prices. In the 1960s, Robert Moog, using the development of the transistor as his building block, designed analog synthesizers for the mass market. These smaller more accessible keyboards quickly became popular with the public, and Moog's name became synonymous with electronic keyboards.

Wendy Carlos, who met Robert Moog and became one of his earliest customers, dreamed of new possibilities in the creation of music. She took Bach compositions and performed them on Moog's electronic instruments, and the resulting album, *Switched on Bach,* became one of the best-selling classical albums of all time.[33] The race for new and better synthesizers had begun.

The public demand for synthesizers drove the market to invent a variety of new electronic instruments. It seemed that as soon as a new synthesizer was purchased, another model took its place on the store shelves. With the increasing availability of electronic instruments and new technologies to create sounds, the musical world began to recognize synthesizers as a legitimate instrument in the evolution of music.[34]

The early analog synthesizers did not have the ability to connect or communicate with one another. Each keyboard had its own strengths and weaknesses, and many of the touring musicians performed with multiple keyboards to create a

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[33] See <http://www.infocellar.com/sound/midi/history.htm>, June 2006.

[34] See <http://www.midi.com>, June 2006

variety of sounds. In addition, musicians desired the ability to "stack" sounds from multiple keyboards in order to create a rich, thick sound. However, the musicians were limited by having only two hands with which to play. This drove several of the large companies from the United States, Japan, and Europe to begin development on a standard that would transmit musical performance information between all types of electronic instruments. The results of this development led to a proposal called UMI, for Universal Musical Interface, and after several more meetings and revisions, the Musical Instrument Digital Interface was released: MIDI 1.0.[35] Once introduced, MIDI was quick to gain universal acceptance.

> MIDI is a fully documented operating protocol and a defined instruction set. (Via MIDI), instruments can be played simultaneously or remotely; entire compositions, consisting of monophonic and polyphonic sequences and rhythm, can be played at one touch; a computer terminal can be used for composing, sequence creation, and editing; and video synthesis can be integrated with music synthesis.[36]

MIDI is essentially an electronic language that communicates data between devices using a series of numbers or bytes. The MIDI language uses numbers from 0 to 127. The creators of MIDI chose a simple five-pin plug called a *Din plug* to transmit data. Keyboards and other MIDI devices can be connected to a computer or another MIDI device to send messages back and forth. The types of messages sent include note-on, note-off, velocity (how hard a note is struck), pitch, and duration. Musical parameters such as volume, timbre, sustain, and most importantly for this

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[35] See < http://www.midi.com>, July 2005.

[36] Mager, "The Status of MIDI in the Curricula of Higher Education Institutions Offering Degree Programs in Music.", 16.

document, pitch, can be manipulated using MIDI messages.[37]

According to the specifications, MIDI devices must have a MIDI IN, MIDI OUT, and MIDI THRU ports. One device will send information to another via its MIDI OUT port and receive information in return through its MIDI IN port. MIDI keyboards are designed to capture the performance of a musician and pass the data on to other MIDI devices or computers. This allows keyboards to be connected together or “stacked” and therefore allows musicians to play multiple keyboards at once.

Sequential Circuit was the one of the first companies to ship a synthesizer utilizing the still infant MIDI technology. The company’s synthesizer, the PROPHET 600, successfully connected with Roland’s JP-6, thus officially beginning the MIDI race.

As computers developed, more and more possibilities began to open up in the world of MIDI. Since MIDI sends musical performance data, computers can capture the data and then play it back, essentially playing the instrument with all of the parameters of the original performance. Musicians can play layer after layer of data into the computer and have it played back so that the synthesizer becomes an orchestra in and of itself. One is only limited by the amount of sounds the synthesizer is capable of playing at once (or its multi-timbral capability). With each passing generation of keyboard and computer, more complexity becomes possible.

The MIDI control over pitch is the one directly related to this document. Using MIDI data, one can send pitch bend data to each note on a keyboard. It is this

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[37] Al Willis and Nicole Hampton and Adam Wallace, “MIDI: A Beginner’s Guide.” (< http://www.mtsu.edu/~dsmitche/rim419/midi/HTMLs/Contents.html>, June 2005).

control that allows the software accompanying this document to provide a simulated environment in which the conductor can manipulate pitches and practice tuning.

MIDI AND MUSIC EDUCATION

The technology of MIDI has infiltrated all levels of education and is expanding with each passing year. From classes for the youngest of children to classes for college music majors, MIDI has enabled instructors to develop new curriculae for the teaching of music skills. MIDI enables the user to control musical parameters, thus allowing one to experience and create a great variety of music with a simple keyboard and computer. Computers can also “test” musical skills and provide instant and intuitive feedback. This opens the door for the development of a wealth of software designed for the pedagogy of music skills.

Several studies have shown that computer-assisted instruction (CAI) is an effective tool for gaining music skills. Even as early as 1984, shortly following the invention of MIDI, studies began to determine the effectiveness of CAI in music education. John J. Deal’s study at the University of Iowa determined that software could significantly help music majors develop skills in error detection.[38]

David L. Jones developed a software system that would allow students to practice error detection skills.[39] He then studied the results of students using his software against traditional education methods and determined that the CAI method proved more effective.

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[38] See Mager, “The Status of MIDI in the Curricula of Higher Education Institutions Offering Degree Programs in Music.”

[39] Ibid.

Louis A. Hesser also worked on a system using CAI.[40] His primary purpose was to help students acquire music reading skills. The results of his study also show that students using his software achieved a greater aptitude for reading music.

Recently, there has been a rapid growth in software offered for the training of skills in music fundamentals. Software designed for this purpose allows students to work at their own pace and on specific skills of their choice. By working on the software at their own pace and by making infinite repetitions, students can master skills more quickly than those students utilizing only the traditional classroom. There are many software titles available on the market, and more are being developed.

Ars Nova Software is the maker of one of the largest software programs for the training of music skills. The software *Practica Musica* has exercises designed to train students in the fundamentals of music and is used by thousands of schools and colleges worldwide.[41] The exercises range from building scales to advanced composition, and include ear-training exercises for chords, rhythms, and melodies. One of the most innovative features of this software is its ability to cater the training to the individual students. For example, if a student answers a problem incorrectly, the software adjusts the exercise to ensure that the skill is mastered. Using MIDI technology, the student can utilize a piano keyboard to input answers into the computer which enhances the learning experience, especially for tactile learners. The software records the progress of each student and reports to the instructor, thus allowing the instructor to monitor the progress of each individual in the class and then

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[40] Ibid.

[41] See <http://www.ars-nova.com>, June 2006.

adjust classes to work on deficiencies.

Auralia, by Rising Software, is another popular music theory software title. It includes many of the same types of exercises as *Practica Musica.* One difference is that *Auralia* allows the user to input answers via a microphone. For instance, the software will play a chord and then ask the student to identify and sing the notes of the chord into the microphone. The software recognizes the notes sung by the user and then provides feedback.

Some other music theory software titles are:[42]

1. MacGamut
2. ECS Software
3. Music Ace
4. Musica Analytica
5. Musition
6. Teoria
7. Ear Master
8. IMAJA Creativity Software
9. Music Study
10. Score Scan

Another area in which software has been helpful is the education of children. One company that continues development in this area is MIDI For Kids which "exists to help students learn to love music by developing their instrumental performance skills in digital keyboard and guitar, to guide students in the exploration of creative musical concepts, and to help students apply these concepts to other subjects."[43] This program allows children to create music with the support of surrounding MIDI orchestration. Though it cannot realistically duplicate a live orchestra, MIDI can provide a reasonable simulation, and, by encouraging creative music in a fun

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[42] See <http://www.pldi.net/~murrows/tpsoft.htm>, June 2006.

[43] See <http://www.midiforkids.com>, June 2006

environment, MIDI For Kids teaches the elements of music and develops improvisational skills.

A catch phrase in music technology for children is “Music-Minus-One.” This technology in piano instruction allows the keyboard to play one of the hands at a steady tempo while the student plays the other. This allows the student to play the music in context at any tempo and take as many repetitions as needed.

Teachers also use MIDI in their classrooms to accompany music lessons. Since MIDI music provides a variety of adjustments, teachers find it very helpful. They can slow down the accompaniment or change the key to fit the situation, and they can also omit certain instruments and have students play the omitted music in its place.

There are many websites dedicated to developing music skills. One of these, Creating Music, at www.creatingmusic.com, allows the user to compose music on a screen based sketch pad. Once the music is “written down,” the user can play the music back using MIDI messages sent to sound card of the computer. Most computers have a built in sound card that can respond to MIDI messages and play a variety of simulated instruments. The software encourages creative composition and, with the ability to immediately hear the product, keeps the interest of the user.

One of the fastest growing aspects of MIDI is the proliferation of files available on the internet. A large number of pieces from classical to pop are available for download on the internet, and these files allow students to hear and, most importantly, manipulate music pieces. Students can “solo” certain members of the orchestra in a complicated piece in order to hear and understand the function of that part. They can also change articulations, durations, attacks, etc. in order to hear the most effective performance of the piece. Teachers are finding that this is a very effective tool in music composition.

MIDI SOFTWARE

The last decade has seen tremendous growth in the availability and the functionality of music software titles. The two largest types of music software utilizing MIDI technology are notation and sequencing. Each of these software packages provides unique and professional possibilities to anyone from home computer users to recording studios. Notation software is used for printing music, and sequencing software is used for recording music.

With notation programs, music can be inputed into a computer and then laid out for printing. This technology has proven to be very beneficial for composition courses along with any other course involving the creation of music. Students can immediately hear their work as the software has the ability to play back the notes being entered. With training, publication level music can be engraved by any person with a computer and the appropriate software.

Finale, by Make Music Incorporated, is one of the largest and most comprehensive notation software on the market. *Finale* has the ability to create almost any type of print music imaginable allowing the user to input anything from full orchestrations to avante garde scores. The notes can be entered by typing them in or by inputing them with a keyboard via MIDI. *Finale* can even “listen” to someone playing the MIDI keyboard and notate the performance. With the instant feedback provided by the software, the composer can check the accuracy of the music. The software even plays back the music using the appropriate orchestral sound selected by the user, thus giving the composer a feel of the piece's effectiveness.

Finale's primary competitor on the market is *Sebelius. Sebelius* continues to grow, develop, and capture more of the market away from *Finale.* Essentially, *Sebelius* has similar features, but the methods of input and layout are different. With musicians devoted to *Sebelius* arguing for its ease of use, recent editions of *Finale* have attempted to incorporate some of the user friendly functions of its competitor.

Early in its development, sequencing referred to the ability to record electronic musical instruments. However, as computer speeds and capabilities increased rapidly in the 1990s, audio recording and sampling was added to the package. This advanced set of software is now often referred to as a digital audio workstation (DAW). Unlike notational software, sequencing software does not create music for the purpose of print. Instead, sequencers record MIDI tracks performed by synthesizers, drum machines, and samplers, and audio tracks can be recorded and combined with the MIDI tracks.

While a myriad of DAW software is available on the market, a few of them have emerged as industry leaders. The Steinberg company program, *Cubase SX3*, combines audio and MIDI recording and editing, virtual instruments (explained later in this document), and music notation.[44] This software alone in a studio has the power to accomplish what previously would have taken an entire room of equipment.

One of the primary competitors to Steinberg is the Cakewalk company and its

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[44] See <http://www.steinberg.net>, June 2006.

DAW software platform, *SONAR*.[45] Though it has a different look and feel than *Cubase*, it is very similar in function.

On the Macintosh platform, one of the most popular DAW software packages is designed by a company named MOTU (Mark of the Unicorn).[46] *Digital Performer* has been a standard for professional audio studios since its inception, and has powerful features combined with intuitive operation. This software is not available for the PC at this time.

One of the most exciting developments of recent years is the technology of soft synths. Computer software can now contain sounds that previously had to be stored inside synthesizers and keyboards. With MIDI connections a keyboard can access the sounds housed on the computer allowing users to collect large libraries of sounds without having to purchase additional synthesizers.

Virtual orchestras are available in software format. With these, actual symphonic musicians are sampled (recorded) in a studio playing each note of their instrument, and these notes are then transferred onto computers. Users can then access these notes via MIDI. Virtual orchestra packages are available in very simple format around $100 to detailed and sophisticated packages costing thousands of dollars.

One of the most complete virtual orchestra packages available is the *Vienna Symphonic Library*. Upon its release in 2003, this library won numerous awards for its incredible detail and realism.

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[45] See <http://www.cakewalk.com>, June 2006

[46] See <http://www.motu.com>, June 2006

> The Vienna Symphonic Library's symphonic editions are orchestral sample libraries of unprecedented sonic dimension. The complete range of the modern symphony orchestra has been recorded in a specially constructed recording stage designed expressly for the rigorous demands of orchestral sampling. [The] revolutionary Performance Tool allows for playing techniques such as true legato and repetitions, which are key to making this library sound so uniquely real, and have no equal in any other sample libraries.[47]

The engineers for this software designed a special room in which to record each of the instruments in the orchestra playing all types of articulations such as legato or pizzicato etc. These articulations can then be called up by the user when recording or playing back sounds. Though it still does not replace a live symphony orchestra, the technology is very realistic and provides a great option for the creation of music. The cost of this software ranges between $2,000 to $3,000.

The next decade will continue to see rapid growth in the capabilities of the software. One of the difficulties will be staying on top of the changes in music technology. However, more and more can be accomplished, and when used correctly, technology can be a very useful tool for education and performance.

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[47] See <http://www.vsl.com>, June 2006

CHAPTER FOUR

TUNING SOFTWARE DEVELOPMENT

The Design

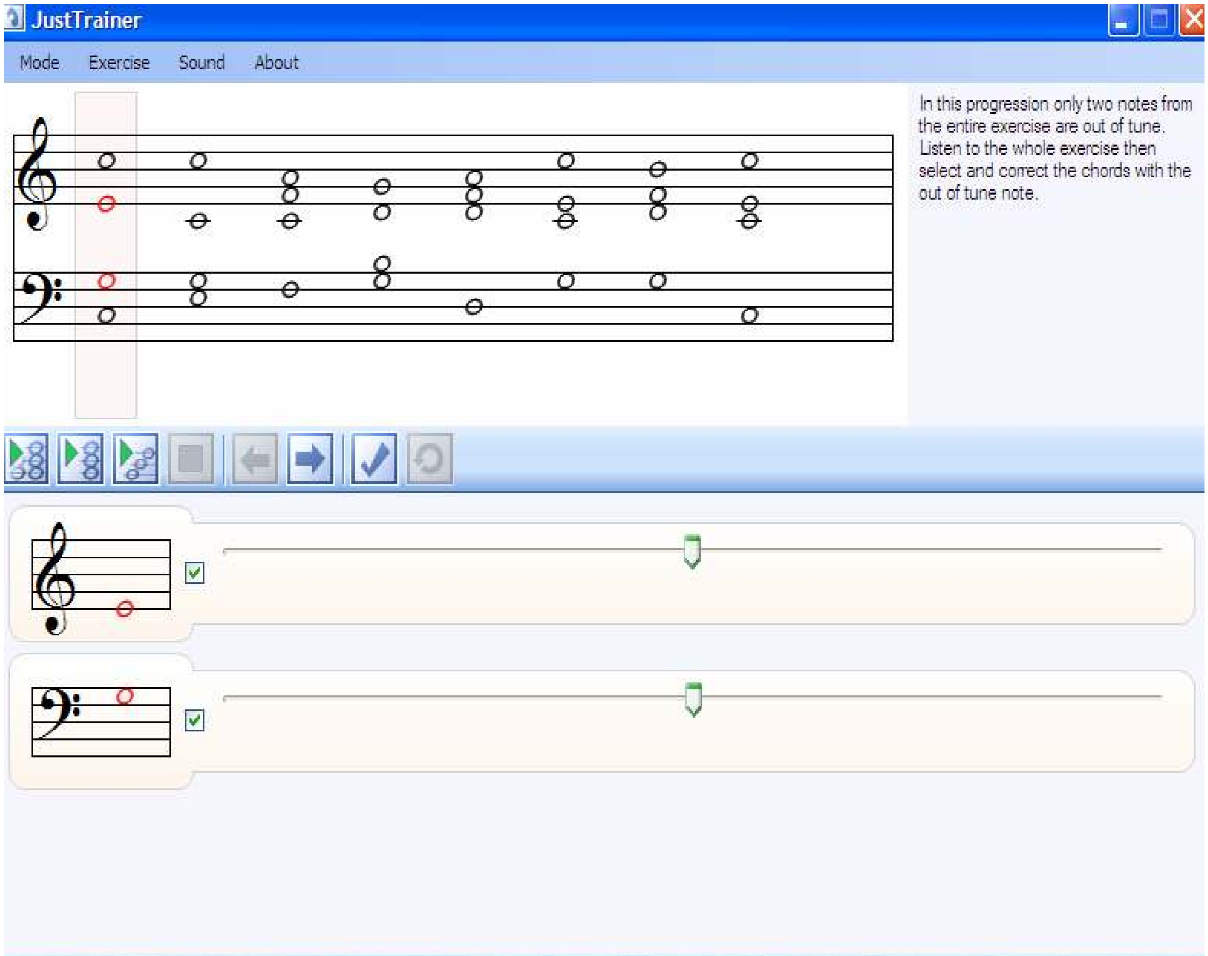
While a large variety of music software packages are available, only a few address the issue of intonation. As research for this document progressed, it became clear that with the technology available and with tuning being a high priority for musicians, software should be developed to assist in the pedagogy of intonation.

The initial research for tuning software options began with a comprehensive look at the software currently available on the market. As stated earlier, one of the only widely distributed tuning software packages on the market today is CODA Music's *Intonation Trainer.* This software package is most useful for instrumental musicians learning to play in tune against a reference note. It is not as useful for hearing and manipulating a variety of chords and intervals to train proper intonation. However, the ideas for *JustTrainer* (the software accompanying this document) began with a feature included on this software. In *Intonation Trainer,* the user can hear basic chords and move the thirds higher and lower to hear beats. CODA Music has a few competitors on the market such as TuneUp System's intonation software, but they primarily provide the same set of functions.

With these software packages focusing primarily on the intonation of instrumentalists, it became clear that a more comprehensive intonation software package was needed, one specifically designed for conductors or teachers. By creating software utilizing a variety of intervals, triads, and timbres, the user would gain a greater aptitude for hearing intonation in the context of the music. The design would be directed more towards the ensemble directors rather than the ensemble players, although there would certainly be benefits for both.

The first step towards the creation of the software came in designing an overall “look.” The ease of use of any software comes in the ability of the user to comprehend what is happening on the computer screen at any given moment. Because many software programs are abandoned early in the process due to the steep learning curve, it was important in this software to design a screen that was simple yet comprehensive in nature. *JustTrainer* was designed to be simple and to be user-friendly.

Many music software packages, including notation programs, music theory programs, and sequencing programs, were researched during the creation of the screen design for *JustTrainer.* The decision was made to create a screen built with a grand staff across the top to display the intervals and chords being tuned. With this as the central feature, the user would be clear as to what chord or interval is being tuned at any given moment. Control over the individual pitches would be achieved by creating a series of left to right “sliders” that could be manipulated with a mouse. The notes being manipulated would be shown by a staff just to the left of each slider allowing the user to see the entire chord and easily recognize the individual notes being tuned. With these things in mind, the design for the software was as follows:



As the above illustration shows, the staff on the top indicates the series of chords being played that could need tuning. The screen shot shows that the first chord is currently selected for tuning. The individual notes of the chord show up below the staff with the left to right sliders giving the user the option to make the note higher or lower. This design seems to have the ease of use that allows the user to spend the maximum time utilizing the software instead of learning the software.

INITIAL DEVELOPMENT

Once the design was determined, the functions of the software became the priority, and after several consultations and trials, it was determined that having users manipulate a note smoothly using MIDI pitch bend technology would allow them to fine tune their ears. These listening trials were done on a micro-tunable KORG keyboard (synthesizer) that allows for different tuning systems and can receive MIDI pitch bend commands. The user can pick from a variety of tuning systems, including the default equal-temperament or just intonation. Using the pitch bend wheel, notes in triads were manipulated higher and lower. Listening to the difference between just intonation and equal-temperament made it clear that the user can benefit from listening to and adjusting between the two systems. It also showed the feasibility of using keyboard sounds to hear beats in chords.

After determining the design and functions, a meeting was scheduled with the company SEAKINGS[98] to work out the technical aspects of the tuning software. The first of these technical aspects dealt with the most practical way for the user to adjust and listen to the tuning of the chords. The initial thought was to have the software utilize a micro-tunable keyboard, such as the KORG, connected to a computer via a MIDI interface. This setup would allow the user to utilize the pitch bend wheel on the keyboard to tune the notes up or down. The software would also play back the chords using the sounds built into the keyboard. The obvious problem with this idea is that the keyboard would have to be present in order for the software to work. This would restrict the use of the software to users who would happen to have the right type of

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[98] See <http://www.seakings.net>, June 2006

keyboard. Because of this limitation, a new way to create the software had to be found.

The second idea was to create the software to run strictly on the computer (PC) with no external keyboard needed. The software would play back the sounds with the sound card built into the computer, and the tuning would be done using sliders on the screen. As this option was pursued, it became evident that problems were going to arise when using the built-in sound cards. Many different companies make sound cards for computers, so the sound cards are not identical. It would be impossible to predict what card would be present in the computer and how it would respond. Each card has a unique sound, and the differing timbres could affect the intonation. Also, the software sends MIDI pitch bend messages in order to tune the notes. Each sound card would respond in a slightly different manner to the messages. Since MIDI sends messages using numbers between 0-127, one card, responding to a pitch bend command of 5, might move the sound 10 cents while another card might move the pitch slightly more or less. With the whole point of the software being to hear chords precisely in just intonation, a few cents off would negate any benefit of the software.

The final option then was to build the software using sounds that could be included with the software and installed directly onto the computer. This option would ensure that each user was hearing the same timbres and that all of the sounds would react identically to the pitch bend messages. Here is how the sound files work on the *JustTrainer* program:

> In order to playback an instrument, multiple source files are configured for the application. These sound files are assumed

> to be sampled (recorded) from an equally-tempered scale. Each sound file is a recording of the instrument [or voice] at various pitches. Only one sound file is required per instrument, but providing more sound files yields a more natural sound during playback. During playback the sound file is accelerated or decelerated to achieve the correct pitch (similar to speeding up or slowing down a record player).
>
> JustTrainer was written in the C# language utilizing the Microsoft .Net Framework v2.0 for Microsoft Windows. This provided a solid foundation of common windows interface components that Microsoft Windows users are comfortable using. The FMOD Sound Library was also used to implement the sound loading and playback. This development library includes support for loading a number of sound formats including WAV, MP3, OGG, etc., (although compressed formats such as MP3 or OGG may not exhibit the crucial overtones necessary for just-intonation training).[99]

THE SOUND LIBRARY

With the understanding of how the software would utilize sounds, the next step was to build the sound library. One of the significant aspects of this software is its ability to handle various sounds when listening to the tuning. The different timbres provide an assortment of listening options for intonation practice. The sounds needed for this software had to be clean samples that produce clear overtones. They also had to be royalty free and available for public distribution.

Though this software is primarily designed with choral conductors in mind, it is important to have a variety of timbres (both instrumental and vocal) on the software. Vocal samples are among the most difficult sounds to tune due to the complexity of the overtone structure, so it was determined that sounds simpler to tune should be included. With that in mind, many sounds were auditioned for software,

[99] See Ted Wehner.

including strings, keyboards, winds, brass, and vocal. The sounds chosen for the software include a clarinet, french horn, oboe, organ, and several vocal samples.

There were several other sounds that were attempted for use with *JustTrainer* but were rejected for various reasons. The first was a trumpet sample. While the samples provided a bright brass sound, they proved to be troublesome for the software. Even after filtering through *Sound Forge*, the samples had too many variations of pitch, and the timbre was thin and annoying. Another rejected sound was a string sample. Though good string samples are available for purchase, they were not practical for this document since they proved to be difficult when listening for the overtones. The *ILONA* CD (explained later in the document) included “ooh” and “aah” samples that had been processed through a reverb unit which adds “live-room” feel to the sound. These samples sounded as if they had been recorded in a cathedral setting. At first, it was thought that this would provide a nice variation for the tuning software. However, the reverb caused an echo effect in the *JustTrainer* software that made it very difficult to tune. The final rejected sound was the sample of a full choir singing “ahh.” This sample proved to be too thick for the software to handle, and could not be efficiently tuned.

The first sound (and the default sound) needed to be one that created crisp and clear overtones in order for the user to clearly hear the beating in the sound when tuning. A clarinet sample was chosen and inserted into the program. The clarinet sound in JustTrainer uses only one sampled note, F3, which the software accelerates or decelerates to create all of the other pitches. The sound must infinitely sustain so that it continues while the user manipulates the pitch. However, the actual clarinet sample lasts only five seconds which would not provide enough time to hear and then adjust the pitch without replaying the sound over and over. To overcome this problem, looping technology is used. Looping is a way for a sound to automatically replay itself with no breaks in the sound, thus allowing the sample to play for an infinite amount of time.

The looping was accomplished using a program called *Sound Forge 6.0*.[100] *Sound Forge* is an audio editing program that allows users to work with any sound file. In audio editing programs users can work with sound files and adjust a myriad of parameters including volume, length, fades, pitch, and timbre etc. In this case *Sound Forge* was used to create the looping effect. In the five-second clarinet sample, a beginning and ending point was chosen for the loop, with the points matched so that a click or pop will not occur every time the sound loops.

The following two examples of the clarinet wave illustrate the procedure used for matching the loop points. In these graphics, taken from screen shots of the program *Sound Forge*, one can see the actual clarinet wave across the top. One can also see the two points set for the looping. In the bottom part of the screen shot is a magnified view of the beginning wave point and the ending wave point. The line in the middle part of the bottom screen shows the point at which the sample loops from the ending point and repeats back to the beginning point. In the first screen example the loops do not line up and this example would have a pop or click every time it reaches this point. The second screen shot shows a loop point that would flow continuously and seamlessly.

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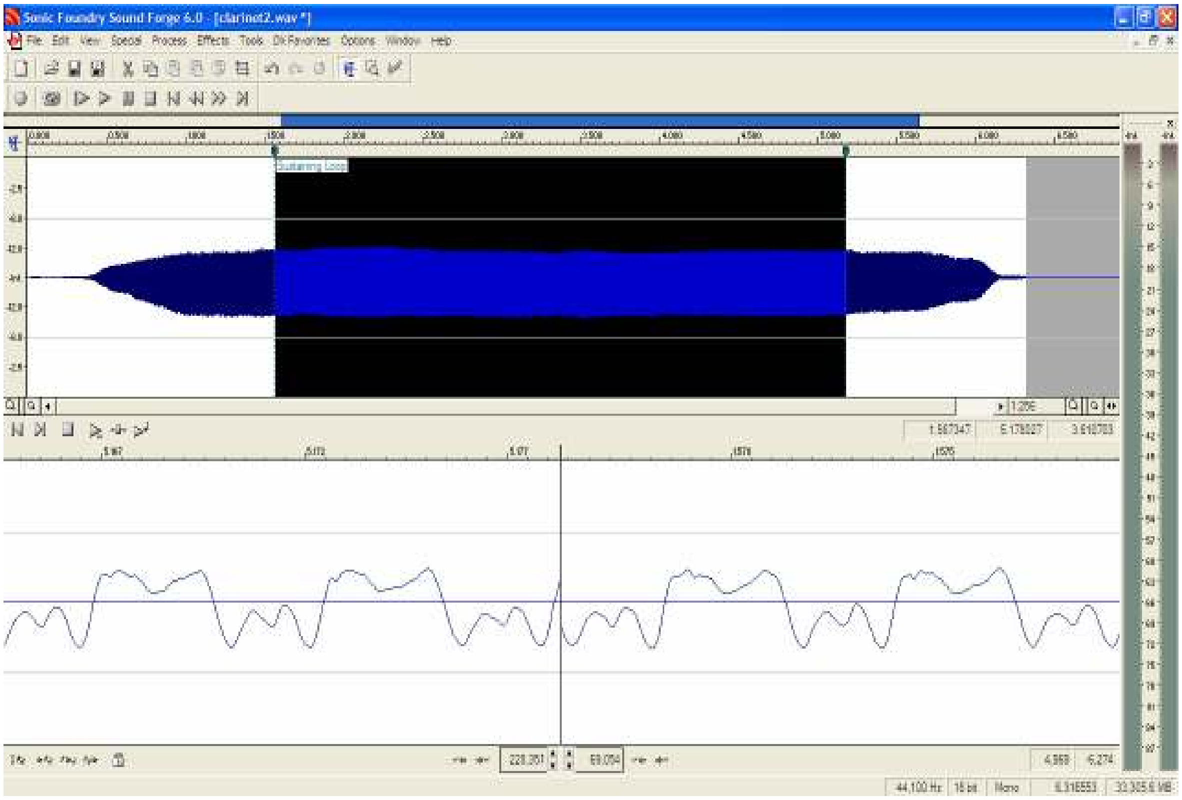
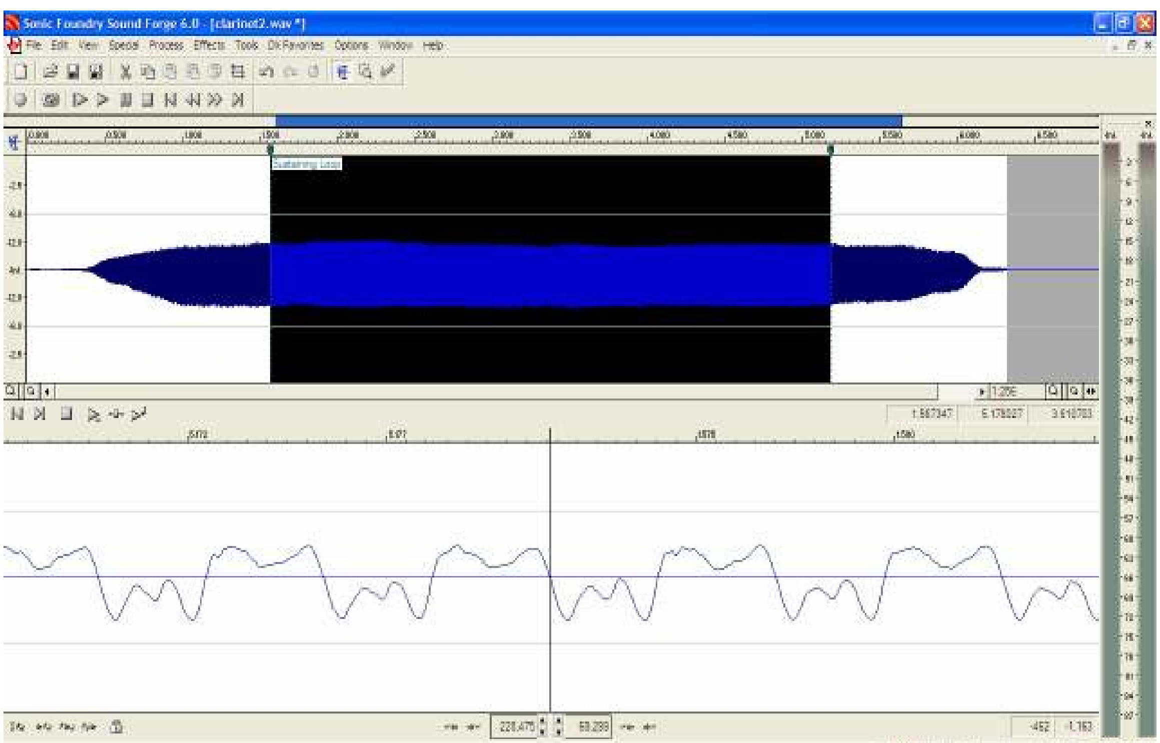
[100] See <http://www.sonicfoundry.com>, June 2006.

Example One: Unmatched Clarinet Loop

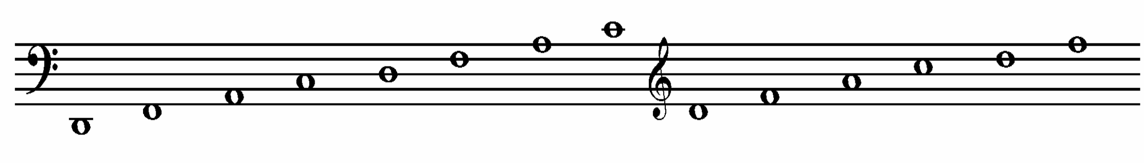


Example Two: Matched Clarinet Loop

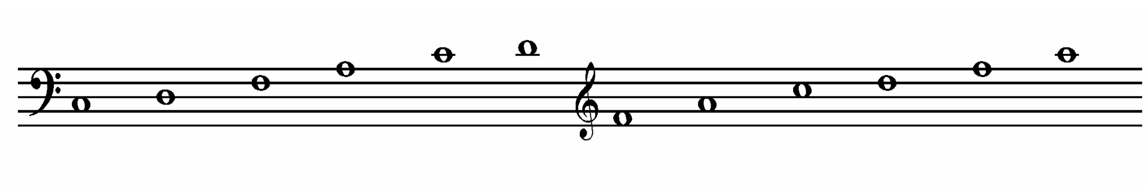


The clarinet sound provides a great beginning sound to use for the software. The overtone beats are clear and quite easy to hear when adjusting the tuning. To provide a nice contrast to the clarinet sound, the next sound loaded into the JustTrainer software was a French horn. The French horn samples were obtained from a virtual orchestra software called the *Garritan Personal Orchestra,* which includes samples of all instruments in a symphony orchestra. The software was loaded onto a laptop computer, and the French horn samples were auditioned. The samples proved to be clear and free of vibrato or pitch variations. A virtual keyboard appears that allows individual notes of the loaded instrument to be played.

As the individual notes were played via the software on the laptop computer, Sound Forge recorded the notes. D2, F2, A2, C3, D3, F3, A3, C4, D4, F4, A4, C5, D5, and F5 were recorded for the French horn.



Organ samples, which also came from the *Garritan Personal Orchestra* software, were the next sounds to be loaded into the software. The organ “prinzipal” sound was chosen, and the pitches C3, D3, F3, A3, C4, D4, F4, A4, C5, D5, F5, and A5 were sampled.

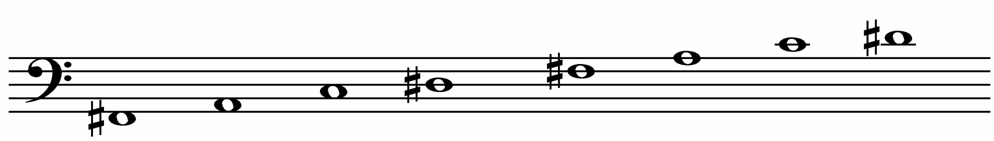


The second organ sound, “Haupt Mix,” uses a fuller pipe organ timbre. For this sound only one note, A3, was sampled.

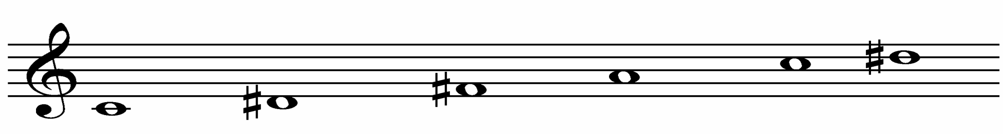
Finding a realistic vocal sample that was license and royalty free proved to be very difficult. Most of the samples that had no royalties were problematic in areas such as distortion, pitch problems, and timbre variations. The decision was made to create vocal samples exclusively for this project.

The first step in creating new samples is setting up a recording session. The recording session was held at the studio owned by Southern Nazarene University in Oklahoma City. For the session, one microphone was plugged into a microphone pre-amp and then routed into the *Cubase* DAW software package. Three singers were booked to come in and provide the vocals for recording. The singers were made up of a baritone, an alto, and a soprano in order to provide a fairly wide range of samples.

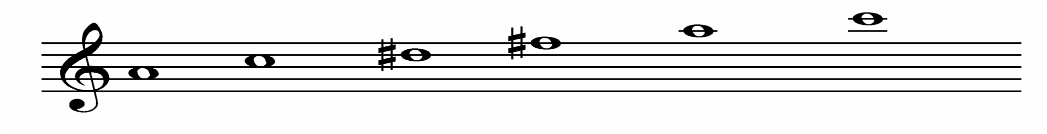
It was decided that samples would be taken at every minor third from F2 to C6. This would allow for the software to provide the most accurate playback of the samples when tuning. The singers were asked to sing a pure “oo” (as in “soon”) vowel that would be held for approximately fifteen seconds. The tone had to be free of vibrato. The baritone began the recording session and recorded F#2, A2, C3, D#3, F#3, A3, C4, and D#4.



The alto recorded C4, D#4, F#4, A4, C5, and D#5.



The soprano recorded A4, C5, D#5, F#5, A5, and C6.

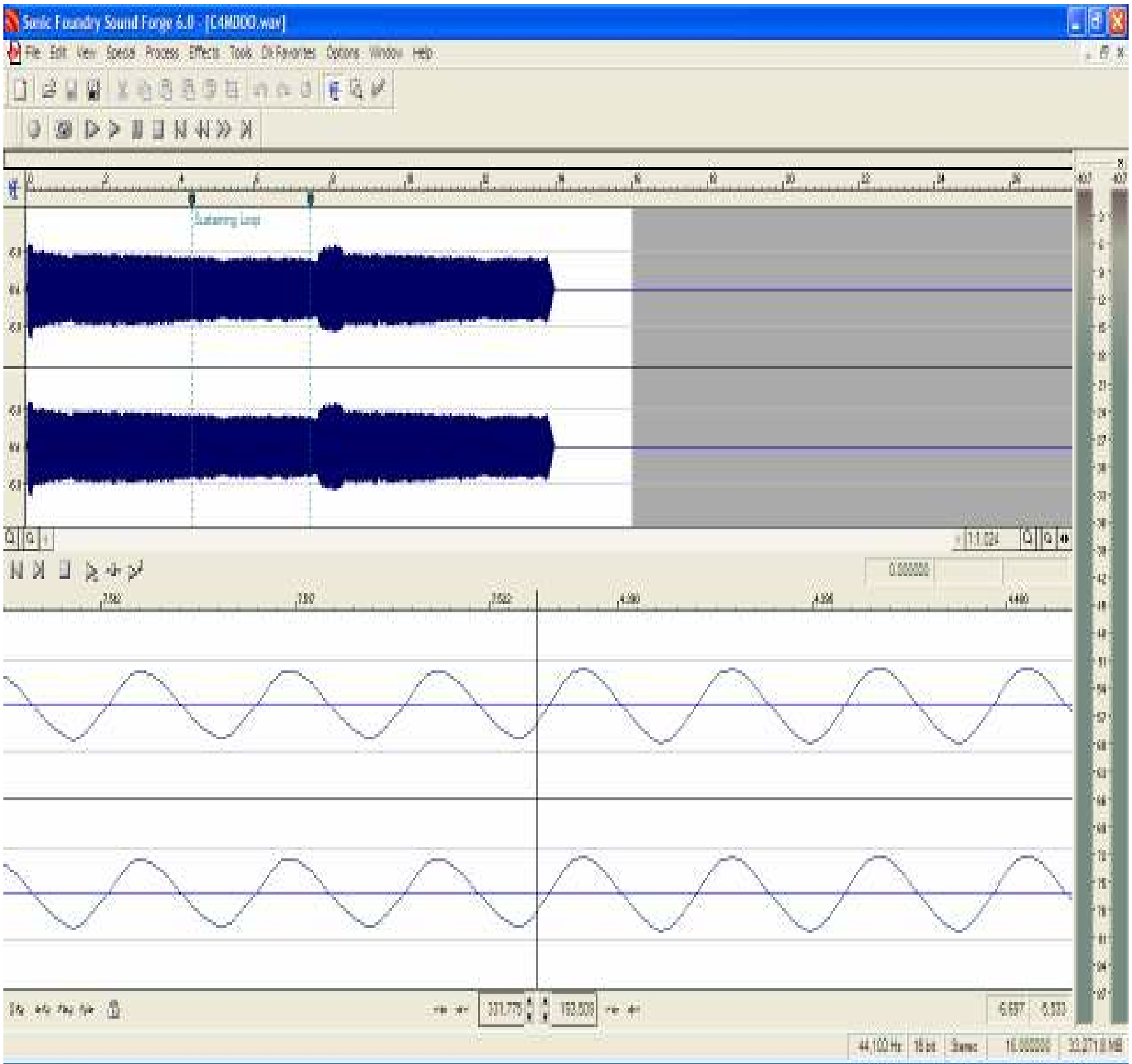


As illustrated above, the three singers recorded notes that overlapped. Each overlapping note was loaded into the program and auditioned to see which provided the clearest timbre and overtones when used within a chord. The notes with the best sound were then chosen for the final copy.

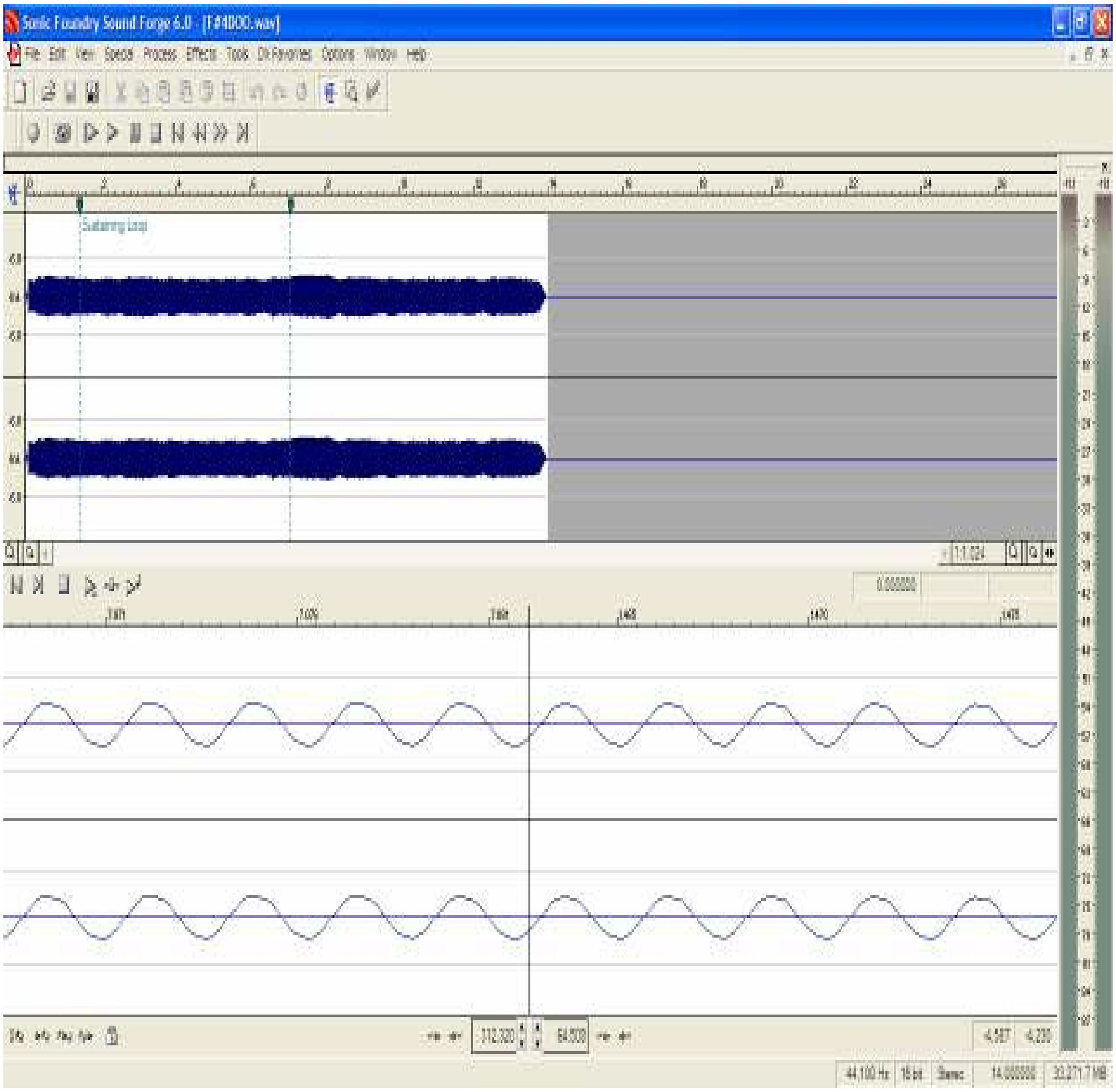
One of the keys to this software working correctly is having all of the samples tuned exactly to the equal-tempered scale. To make sure that all of the vocal sample recordings were accurately tuned to the equal-tempered scale, they were processed through a pitch tuning software called *Antares Auto-Tune. Auto-tune* "looks" at the pitch of any given note and automatically adjusts it up or down to make it accurate. The user tells the software what pitch the sample should be, and the software makes sure there are no pitch fluctuations. *Auto-Tune* can be set to a variety of tuning systems. In this case, since the desired tuning is equal-temperament, the software is set to a chromatic equal-tempered scale. Below is a screen shot of Auto-Tune set to listen to an instrumental sample with the pitch "A":

Once tuned, the vocal sample recordings were then run through the *Sound Forge* to make sure all of the volume levels were similar and all of the loops were created correctly. Below are screenshots of the baritone, alto, and soprano waveforms from *Sound Forge*. In each of the screen shots are the stereo (left and right) waveforms and the properly connected loop points. Note that the lower (baritone) notes have a longer wavelength and the higher notes have a shorter wavelength.

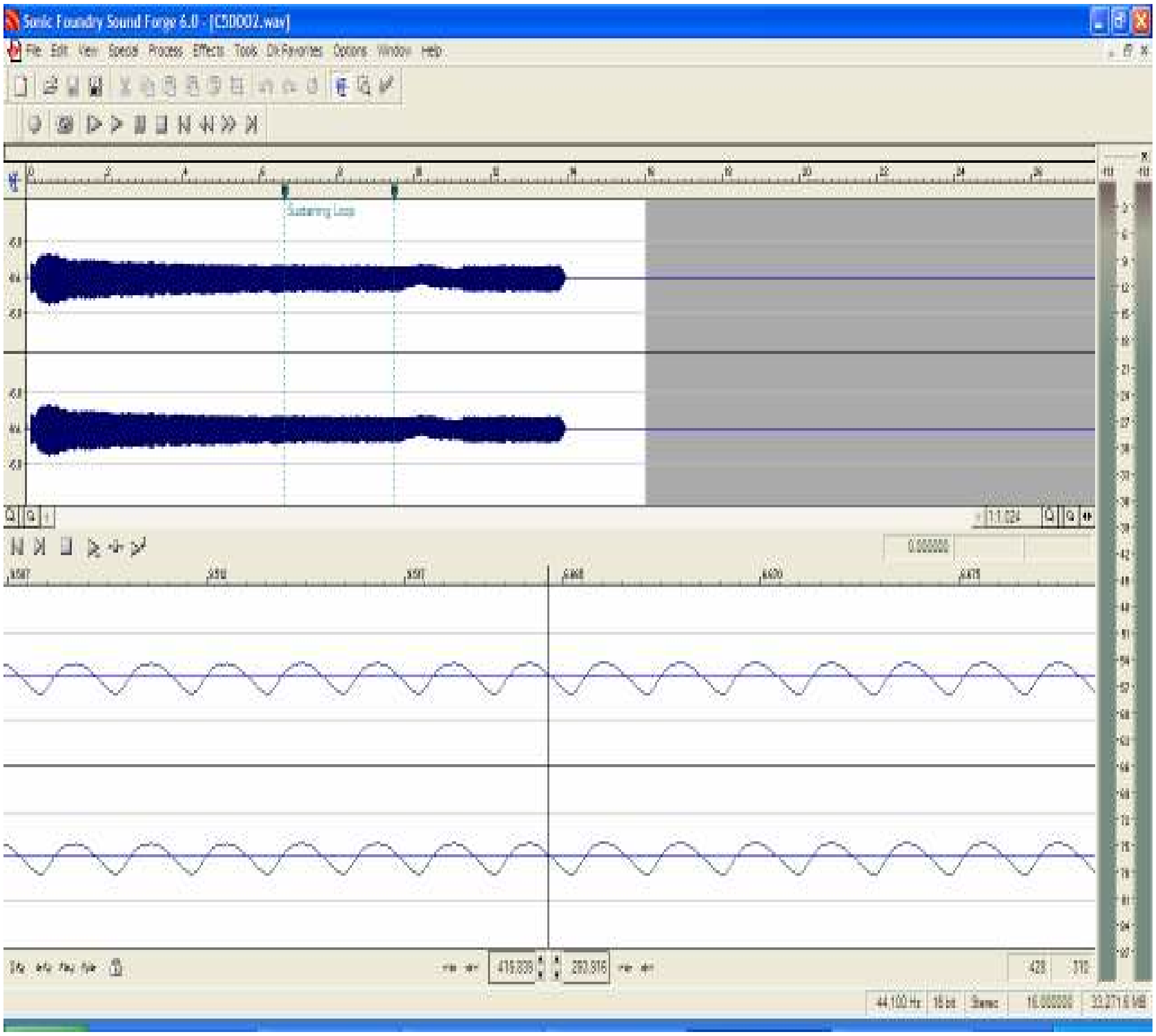
Baritone C4 Sample



Alto F#4 Sample



Soprano C5 Sample



Though these recorded vocal samples provide an excellent sound library for the *JustTrainer* software, it was hoped that several other vocal samples could be loaded in to provide a variety of timbres. As stated earlier, commercial vocal samples free of royalties or high cost are difficult to obtain. However, one of the commercial sources for vocal samples that proved to be practical for the *JustTrainer* software was made by the SONY Corporation, which makes many looped based samples available for distribution. One such series is the *ILONA! Universal Female Vocal Toolkit.*[101] This is a CD Rom based software that contains samples of a female singer named *Ilona*. There are many different types of samples on the CD using different vowels and phrases, and its primary use would most likely be for pop or hip-hop music. However, the samples used for *JustTrainer* are note by note recordings of *Ilona* singing the vowels "oo" and "ah." These samples were extracted from the disc and filtered through both *AutoTune* and *Sound Forge* for accuracy and volume. Since this is commercially distributed software, it was a bit disturbing that these samples initially had quite a few pitch problems. Nonetheless, the pitch problems were fixed and the samples were loaded into the *JustTrainer* software.

THE TUNING PARAMETERS

For *JustTrainer* to work, achieving the desired tuning with precision and without variation is of the utmost importance. Initial research focused on exactly how equal-temperament tuning is achieved and the difference in those notes compared to just intonation. With this information the software was programmed to move back and forth between the two systems.

> During exercise configuration each chord is assigned a tonal center. Internally, when each chord is loaded for playback, an equal-tempered scaling ratio factor is determined for each sound file that scales the sound file pitch to that tonal center pitch. This is used to establish the root point for the just-intonation scale for that chord. The application then calculates a scaling ratio factor for an octave above the tonal center, that factor is stored as 2.0. These two scaling factors are used to adjust the playback speed of the sound file to the proper just pitch (scale the source pitch to the tonal center using the equal-

[101] *ILona! Universal Female Vocal Toolkit* software, (Sony Corporation), June 2006.

tempered scale then scale that result to the target pitch using
the just scale).[102]

The tonal center for each chord in this software is the root of the chord. A rule was placed in the software programming that the root would not be adjustable. Whether the chords are in root position or in an inversion, the root of the chord is fixed. If the root were to be moved, the tuning reference point would be lost, and it would be impossible for the user to determine whether or not a chord was in tune.

As a reminder, here are the ratios for each of the tuning systems.

Just Intonation

Scale Step	Frequency	Ratio
A	**440**	**1/1**
B	**495**	**9/8**
C#	**550**	**5/4**
D	**586.67**	**4/3**
E	**660**	**3/2**
F#	**733.33**	**5/3**
G#	**825**	**15/8**
A	**880**	**2/1**

Equal-Temperament

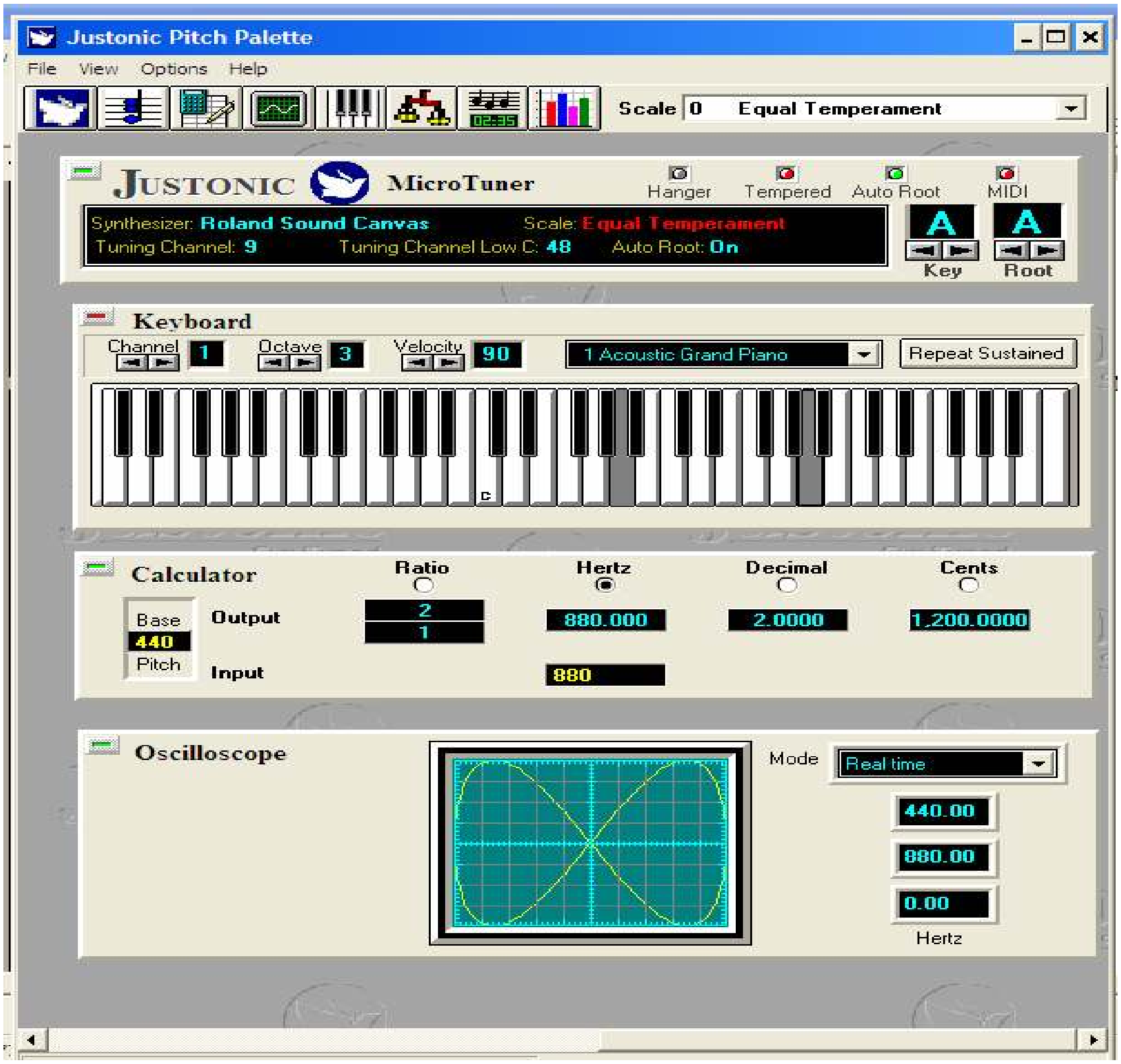
Scale Step	Frequency	Ratio
A	**440**	**1/1**
B	**493.88**	**12347/11000**
C#	**554.37**	**18109/14373**
D	**587.33**	**16823/12603**
E	**659.26**	**12027/8027**
F#	**739.99**	**13451/7998**
G#	**830.61**	**7551/4000**
A	**880**	**2/1**

[102] See Ted Wehner.

For the purpose of the software, the ratios and distances of intervals in hertz were obtained from multiple sources for accuracy. The ratios are available in many tuning books (see related literature), but they were also calculated using the micro-tuning software, Justonic *Pitch Palette*.[103] This software "listens" to notes in a scale and then calculates the hertz of each note and its ratio against a fixed base pitch.

In the screen shot of the Justonic *Pitch Palette* software below, octave "As" were selected for calculation. Using the selected equal-temperament scale, the software calculated that the lower "A" sounded at 440 Hz and the higher "A" sounded at 880 Hz, thus creating a 2:1 ratio.

[103] See *Pitch Palette* Software.



With the *Pitch Palette* software and the tuning books used for research, detailed calculations for each of the scales were programmed into the software. The *JustTrainer* software then used these calculations to accurately play back the sound samples.

THE PROGRAMMING

Below is the actual programming designating the system specifications, the sound library, and the exercises. Though the programming may be confusing to many readers, it is included to help those who may wish to build upon this software design in the future. The programming shows the library of sounds, the notes sampled, the design of the exercises, and the directions. The following points will help clarify some of the programming language.

- The system message setting the threshold at 440 sets the tuning center at A=440

- The playback interval at 2500 sets the speed in milliseconds for how fast the software plays back the chord progressions

- The [Sound] files sets the sounds inserted into the software and tells the software what notes have been sampled. It also designates the folder in which the samples are located

- The [ChordExercise] (note that there is no space in the words "ChordExercise" due to the programming language) files set up the individual interval or triad exercises. The notes below set up the actual exercise. For example the octave exercise A3:A3, A4~ means that A3 is the tonal center, and A3 and A4 will sound in octaves.

- Under each [ChordExercise] heading comes the name of the exercise and the directions. An example in the programming:

    [ChordExercise]
    Interval Exercises/Fourths/Tune the upper note of the fourth to eliminate the beats in the sound. When in testing mode, hit the check mark to check your answer. The user of the software would be selecting "Fourths" under the menu "Interval Exercises" and would see the instructions "Tune the upper note of the fourth to eliminate the beats in the sound. When in testing mode, click the check mark to check your answer."

.

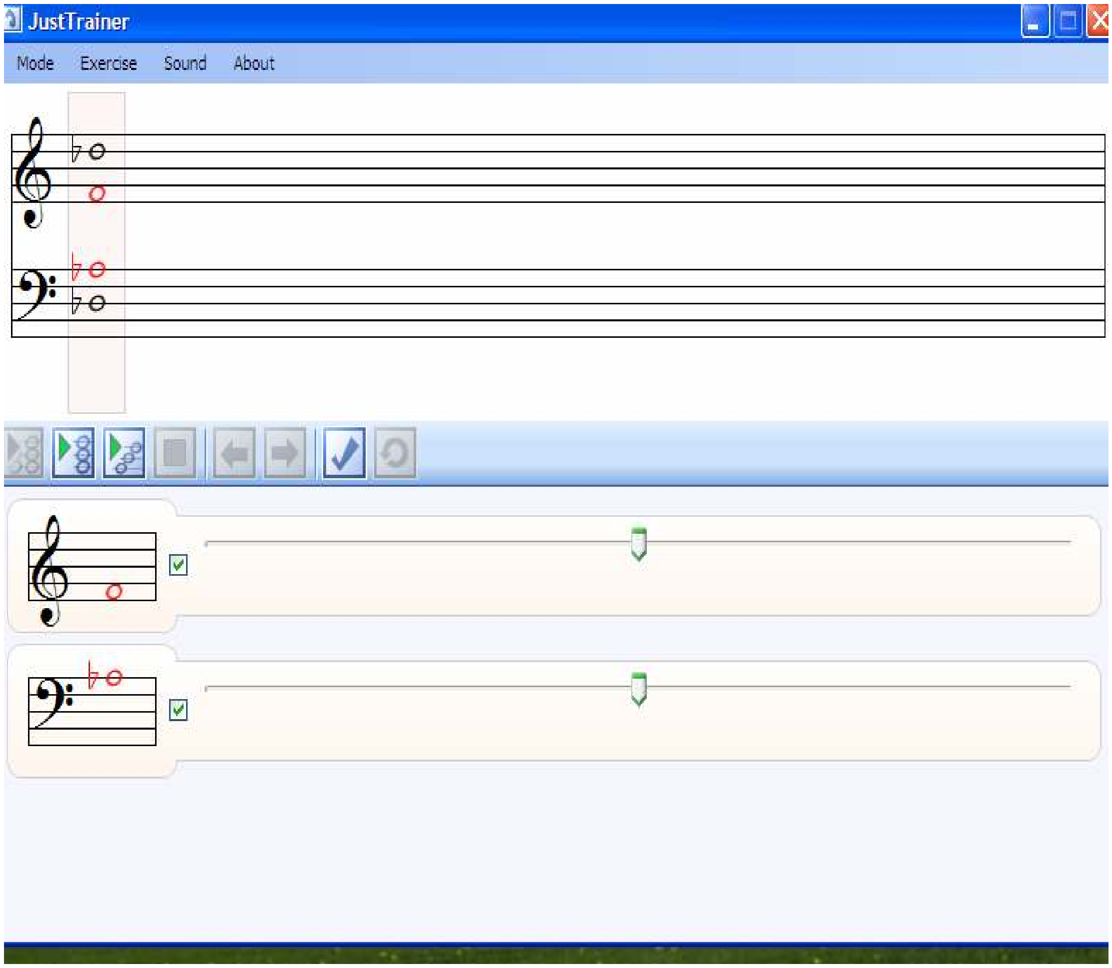
- The symbol ~ means that the note will be adjustable but will sound in tune

- The symbol ? means that the note will be adjustable and will sound out of tune

- The symbol # remains the symbol for sharp while – becomes the symbol for flat since "b" means has to stand for the letter "b"

- Utilizing the above symbols, the programming line "D-3:D-3,A-3~,F4?,D-5" would mean that Db3 (the number 3 indicates the octave below middle C as middle C is designated C4) would be the tuning center, and the chord with

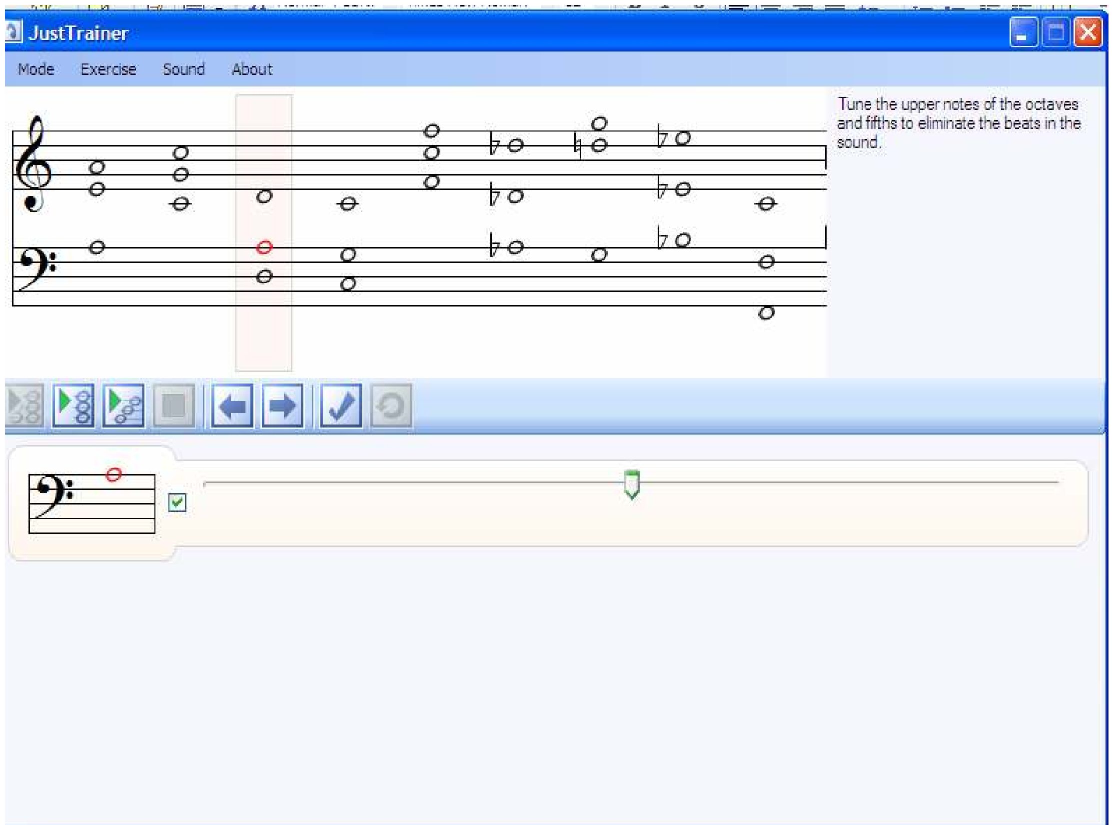
Db3, Ab3, F4, and Db5 would appear. The Ab would be adjustable but sound in tune, and the F would be adjustable and sound out of tune:



- The screen shot below illustrates how the following programming language manifests on the screen.

  [ChordExercise]
  Interval Exercises/Octaves and Fifths/Tune the upper notes of the octaves and fifths to eliminate the beats in the sound.
  A3:A3,E4,A4
  C3:C4,G4,C5?
  D3:D3,A3?,D4
  C3:C3,G3,C4?
  F3:F4,C5?,F5
  D-3:D-4,A-3~,D-5?
  G3:G3,D5?,G5?
  E-3:E-4,B-3~,E-5?

F2:F2,C4?,F3?
B-3:B-3,F5~,B-4~



Programming:

[System] ThresholdAt440=0.5	[This sets the center of tuning at A 440]
Playback Interval=2500	[The speed in milliseconds for the chord progressions to play back]
[Sound] Clarinet F3:Clarinet\Clarinet2.wav	[The note and file name of the clarinet sample]
[Sound] French Horn D2:French Horn\D2.wav F2:French Horn\F2.wav A2:French Horn\A2.wav C3:French Horn\C3.wav D3:French Horn\D3.wav	[The notes and file names of the horn samples]

F3:French Horn\F3.wav
A3:French Horn\A3.wav
C4:French Horn\C4.wav
D4:French Horn\D4.wav
F4:French Horn\F4.wav
A4:French Horn\A4.wav
C5:French Horn\C5.wav
D5:French Horn\D5.wav
F5:French Horn\F5.wav

[Sound]
Organ Prinzipal
C3:Organ\C3.wav
D3:Organ\D3.wav
F3:Organ\F3.wav
A3:Organ\A3.wav
C4:Organ\C4.wav
D4:Organ\D4.wav
F4:Organ\F4.wav
A4:Organ\A4.wav
C5:Organ\C5.wav
D5:Organ\D5.wav
F5:Organ\F5.wav

[The notes and file names for the organ]

[Sound]
Full Organ
A3:Full Organ\A3.wav

[The note and file name for the full organ]

[Sound]
Vocal Sample
F#2:Vocal Ooh\F#2DOO.wav
A2:Vocal Ooh\A2DOO.wav
C3:Vocal Ooh\C3DOO.wav
D#3:Vocal Ooh\D#3DOO.wav
F#3:Vocal Ooh\F#3DOO.wav
A3:Vocal Ooh\A3MDOO.wav
C4:Vocal Ooh\C4MDOO.wav
D#4:Vocal Ooh\D#4DOO.wav
F#4:Vocal Ooh\F#4DOO.wav
A4:Vocal Ooh\A4DOO.wav
C5:Vocal Ooh\C5DOO2.wav
D#5:Vocal Ooh\D#5DOO2.wav
F#5:Vocal Ooh\F#5DOO.wav

[The notes and file names for the vocal samples recorded in the studio specifically for this project]

[Sound]
ILONA! Ooh
F#2:ILONA Ooh\F#2.wav
A2:ILONA Ooh\A2.wav
C3:ILONA Ooh\C3.wav
C#3:ILONA Ooh\C#3.wav
D3:ILONA Ooh\D3.wav
D#3:ILONA Ooh\D#3.wav
E3:ILONA Ooh\E3.wav
F3:ILONA Ooh\F3.wav
F#3:ILONA Ooh\F#3.wav
G3:ILONA Ooh\G3.wav
G#3:ILONA Ooh\G#3.wav
A3:ILONA Ooh\A3.wav
A#3:ILONA Ooh\A#3.wav
B3:ILONA Ooh\B3.wav
C4:ILONA Ooh\C4.wav
C#4:ILONA Ooh\C#4.wav
D4:ILONA Ooh\D4.wav
D#4:ILONA Ooh\D#4.wav
E4:ILONA Ooh\E4.wav
F4:ILONA Ooh\F4.wav
F#4:ILONA Ooh\F#4.wav
G4:ILONA Ooh\G4.wav
G#4:ILONA Ooh\G#4.wav
A4:ILONA Ooh\A4.wav
A#4:ILONA Ooh\A#4.wav
B4:ILONA Ooh\B4.wav
C5:ILONA Ooh\C5.wav
C#5:ILONA Ooh\C#5.wav
D5:ILONA Ooh\D5.wav
D#5:ILONA Ooh\D#5.wav
E5:ILONA Ooh\E5.wav
F5:ILONA Ooh\F5.wav
F#5:ILONA Ooh\F#5.wav
G5:ILONA Ooh\G5.wav
G#5:ILONA Ooh\G#5.wav
A5:ILONA Ooh\A5.wav
A#5:ILONA Ooh\A#5.wav

[The notes and file names for the ILONA Ooh. This is another vocal sample]

[Sound]
ILONA! Aah
C3:ILONA Aah\C3.wav
C#3:ILONA Aah\C#3.wav
D3:ILONA Aah\D3.wav
D#3:ILONA Aah\D#3.wav

[The notes and file names for the ILONA Aah. This is also a vocal sound]

E3:ILONA Aah\E3.wav
F3:ILONA Aah\F3.wav
F#3:ILONA Aah\F#3.wav
G3:ILONA Aah\G3.wav
G#3:ILONA Aah\G#3.wav
A3:ILONA Aah\A3.wav
A#3:ILONA Aah\A#3.wav
B3:ILONA Aah\B3.wav
C4:ILONA Aah\C4.wav
C#4:ILONA Aah\C#4.wav
D4:ILONA Aah\D4.wav
D#4:ILONA Aah\D#4.wav
E4:ILONA Aah\E4.wav
F4:ILONA Aah\F4.wav
F#4:ILONA Aah\F#4.wav
G4:ILONA Aah\G4.wav
G#4:ILONA Aah\G#4.wav
A4:ILONA Aah\A4.wav
A#4:ILONA Aah\A#4.wav
B4:ILONA Aah\B4.wav
C5:ILONA Aah\C5.wav
C#5:ILONA Aah\C#5.wav
D5:ILONA Aah\D5.wav
D#5:ILONA Aah\D#5.wav
E5:ILONA Aah\E5.wav
F5:ILONA Aah\F5.wav
F#5:ILONA Aah\F#5.wav
G5:ILONA Aah\G5.wav
G#5:ILONA Aah\G#5.wav
A5:ILONA Aah\A5.wav
A#5:ILONA Aah\A#5.wav
B5:ILONA Aah\B5.wav
C6:ILONA Aah\C6.wav

[Below are the directions that appear when the software is loaded along with all of the interval and chord exercises]

[ChordExercise]
Directions/Directions/Welcome to JustTrainer intonation software. This software allows you to tune intervals and chords to either just intonation or equal-temperament. Select an exercise from the exercise menu bar. Select either an interval exercise, chord exercise, or a chord progression exercise. Use the sliders below the staff to adjust the notes. Select the training mode to practice and select the testing

mode when you are ready to have the computer check your work. Press the check mark to assess your answers.

[ChordExercise]
Interval Exercises/Octaves/Tune the upper note of the octave to eliminate the beats in the sound. When in testing mode,hit the check mark to check your answer.
A3:A3,A4
C3:C3,C4?
F3:F4,F5?
D3:D3,D4?
C3:C4,C5?
F2:F2,F3?
D-3:D-3,D-4~
G#3:G#4,G#5?
E-3:E-4,E-5?
A3:A4,A5?

[ChordExercise]
Interval Exercises/Fifths/Tune the upper note of the fifth to eliminate the beats in the sound. When in testing mode,hit the check mark to check your answer.
A3:A3,E4
C3:C4,G4?
F3:F4,C5?
D3:D3,A3?
D-3:D-4,A-4?
F2:F2,C3?
C3:C5,G5~
G#3:G#4,D#5?
E-3:E-4,B-4?
A3:A4,E5?

[ChordExercise]
Interval Exercises/Fourths/Tune the upper note of the fourth to eliminate the beats in the sound. When in testing mode,hit the check mark to check your answer.
A3:A3,D4
C3:C4,F4?
F3:F4,B-4?
D3:D3,G3?
E-4:E-4,A-4~
B4:B4,E5?
F#3:F#4,B4?
G2:G3,C4?
G#3:G#4,C#5~
D-3:D-4,G-4?

[ChordExercise]
Interval Exercises/Octaves and Fifths/Tune the upper notes of the octaves and fifths to eliminate the beats in the sound.
A3:A3,E4,A4
C3:C4,G4,C5?
D3:D3,A3?,D4
C3:C3,G3,C4?
F3:F4,C5?,F5
D-3:D-4,A-3~,D-5?
G3:G3,D5?,G5?
E-3:E-4,B-3~,E-5?
F2:F2,C4?,F3?
B-3:B-3,F5~,B-4~

[ChordExercise]
Interval Exercises/Octaves and Fourths/Tune the upper notes of the octaves and fourths to eliminate the beats in the sound.
A3:A3,D4,A4
C3:C4,F4,C5?
D3:D3,G3?,D4
C3:C3,F3,C4?
F3:F4,B-4?,F5
D-3:D-4,G-3~,D-5?
G3:G3,C5?,G5?
E-3:E-4,A-3~,E-5?
F2:F2,B-3?,F4?
B-3:B-3,E-5~,B-4~

[ChordExercise]
Interval Exercises/Dominant Sevenths/Tune the upper notes of the chord to elimate beats in the sound. The justly tuned seventh will seem really 'low' if you are used to equal-temperament and you may even find you prefer a seventh slightly higher than the just tuning. Experiment with where you find the seventh most pleasing.
A3:A3,G4~
A3:A3,G4~
C3:C4,B-4?
F3:F3,E-4?
G3:G3,F4?
A3:A3,G4?
C3:C4,E4,G4,B-4?
C3:C4,E4,G4,B-4?
A3:A3,C#4?,E4,G4~
F3:F3,A3?,C4,E-4?
B3:B3,D#4,F#4~,A4?
D3:D4,F#4~,A4?,C5?

[ChordExercise]
Chord Exercises/Major Triads (Closed Voicing)/Tune the upper notes of the chord to eliminate beats in the sound.
A3:A3,C#4~,E4,A4
C3:C4,E4~,G4,C5
C3:C4,E4,G4?,C5
F3:F4,A4?,C5,F5
E-2:E-3,G3,B-3,E-4?
F3:F3,A3?,C4~,F4
D3:D3,F#3~,A3?,D4
B-3:B-3,D4?,F4,B-4?
E3:E4,G#4~,B4?,E5?

[ChordExercise]
Chord Exercises/Major Triads (Open Voicing)/Tune the upper notes of the chord to eliminate beats in the sound.
A2:C#3?,A3~
C2:E3?,C4,G4~
D2:A3~,F#4?,D5
A2:A2,E3~,C#4?,A4
C3:C3,G3,E4?,C5
C3:C3,C4,E4?,G4
D3:D3,A3,D4,F#4?
F2:F2,F3,C4?,A4
B-2:B-2,D4?,F4,B-4
E3:E3,B3,G#4?,E5~
G2:G2,D3?,G4,B4~
A-2:A-2,A-3?,C4?,E-4
B2:B2,D#4?,F#4?,B4?
E3:E3,B3,D#4?,F#4?

[ChordExercise]
Chord Exercises/Dominant Sevenths (Open Voicing)/Tune the upper notes of the chord to elimate beats in the sound. The justly tuned seventh will seem really 'low' if you are used to equal-temperament and you may even find you prefer a seventh slightly higher than the just tuning. The justly tuned seventh does eliminate the beats. Experiment with where you find the seventh most pleasing.
A2:A2,G3,C#4,E4
C2:C3,C4,E4,B-4?
B2:B2,D#4,F#4,A4?
D3:D3,A3,C4?,F#4
F2:F2,A3?,C4,E-4~

[ChordExercise]
Chord Exercises/Minor Thirds (Closed Voicing)/Use the training mode to hear the difference between the equal and just minor thirds. You may find you prefer the

slightly higher equal third over the just third.
A3:A3,C4,E4
A3:A3,C4?,E4
C4:C4,E-4?,G4
D4:D4,F4?,A4
G3:G3,B-3?,D4
F3:F3,A-3,C4?
E3:E4,G4?,B4~
A4:A4,C5~,E5?
D-4:D-4,F-4?,A-4?
B-3:B-3,D-4~,F4~

[ChordExercise]
Chord Exercises/Minor Thirds (Open Voicing)/Use the training mode to hear the difference between the equal and just minor thirds. You may find you prefer the slightly higher equal third over the just third.
A3:A3,E4,A4,C5
A2:A2,E4,C4?
C3:C4,G4,E-5?
D3:D3,A3,F4?
B2:B2,D4?,B4
E3:E3,B3,E4,G4?
F2:F2,A-3?,C4,F4
G2:G2,G3,B-3?,D4
A-2:A-2,C-4?,E-4?,A-4
D3:D3,D4,F4?,A4?

[ChordExercise]
Chord Exercises/Triad Inversions (Closed Voicing)
A3:C#4,E4,A4
C3:G3,C4,E4?
F3:C4,F4,A4?
D3:A3,D4,F#4?
E3:B3,E4,G#4?
F#3:A#3?,C#4,F#4
B-3:F4?,B-4,D5
A3:E4~,A4,C#5?
G3:D3?,G3,B3?
C3:E4?,G4?,C5

[ChordExercise]
Chord Exercises/Triad Inversions (Open Voicing)
A3:E3,A3,C#4,A4
C3:G3,C4,E4?,C5
E3:G#3?,E4,B4,E5
G2:D3,B3?,D4,G4

F3:A3,F4,C4?
D-3:A-3,D-4,F3?,D-4
F#3:C#3,A#3?,C#4,F#4
B2:D#3~,B3,F#4?,B4
A3:E3,E4,A4,C#4?
C3:G3?,C4,E4?,C5

[ChordExercise]
Chord Exercises/Jazz Chords
C3:B-3?,D4~,G4~,C5
D3:F3~,C4~,E4~,A4,D5
G3:F3?,B3~,E4,A4~,D5,G5
C3:C3,A3,E4~,B4~,D5~
E3:D3?,G3~,B3~,E4~,A4~
A2:C#3~,G3?,B3,E4~,A4
D2:C#3~,F#3?,B3,E4~,A4
G2:F3?,B3?,D4,G4,C5
F2:E3~,A3?,D4,G4~,C5

[Below are the chord progressions included on the software]

[PhraseExercise]
Chord Progression Exercises/Chord Progression 1/In this progression only two notes from the entire exercise are out of tune. Listen to the whole exercise then select and correct the chords with the out of tune note.
D3:D3,F#4~,A4,D5
D3:G3,G4,B4?,D5~
E3:E3,G4~,B4~,E5
A3:A3,G4~,A4,C#5?
D3:D3,F#4~,A4,D5

[PhraseExercise]
Chord Progression Exercises/Chord Progression 2/In this progression only two notes from the entire exercise are out of tune. Listen to the whole exercise then select and correct the chords with the out of tune note.
D3:D3,F#4~,A4,D5
D3:E3,E4,A4,C#5~
D3:F#3?,D4,A4~,D5
D3:G3,D4,G4,B4~
G3:E3,G4~,B4~,D5~
A2:A2,G4~,A4,C#5~
D3:D3,F#4?,A4~,D5

[PhraseExercise]
Chord Progression Exercises/Chord Progression 3/In this progression only two notes from the entire exercise are out of tune. Listen to the whole exercise then select and correct the chords with the out of tune note.
C2:C3,G3~,E4?,C5
C2:E3~,G3,C4~,C5
C2:F3,C4,F4,A4~
C2:G3,B3~,D4,G4~
D2:D3,D4,F4,A4
C2:G3,C4,E4~,C5
G2:G3,D4,F4?,B4~
C2:C3,C4,E4,C5

[PhraseExercise]
Chord Progression Exercises/Chord Progression 4/In this progression only two notes from the entire exercise are out of tune. Listen to the whole exercise then select and correct the chords with the out of tune note.
A2:A2,A3,E4,C#5
E2:B2,G#3~,E4,D5~
A2:C#3?,A3,E4,E5
B2:D3,B3,F#4~,D5
A2:E3,G#3?,E4,B4~
E2:E3,D4,E4,G#4~
A2:A2,C#4~,E4,A4

[PhraseExercise]
Chord Progression Exercises/Chord Progression 5/In this progression only two notes from the entire exercise are out of tune. Listen to the whole exercise then select and correct the chords with the out of tune note.
G2:G2,G3,D4,B4~
D2:C3~,F#3~,D4,A4~
G2:B2~,G3,D4,D5~
A2:C3,A3,E4,C5
G2:D3,F#3?,D4,A4~
G2:B2~,G3,D4,G4
A2:A2,A3,E4~,C5~
D2:D3,A3,F#4~,C5~
G2:G2,G3,D4,B4

[PhraseExercise]
Chord Progression Exercises/Chord Progression 6/In this progression only two notes from the entire exercise are out of tune. Listen to the whole exercise then select and correct the chords with the out of tune note.
B2:B2,B3,F#4,D#5
B3:D#3~,B3,F#4,B4
B3:E3,B3,G#4~,E5

B3:G#3~,B3,E4,E5
B3:A#3~,C#4,F#4,C#5?
B3:B3,D#4~,F#4~,B4
B3:F#3,B3,F#4,D#5?
B3:F#3,A#3~,F#4,C#5
B2:B2,B3,D#4~,B4

[PhraseExercise]
Chord Progression Exercises/Chord Progression 7/In this progression four notes from the entire exercise are out of tune. Listen to the whole exercise then select and correct the chords with the out of tune note.
A3:A3,E4,A4,C#5
A3:G#3~,E4,B4
E3:E3,E4,G#4~,D5?
A3:A3,E4~,A4,C#5~
A3:C#3?,E4,A4,E5
A3:D3,F#4?,A4~,D5
A3:E3,E4,A4,C#5~
E3:E3,D4~,G#4?,B4
A3:A3,C#4~,E4,A4

[Below are the excerpts from choral works]

[PhraseExercise]
Choral Excerpt/Mozart: *Te Deum*/These chords are taken from a section in the *Te Deum* by Mozart. Several of the chords need adjustment. Use the testing mode to adjust the chords and then check your work by pressing the check mark.
G3:G3,D4,G4,B4
G3:B3~,D4,G4,D5
G3:G3,D4,G4,B4
G3:D4,G4,B4?
G3:D3,D4,F#4?,A4
A3:A3,E4,C5~
A3:C4~,E4,A4,E5
A3:E4?,A4,C5~
E3:E3,E4,G#4?,B4

[PhraseExercise]
Choral Excerpt/Ralph Manuel: *Alleluia*/These chords are taken from the *Alleluia* by Manuel. Several of the chords need adjustment. Use the testing mode to adjust the chords and then check your work by pressing the check mark.
E3:E3,G#3,B3,G#4
E3:E3,G#3,B3,G#4
E3:D#3?,G#3,B3,G#4
E3:D#3,G#3~,B3,F#4~

C#3:C#3,G#3,C#4,F#4
C#3:C#3,G#3,C#4,E4~
E3:B2,G#3?,D#4~,E4
E3:B2,G#3~,D#4
A2:A2,A3,C#4?,C#5
A3:A3,C#4?,E4,C#5
D3:A3,D#4,F#4~,C#5~
B3:A3,B3,F#4,D#5~
C#3:G#3,B3~,E4,C#5
E3:G#3?,B3,E4,B4

[PhraseExercise]
Choral Excerpt/Mendelssohn: *Thanks Be To God*/These chords are taken from Mendelssohn's *Elijah*. Several of the chords need adjustment. Use the testing mode to adjust the chords and then check your work by pressing the check mark. The seventh chords (Chords #2,3,8,9) are especially interesting to tune. You may find you desire a tuning that is neither just nor equal.
E-3:E-3,G4~,B-4~,E-5~
B-3:F3,F4,A-4~,D5~
B-3:A-3~,D4,F4,C5
E-3:G3?,E-4,B-4
E-3:A-3,C4~,E-4,B-4
E-3:A-3,C4~,E-4,A-4
E-3:E-3,B-3,E-4,G4~
B-3:E-3,F3,D4~,A-4~
B-3:E-3,A-3~,D4?,F4
E-3:E-3,G3?,E-4,B-4

[PhraseExercise]
Choral Excerpt/Daniel Gawthrop: *Trust In The Lord*/These chords are taken from *Trust In The Lord* by Gawthrop. Several of the chords need adjustment. Use the testing mode to adjust the chords and then check your work by pressing the check mark. Note the C# in the second chord: You may find you like the tuning higher than Just because of the melodic line.
G2:G2,D3,A3,B3
A2:G2,E3,A3,C#4~
D2:F#2?,D3,A3,D4
G2:G2,E3,D4,B4~
G2:G2,F#3,D4,B4~
A2:A2,G3,C#4?,A4
B2:B2,F#3,D4,F#4
D2:A2,F#3,E4,F#4?
D2:A2,F#3~,D4,F#4

[PhraseExercise]
Choral Excerpt/Schutz: *Also hat Gott dei Welt Geliebt*/These chords are taken from

Schutz . Several of the chords need adjustment. Use the testing mode to adjust the chords and then check your work by pressing the check mark.
A3:A2,A3,C4,E4,A4
E3:E3,G#3?,B3,E4,B4
A3:A2,A3,E4,A4,C#5~
D3:D3,D4,A3,F#4?,D5
G3:G2,G3,D4~,G4,B4~
C3:C3,G3,E4?,G4,C5
G3:G2,G3,D4~,G4,B4~
D3:D3,A3,D4,F#4~,A4

[PhraseExercise]
Choral Excerpt/Brahms: *How Lovely Is Thy Dwelling Place*/These chords are taken from a section by Brahms. Several of the chords need adjustment. Use the testing mode to adjust the chords and then check your work by pressing the check mark. You may find you prefer tuning that is neither Just nor Equal.
E-2:G3~,B-3~,E-4
E-2:E-3,E-4,G4~
E-2:E-3,D4~,E-4,G4~
E-2:E-3,C4?,E-4,A-4
E-2:E-3,B-3,G4~,B-4
E-2:E-3,G3~,E-4~,C5
E-2:C3,C4,G4~,E-5~
B-2:D3?,B-3,A-4~,F5~
E-2:E-3,B-3,G4?,E-5
B-2:F3,B-3,A-4~,D5~
E-2:G3~,B-3,G4,E-5
E-2:E-3,B-3,B-4,G5?

[PhraseExercise]
Choral Excerpt/Buxtehude: *Das neugeborne Kindelein*/These chords are taken from *Das neugeborne Kindelein* by Buxtehude. Several of the chords need adjustment. Use the testing mode to adjust the chords and then check your work by pressing the check mark. The fifth and the eigth chord provide for some interesting tuning. You may find you prefer something between the equal and just tunings.
C3:C3,C4,G4,E5~
C3:C3,C4,E4~,E5
C3:F3,C4,A4?,C5
C3:F3,C4,F4,A4~
G3:D3,D4,F4~,B4~
E3:E3,B3,E4,G#4?
E3:E3,C4~,E4,A4
G3:D3,D4,F4~,B4~
E3:D3~,B3,E4,G#4
E3:C3~,A3,E4,A4
E3:E3,G#3?,E4,B4~

E3:A2,A3,E4,A4

THE PROCEDURES

In order to use the *JustTrainer* software it must first be installed onto a PC computer. The software will not work on Macintosh computers. Insert the CD rom into the drive and wait for the instructions to appear on the screen. The instructions will walk you through the installation procedures.

Once installation is complete, the software will be ready for use. Find the folder where the *JustTrainer* icon is located and double-click to launch the software. The software opens to a set of direction which are as follows:

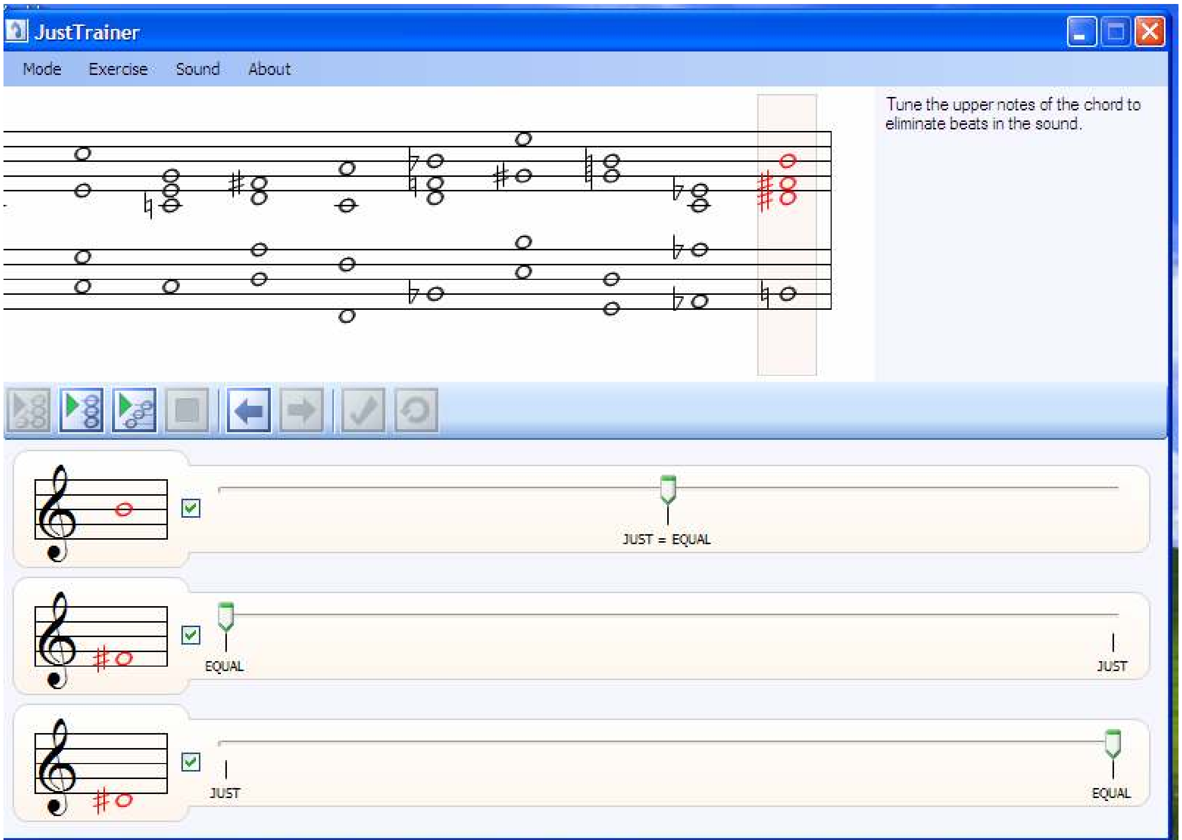
> Welcome to JustTrainer intonation software. This software allows you to tune intervals and chords to either just intonation or equal-temperament. Select an exercise from the exercise menu bar. Select either an interval exercise, chord exercise, or a chord progression exercise. Use the sliders bellows the staff to adjust the notes. Select the training mode to practice, and select the testing mode when you are ready to have the computer check your work. Press the check mark to assess your answers.

THE OPERATING MODES

During the design phase, it became clear that the best option would be for the software to operate in two modes: training and testing. The two modes operate differently, as one provides the user with practice opportunities and the other tests the user's skills.

The training mode is important in order to give a user experience in testing. Musicians, especially choral conductors, have very little practice opportunities for hearing "in tune." However, because tuning is a natural occurrence (aligning to existing overtones), musicians can certainly tune with instinct and careful listening. This software can help confirm and fine tune those instincts and provide a solid foundation for intonation. In training mode, the user can adjust the chords by moving the notes back and forth between equal-temperament and just intonation. By doing this, the user can hear the differences in the beats of the overtones between the just third and equal-tempered third. Even the subtle difference between the just fifth and the equal-tempered fifth can be heard. In the training mode, the user can see exactly where just intonation and equal-temperament are on the sliders. The user can move the sliders precisely into position for either scale as well as hear the pitch as it moves between them.

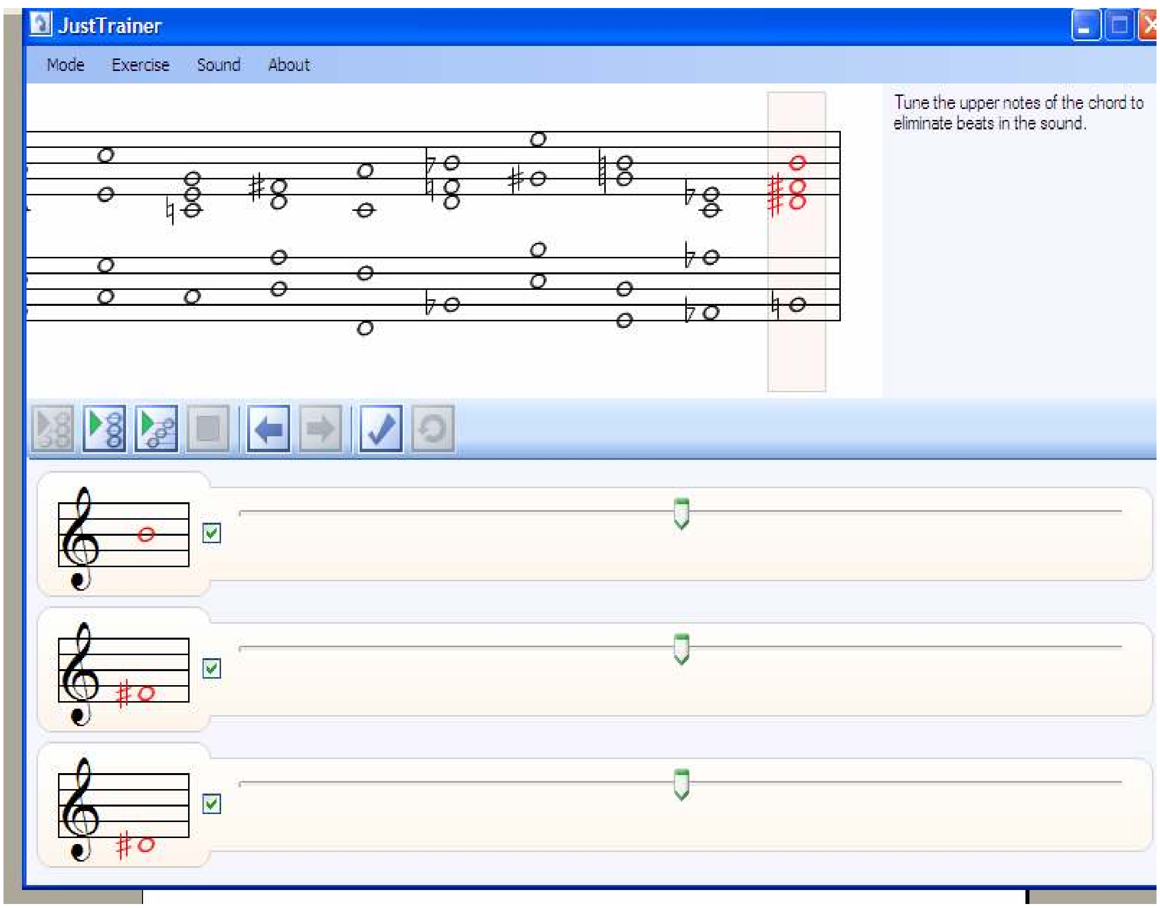
Below is a screen shot showing the training mode with the just intonation and equal-temperament markings appearing on the sliders. This is an exercise with various major triads that the user would tune one by one.



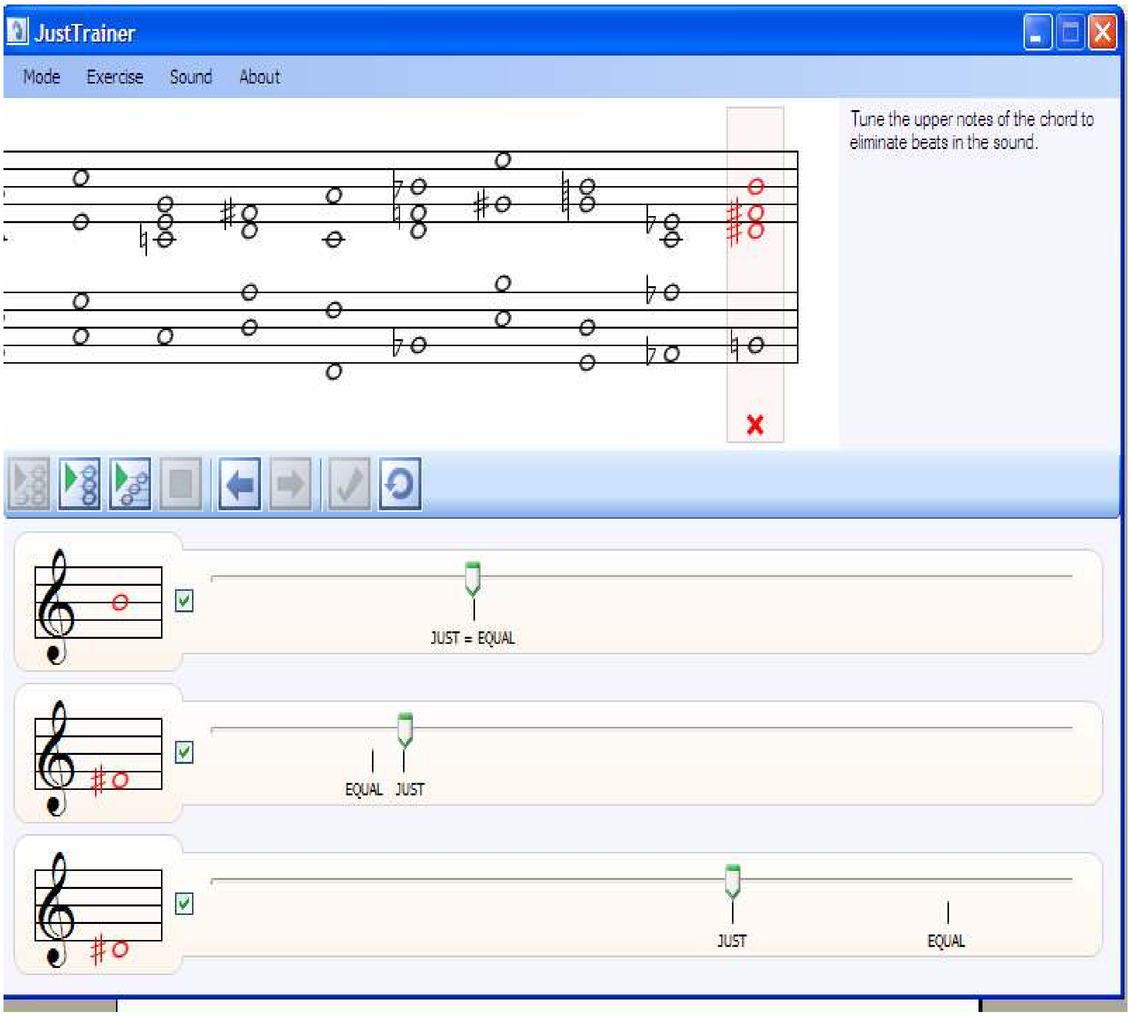
In this case, the B Major chord on the right side of the top screen is selected for tuning. The third, fifth, and the octave appear in the bottom area of the screen for adjustment. As one can see, the third (D#) slider is currently adjusted to equal-temperament. The user would move the slider to the left side to hear the third in just intonation. Moving the slider to the left will always result in lowering the pitch of the given note. The fifth (F#) is also currently selected for equal-temperament. However, the equal-tempered fifth is lower than the just fifth, so the just intonation marking appears on the right side of the screen. The octave is identical in both tuning systems, so the slider indicates the Just=Equal point in the middle. The user can adjust the octave higher or lower to hear the octave out of tune.

In the other mode of operation, the testing mode, the equal and just indicators do not appear initially on the sliders. The sliders begin in a neutral middle position and the user manipulates the note until the he or she believes the note is in tune. At that point, the user clicks the check mark appearing in the middle portion of the screen. The equal and just points appear on the sliders and the user can see if the sliders were placed in the correct position. Below are two screen shots, the first before the check answer is hit and the second after it is hit. In the second screen shot, the sliders are also placed correctly for just intonation.

Screen shot in testing mode prior to checking answer

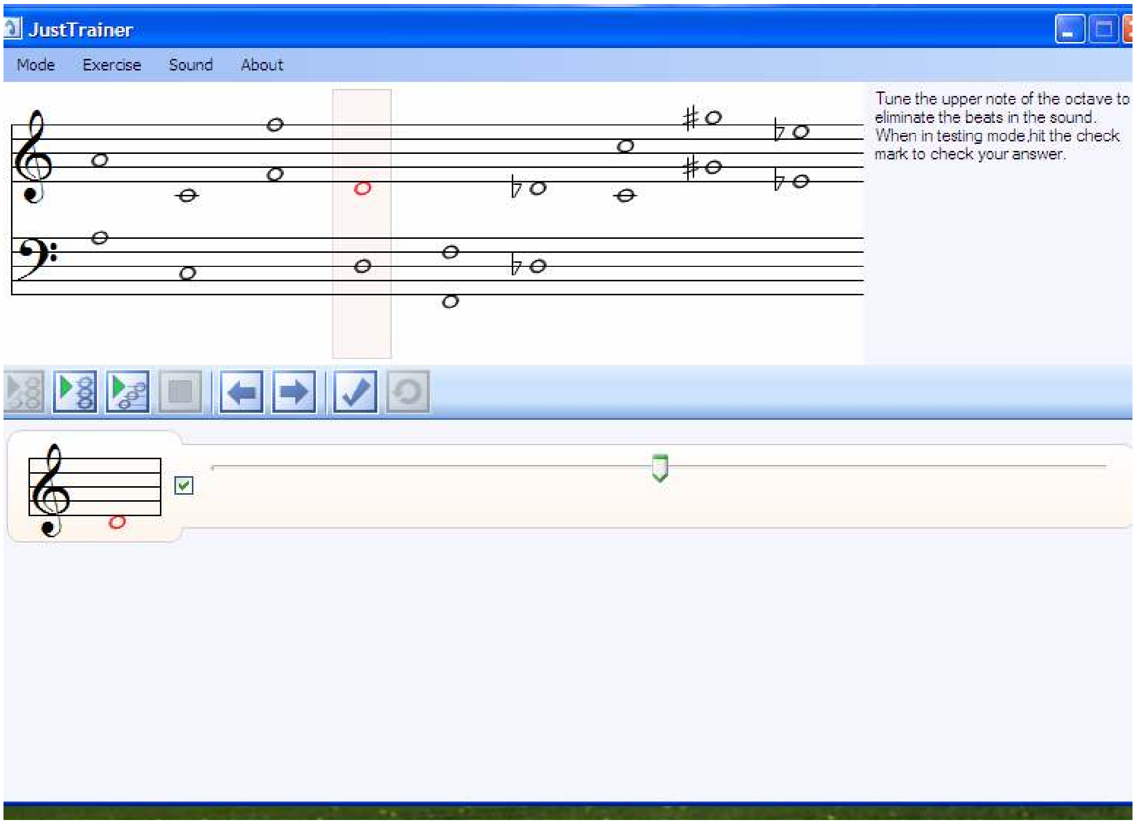


Screen shot in testing mode after checking the answer

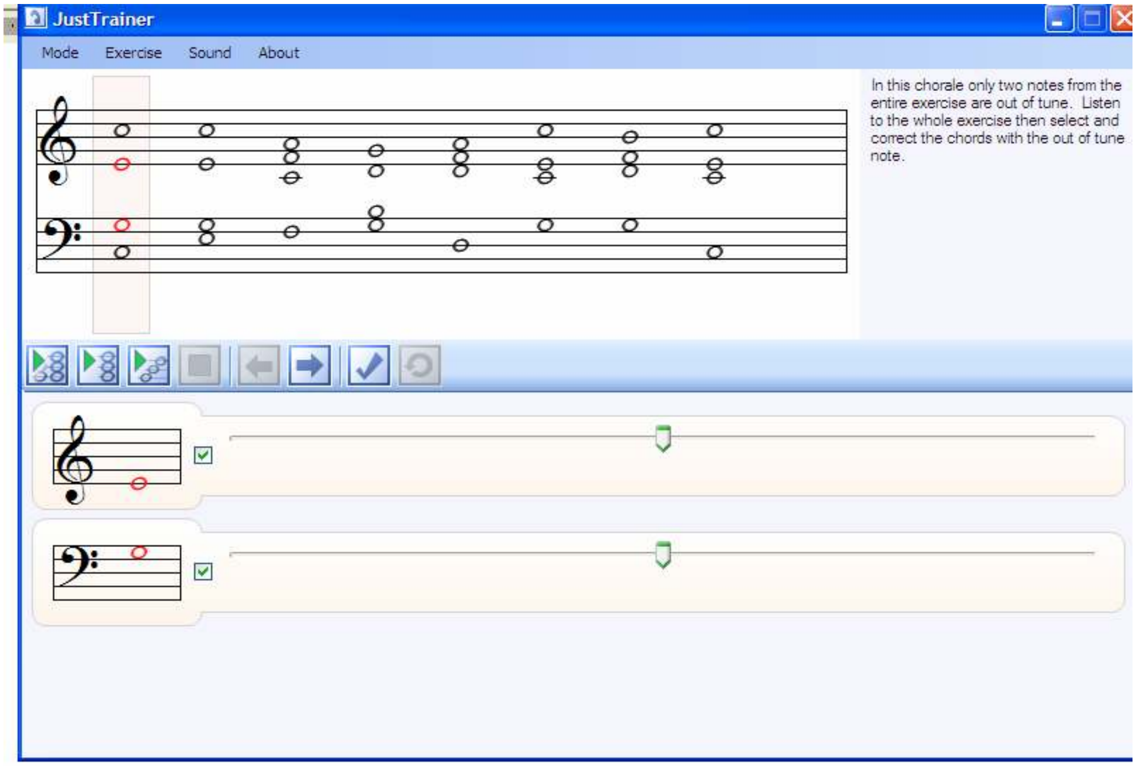


THE EXERCISE TYPES

The *JustTrainer* program allows for two types of exercises to be created. The first type consists of intervals and triads. The software allows for individual chords or intervals to be programmed for practice. The user listens to one chord or interval at a time and makes the proper adjustments, and the software grades or checks the answer. Below is a screen shot showing octaves in this first mode of operation.



The second type of exercise that can be programmed into the *JustTrainer* software consists of chord progressions. The software plays a series of chords, and the user chooses which chords were played out of tune. The user then can adjust the individual chords that were played out of tune. Utilizing this method, series of chords taken directly from choral pieces can be loaded into the software for tuning. Below is a screen shot of the software in that mode.



In the chord progression exercises, only a few notes will sound out of tune, as too many notes sounding out of tune would not prove as effective. The point of the chord progressions is to identify the few out of tune chords amidst a majority of in tune chords.

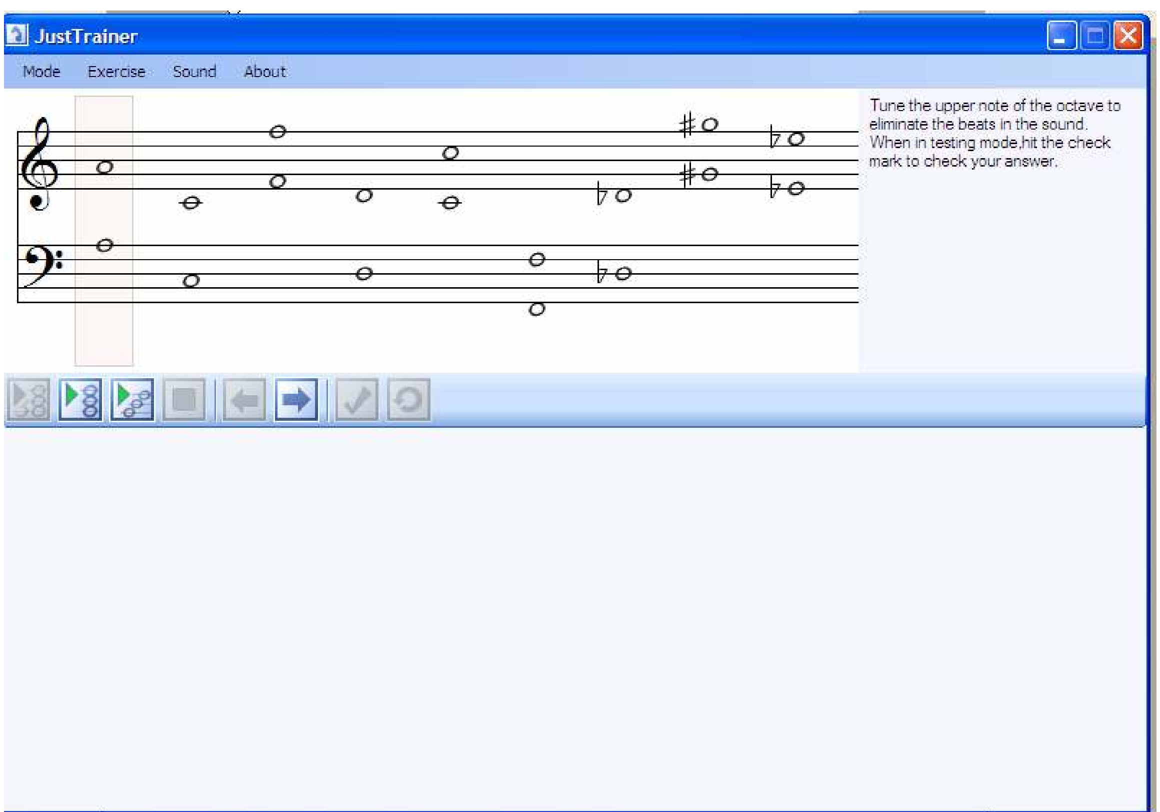
CHAPTER FIVE

EXERCISES FOR THE CONDUCTOR

INTERVALS (OCTAVES, FIFTHS, FOURTHS, SEVENTHS)

These exercises were designed to begin with the basics of building skills in intonation. The first exercise is the interval of the octave, the first overtone in the harmonic series. For example, an A2 at 110 Hz has a primary overtone sounding at A3 220 Hz. Thus, the octave is the easiest interval to line up correctly in the *JustTrainer* software. When an octave is out of tune, the beats in the overtones are very noticeable and help to make the proper tuning adjustment.

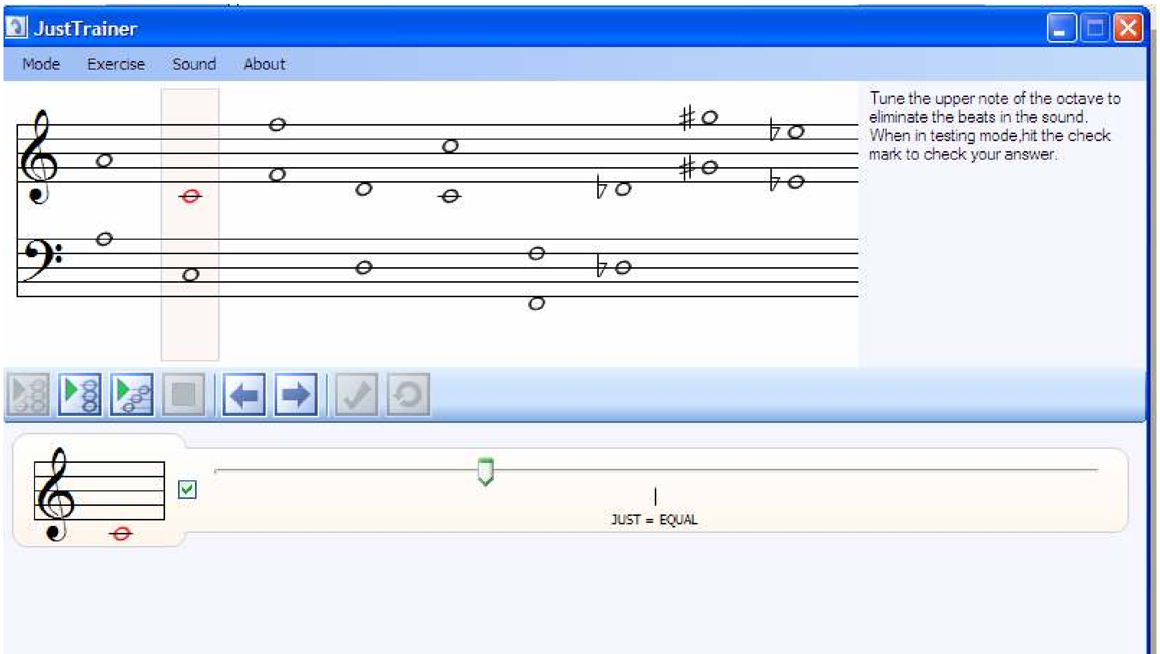
To access the octave exercises, first launch the *JustTrainer* software. Second, use the Exercises menu to select Interval Exercises/Octaves. At this point the following screen will appear:



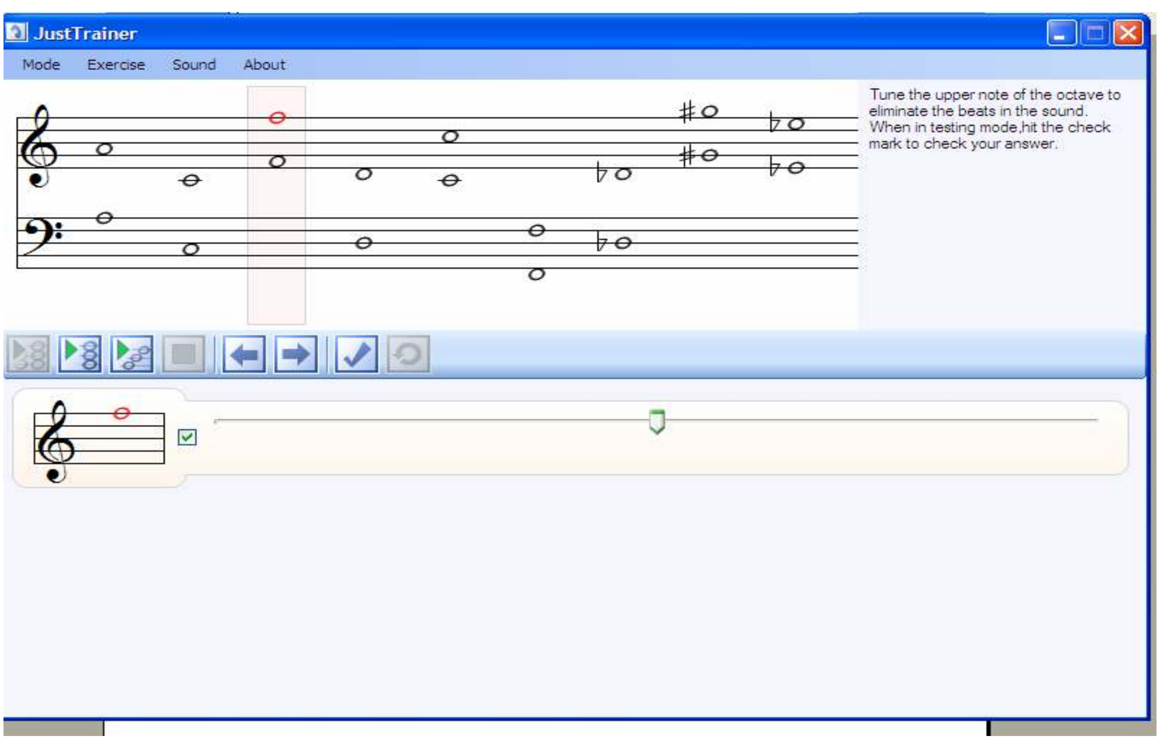
The first sound in the Sound Library, the clarinet, will automatically load as the default. It is recommended that the user of this software begin with the clarinet sound, as it provides clear and obvious overtones.

The training mode is also the default mode. In this mode, the user can play the octave and adjust the slider while seeing where the slider needs to be for the note to sound in tune. To hear the first octave, press the play button in the middle of the screen (the play button is the second button from the left and has a triad stacked vertically). The octave will sound and will continue sounding until the button is pressed again. The first example in every exercise sounds in tune and is not adjustable. This provides a reference point for the other examples. To advance to the next octave, press the button with the arrow pointing to the right. One can also return to the previous octave at any time by pressing the left arrow.

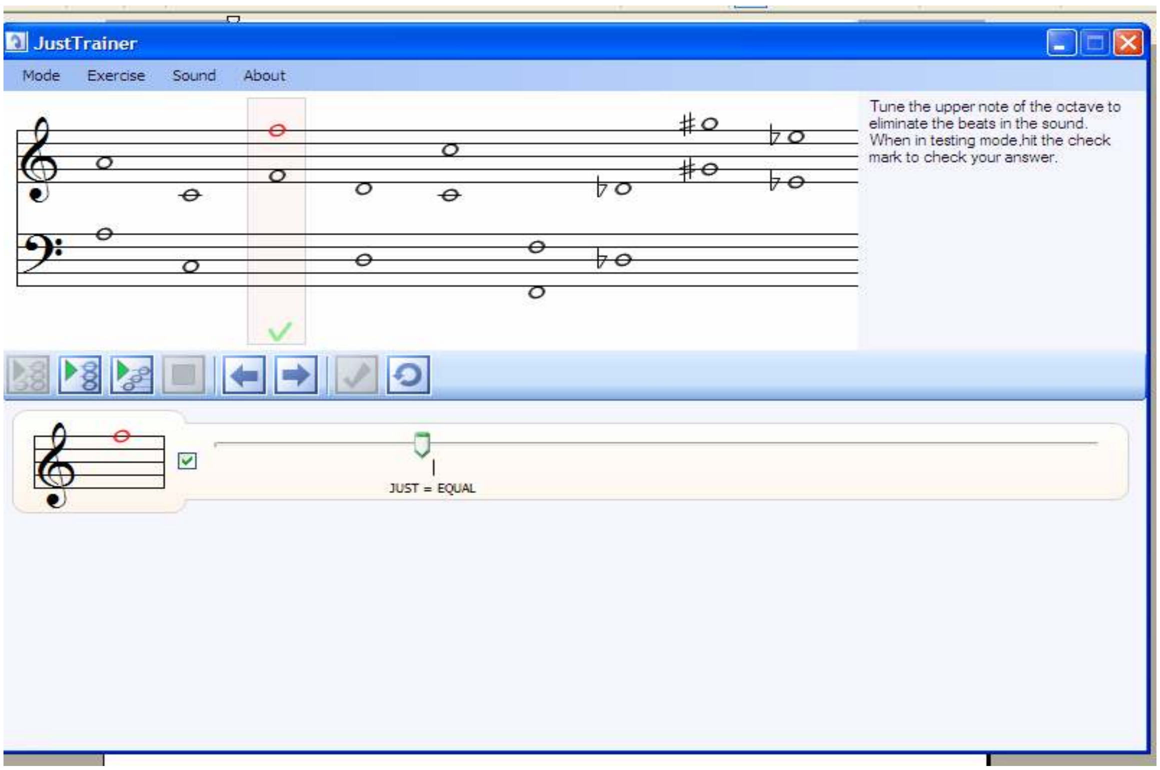
Once the user advances to the second octave the upper note of the interval becomes adjustable. In the training mode, a marking on the slider indicates Just=Equal. This is the point where the octave is sounding in tune (remember that the octave is the same in both just intonation and equal temperament). Listen to the octaves in and out of tune by moving the slider left or right.



Once sufficient practice has occurred, select the testing mode from the Mode menu. In the testing mode, the indicator for the correct tuning point no longer appears on the slider:



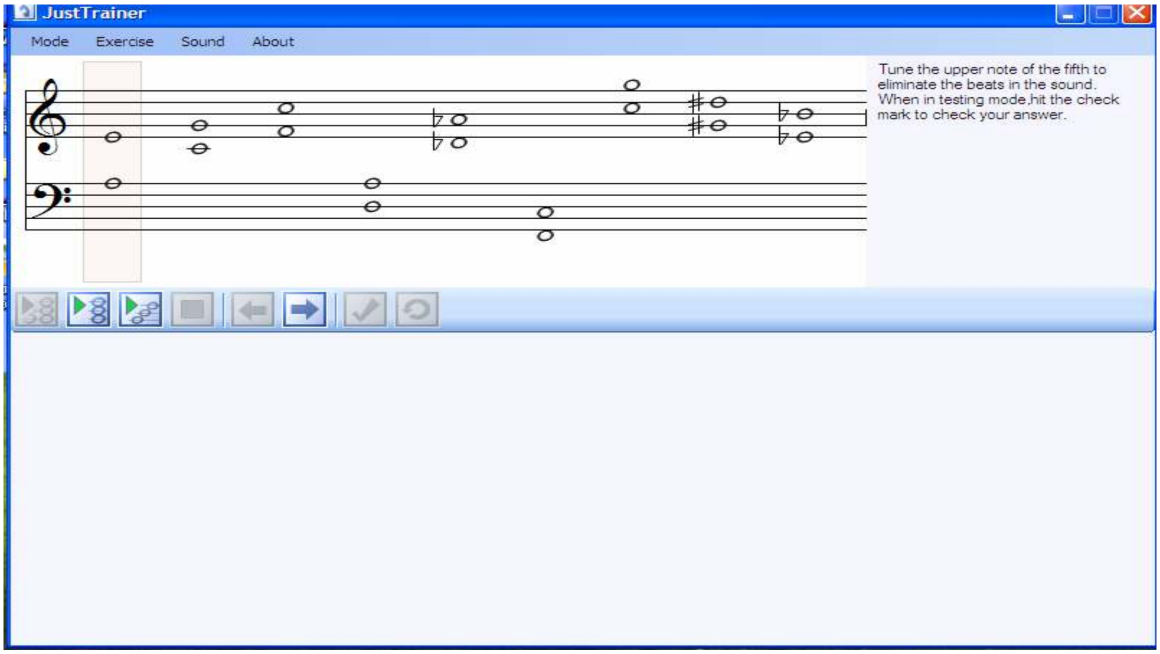
Press the play button and adjust the slider until the overtones have stopped beating. Once the interval is believed to have been properly tuned, press the checkmark to have the software assess the answer. The software then places the correct point on the slider and places a green checkmark beneath the octave if the answer was correct (or within a small margin of error).



If the answer was incorrect, the software would place a red X underneath the octave. The checkmarks and Xs are simply a way to monitor progress. To try the octave again, press the button on the right which is a circle pointing backwards. This will allow a redo of the interval.

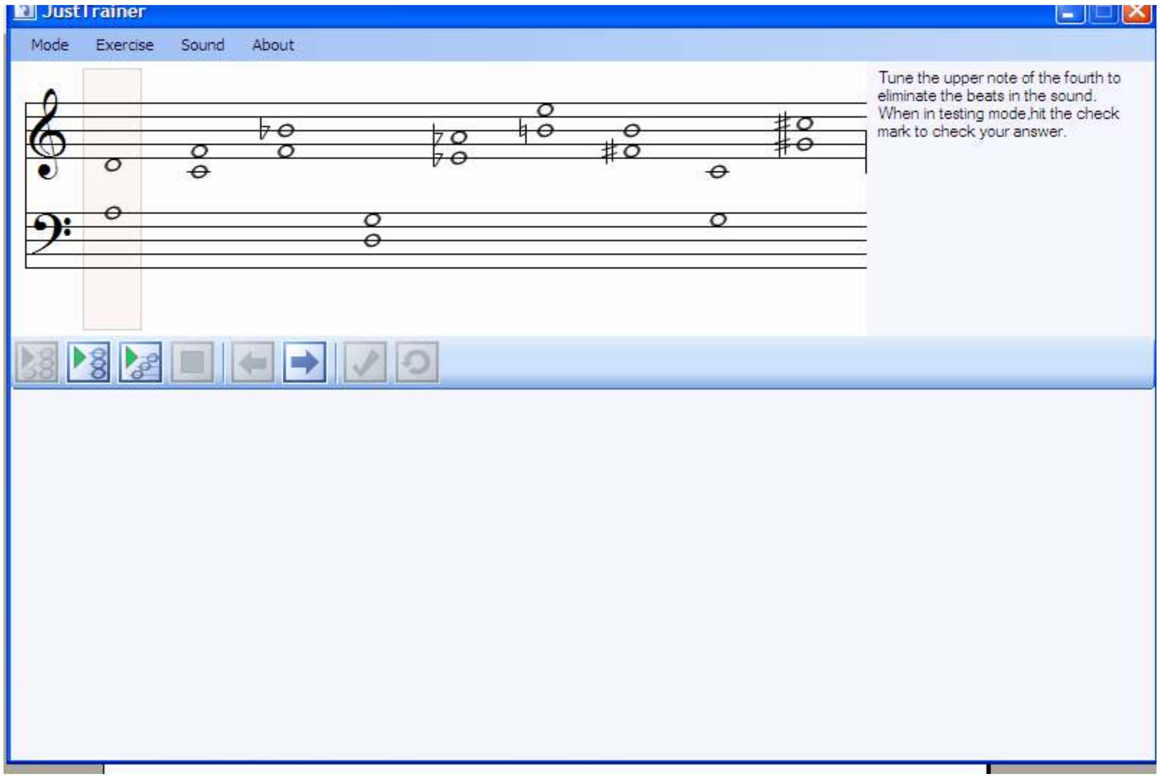
The next exercise is the perfect fifth, the third partial (overtone) sounding at a ratio of 3:2. The overtones beating in the fifth are also clear and easy to hear. It is recommended that the user again utilize the clarinet sound when beginning with this exercise.

To access the fifths in *JustTrainer*, select Exercise/Interval Exercises/Fifths. The following screen will appear:



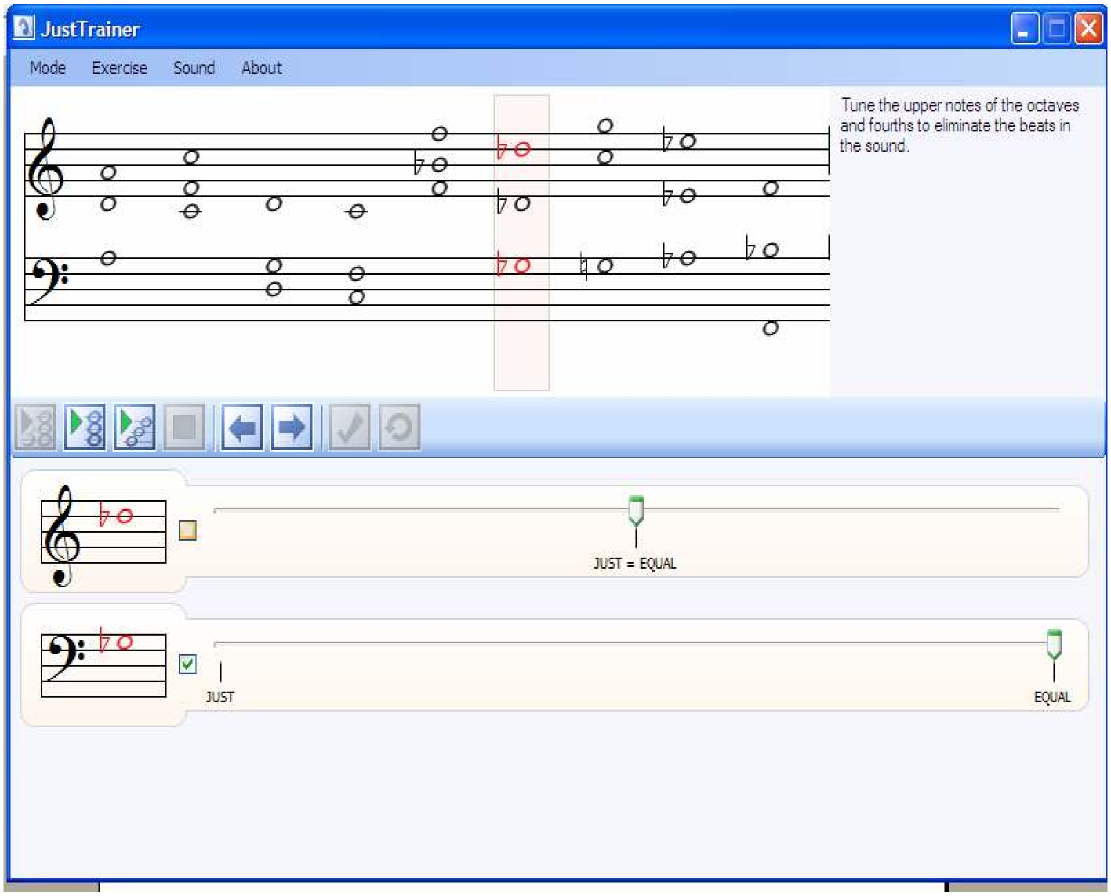
Using the same procedures as the octave exercises, begin with the training mode and move the slider to hear the chord in and out of tune, then use the testing mode to check your accuracy on the tuning. Once you have mastered the clarinet sound, try other sounds, as each provides a different timbre with which to practice tuning.

The fourths are next in the interval exercises, sounding in the overtone series at a ratio of 4:3 to the fundamental. The fourths also provide a good entry level tuning exercise, as the beats in the sound are easier to hear. It is important to note that the equal-tempered fourth and the just fourth are very close in distance. To access the fourths in JustTrainer select Exercise/Interval/Exercises/Fourths. The following screen will appear:

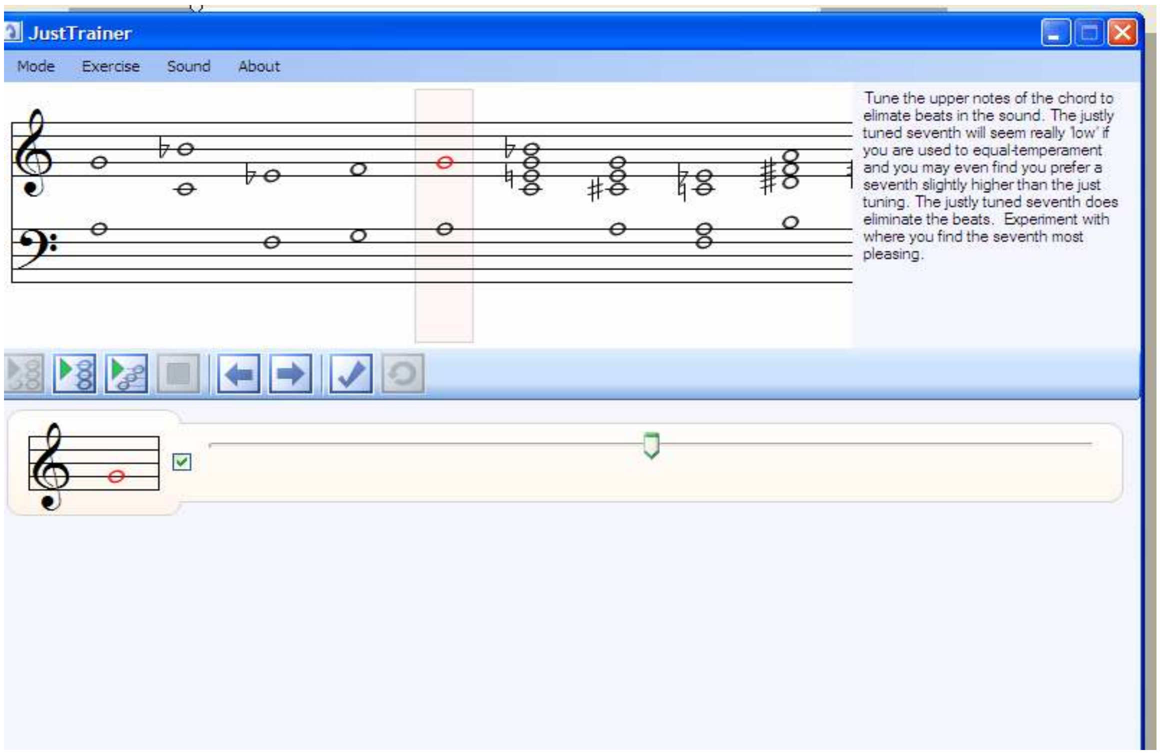


The next two sets of exercises are combinations of the octave with the fifth and the octave with the fourth. In these sets of exercises either the octave, fifth, or fourth above the root can sound out of tune. To access these select Exercises/Interval Exercises/Octaves and Fifths (or Octaves and Fourths).

One of the handy functions of the software is the ability to turn off individual notes in the exercise. Just to the left of the sliders is a box with a checkmark. This function can be used to isolate intervals out of tune. To turn off a note, click on that box. The checkmark will disappear and the note will mute. Clicking again will turn the note back on. Here is a screen shot of the octaves and fourths exercise with one of the notes muted:



The dominant seventh, which sounds in the overtones as the seventh partial at a ratio of 15:8 to the fundamental, is the final interval exercise in the JustTrainer software. To access this exercise select Exercise/Interval Exercises/Dominant Sevenths. When working with this exercise one will find that the just seventh is considerably lower than the equal-tempered seventh. In fact, because equal-temperament is the most common tuning system, the just seventh may sound flat when first working with it. When working with an ensemble the seventh can be used to “color” the sound. The lowered seventh is a mellower sound and can be used to give a “blues” feeling. The higher seventh is more active and bright and can be used when that effect is needed. Use the practice mode to get accustomed to the sound before moving to the testing mode. Below is the screen for the sevenths:



CHORD EXERCISES (MAJOR, MINOR, DOMINANT, JAZZ)

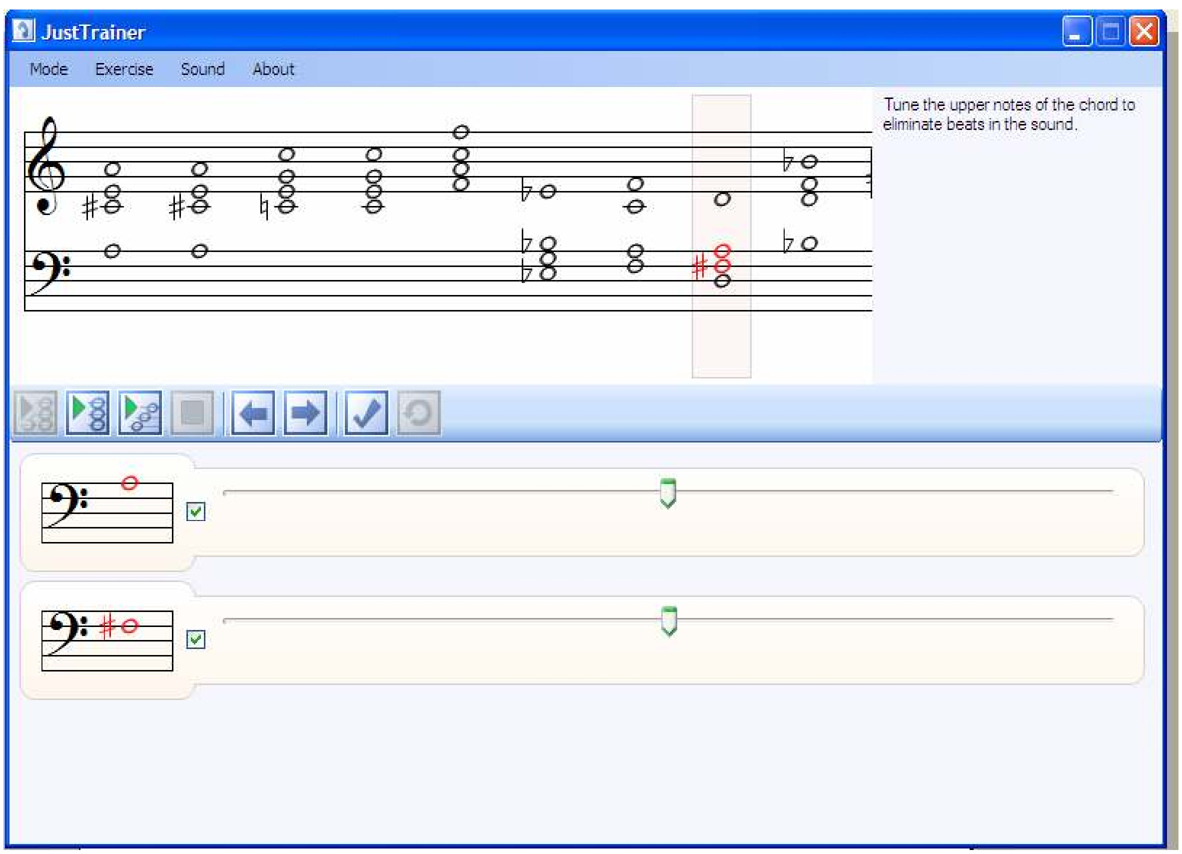
After finishing with the interval exercises, move on to the chord exercises. In this set of exercises, one can tune triads in both closed and open voicing. These sets of exercises can prove helpful for ensemble directors, as triad tuning is one of the most important intonation elements for a group.

Within triads, the major third is one of the most interesting and debated intervals in music. As stated earlier, there have been many tunings throughout history for this interval. The just third exists naturally as the fifth partial sounding at a ratio of 5:4 to the fundamental. However, the Pythagorean and the equal-tempered third are also common tunings for this interval. Some insist that the just third is correct because it eliminates the beating, but others find the just third to be to dull and lifeless. Some ensemble directors like a high third which causes a bright and active effect. This software points out the positions for the just and equal-tempered third, and the user can decide which one is preferred. The most important aspect is to know the difference and have options as an ensemble director.

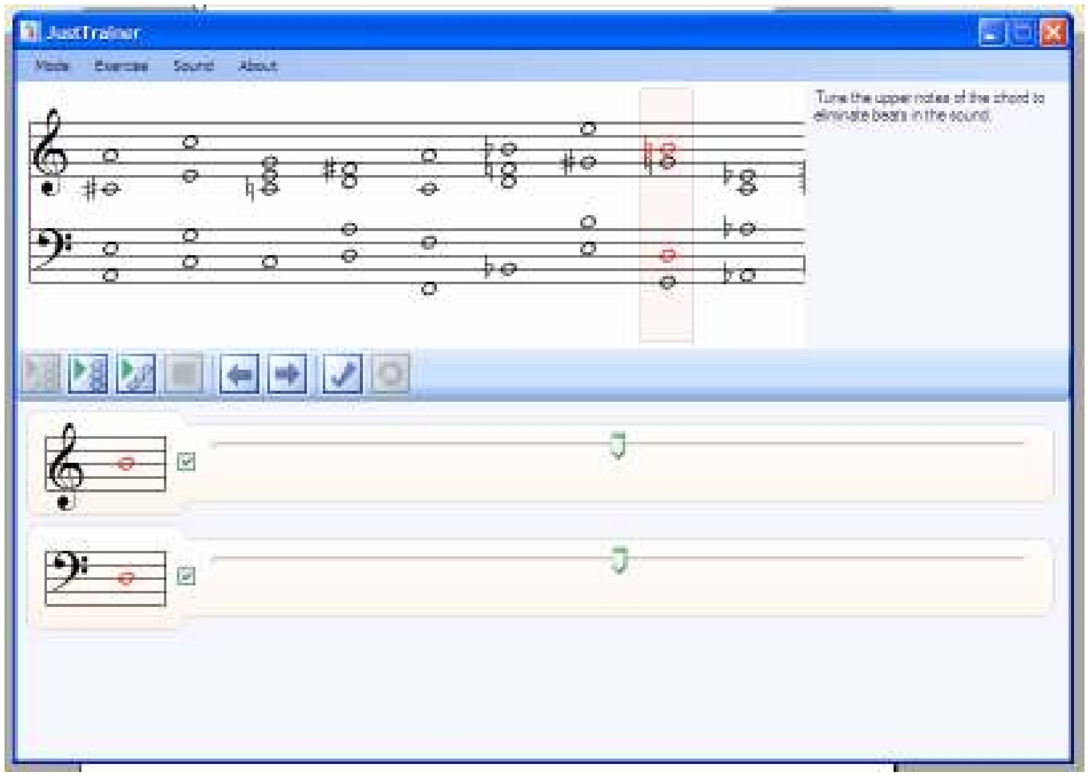
The exercises provide both closed and open voicing triads to attempt to give some triads that would occur in music. It is recommended to utilize the different sounds and timbres when tuning, as one may find that preferences for the tuning changes with the timbre.

Here are several examples of screen shots of the chord exercises. These can all be accessed under the Exercises/Chord Exercises section of the JustTrainer software.

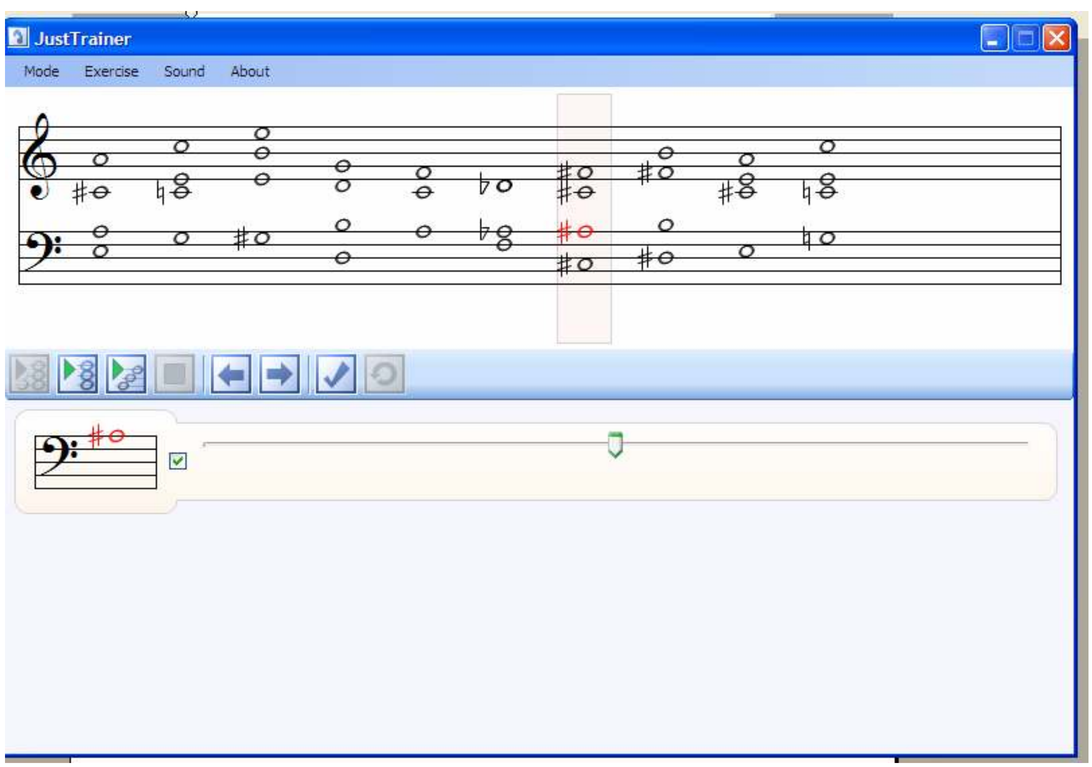
Major Triads (Closed Voicing)



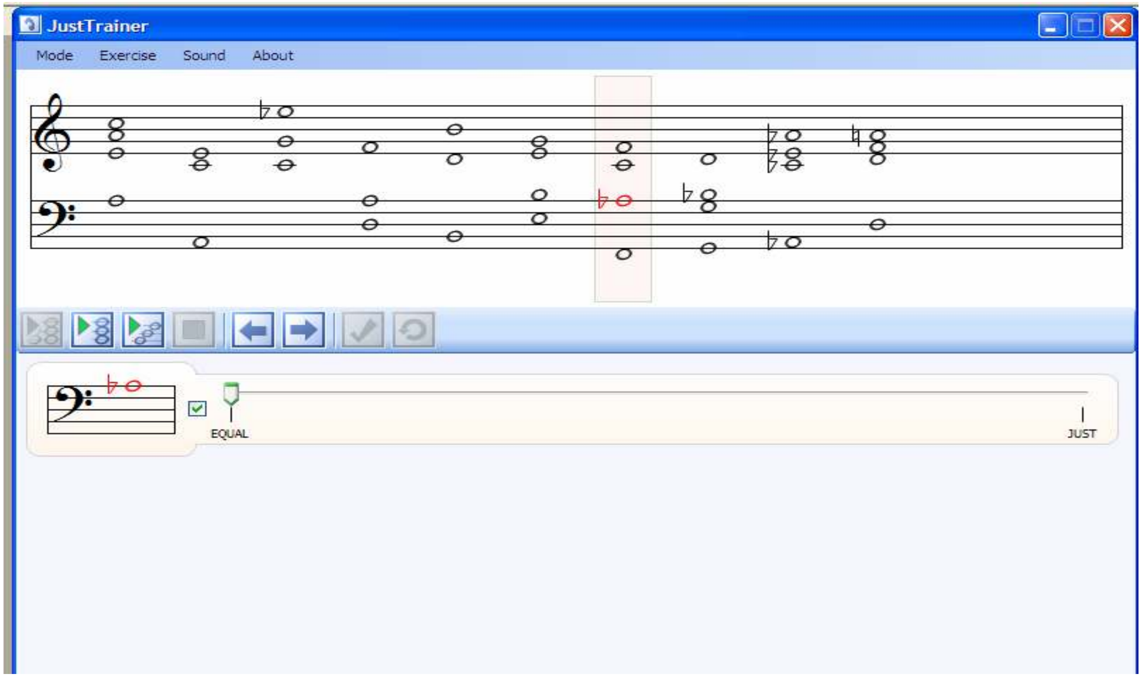
Major Triads (Open Voicing)



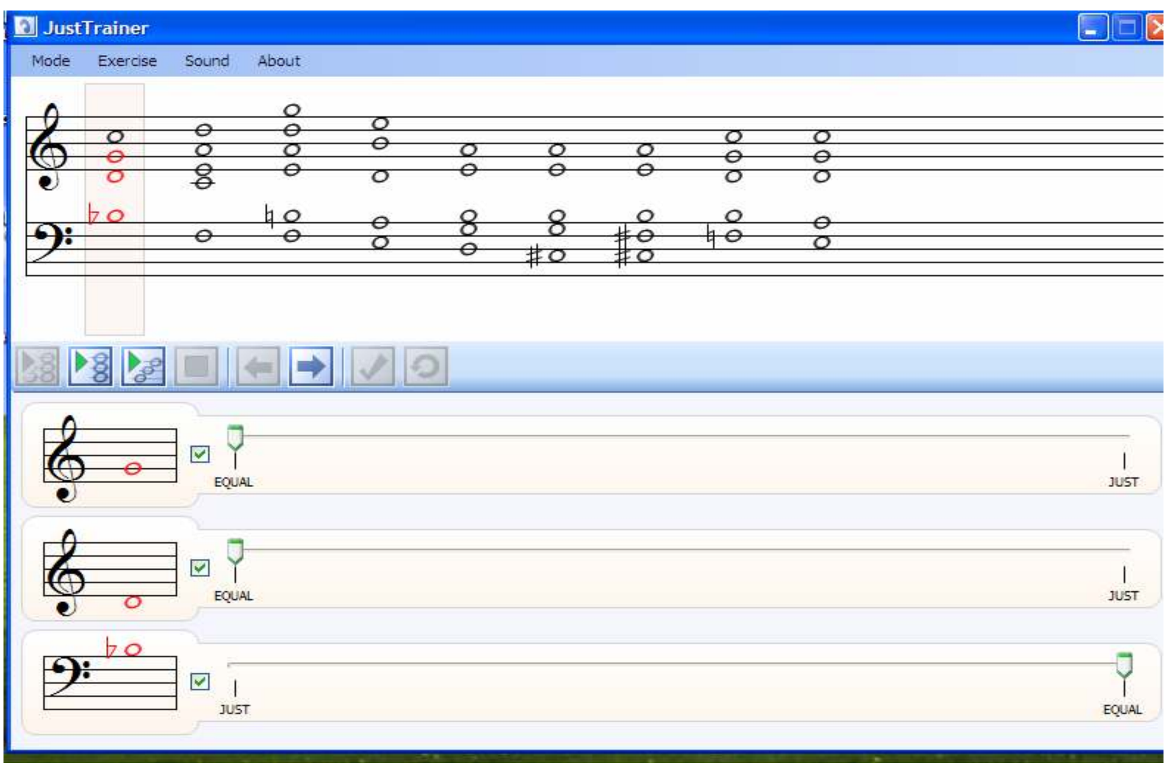
Triad Inversions (Open Voicing)



Minor Thirds (Open Voicing)



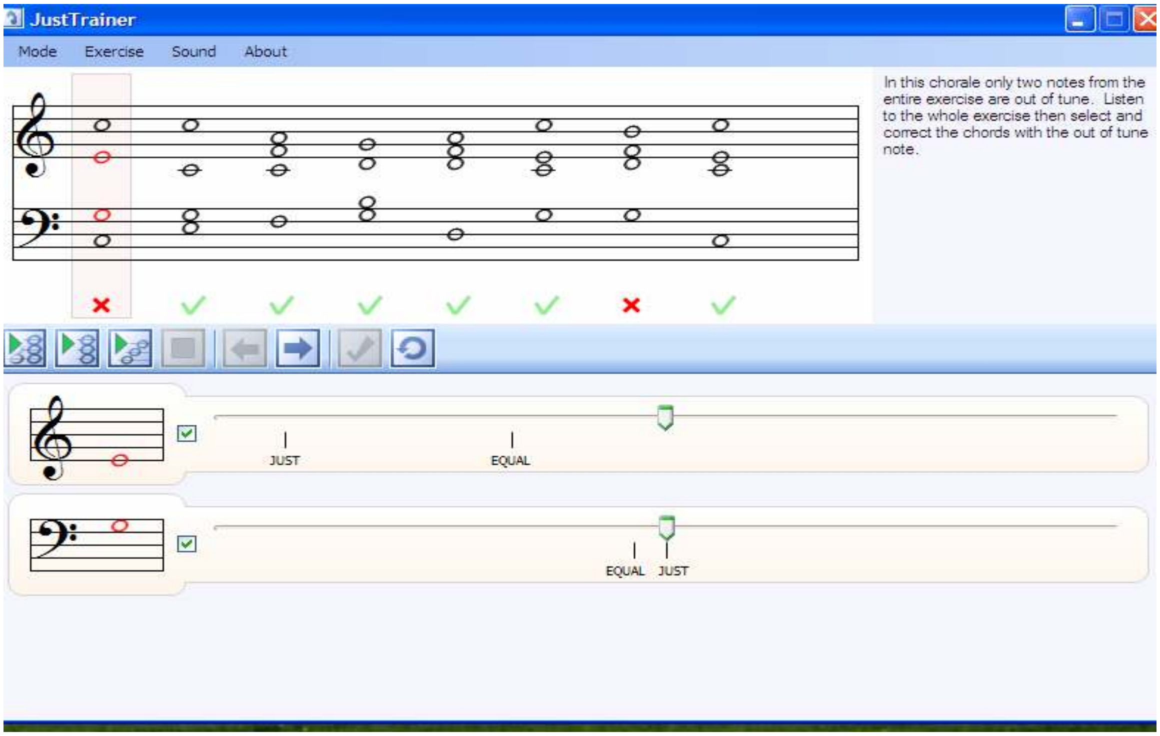
Jazz Chords



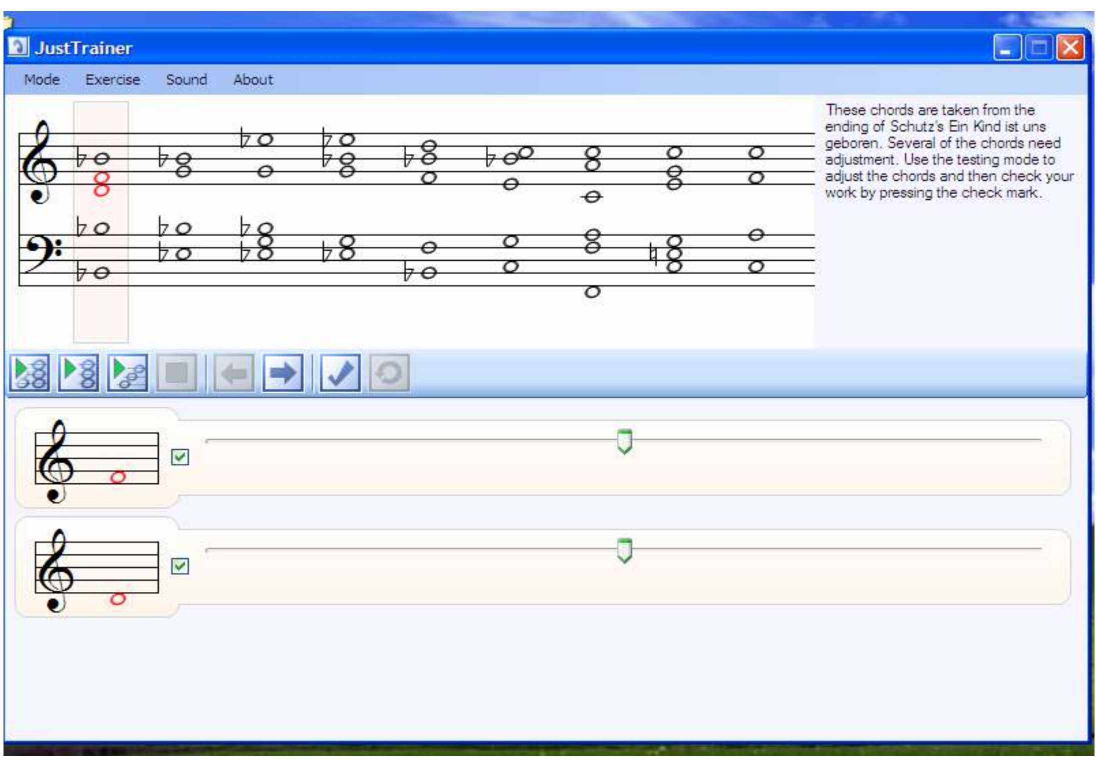
CHORD PROGRESSIONS AND CHORAL EXCERPTS

The final sets of exercises in the JustTrainer software consist of chord progressions and progressions taken from choral pieces. In these exercises, a series of chords play instead of one chord at a time. The user listens to the entire progression and attempts to pick out the chords that were played out of tune. Once the out of tune chords are identified, the user then selects those specific chords and makes the necessary adjustments. In testing mode, the computer checks the answers. If the chords were correctly identified and tuned the computer places a green checkmark underneath the chord. If a chord was adjusted unnecessarily, or if a chord was tuned incorrectly, the computer places a red X underneath the chord. The software cannot replicate the actual rhythms in the choral pieces as it is limited to whole notes. It is hoped that future versions of the software be programmed to handle more rhythmic features. However, the chords can be adjusted as they relate to each other in the progression. Below is a screen shot of a generic chord progression followed by a screen shot of a progression taken from Schutz's *Ein Kind ist uns geboren*:

Chord Progression



Choral Excerpt from Schutz



CONCLUSION

This document and the accompanying software have sought to provide musicians, particularly choral conductors, with an opportunity to practice tuning and to provide a general overview on how overtones affect intonation. With ensemble time being limited for undergraduate and graduate students studying conducting, this software offers an outlet in which to practice intonation without an ensemble and away from the rehearsal setting. It also demonstrates the difference between the accepted standard of tuning, equal-temperament, and natural tuning, just intonation. Most undergraduate music students would have a difficult time explaining the difference, as it is often not part of the curriculum. I believe that understanding and hearing the difference only enhances the ear of the musician.

SUGGESTIONS FOR ONGOING DEVELOPMENT

Technology in the last decade has seen an incredible rate of growth. Each year more and more possibilities emerge in the realm of music and computers. The software developed for this document will most likely be outdated in just a few short years as computer speeds increase and sample technology improves. This document utilized many recent developments such as .net framework programming, sample technology, and virtual orchestras. The growth in these technologies will continue to allow more and more capabilities.

The potential for practicing music skills using MIDI technology and sampling is far greater than is being utilized today. Though computers can never completely imitate a live ensemble, the realism will continue to improve and more possibilities will emerge. Musicians practice skills in a simulated environment to better prepare for working with live ensembles. Many skills can be practiced such as tuning, balance, tempo, voicing, timbre, duration, articulation, etc. Programs utilizing these skills should be researched and developed.

This software has been programmed so that it can adapt to the changes in sampling technology. It can incorporate any audio file into the sound library for the practice of tuning. One of the greatest improvements to this software can come in the area of the sound library. It would be a benefit to have a full choral ensemble sampled note by note. A recording of a choral ensemble singing unison on a neutral vowel could be made and then loaded into the software. This would provide an even better environment in which choral conductors could practice. More realistic and more detailed instrumental samples will also become increasingly available and affordable.

An area that could use additional study and development is the issue of choral ensembles and vibrato. This software does not have the capability of handling vibrato in the samples. Because this software relies on the ability to exactly center the pitch of a note, it would get confused when dealing with vibrato. However, vibrato is certainly a reality in dealing with ensembles so the development of tuning software that could incorporate vibrato would be a benefit.

A dream for this developer would be software that could scan in a piece of choral or instrumental music and then play it back through the tuning engine. The user could select the sound with which to play back the music, including a full orchestra sonority or choral ensemble sample. The software would then make random errors in areas such as tuning, balance, notes, etc., and the user could identify them and make the corrections. The programmer of such software could also attempt to help the computer make “smart” errors (errors that would most likely appear in real ensembles).

This technology, if it is not already possible, will certainly become a possibility soon. Such a piece of programming would be invaluable practice for young and emerging conductors as well as ensemble players. It is the hope of this author that the *JustTrainer* software accompanying this document will be a launching point for new and exciting creative ideas. The world of education has, unfortunately, been a bit distanced from technology due to fear of its learning curve. Programs such as the one included with the document can and should be continued to be developed to enhance the education of music students.

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