Perfecting Intonation

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Equal Temperament & Just Intonation
meet.

Method book with play-along CD

by
David Beecroft

Berlin, Germany

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Contents

Introduction

If there is any truth to the statement: “You are a product of your environment” then today we as musicians must be a product of the keyboard and “equal temperament”. Every day our ears are saturated with music. Music produced in studios where the midi keyboard and sequencing software rule the roost. We are inundated with music played by small game computers, telephones, automated call waiting, music for television stings, radio program introductions, “chill out” music for hair salons, drum and bass grooves, DJ productions etcetera. Music that for the most part is created in the computer environment. There is no conscious thought about intonation. Tuning is a “pre-set”.

Young musicians are told to look at a tuner as a learning aid for playing in tune. We are told that a piano is “in tune” and accept it without ever questioning what this means. Because most music comes out of a box and not out of our own mouths we are gradually losing the consciousness that music is a form of *human* expression. We, as a culture, (Western, that is), are losing the ability to *blend* our voices together. Equal temperament, while enabling us to make incredible music has a dark side, (oooooooh!).

You might be tempted to ask: “Is this a problem?” And to answer your question I am tempted to reply with the second most favourite saying of my father. His most favourite saying was: “Fathers are a sorry lot.” True for some I am sure but not very relevant here. Almost as often he used to say: “They don’t know, and they don’t know that they don’t know”. And yes, as kids my brothers and I used to howl: “DAD! You can’t say stuff like that, it’s totally arrogant”. Well, arrogance aside, it does help illustrate my point though, which is this: if you have been fed a (life) long diet of harmony as expressed through equal temperament then it is less likely that you will have internalised, or could appreciate the sound of two or more tones in a perfect intervalic relation to one another.

Isn’t perfectly tuned equal temperament perfectly in tune? No. Equal temperament is a system of tuning that was invented to allow music to be played in all keys on instruments that have fixed note positions. For voice and string instruments such as violin, viola, cello and contra bass, equal temperament plays less of a role, but for musical instruments such as piano, any electronic keyboard, guitar or other fretted instrument, equal temperament is indispensable. As I said, it is to date, the only viable tuning system that allows the music to be played in any of twelve key centres using only twelve discrete pitches within one octave. But what about the world of brass and woodwinds? Aren’t these instruments also designed to play in all keys equally. Yes, but the difference is that brass* and woodwind players can alter the pitch of a note away from equal temperament by changing embouchure and air stream.

*Valved brass instruments play tones derived from various combinations of the (three) valves with the natural overtone series. I am a woodwind player, life for us is easy. I wouldn’t wish a trumpet on my worst enemy (if I had one).

Introduction

Brass and woodwind players play instruments designed to play tones using a tuning system that we can not naturally sing. A player sensitive to the art of blending can alter the natural (equal tempered) pitch of their instrument to blend perfectly with other instruments, but more on this later.

What is perfectly in tune? The overtone series represents a series of intervals or frequencies of resonance that can occur in natural materials and resonating cavities. It is a series of intervallic relationships that can be represented mathematically as whole number ratios. Whole number ratios are what we would recognize as being perfectly in tune, even whole number ratios that do not occur in the natural overtone series.

So, what is the problem? Actually, there are a few problems or there is no problem, depending upon how you make music. If you make monophonic music or melodies that are played over a single note drone as in the music of traditional Oriental cultures then all is fine with the world. When you wish to make polyphonic or chordal music, or music that changes key then there is a big problem. Basically the problem is this; when you change the root or lowest tone that is heard, then you create a whole new set of relationships between all of the tones above. When you change the lowest tone, you must change the tuning of every note of the scale above it. This is something a singer can do without a single thought, but with a keyboard it isn't possible. Experienced wind, brass and string players can and do alter their tuning to some degree as they tend to gravitate towards natural tuning simply because it "sounds right". Playing in tune isn't about being tough and insisting you are right, and it is a little more complicated than simply checking your pitch with an electronic tuner to "see if you are right".

What *is* playing in tune? An important clue came to me through an older saxophonist friend of mine. He related a story about Jerry Toth, another Toronto based musician and former lead alto player of the Boss Brass among other things. When asked about his perfect intonation, he said that playing in tune is very simple, *you focus on making the other person sound good*. Aside from illustrating his lack of ego and a deep respect for the musicality of his colleagues, this anecdote points to an aspect of music that is rarely taught in books** or music schools. This aspect of music is the art of blending or harmonizing with other monophonic instruments, with or without accompaniment from piano or other fixed pitch instruments.

****Chase Sanborn** has published a book called "**Tuning Tactics**" which does address the problem of intonation through playing along with perfect fifths.

Introduction

Blending or harmonizing is something that comes naturally when two people sing different pitches at the same time. We seek to find a pleasing relationship between the two tones. What we naturally feel as pleasing or would agree with as being “in tune” are intervals that are described mathematically as tones that are related by ratios of whole (rational) numbers, i.e. 1:1 (unison), 2:1 (octave), 3:2 (5th), 4:3 (4th), 5:4 (maj 3rd), 6:5 (mi 3rd) etc. Without becoming too technical this means that for the interval of an octave to be created, one tone, (the higher one), must vibrate at twice the frequency of the lower tone. For the interval of a 5th to be created the higher tone must vibrate three times for every two times the bottom tone vibrates and so on. It is not something we have to give thought to as the process of interval recognition is automatic. You may not (at first) know the name of the interval but you do readily recognize whether or not they are blending, which is to say, maintaining a rational or whole number ratio.

On a piano that is tuned to **equal temperament** there are only 12 different pitches within the octave and every interval maintains the same relationship regardless of key centre. Other than octaves, *there are no perfectly in tune intervals to be found on the piano*. Some intervals are closer to their whole number ratio or **just intonation** counterparts than others. 4ths and 5ths are intervals that we would recognize as in tune or blending as they are quite close to perfectly tuned 4ths and 5ths. But 3rds, 6ths, 2nds, 7ths (both natural and lowered) and tritones, are quite far from that which we would naturally hear or sing.

Just intonation is any musical tuning in which the frequencies of notes are related by ratios of whole numbers. Any interval tuned in this way is called a just interval; in other words, the two notes are members of the same harmonic series.

Equal temperament is a musical temperament, or a system of tuning in which every pair of adjacent notes has an identical frequency ratio. In equal temperament tunings an interval - usually the octave - is divided into a series of equal steps (equal frequency ratios). For modern Western music, the most common tuning system is twelve-tone equal temperament, sometimes abbreviated as 12-TET, which divides the octave into 12 (logarithmically) equal parts. It is usually tuned relative to a standard pitch of A=440 Hz (442 in Europe with some orchestras tuning to 443).

*The **cent** is a logarithmic unit of measure used for musical intervals. Typically cents are used to measure extremely small intervals, or to compare the sizes of comparable intervals in different tuning systems, and in fact the interval of one cent is much too small to be heard between successive notes. 1200 cents are equal to one octave, (a frequency ratio of 2:1), and an equally tempered semitone (the interval between two adjacent piano keys) is equal to 100 cents.

Although a musician may equally identify a just or equal tempered interval he or she would not gravitate toward the equal tempered version while singing. Equal tempered intervals do not have an exact and recognizable position within us the way just intervals do. We naturally sing just intervals when we blend with another. To illustrate what is happening let's look at the interval of a 3rd.

The interval A to C# above, a just major third, an interval that we can easily recognize could be described thus; A perfectly in tune major third has a vibration ratio of 5/4, (5 cycles of the higher tone for every 4 cycles of the lower tone). One could also say that the upper tone has a wave that vibrates 1.25 times faster than the bottom tone, (5/4 = 1.25). When our A is vibrating at 440 cycles per second then the C# (major 3rd higher) would be vibrating 550 cycles per second. You could find and play this frequency with pinpoint accuracy as long as the A is sounding.

The interval of a major third in equal temperament, can be found by multiplying the lower frequency by 1.259921 (rounded off). At the risk of being overly complicated, this number is derived from the formula: 2 to the power of 4 over 12 ($2^{\frac{4}{12}}$). The numbers 4 and 12 come from the practice of dividing the octave into 1200 equal "cents". Each semitone equals 100 cents* and a major 3rd which is made up of 4 semitones and therefore 400 cents. An octave equals 1200/1200 therefore a major 3rd equals 400/1200 which is then reduced to 4/12. To determine the exact frequency of our C# in equal temperament we multiply the frequency of the lower note (440 hz) by 1.259921 to find the frequency of C#. In this instance the lower frequency of 440 hz is multiplied by 1.259921 to give an upper frequency of 554.36542 hz. These are not a frequencies I would like to bet my life on by having to whistle them.

In the most perfect of perfect worlds, i.e. perfect temperature, perfect instrument and perfect embouchure, your woodwind instrument may play pretty close to equal temperament but when, if ever, is this the case? In the real world we always have to adjust our tuning to blend. The real question is, what to adjust it to. I defy anyone to find by ear 554.36542 hz. If you were to play your C# along with an A from the piano, with a will to blend with that note, you would naturally gravitate to 550 hz, the just third. You could not, (in a million years), hear and play with any certainty a C# of 554.36542 hz, the equal temperament equivalent. Your mind is not made this way. With that said, we can forget the maths because equations will not help us play in tune.

Woodwind, brass and string players do have the option of learning the feel of equal temperament to help them play in tune. By practising while watching a tuner it is possible to approximate equal temperament. With repetition one can remember the feeling of each of the twelve tones. This could work, but only when you perform in the same environment you practice in and if the musicians you play with never vary from the tuning ideal (i.e. A=440) that you have learned. We can approximate equal temperament this way but I don't believe one can be sure that one is really playing in tune. Since insecurity breeds tension we as players need to be sure of our intonation.

Equal temperament only works because no key centre or chord is more in tune than any another. The equal temperament deception works best on instruments with fixed tunings because these instruments do not favour any particular keys, chords or intervals. While this is very practical it is not actually possible for woodwind, brass, or string players to accurately duplicate. If we opt to use our ears, then our natural feeling for blending gets in the way. Playing by rote breeds insecurity.

When playing with "in tune" intervals or less complicated perfectly tuned chords, we can find a point where our note is exactly in tune with the other tones. There is no exact placement or perfectly in tune spot for our note in an equal tempered chord. In equal temperament the only two intervals that are close to being in tune are the 4th and the 5th, all others are quite far off the mark. In my opinion, we, as humans, were not designed to harmonise within equal temperament. We just don't hear intervals this way. No matter how hard we try or how long we practice we will never be able to accurately sing or play a scale or individual tones within a chord tuned to the equal tempered ideal. The only exception to this would be when we are singing in unison, or in octaves, with a keyboard instrument. We might come close but that only counts with horse shoes and amateur big bands.

How then do we sing or play wind instruments together? How do we then decide what is in tune? The answer is, like every other thing connected to the human condition, that we must simply try to make the best of it. **We can however improve our chances to blend in a pleasing manner with other instruments by becoming adept at harmonizing with various just intervals**. By deciding to educate and then trust our ears we will always sound right, even though there may be a discrepancy to equal temperament. Real world tuning means blending with that which you hear as best you can. Melody or lead players blend with the bass. A section player blends with the lead player. The exact tuning of individual notes varies with each chord or key centre.

The exercises in this book, (along with the playback tracks on the CD), are designed to educate and sensitize your ears. By learning the art of blending with a variety of just intervals that represent real world musical situations, you learn to find the best fit for the richest sounding chord. You also learn how the various scale degrees within any given key centre can be slightly altered so as to be in tune with the root or lowest sounding tone. By repeatedly being exposed to perfect intonation, you refine your musical imagination. By singing along, you train your ears to recognise intervals and chords. You deepen your appreciation of the beauty of harmony and your role in it. By hearing exactly how the note you play or sing fits within the harmony, or with the bass, you become a more sensitive player. Knowing what is in tune, means being able to feel the expressiveness of varying degrees of sharp or flat. Intonation is an emotion packed tool which is largely overlooked. Much of what we think of and appreciate as a great sound is, in my opinion, a personal feeling and mastery of intonation.

I highly recommend that you sing each exercise before you play it. I highly recommend that you sing each exercise after you play it as well. Open your mouth *w i d e* and **live** the intervals you create. To blend with another is one of the greatest joys of making music.

What to listen for

In order to insure success while using this book, it is important that you know what is special about the tracks, and what you will be focusing on while playing with them. On the cover page is the statement “The place where Equal Temperament & Just Intonation meet”. What this means is, that with all of the intervals on the play-along CD’s, the lowest tones come from the equal tempered scale and the intervals above the lowest tones are of a rational number ratio to the lowest note. This means that while the lowest note will be in tune with your piano (where A=440 or 442 depending upon which version you have purchased), the upper note will not. Depending upon which interval you are hearing, the difference will vary from 2 cents to 17 cents, sharp or flat from equal tempered. You are to focus on the quality of the intervals heard on the track and what happens i.e. what you hear and feel when you play along with the tones on the accompanying exercises. The first and most important aspect of the play-along tracks is that you will not hear “beats” when the two tones are sounded. The intervals sound rich and placid. As stated earlier, the intervals are tuned to a perfect, (whole number) ratio of each other. This makes it much easier to hear how “in tune” you are when you play your additional third tone. Your job is to play at the same volume or quieter than the track, so that you can hear your tone in relation to the sounded intervals. You will need to be able to “bend” or alter your pitch slightly up or down while playing along in order to eliminate the “beats”. You will need to take your time. When the key centre of the interval changes after 30 seconds, *stop playing and listen for a moment*. You will need to readjust each time the key changes.

The ability to move your pitch up or down is very important and you will not have success with out being able to do this. If you play a wind instrument, altering your pitch may be accomplished by making small variations in embouchure, air stream or tongue position, (voicing the tone using specific vowel shapes), If you play an un-fretted string instrument, by slightly altering the position of your finger on the fingerboard. Before playing along with the tracks, practice making subtle changes to the tuning of various tones on your instrument. If you are a woodwind player, then you will discover that the upper register can be altered more easily than the lower one. Some experienced woodwind players may have difficulty with bending the pitch if they play with a tight embouchure, or cannot change the position of the jaw. Playing with less “bite” or pressure of the teeth allows you a much greater flexibility of pitch. The muscles holding the jaw are very strong and tend to be hard wired to the breathing muscles and your present sense of pitch. Learning to open, or otherwise alter the position of the jaw, means learning a corresponding alteration in air support. It also means altering the mouthpiece tuning position. It is possible, for instance, to open the jaw, use more air (support) and play quietly at the same time.

Using the play-along tracks

The play-along tracks consist of a variety of harmonized twelve tone rows. As stated earlier, the lowest tone is equal tempered and the upper tone is just tuned to the bottom one. At first, simply play the exercises along with the appropriate track. Later, you may begin to do without reading by learning the exercise sequences, and then transposing them as you follow along the various 12 tone sequences. More on this later. Play the notes slowly and quietly, at first bending your notes a little higher or lower to find the best blend or position. Hold each note for at least one second, long enough to know whether you are flat or sharp. Your instrument will not naturally be in tune and you will have to adjust everything you play to blend perfectly. If you are not sure which way to alter your notes there is a guide on page 14 that will give you an idea where to start. The placement of your note(s) may change depending upon the interval being played. There is an exact and recognisable place for every scale degree you will play and it may take you some time to find it. **You will have 30 seconds to play along with an a given interval and in six minutes you will be taken through all 12 keys**. If you are unsure go back and repeat the track. If you get lost, sing along to find the interval. This you should do anyway. **You are a musician and musicians sing**. There are only two notes being sounded and the lowest one, coming from the left channel of your stereo, CD or mp3 player, corresponds to the key centre written in the exercises. For example if the lower note of the sounding interval is an A, the key centre will be three sharps even if the interval is minor, flat sixth or a flat seventh. The last interval of each series always has a C concert as the lower tone. There are several variations for each track and you should stay focused on one variation each time you play a track. Become aware of the intervals you are asked to play and their relationship to the root and other sounded intervals. You will find that each interval has a tendency to be high or low and that it is consistent throughout all of the transpositions of the of the exercise.

Playing "in tune" is not as simple as finding a fixed position for each note you play. If you were to play for example, a simple melody over a drone (pedal tone) you would indeed discover, (for that particular drone), that for all the notes of your melody there would be predictable alterations from the equal tempered tuning of your instrument. You would discover that the just major 3rd is (13.7 cents) lower than that which your instrument might naturally play. You would also discover that the just minor 3rd would need to be played (15.6 cents) higher than your instrument might naturally play it as well. The same can be said for sixths, both normal and flatted, as well as 2nds and 7ths. The just 4ths and 5ths are quite close to equal tempered but the tritone has several possibilities. *But changing the drone note to another scale degree under the same melody notes would necessitate that you change the tuning of each note of your melody to once again blend or sound in tune.* Even though another drone note may be "in tune" with the old drone, your notes would still have to change slightly. **In the real world, tuning is a dynamic relationship between melody, harmony and bass.**

Another complication that arises is that the perceived best position for your tone while playing with two (or more) tones is dependent upon the intervals the other tones create. You could be in tune with one of the tones of a chord but out of tune with the other. A good example of this is when consecutive major 3rds (or other consecutive like intervals) are played. For example, when a chord is created by stacking major 3rd intervals, where each major 3rd is tuned to the note directly below it, the resulting top note is a very flat minor 6th interval to the root. Although the resultant minor 6th interval is "just" or can be expressed as a whole number ratio, it sounds rough or sour. The numbers that express the ratio are quite high*. By comparison, when you play a minor 3rd on top of a perfect 4th the resulting top note is a very pleasing minor 6th and all tones in the chord are "in tune" with each other *and* the root.

Let's do a little math. The following triads both have a minor 6th interval between the top note and the root:

major 3rd + major 3rd (5/4 x 5/4 = 25/16)** = a very flat and sour sounding minor 6th interval

perfect 4th + minor 3rd (4/3 x 6/5 = 24/15 or 8/5) = accepted just minor 6th

Consecutive like intervals (b2, 2, b3, 3 & +4) do not create an octave when stacked one on top of the other. This means that chords built of consecutive like intervals can not sound pleasantly in tune. The series "major 3rd + major 3rd + major 3rd" does not equal an octave the way it does in equal temperament, nor does the series "minor 3rd + minor 3rd + minor 3rd + minor 3rd" create an octave either. Consecutive 4ths, 5ths or the other intervals do not in reality eventually "go full circle" to return to the same beginning tone. This is only possible with equal temperament.

Here is the bad news: The above discussion only touches lightly upon the complexity of the just tuning system. If you are interested to dig deeper into this world, I would highly recommend reading "Genesis of a Music" by Harry Partch. He is a pioneer of just intonation as it applies to fixed pitch instruments and has inspired many to carry the just intonation torch.

Ah, yes and here is the good news: You don't need to be a mathematician to play in tune, with a little training, your ear does it automatically. Remember, your ears and your brain are designed to do this. It is a neat little feature built in to every human who is even remotely musical or should I say, every musician who is even remotely human...

* It is important to note that intervals that can be expressed in lower whole number ratios are more "consonant" sounding than intervals that must be expressed in higher order whole number ratios.

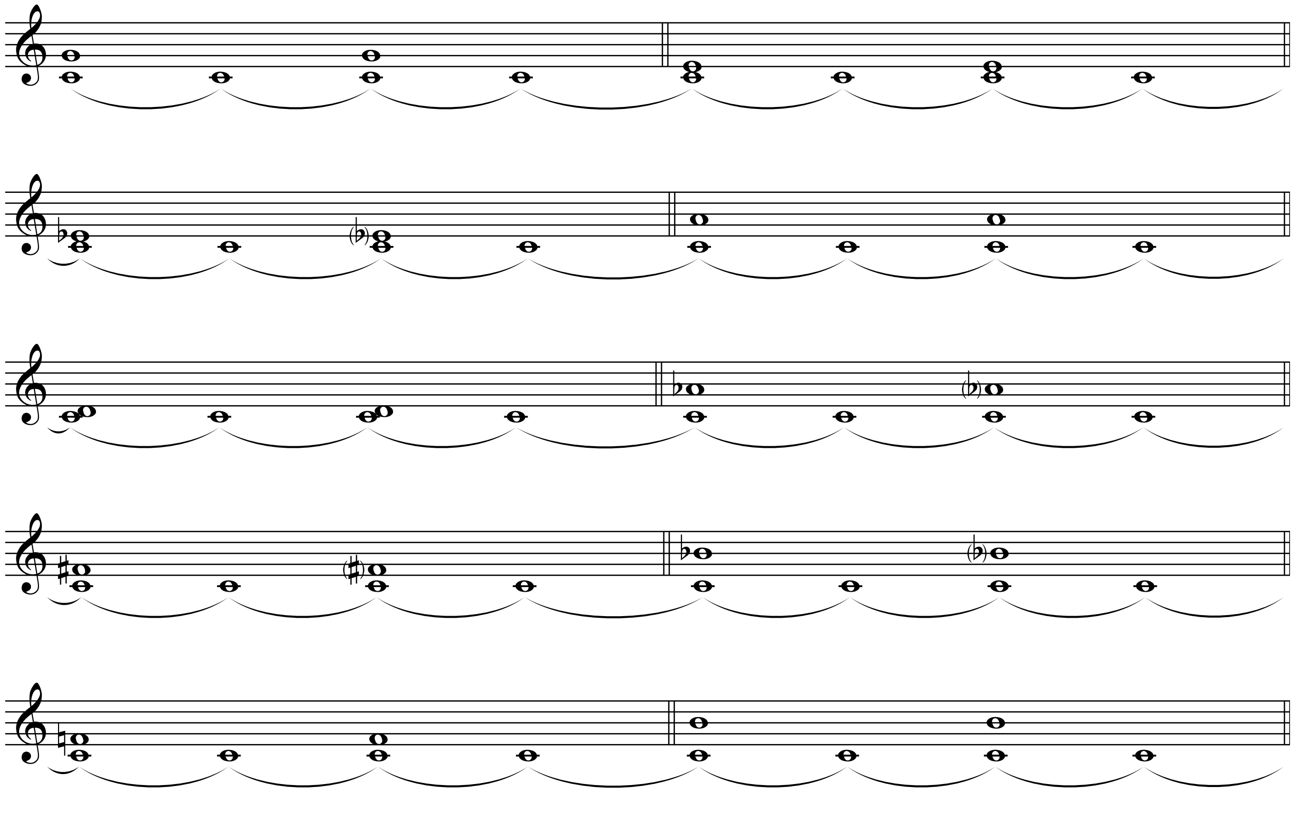
** Interval ratios are "added" together by multiplying them, top number times top and bottom number times bottom.

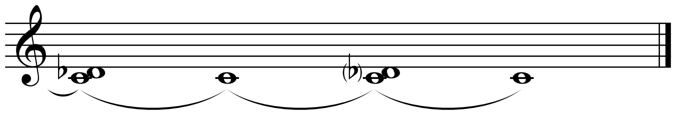
Track 1, an introduction just intervals

Track 1 on the CD is an introduction to just intonation. Twelve intervals will sound in relation to a drone. Your first task is to listen to the track. Then, play the track again and s*ing* along with the upper interval. When the upper interval stops sounding sing your pitch again. Strive to recreate the same quality you heard. You will check your intonation when the interval is again sounded. After you have completed the first task, play your instrument along with the track. Although the instrument on the playback is a keyboard *the tuning of the upper notes is not from the equal tempered scale*. Just to hear how far away some of the intervals are from equal temperament play the upper notes on piano along with the track. The bottom note of the interval should be in tune with your piano if it is tuned to A=440 (A=442 European version).

When you sing or play along with the tracks *take the time* to carefully listen to your note in relation to the notes being sounded. Strive to “blend”, to make a smooth, stable sound with out the beating quality heard with intervals or unisons that are out of tune. Can you bend your notes down and up? Try to play purposefully sharp, flat and then in tune.

C Instruments





Tones sound one octave lower than written.

If you play Bb or Eb transposed instruments this music example will be found on the following two pages.

Track 1, an introduction just intervals

What did you notice when you played along? Were there some notes that were higher than you would naturally play them? Some that were lower? Some that felt fine, just as they were?

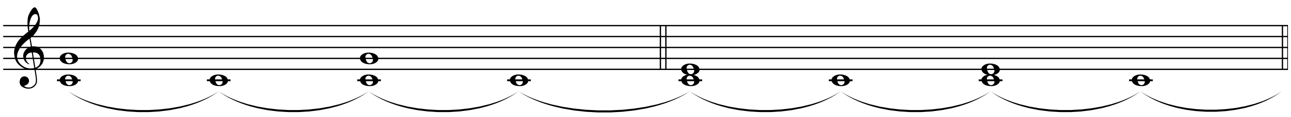
Could you hear beating when you purposefully played sharp and flat? This is very important.

It is also important that you match the played upper tones exactly and that you hear and feel through your instrument that they occupy a specific place. This is easier heard with the 5th, 3rds, 4th and 6ths. The 7ths take a little time to hear.

The following is once again the interval series, but with the cent markings for how much the just intervals are at variance with their equal tempered counterparts. The markings indicate how much you must alter equal temperament to achieve just tuned intervals.

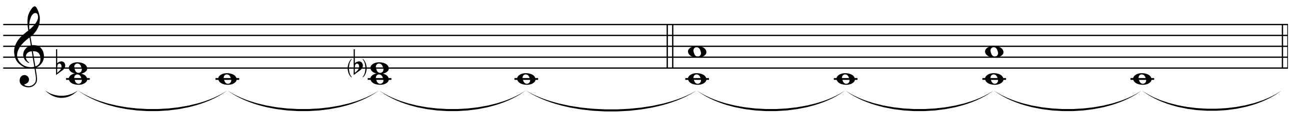
5ths: +2 cents, maj 3rds: -14 cents, mi 3rds: +16 cents, maj 6ths: -16 cents, maj 2nds: +4 cents, mi 6ths: +14 cents, tritone: - 17.5 cents (or + 17.5 cents), b7: -4cents, 4th: -2 cents, maj7: -12 cents, mi 2: +12 cents. (These figures are approximate)

C Instruments



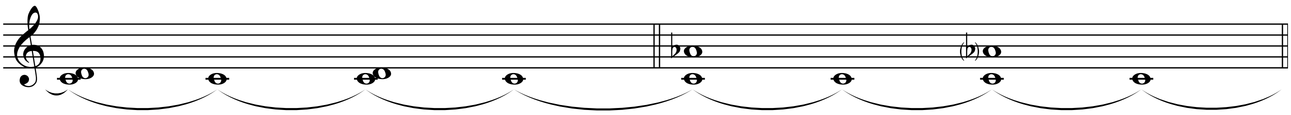
P5, +2 cents, Ratio: 3/2

Major 3rd, -14 cents, Ratio: 5/4



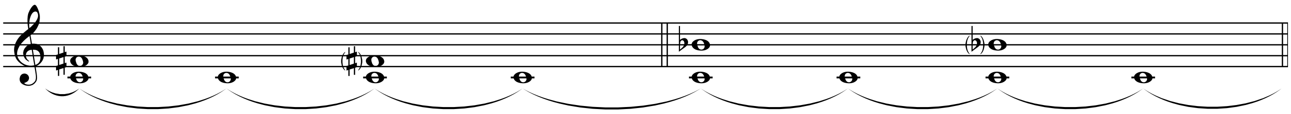
Minor 3rd, +16 cents, Ratio: 6/5

Major 6th, -16 cents, Ratio: 5/3



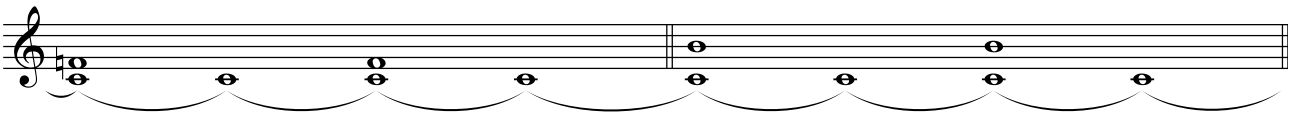
Major 2nd, +4 cents, Ratio: 9/8

Minor 6th, +14 cents, Ratio: 8/5



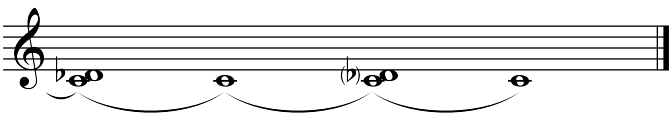
Tritone, -17.5 cents, Ratio: 10/7

Flat 7, -4 cents, Ratio: 16/9



Perfect 4th, -2 cents, Ratio: 4/3

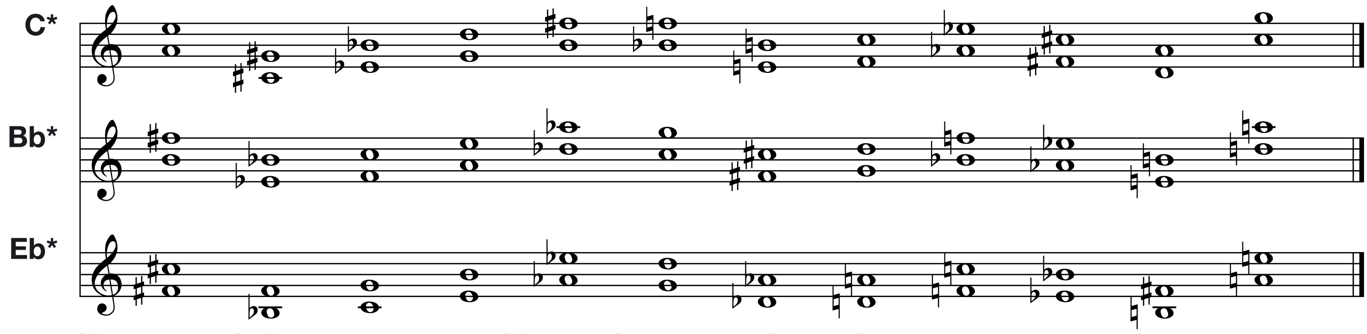
Major 7th, -12 cents, Ratio: 15/8



Minor 2nd, +12 cents, Ratio: 16/15

Track 2, Perfect 5ths, a good, clean start.

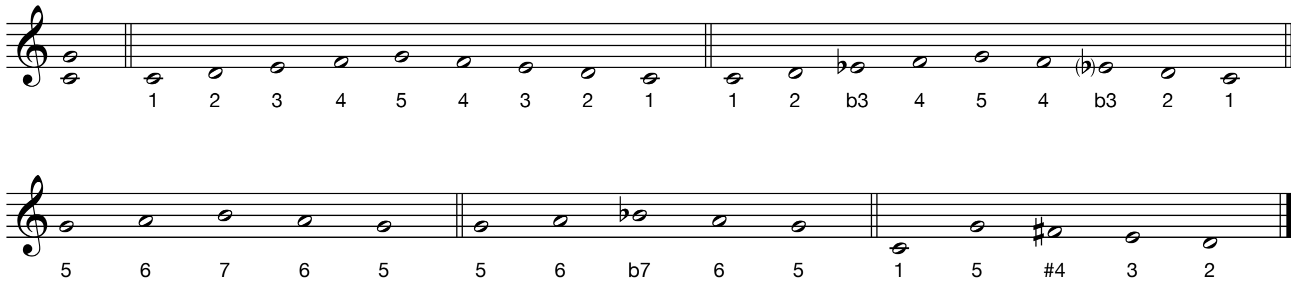
This track contains the following sequence of tones. To the left of the staves is a letter that refers to the transposition. **C*** is for Concert or non transposing instruments, **Bb*** is for Bb saxophones or clarinet, **Eb*** is for Eb saxophones or clarinet. This sequence is a series of perfect 5ths randomly transposed throughout all 12 keys.



Note: recorded tones may sound in an other octave than written.

The exercises below are written out in the key of C. Everything you will play is then written out on the following pages. Later you may also memorise the exercises and transpose them for each pair of intervals in the sequence. But for now, I recommend that you read the written out and transposed sequences that follow this page and concentrate upon blending. To help with transposition, the notes of each exercise variation are annotated with scale degree numbers. Sing the exercises first. If you can't sing it, you don't hear it, and if you don't hear it, you can't play it.

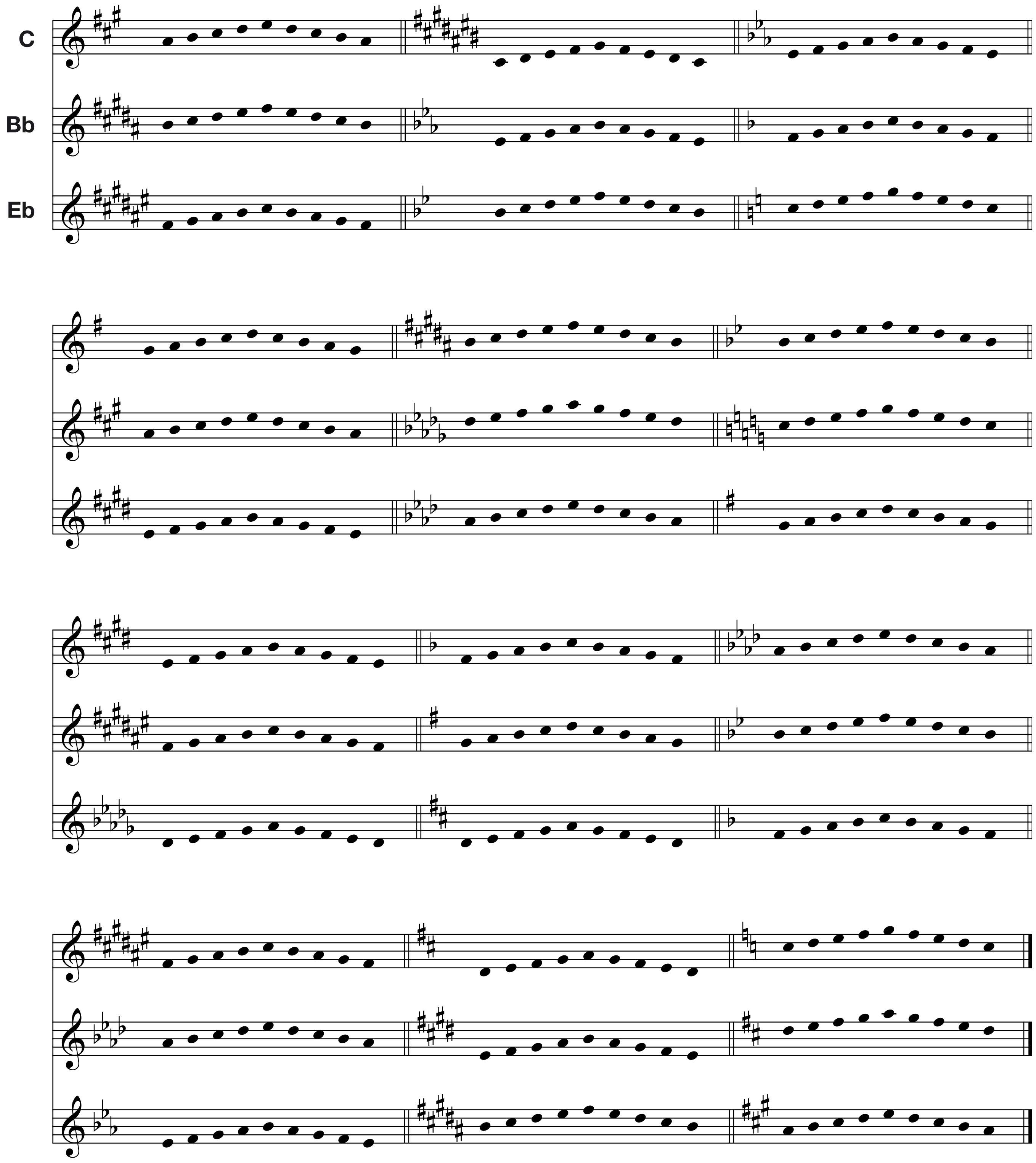
Exercises to be played along with track 2



Do not rush through the sequences. Enjoy each note. Alternate between the first and second notes, the second and third notes etc. Make sure you are really in tune. Go forward and back along the series, make jumps or improvise with the notes. Play each tone at least a full second. Longer is better. Invent your own variations to the play-along tracks but remember; **play slowly, listen and expect to change the tuning of your pitches!**

Exercise 1

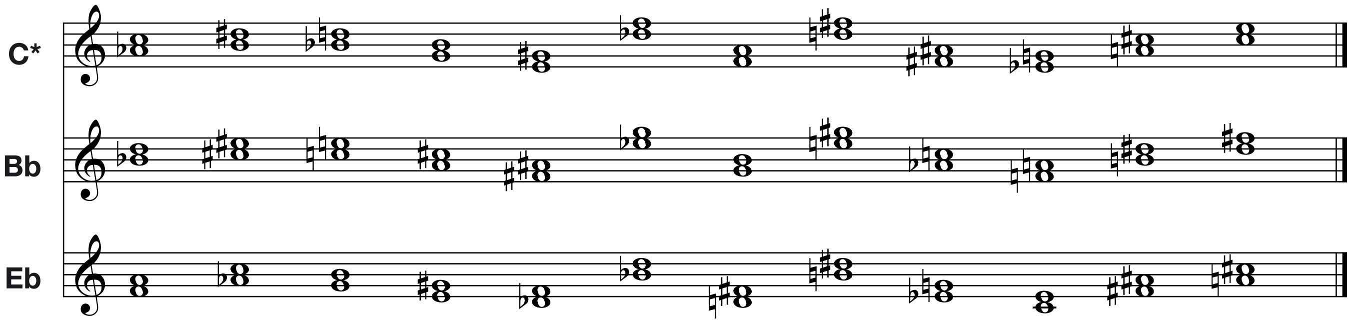
Play the examples in all registers of your instrument. Pay extra attention to the 3rd scale degree. In just intonation it is almost 14 cents lower than the equal temperament counterpart.



Track 3, Major thirds, how low can you go?

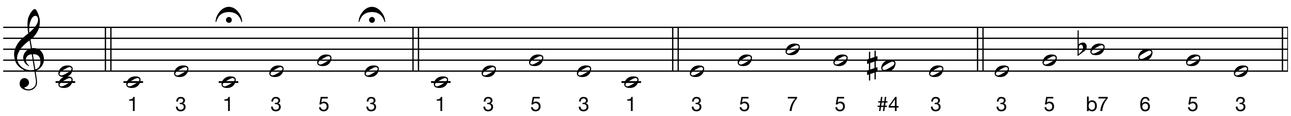
Learning to hear the correct placement of this interval within a chord or in relation to one other note is important. It is the difference between a chord or interval that sounds rich and full and one that sounds strident and unsettled. When we try to match the just 3rd it feels quite low. We must adjust our note about 14 cents downward from the equal tempered 3rd our modern instruments would naturally play. The following exercises may be a little unsettling, as it is quite surprising how far some pitches must be adjusted. You might find yourself saying “Hey! What the heck was that?” Be prepared to adjust the major 7th and the flatted 7th interval as well.

This track contains the following sequence of tones:



* Notes may sound one octave higher or lower than written.

Exercises to be played along with track 3



Transpositions of all the exercises sequences are on the following pages.

Track 3, Major thirds, how low can you go?

Exercise 1