A History of String Intonation

By Hasse Borup

As string players, we have all experienced situations where issues of intonation arise, but with no clear answers at hand. In a string quartet rehearsal, for instance, the issue might be the eternal struggle between the way we hear the perfect fifth and where the middle voices place the third or the seventh. A violinist and a cellist will hear things differently, just by nature of approaching a chord from different “places”: the bottom or the top. The question is whether musicians have always had the same ideal concerning how they hear a note “in tune” or “out of tune.” And if, indeed, the perception has changed over time, should that affect the way we perform baroque and classical repertoire?

The purpose of this article is to make string players aware of the intriguing problems concerning pitch and tuning in order to better understand the true nature of diatonic music. By looking at a number of sources, we can see how the perception of pitch has changed over the past 250 years. Also, by looking at the problems of tuning fixed pitch instruments, we can gather some important information about how musicians of earlier times approached intonation. This information should give today’s string player better judgment to fully explore the full “palette” of tone colors available on the violin, viola and cello.

Useful Terms

Before we take a closer look at the history of intonation, let us clarify the main vocabulary.

Cent
A cent is the unit measuring intervals. Each equal-tempered half step has a value of 100 cents. In other words, one octave is 1200 cents.

Comma
The comma is the difference between the same pitch in two different tuning-systems. For instance, in equal temperament B-sharp and C has the ratio 1/1 but in Pythagorean tuning the ratio is 531441/524288, also called the Pythagorean comma.

In western diatonic music, the following intonation and tuning systems have been used over the last 300 years. First of all, we have the “natural methods,” meaning they are based on perfect intervals.

Pythagorean Tuning
Pythagorean Tuning is based on the pure fifth (3:2). All tones of the scale are determined by stacking perfect fifths without alterations. It is reasonably satisfactory for diatonic melodies, but when chromaticism is introduced major problems occur (the Pythagorean comma).
Just Intonation

Just intonation is calculated from the natural harmonics of a vibrating string. The rest of the intervals are found by multiplying or dividing the given interval into these natural pitches. The diversions occur on major thirds and sixths, where the arithmetic leads to wider thirds and narrower sixths (Pythagorean first three scale steps: 1:1, 9:8, 5:4, just intonation: 1:1, 9:8, 81:64). The third here is calculated by multiplying one major second with another major second (9² x 8²). This system favors the pure third over the perfect fifth, and its emergence coincides—not surprisingly—with the Renaissance period when the church modes were being replaced by the diatonic scale. It is interesting to note that several contemporary composers, including Terry Riley, have renewed the interest in just intonation.

Today, we are more familiar with the tempered tuning systems. They are:

Mean-tone Temperament

Mean-tone temperament is based on a fifth, which has a ratio slightly smaller than the pure ratio of 3:2. The third of just tuning (81:64) is expanded into 2 octaves and this interval is divided into four equal fifths. This was the predominant system in the sixteenth and seventeenth centuries, but proved unable to handle modulations more complicated than within a strict tonal cadence. Mean-tone temperament is in some ways a compromise between Pythagorean and just intonation, utilizing key elements of both systems.

Equal Temperament

This tuning is today’s standard on virtually all keyboard instruments. Equal temperament is simply the octave divided into twelve equal half steps, thus making the perfect intervals ‘imperfect.’ Speaking in Pythagorean terms, only the octave is pure. All other perfect intervals are altered. However, modulations, even to distantly related keys, are effortless but the full richness and signature of each key is severely diminished. To the seventeenth century musician, equal temperament would most likely sound unmusical and flat. But gradually, over the past 250 years, this system has become the norm. The system was described already by Vincenzo Galilei in 1581 but was not fully adopted until the mid-nineteenth century.

Kammerton

It is a well-known fact that the “Kammerton” (the “A” or “La”) was lower in the baroque and classical periods than it is today. However, even at that time a large number of pitch classifications were in use, varying in pitch from 414 to 435 Hz, creating problems for makers of wind instruments, harpsichord tuners, etc. Through the twentieth century the Kammerton has settled somewhere between 440 and 445 Hz.

Physiological Factors in Pitch Perception

Before we dive into the background for why we hear sounds a certain way, some physical aspects concerning the sense of pitch are helpful. An ear for music literally means a sense of pitch. In average individuals this varies between 6 and 40 cents. Learning and practicing music may lower an existing level of threshold value relatively
quickly to a considerable extent. The German acoustical engineer Anton Guttman’s research, in the late 1920s, shows that the sense of pitch is most sensitive in singers, string and wind players. The threshold of sensitivity improves markedly with age and by schooling: by six years it is about 70 cents, and by nineteen years it is about 14 cents. Though a sense of absolute pitch is of advantage for a musical career, it cannot be a decisive factor in the success of the individual. A sense of absolute pitch, even an extraordinarily high sensitivity relative pitch, would be insufficient to warrant musical talent. There are many children who, though having excellent ears, do not understand, and cannot experience emotions induced by music. Neither do they feel an urge to express such emotions. Others may not have an ear of outstanding sensitivity, but they are able to grasp, and have the power to express the feelings conveyed in music. The sense of pitch is, certainly in the tradition of western music, interconnected to the sense of tonality and harmony. The sense of tonality is characterized primarily by the fact that it registers specific notes as the outstanding main notes of a tune, i.e. it recognizes their particular function within the melody. The tonic, the sensation of conclusion, is generally first recognized between eight and eleven years of age. The recognition of the dominant becomes common by age eleven or twelve. The sense for pureness of intonation is a yet more complicated function, because the assessment of intonation depends mainly on emotions.

As far as hearing is concerned, the question of pureness in music is further complicated by two sets of problems: 1) non-diatonic (or equal temperament) intonation and 2) ‘zonal’ nature of hearing. The first is of course a well-known point for most string players and singers: C-sharp and D-flat are not the same note. The twentieth century tradition is to play sharps leading to the upper neighbor note, and flats leaning to the lower neighbor note. More about other practices later.

With these basic principles and terms established we are ready to take a closer look at the teaching and perception of pitch from the late baroque to the twentieth century.

Intonation Practice in the Eighteenth and Nineteenth Centuries

First of all, the reason for being concerned about intonation has mainly occurred when string players need to play together with other string instruments or with a fixed pitch instrument. In the classical period many string players were opposed to adopting a method other than just intonation, but a number of pedagogues advocated the use of tempered pitch to beginners and most other musicians, thus easing the problems arising when playing with keyboard instruments. Louis Spohr writes in the preface to his “Violinschule:”

*Extreme patience and perseverance must be devoted to the fourth section, which lays the foundation of pure intonation for the student. The teacher can indeed save himself great trouble in the future if he insists with uncompromising strictness right from the outset on the absolutely pure intonation of the pupils stopped notes.*

The most significant part related to our investigation, appears in the footnote:
By pure intonation is naturally meant that of equal temperament, since in modern music no other exists. The budding violinist needs to know only this one intonation. For this reason neither unequal temperament nor small or large semitones are mentioned in this method because both would serve only to confuse the doctrine of the absolutely equal size of all 12 semitones.

Obviously, he is attempting to make violin playing sound simple. A wise approach when addressing a beginning student. Yet, it is quite a statement, seen from the perspective of the twentieth century string player, who is used to coloring his half steps and playing close to a hybrid of just, tempered and Pythagorean tuning. It has to be said that Spohr’s view probably was not shared by many violinists of that time and the school of thought was adopted for pedagogical simplification rather than artistic integrity (not unlike Suzuki’s view on intonation in the very beginning stages of a young violinist’s life).

As Robin Stowell points out, a compromise invariably resulted between mean-tone temperament (which was the most commonly used in tuning eighteenth century keyboard instruments), equal temperament and substantially just intonation. Campagnoli confirms the need for such flexibility:

Correctness of intonation prohibits temperament on the violin, except in certain cases: 1st, to lessen the movements of fingers, 2ndly, to satisfy the delicacy of the ear when accompanying other instruments, 3rdly, to facilitate performance; for instance when A-flat and G-sharp successively occur on the third string, it is not necessary to withdraw the fourth finger in order to employ the third, but the fourth must be kept pressed upon the string, and its position be modified as the nature of the harmony may require.

The addition of vibrato is nowadays considered one of the most effective ways of constantly adjusting string intonation (Douniz recommended his students to play with vibrato at all times), but there seem to be no indication of active participation of vibrato in intonation in the classical period.

**Tuning the Instrument**

Open strings naturally further complicated matters in such a fluid intonation system, since only one open string of a violin tuned in perfect fifths will correspond with most keyboard instruments. Some performers claim that the violin can only be tuned perfectly in the key of D major, since only then are the fifths actually perfect; in other keys, certain open-string tunings have to be tempered and this is best achieved by avoiding open strings and stopping the notes in question. This question arises acutely when a string quartet is playing in a key where an open string is the major third (for instance, F major, B-flat major, etc.). Since there are six differently-pitched open strings in a quartet it—in reality—affects 12 keys. That is half of the circle of fifths! Therefore, many quartets choose to tune close to a mean tone-inspired tuning, with the so-called “tight” or close fifths. Unfortunately it does not solve the problems of having to raise the tonic note completely. Leopold Mozart and Quantz agree on how to tune to keyboard instrument. Quantz, in his *Versuch Einer Anweisung die Flöte Traversiere zu Spielen* from 1752, explains:
To tune the violin quite accurately, I think you will not do badly to follow the rule that must be observed in tuning the keyboard, namely that the fifths must be tuned a little on the flat side rather than quite truly or a little sharp, as is usually the case, so that the open strings will agree with the keyboard. For if all the fifths are tuned sharp and truly, it naturally follows that only one of the four strings will be in tune with the keyboard. If the a is tuned truly with the keyboard, the e a little flat in relation to the a, the d a little sharp to the a, and the g likewise, the two instruments will agree with each other.  

It becomes clear that the classical period of music had its troubles with intonation, just as we have now. Today, we are used to the idiom of differentiating between melodic and chromatic half steps, for example playing a G-sharp higher than an A-flat, and consequently raising the seventh step of the scale. As we have discovered, a confusing variety of tuning systems coexisted in the classical period. But few violin methods discussed the problems, concentrating merely on the violin’s melodic role in the tuning of tones and semi-tones rather than large intervals, especially fifths and thirds, which are so essential to the more chordal role of keyboard instruments and their tuning systems. Contrary to the previously mentioned modern practice, most eighteenth century violinists adopted a modified type of mean tone temperament, in which a sharpened note was considered a comma (about 22 cents) lower in pitch than the flattened form of a tone higher. Historically, a main factor in string intonation was the invention of steel strings and the disappearance of gut strings. It is an interesting ‘coincidence’ that the practice of ‘tensioning’ the harmonies (by raising leading tones, coloring half-steps) occurred at about the same time as introduction of steel strings. On the issue of intonation, Leopold Mozart writes:

On the keyboard, G-sharp and A-flat, D-flat and C-sharp, and so on, are on the same note. This is caused by the temperament. But according to the ratio, all the notes lowered by a flat are a comma higher than those raised by a sharp. For example: D-flat is higher than C-sharp and so on. Here the good ear must be the judge, and indeed it would be good to introduce pupils to the mono-chord.

Another source supporting this view is Prelleur’s fingerboard diagram. It clearly shows the different placement of sharpened and flattened notes. Leopold Mozart provides two scales (Ex. 2), leading through the flats and sharps respectively, intended as an intonation exercise in distinguishing between the large diatonic semitones and small chromatic semitones.
When an enharmonic interval or modulation occurs in a string quartet, special problems arise. Some examples from Mozart, Haydn and Beethoven quartets require the players to consider “fifths” that are notated as augmented intervals (for example C-sharp and A-flat). Or, even more interestingly, what happens when two enharmonically identical pitches are repeated? Take a look at example 3:

According to Spohr, the first violin, viola and cello should play the exact same pitches in both measure 71 and 73. But if we follow L. Mozart’s indications, the E-flat should be slightly higher than the D-sharp. This makes sense; even though Beethoven was primarily a pianist he was a sensitive string player as well, fully capable of understanding and using these fine pitch distinctions. Another pitch-related indication could be the dynamics: the slightly “higher” pitch is piano, while the slightly “flattened” is pianissimo. It goes without saying that it takes a very advanced group to execute a fine nuance such this.
The Scale as Intonation Aid

The tool that standardized the development of pitch was the inclusion of scales as a pedagogical mean. The appreciation of scales in the training and discipline of the left hand was not fully acknowledged until the second half of the eighteenth century when, following Geminiani’s and Leopold Mozart’s surveys, writers normally included scales in some form in their methods. The scales were meant to encourage the cultivation of accurate intonation, finger independence, elasticity and agility, strong finger action for tonal clarity and a variety of bowing disciplines. The great violinist Baillot’s survey is rather more conservative. After preliminary pages of twenty-four one-octave scales in all keys, he goes through a rigid program of scales travelling the entire circle of fifths. He writes:

*We have acknowledged that the common habit of playing scales slowly was the reason why pupils rejected them or refused to practice them; it has been said elsewhere why scales played too slowly were not as beneficial as those played with sufficient movement to establish their tonality. But it has not proved possible to reject slow scales altogether, since those which are destined to establish good intonation with regard to harmony and form part of studies and are in 1st position must be played with a certain slowness.*

The C major scale was commonly recommended in the eighteenth century as the initial scale for beginning violinists to study, but G major gradually gained favor towards the end of the century because of its more natural distribution of the fingers on the fingerboard. Viotti gives a thorough explanation in his survey:

*It is the scale, which establishes good intonation, beautiful tone quality. Which makes the voice or the fingers flexible; which steadies the bow on the string. Finally it is the scale which opens the arena to our tumbling footsteps, which makes us gradually steadier, helps us surmount obstacles and serves as a reliable escort through immense difficulties.*

It is interesting to note that throughout the nineteenth century the violin duet gained popularity as a pedagogical tool and intonation aid. In addition to encouraging accurate intonation and exercising students in a number of basic technical matters, the duet helped to add informality to the relationship between master and pupil. The accompanying second violin part guided the student in a variety of disciplines (rhythm, harmony, style and expression). Pedagogues, such as Lohlein and Spohr, composed a great number of duets.

The Teaching of Intonation by Wolfgang Amadeus Mozart

Before we leave the eighteenth century practice it is worth briefly mentioning a document existing with reports on W.A. Mozart’s teaching of intonation. The young Englishman, Thomas Attwood, studied composition with Mozart in the mid-1780s. It was very rare that Mozart took any students, generally only those with either incredible talent or money. The manuscript of Attwood’s studies with Mozart is the largest and
most comprehensive of the manuscripts surviving from Mozart’s teaching of composition and theory. In this manuscript, there are examples of chromatic scales with enharmonic equivalents showing, variously, the German and Italian manners of distinguishing the flats and sharps, the large and small half steps, the names of intervals, and the sizes of intervals as sums of whole steps and either large or small half steps. The distinction made by Mozart between large and small half steps is undoubtedly that of mean tone temperament: diatonic half steps are large and chromatic half steps are small. The chromatic scales in Attwood’s manuscript vary in the number of tones they contain, some going into double flats and sharps, others not going that far from the natural notes in the circle of fifths. Thus the scale, in this manuscript, contains at least seventeen notes: seven natural notes, five flats and five sharps. Since Mozart does not qualify his distinction between large and small half steps in any way, particularly in a manner that would suggest temperament, he would appear to be saying that in his tuning system there are more than twelve equal notes to the octave. Indeed, the systems of tuning led some keyboard instrument makers to manufacture harpsichords, clavichords and other earlier keyboard instruments with split-keys for better intonation. Some harpsichords would have the octave divided into as many as 36 keys, two for each half step, thereby enlarging the possibilities of enriching the given keys. Example 4 shows the graph which was made from the Attwood manuscript. Mean tone temperament and irregular temperament (circles) are shown with the variations in cents from the equal temperament. It is clear that flattened notes were closer to their main note, than was the sharpened note of the neighbor note below.

Ex. 4. Equal and mean tone temperaments compared. The sharpening of a note keeps it closer to its attachment (as described by L. Mozart).

Intonation Practice in the Twentieth and Twenty-first Centuries

For the last one hundred years, the predominant view on intonation has been to adopt a combination of the three main intonation systems, just tuning, equal temperament and Pythagorean tuning. Carl Flesch writes in *The Art of Violin Playing*:
Violinists, be they ever so important in other respects, whose intonation is tempered pianistically, and who, for example, take E-flat and D-sharp in the selfsame spot, or do not raise the leading note B in the scale of C, are poor quality in my opinion.\textsuperscript{15}

Herter Norton is in agreement with Flesch, and in the book \textit{The Art of String Quartet Playing} he encourages the player to rely on his ear.\textsuperscript{16} According to Norton, string players devise their own tempered scales according the relations of tones among all four members of the quartet. Using what Norton calls a ‘self-engendered process of modulation’ scale tones will require different pitches when in different harmonic contexts. In a different description of the same intonation system, Joseph Szigeti names it ‘functional intonation.’ Here, he states that functional intonation is founded on the harmonic structure of the music and is not invariable. Any note of the scale may vary in frequency depending on its function so that when behaving as a leading tone it will be sharper than in other contexts. According to Rebekkah Brown, there is evidence that Joachim implied a very strict sense of just intonation, and several nineteenth century violin teachers explicitly recommended the shading of the pitches in direction of their ‘attachment’ to achieve an animated performance (flats higher than sharps of the neighboring note).\textsuperscript{17} In contrast, the most highly acclaimed violin pedagogue of the twentieth century, Ivan Galamian reaffirmed literally every statement on intonation by Carl Flesch in his \textit{Principles of Violin Playing}. Galamian sums up the entire concept by stating that the only safe intonation is one that instantly adjusts to the demands of the moment. Galamian advocates the often-stated twentieth century opinion that violinists cannot adjust intonation according to ‘mathematical formulas.’ Acknowledging both tempered and natural tunings in violin performance, Galamian advises the violinist to match the intonation of the accompanying medium. Thus, it is at times necessary to use a tempered tuning when performing with pianos, while other performance situation may require a different intonation. The use of the term ‘natural intonation’ by Galamian, and twentieth century violinists in general, likely suggests an intonation that adjusts each pitch to agree with the ear and not a defined fixed pitch tuning whereas a century before, other pedagogues would refer to just intonation.\textsuperscript{18} Therefore the controversy concerning whether violin performance should or does confirm to equal, just or Pythagorean tuning was once of great concern to theorists but among many contemporary violin pedagogues has fallen aside due to the evidence of its inappropriateness. Leopold Auer briefly touches on the issue of intonation in his \textit{Violin Playing as I teach it}.\textsuperscript{19} Apart from practicing diatonic scales, he strongly urges the player to practice chromatic scales as an aid for good intonation. Whether it is twelve equal half steps is not explicit. The practicing of the chromatic scale has been adopted by many of the great teachers of today. Roland Vamos is a strong believer in this approach, and so was Rudolf Kolisch. Kolisch allegedly only practiced chromatic and whole-tone scales. He did this mainly to facilitate a sense of playing in ‘no position’ but also as an intonation aid.

Kato Havas is a strong advocate for developing the sense of pitch through ear training. She claims in her book \textit{A New approach to Violin Playing} that the endless practicing of scales and exercises will not improve intonation, unless the ear is trained simultaneously.\textsuperscript{20} She wants the student to be able to hear the pitch before playing it, and outlines, in her \textit{12 Lessons}, a study of singing pitches and playing them on the instrument. Even singing and playing duets or canons simultaneously is a powerful
exercise in control. This technique without any doubt have roots in the Hungarian tradition of ear-training and is an aspect that is much to often forgotten in the early stages of teaching an instrument.

However, intonation in artistic violin playing can not be a random phenomenon; some pattern must exist or there would be no distinction between good and bad intonation. Physicists throughout history have attempted to uncover the laws governing musical intonation but it is only in relative recent history that, within the science of acoustics, the techniques for studying the frequencies of sounds have been developed sufficiently to be applied to violin performance.

**Scientific Surveys of Intonation and Final Thoughts**

The Russian acoustician N.A Garbuzov made one of these studies in 1948. He found experimental evidence for his observation that the musical ear is sensitive to pitch zones around the given sound and not tones of a definite frequency. In respect of physiology, our present system of music is arranged into twelve zones instead of twelve semitones. Garbuzov made numerous analyses of recordings by Zimbalist, Oistrakh and Elman and in this respect could show the tendency to avoid neutrality of adjacent intervals in intonation, i.e. to make precise distinction between the respective pitch relations. Between the recitals of the three artists the difference of intonation was so great that it was impossible to include them into a common system, so that only the respective order of intonation used in the recital could be assessed!

With the knowledge in mind that even some of the greatest violinists of the twentieth century did not agree on intonation, it is appropriate to reflect that intonation on a string instrument is indeed a treacherous undertaking. By gaining as much knowledge as possible about the problems, it is possible for the player to come to his own conclusions when confronted with problems that require more through than whether or not a chord or interval is “in tune.” We can obviously never “fool” our ear, but by informing ourselves we can enhance a performance with stylistic and interpretational finesse.

---

3. Louis Spohr, *Violinschule* (Vienna: 1832), preface for parents and teachers, p. 3.
12 Stowell, 354.
14 Ibid., 269.
17 Rebekah A. Brown, *Dynamics of Intonation in Performances by Artist Violinists* (Ph.D
Diss., Indiana University, September 1996), p. 27.
18 Ibid., p. 24.
40.
21 O. Szende & M. Nemessuri, p. 141.