

Seminar in Music Theory:

Computational Musicology: Musical Signal Processing

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## “Spectral Richness”: Equal vs. Just Intonation

The history of intonation in Western music had a quick change during the baroque era when equal temperament became the preferred tuning method due to its homogenous balance of the chromatic scale throughout the registers, no matter what key. This tuning disregards the whole number ratios of the overtone series. Instead, frequencies of notes are related to their neighboring semitones by a fraction of the twelfth square root of two (approximately 1.059463094...). A just scale however depends on the fundamental, or tonic and whenever that is changed, the whole scale's makeup is based on the new fundamental. This means there is a much larger number of notes than in the equal system since the tuning of just scales incorporates differences in frequency of the size of single cents up to several Hertz, hence my hypotheses of this research project that looks at the two tunings, equal and just, juxtaposing them with the focus on the sound experience listeners might have:

Due to the richness of distances to neighboring notes caused by the ratios of just temperament, there is a spectral richness within just tempered music and its harmonies which is richer and contrasts strongly from its counterpart, the Equal Temperament with its equal distances in the chromatic scale.

The expression *spectral richness* refers to the aspect of sound one might call color, or “timbre”. But since these parameters of sound cannot be evaluated technically, only as subjective observations and impressions, I tried to find an aspect of sound evaluation that is closest to the *color* factor of sound to relate that to the listening experience.

The material evaluated for this research are audio wave-files I created by recording of simple three-part chord progressions, all in C major, to be able to create a close relationship of the recorded material in order to have the most clear and strong comparison in my spectral analysis. Some of the recordings were done with my voice, and most with digital piano, all based on A4 being at 440 Hertz, recording voice by voice, layering them in Logic Pro X and finetuning them with Melodyne to equal intonation. Subsequently, I detuned these created files cent-wise into just tempered versions. The just scale was based on the overtone series with the fundamental being C, and all the cadences were in the range of G3 – C5 with the following frequencies, contrasted to the equal tempered counterpart, and the approximate difference in cents (even though the difference is technically in Hertz, in order to detune the audio recording I needed to detune them in steps of cents):

Pitch	Just Frequencies in Hertz	Equal Frequencies in Hertz	~ Difference in Cents
G3	196.22	196	-1
A3	218.02	220	8
B3	251.16	246.94	-17
C4	261.63	261.63	0
D4	294.33	293.66	-3
E4	327.03	329.63	10
F4	348.83	349.23	2
G4	392.44	392	-2
A4	436.05	440	16
Bb4	470.93	466.16	-19
B4	490.55	493.88	13
C5	523.25	523.25	0

The Cadences used are as follows:

	Chord 1	Chord 2	Passing	Chord 3	Passing	Chord 4
<b>Authentic</b>	G4	A4		G4		G4
	E4	F4		D4		E4
	C4	C4		B3		C4
<b>Imperfect</b>	G4	A4		C5		B4
	E4	F4		G4		G4
	C4	C4		E4		D4
<b>Plagal</b>	C5	A4	G4	F4		E4
	G4	F4	E4	C4		C4
	E4	C4	C4	A3		B3
<b>Deceptive w/ Bb</b>	C5	Bb4	A4	G4	F4	E4
	G4	F4		D4		C4
	E4	C3		B3		A3

These cadences include these intervals: minor third, major third, perfect fourth, perfect fifth, minor sixth, major sixth and minor seventh.

When listening to the created recordings, comparing them one to one, also with extracted two voice versions (top two voices, bottom two voices, top and bottom voice), the differences were obvious. Some stronger than others, depending on the interval class. When it comes to strongly consonant intervals, and intervals based on simple ratios such as major thirds (ratio of  $5/4$ ), perfect fourths (ratio of  $4/3$ ) or perfect fifths (ratio of  $3/2$ ), the differences seem less obvious, as soon as it comes to intervals that are based on more complicated ratios, such as minor sixth (ratio of  $8/5$ ) or major seventh (ratio of  $15/8$ ) the whole color seems more unstable, suspended. The intervals and chords seemed to have more of a *noisy color*, are oscillating faster. The differences were clearer in the piano versions due to the vocal inconsistencies like vibrato, which made it complicated to distinguish strong pitch centers.

In order to proof or debunk my listening observations I decided to do a spectral analysis on the audio files as well, using tools like Python's *analyzeAudio.py*. I looked at three different spectral tools and aspects specifically:

Mel Spectrogram, Spectral Centricity, and Spectral Flatness.

The differences were significant in some of those. For example, the spectral centricity and the spectral flatness much higher in the just versions than in the equal ones. Some peaks of the just piano versions in the spectral flatness diagram are twice as high than in the equal versions. This strongly suggests that the spectrum of just tempered chords and intervals shows to be more of *noise-like* character (according to Western standards), which correlates with my listening

observation of the just tempered sounds being of “richer” *color*, or at least of different kind than the tone-like sound of the equal counterpart – whatever that means, which brings me to my conclusion.

Listening to and analytically comparing the distinct versions of several equal and just tempered sequences of the same recording helps providing a somewhat coherent tool in order to distinguish differences between three-part chords, intervals and progressions. The direction from chord to chord, the richness of the spectrum, the *colors* are different. If one is actually richer than the other can be discussed, even though spectrograms provide strong evidence for higher levels of flatness in the just versions.

Probably the most difficult challenge is to find the right terminology for the issue of describing the subjective, cognitive experience and its differences of listening to equal and just tempered sounds: Is it about the “timbre”, “color”, or “richness of sound” in general? And how can those be evaluated or expressed?

On the other hand, the listening aspect is always individual. One thing majority of people in Western societies might have in common, due to conditioning to equal temperament, is, that just intonation sounds “different”, or “off”. Does that maybe deceive the description of the sound being “richer”?

The field of researching the *qualitative* differences of just and equal temperament is endless and hopefully will be explored much more in the future.