<u>Consonance & Dissonance</u>:

<u>Consonance</u>: A combination of two (or more) tones of different frequencies that results in a musically ***<u>pleasing</u>*** sound. Why???

<u>Dissonance</u>: A combination of two (or more) tones of different frequencies that results in a musically ***<u>displeasing</u>*** sound. Why???

⇒ *n.b.* Perception of sounds is also wired into (different of) our <u>emotional centers</u>!!! Why???/How did ***<u>this</u>*** happen???

The Greek scholar Pythagoras discovered & studied the phenomenon of consonance & dissonance, using an instrument called a ***<u>monochord</u>*** (see below) – a simple 1-stringed instrument with a movable bridge, dividing the string of length L into two segments, x and $L–x$. Thus, the two string segments can have any desired ratio, $R \equiv x/(L–x)$.

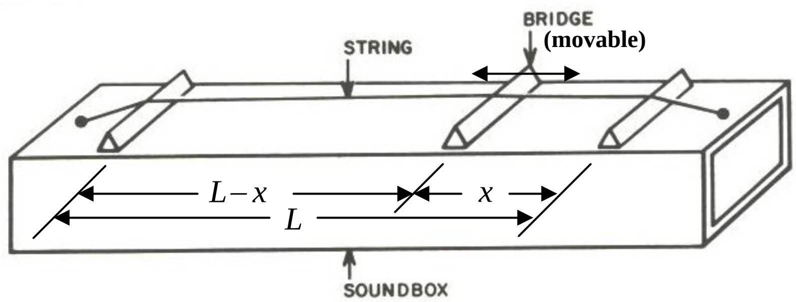


FIG. 1. The monochord.

When the monochord is played, both string segments vibrate simultaneously. Since the two segments of the string have a common tension, T, and the mass per unit length, $\mu = M/L$ is the same on both sides of the string, then the speed of propagation of waves on each of the two segments of the string is the same, $v = \sqrt{T/\mu}$, and therefore on the x-segment of string, the wavelength (of the fundamental) is $\lambda_x = 2x = v/f_x$ and on the $(L–x)$ segment of the string, we have $\lambda_{L-x} = 2(L–x) = v/f_{L-x}$. Thus, the two frequencies associated with the two vibrating string segments x and $L – x$ on either side of the movable bridge are:

$$f_x = \frac{v}{2x}$$

$$f_{L-x} = \frac{v}{2(L-x)}$$

Thus, the ratio of the lengths of the two string segments R is also the {inverse} ratio of the two frequencies associated with the vibrating string segments on either side of the bridge:

$$R = \frac{x}{L-x} = \frac{v/2f_x}{v/2f_{L-x}} = \frac{f_{L-x}}{f_x}$$

Consonance occurs when the lengths (frequencies) of the two string segments are in very special/unique ***integer*** ratios, R (and/or $1/R$), respectively of:

$$R = \frac{x}{L-x} = \frac{f_x}{f_{L-x}} = 1:1,\;\; 1:2,\;\; 2:3,\;\; 3:4,\;\; 4:5,\;\; 5:6,\;\; ....$$

$$1/R = \frac{L-x}{x} = \frac{f_{L-x}}{f_x} = 1:1,\;\; 2:1,\;\; 3:2,\;\; 4:3,\;\; 5:4,\;\; 6:5,\;\; ....$$

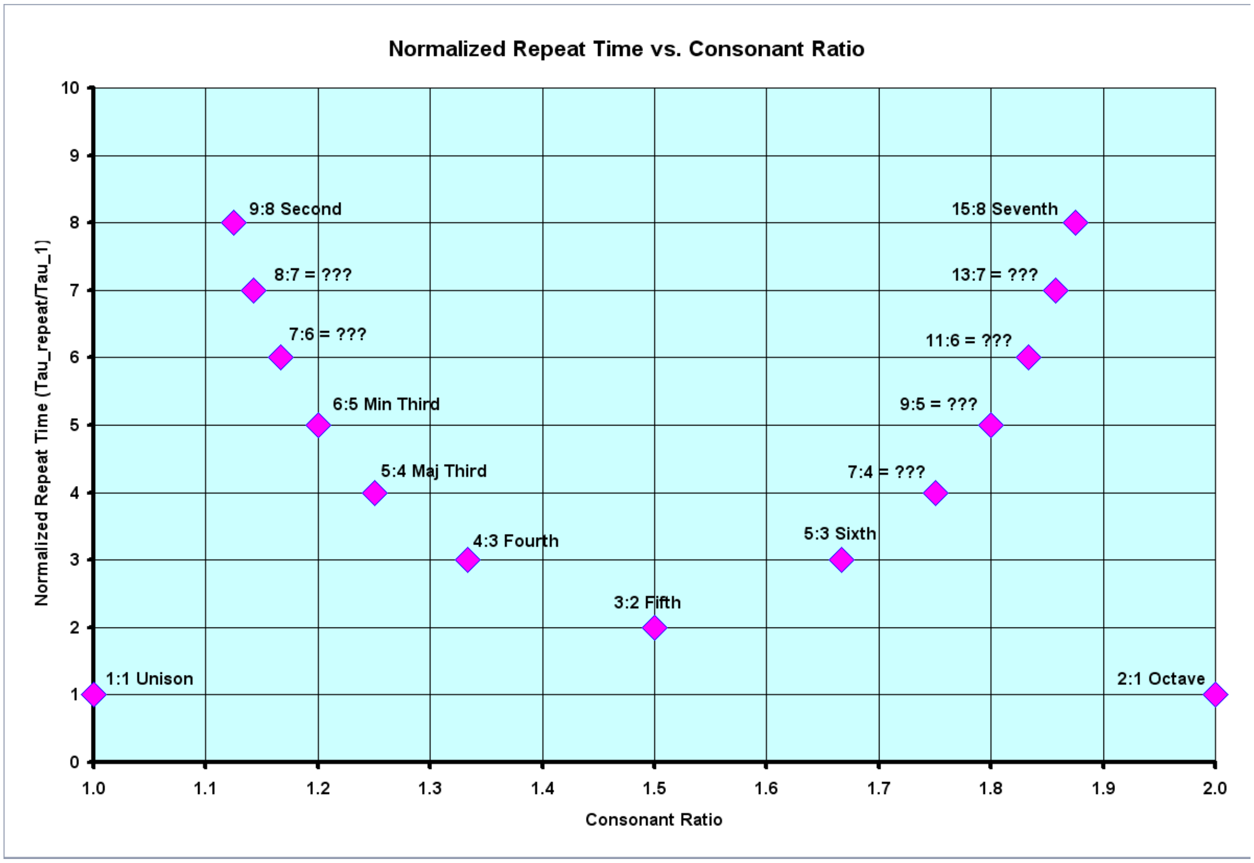
Unison, Octave, Fifth, Fourth, Major Third, Minor Third

These ***integer*** frequency ratios relate ***directly*** to two notes played in unison, octave, fifth, fourth, major/minor thirds and second of the ***just diatonic musical scale*** – (see below)!

Dissonance occurs when the length of string segments (*i.e.* frequency ratios) are ***far*** from/are ***not*** integers.

When two (or more) musical tones are consonant, the ***phase relation*** of higher frequency relative to the lower frequency is ***time-independent***. The resulting overall waveform is ***stationary/time-stable***, with a ***repeat time*** of the waveform that is relatively short – min{m:n} where $1/R = m/n$ {see figure on next page}.

The phase-stability of the waveform for a consonant sound makes it particularly easy for the human ear/brain to recognize (analyze). Also, note that the harmonic(s) of the higher frequency tone – *e.g.* maj. 3rd or fifth, tend to line up/coincide with the harmonics of the lower frequency tone! (Quadratic) non-linear responses present in the human ear/brain generate/create sum & difference frequencies, $(\boldsymbol{f_{L-x}} + \boldsymbol{f_x})$ and $|\boldsymbol{f_{L-x}} - \boldsymbol{f_x}|$ that also perfectly/exactly line up with the harmonics of the two tones, and again which have a time-independent/stationary phase relation relative to the fundamental of the lowest tone! The human ear/brain thus perceives consonant tones as very special and unique!



When two (or more) musical tones are dissonant, the *phase relation* of higher frequency relative to the lower frequency is ***not*** time-independent (time stable). The resulting overall waveform is also not stationary/time-stable. This waveform is ***not*** easy/is more difficult for the human ear/brain to recognize (analyze).

For dissonant tones, the harmonic(s) of the higher frequency tone do ***not*** perfectly/exactly line up with the harmonics of the original lower frequency and/or higher frequency tones. Additionally, quadratic non-linear responses present in the human ear/brain generate/create sum & difference frequencies, *e.g.* $(f_{L-x} + f_x)$ and $|f_{L-x} - f_x|$ that do ***not*** perfectly/exactly line up with the harmonics of these two original tones, and again the generated sum/difference do ***not*** have a time-independent/stationary phase relation relative to the fundamental of the lowest and/or higher original tones!

Because there is a continuum of possible non-integer frequency ratios, with the above properties, the human ear/brain perceives dissonant tones as non-special, non-unique and (much more) brain-intensive/difficult to perceive/analyze such sounds.

From recent fMRI studies, we now know that the human brain has in fact ***two*** separate centers for processing sounds as consonant *vs*. dissonant – which in turn are wired into to different emotional centers of our brains – thus explaining why we (anthropo-centrically) experience "pleasure" at hearing consonant sounds *vs*. "displeasure" at hearing dissonant sounds [1], since our own human singing voices are inherently consonant in nature (*i.e*. have integer-related harmonics).

Is this solely the explanation for why our brains have ***separate*** processing for discriminating between these two types of sounds, experiencing pleasure for {human-like} consonant sounds *vs*. displeasure {non-humanlike} dissonant sounds?

Note that dissonant sounds – complex sound waveforms with non-integer-related harmonic content can arise *e.g*. from non-everyday sounds in the environment, such as a rock slide or avalanche, gales/high winds, or a tornado, *etc*. as well as human and/or animal sounds that are more of negative or threatening nature…*e.g*. groans, cries, shrieks, growls, howls, roars, *etc*…thus, the differing human response to sounds perceived as consonant *vs*. dissonant may possibly have arisen from this as well.

See/hear the Physics 406 consonance/dissonance demo! Please see/read/think about the information contained in additional Physics 406 lecture notes on consonance & dissonance!

Musical Scales:

Anthropocentric in origin – *i.e*. we humans (as are other animals…) are primarily interested in the sounds that our ***own*** species make… Thus, the musical scale(s) that we have developed in our culture(s) over the millennia are ***not*** disconnected from the fact that complex sounds associated with the singing human voice have integer-related harmonic content, due to our vocal cords vibrating as a 1-D mechanical system, and associated consonance/dissonance phenomena…

Nevertheless, there are many kinds of musical scales! We'll see why! First, remind ourselves of the notes *e.g*. on the keyboard of piano:

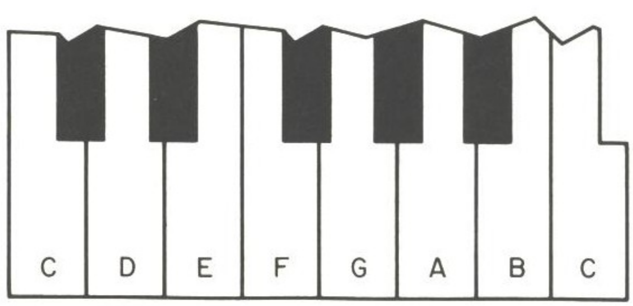


FIG. 2. A portion of the piano keyboard.

A.) Pentatonic (5-Note) Scale:

This is the "simplest" musical scale. Use the octave, 4th and 5th as ***consonant*** intervals (as expressed by their respective frequency ratios) to build up the so-called pentatonic/5-note scale:

1. **Start with the note C, with frequency *f*. This is the note low-C.**
2. **The octave is another C with frequency 2*f*. This is the note high-C.**
3. **Go down a 5th from high-C (= going up a 4th from low-C).**
   This is the note F, with frequency $^4/_3\, f$.
4. **Go up a 5th from low-C (= going down a 4th from high-C).**
   This is the note G, with frequency $^3/_2\, f$.
5. **Go down a 4th from G (= going up a 5th from G and then down an octave).**
   This is the note D, with frequency $^3/_4 \bullet {}^3/_2\, f = {}^9/_8\, f$.
6. **Go up a 5th from D. This is the note A, with frequency $^3/_2 \bullet {}^9/_8\, f = {}^{27}/_{16}\, f$.**

The 5-Note Pentatonic Scale:

Note:	C	D	F	G	A	C
Frequency:	f	$\frac{9}{8}f$	$\frac{4}{3}f$	$\frac{3}{2}f$	$\frac{27}{16}f$	$2f$

FIG. 3. A pentatonic scale.

Relative Ratio (to fundamental):	1		$^9/_8$		$^4/_3$		$^3/_2$		$^{27}/_{16}$		**2**
Interval (Frequency Ratio):		$^9/_8$		$^{32}/_{27}$		$^9/_8$		$^9/_8$		$^{32}/_{27}$	

B.) Pythagorean (7-Note) Scale:

The pentatonic 5-note scale has 2 notes missing (E & B), so we continue:

7. **Go down a 4th from A. This is the note E, with frequency $^3/_4 \bullet {}^{27}/_{16}\, f = {}^{81}/_{64}\, f$.**
8. **Go up a 5th from E. This is the note B, with frequency $^3/_2 \bullet {}^{81}/_{64}\, f = {}^{243}/_{128}\, f$.**

The 7-Note Pythagorean Scale:

Note:	C		D		E		F		G		A		B		C
Frequency:	1		$\frac{9}{8}$		$\frac{81}{64}$		$\frac{4}{3}$		$\frac{3}{2}$		$\frac{27}{16}$		$\frac{243}{128}$		2
Interval:		$\frac{9}{8}$		$\frac{9}{8}$		$\frac{256}{243}$		$\frac{9}{8}$		$\frac{9}{8}$		$\frac{9}{8}$		$\frac{256}{243}$	

FIG. 4. The Pythagorean scale.

<u>Note that</u>:

- The adjacent note pairs (E & F) and (B & C) have smaller musical intervals than (C & D), (D & E), (F & G), (G & A), and (A & B).
- Compare the interval (*i.e*. frequency ratio) of:

  $^{9}/_{8}$ = 1.125, which is known as a ***<u>Pythagorean wholetone</u>*,**

  to that of:

  $^{256}/_{243}$ = 1.053, which is known as a ***<u>Pythagorean diatonic semitone</u>*.**

- The seven notes of the Pythagorean scale correspond to the seven white keys on the piano.

What about the black keys of the piano?

9. Go down a 4th from B. This is the note F$^{\#}$, with frequency $^{3}/_{4} \bullet {}^{243}/_{128}\, f = {}^{729}/_{512}\, f$.
The interval (frequency ratio): F$^{\#}$ - G = $^{3}/_{2}$ / $^{729}/_{512}$ = $^{256}/_{243}$ = 1.053,
which is a Pythagorean diatonic semitone.
The interval (frequency ratio): F - F$^{\#}$ = $^{729}/_{512}$ / $^{4}/_{3}$ = $^{2187}/_{2048}$ = 1.068,
which is known as a Pythagorean *<u>chromatic</u>* semitone.

Thus, there are two different sizes of semitones:

Pythagorean Wholetone = $^{9}/_{8}$ = 1.125
Pythagorean Diatonic Semitone = $^{256}/_{243}$ = 1.0534979
Pythagorean Chromatic Semitone = $^{2187}/_{2048}$ = 1.0678711

The Chromatic Semitone is slightly larger than the Diatonic Semitone!

10. Go up a 5th from F$^{\#}$. This is the note B$^{\#}$, with frequency $^{3}/_{2} \bullet {}^{729}/_{512}\, f = {}^{2187}/_{1024}\, f$.
> 2*f* (= high C)!

This key doesn't exist on the piano! B$^{\#}$ is the enharmonic equivalent to C, but it is *<u>not</u>* the note C in the Pythagorean musical scale!

We have more problems – start with F and use the *<u>circle of fifths</u>* to generate the notes of the black keys on a piano: F-C-G-D-A-E-B-F$^{\#}$-C$^{\#}$-G$^{\#}$-D$^{\#}$-A$^{\#}$-E$^{\#}$

The key E$^{\#}$ doesn't exist on the piano! E$^{\#}$ is the enharmonic equivalent to F, but it is *<u>not</u>* the note F in the Pythagorean musical scale! The frequency ratio of E$^{\#}$:F is $\{[^{3}/_{2}]^{12} \times [½]^{7}\}$:1 = 531441:524288 = 1.01364.. *i.e*. E$^{\#}$ is higher than F by this amount!

This interval (frequency ratio) is also the same as that between the Pythagorean chromatic semitone and the Pythagorean diatonic semitone, *i.e*. $^{2187}/_{2048}$ / $^{256}/_{243}$ = 1.01364, which is known as the *<u>Pythagorean comma</u>*.

C.) Cents:
All musical scale(s) have fundamental problems, as seen from above. That's just the reality of the way things are – causes problems playing music in different keys!

Create an interpolated musical scale, known as the tempered scale with 12 equally-spaced semitones for 12 notes of this musical scale – divide up the octave into 1200 cents. Then define 100 cents as = 1 tempered semitone. Then one octave = 12 tempered semitones.

D.) Meantone Tuning:

Pythagorean major 3rds are too sharp! Flatten them slightly.
Pythagorean minor 3rds are too flat! Sharpen them slightly.

See *p*. 141-3 in *Acoust. Found. of Music* for details of how this is accomplished.

E.) The Just Scale:

Major triad – add major third (4:5) to minor third (5:6) – creates 3 notes with interval (frequency ratio) 4:5:6!

F	A	C				
		C	E	G		
				G	B	D
$\frac{2}{3}$	$\frac{5}{6}$	1	$\frac{5}{4}$	$\frac{3}{2}$	$\frac{15}{8}$	$\frac{9}{4}$

FIG. 7. Building the just scale.

F.) The Just Diatonic Scale:

Note:	C	D	E	F	G	A	B	C
Frequency:	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
Interval:	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{16}{15}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{9}{8}$	$\frac{16}{15}$	

FIG. 8. The just diatonic scale.

G. The Tempered Scale:

Make all intervals the same for the 12 notes. Create an interpolated musical scale, known as the tempered scale with 12 equally-spaced semitones for the 12 notes of this musical scale – then divide up the octave into 1200 cents. Thus, 100 cents = 1 tempered semitone, and one octave = 12 tempered semitones. Not a "perfect" musical scale by any means, but the main advantage is can then play a given piece of music in any key, without it sounding "worse" in one key than another.

We can mathematically define the semitone in the tempered scale as: $\boldsymbol{a} = (2)^{1/12} = 1.05946$. Then one cent, $1¢ = (2)^{1/1200} = 1.000577$ in the tempered scale. Each note is built up from previous note by adding one power of the semitone, $\boldsymbol{a}$, as shown in the figure below:

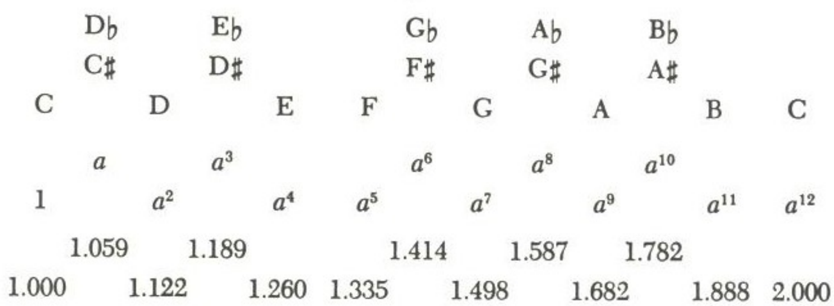


FIG. 10. The tempered scale.

The 2nd note D is obtained from C by a^2, the twelfth (*i.e.* octave) high-C note is obtained from the low-C by a factor of a^{12}, etc.

H.) Location of Frets on the Fretboard of a Guitar (Tempered Scale):

For the tempered semitone, $\boldsymbol{a} = (2)^{1/12} = 1.05946$, then for a scale length $\boldsymbol{L}$:

For the first 12 frets on the fretboard (first octave), where $\boldsymbol{n}$ = fret # (1-12):

$$Fret\ Location_{n-th\ fret} = L \big/ 2^{\frac{n}{12}}$$

For frets 13-24 on the fretboard (2nd octave), where $\boldsymbol{n}$ = fret # (13-24):

$$Fret\ Location_{n-th\ fret} = \tfrac{1}{2} L \big/ 2^{\frac{n}{12}}$$

For frets 25-36 on the fretboard (3rd octave), where $\boldsymbol{n}$ = fret # (25-36):

$$Fret\ Location_{n-th\ fret} = \tfrac{1}{4} L \big/ 2^{\frac{n}{12}}$$

<u>I.) Other Octave Divisions</u>:

It is certainly possible to divide up the octave into finer divisions than just 12 semitones. Here are some other (reasonable) possibilities!

One could divide the octave up into arbitrarily small intervals, but the human ear's ability to discern/distinguish such fine intervals becomes increasingly difficult!

TABLE I

OCTAVE DIVISION (M)	NUMBER OF SMALL DIVISIONS (m)	CENTS	CLOSEST JUST INTERVAL	CENTS DEVIATION FROM CLOSEST JUST INTERVAL
19	2	126	Diatonic semitone (112 cents)	+14
	3	190	Small whole tone (182 cents)	+8
	5	316	Minor third (316 cents)	0
	6	379	Major third (386 cents)	−7
	11	695	Fifth (702 cents)	−7
31	3	116	Diatonic semitone	+4
	5	194	Small whole tone	+12
	8	310	Minor third	−6
	10	387	Major third	+1
	18	697	Fifth	−5
53	5	113	Diatonic semitone	+1
	8	181	Small whole tone	−1
	9	204	Large whole tone	0
	14	317	Minor third	+1
	17	385	Major third	−1
	31	702	Fifth	0

The earliest-known musical instruments – *e.g.* a {griffon vulture} bone flute – recently found in a cave near Hohle Fels (SW Germany) in 2008 – see pix below – was carbon-dated to be > 35 K yrs old!

An exact copy of this flute was made (via laser scan ⇒ 3-D printing), which was given to professional musician, who, after learning how to play it, was able to play "Amazing Grace" on it (key of D - uses the 7 ***white*** notes on piano) ***and*** the German National Anthem – (uses both the white ***and*** the black notes on piano) !!!

⇒ Evidence for 12-note natural/"consonant" musical scale in existence at ***that*** time, ~ 30,000 years before the Greeks !!!

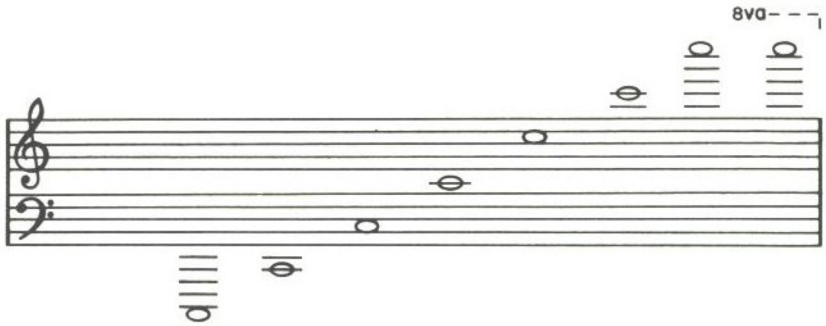
⇒ Presumably ***this*** flute was also ***not*** a ***prototype*** !!!

Table II

Frequencies of notes in the tempered scale

C_0	16.352	C_3	130.81	C_6	1046.5
	17.324		138.59		1108.7
D_0	18.354	D_3	146.83	D_6	1174.7
	19.445		155.56		1244.5
E_0	20.602	E_3	164.81	E_6	1318.5
F_0	21.827	F_3	174.61	F_6	1396.9
	23.125		185.00		1480.0
G_0	24.500	G_3	196.00	G_6	1568.0
	25.957		207.65		1661.2
A_0	27.500	A_3	220.00	A_6	1760.0
	29.135		233.08		1864.7
B_0	30.868	B_3	246.94	B_6	1975.5
C_1	32.703	C_4	261.63	C_7	2093.0
	34.648		277.18		2217.5
D_1	36.708	D_4	293.66	D_7	2349.3
	38.891		311.13		2489.0
E_1	41.203	E_4	329.63	E_7	2637.0
F_1	43.654	F_4	349.23	F_7	2793.8
	46.249		369.99		2960.0
G_1	48.999	G_4	392.00	G_7	3136.0
	51.913		415.30		3322.4
A_1	55.000	A_4	440.00	A_7	3520.0
	58.270		466.16		3729.3
B_1	61.735	B_4	493.88	B_7	3951.1
C_2	65.406	C_5	523.25	C_8	4186.0
	69.296		554.37		4434.9
D_2	73.416	D_5	587.33	D_8	4698.6
	77.782		622.25		4978.0
E_2	82.407	E_5	659.26	E_8	5274.0
F_2	87.307	F_5	698.46	F_8	5587.7
	92.499		739.99		5919.9
G_2	97.999	G_5	783.99	G_8	6271.9
	103.83		830.61		6644.9
A_2	110.00	A_5	880.00	A_8	7040.0
	116.54		932.33		7458.6
B_2	123.47	B_5	987.77	B_8	7902.1

J.) Octave Notation:



U.S.A. STD:	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
HELMHOLTZ:	$C_{,}$	C	c	c'	c''	c'''	c''''	c^{v}
PIANO:	C_4	C_{16}	C_{28}	C_{40}	C_{52}	C_{64}	C_{76}	C_{88}
ORGAN:	CCC	CC	C	c^1	c^2	c^3	c^4	

FIG. 11. The octave notation recommended by the U.S.A. Standards Association, together with some others that have been used.

K.) Playing Ranges of Musical Instruments:

TABLE III
Playing ranges of musical instruments—concert pitch

	LOWER LIMIT	APPROXIMATE UPPER LIMIT
Violin	G_3	E_7
Viola	C_3	C_6
Violoncello	C_2	E_5
Double bass	E_1	B_3
Flute	C_4	C_7
Oboe	$B\flat_3$	F_6
English horn	$E\flat_3$	$B\flat_5$
Clarinet ($B\flat$)	D_3	$B\flat_6$
Bass clarinet ($B\flat$)	D_2	F_5
Bassoon	$B\flat_1$	$E\flat_5$
Contrabassoon	$B\flat_0$	$E\flat_3$
Horn (double, F and $B\flat$)	B_1	F_5
Trumpet ($B\flat$)	E_3	$B\flat_5$
Trombone (tenor)	E_2	$B\flat_4$
Trombone (bass)	B_1	$B\flat_4$
Timpani (28″ and 25″)	F_2	F_3
Harp	B_0 ($C\flat_1$)	$G\sharp_7$

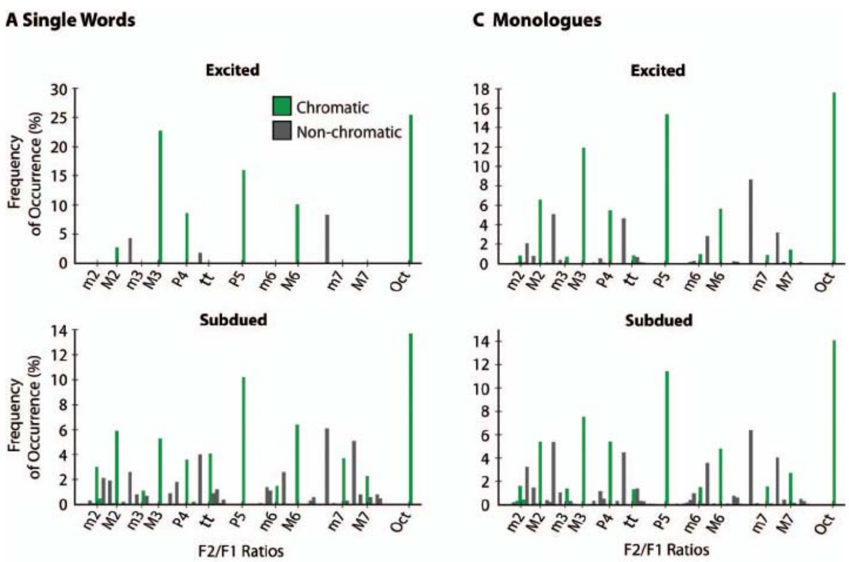
<u>Why does playing music/listening to music affect our emotions</u>?

No question about it – music communicates emotional information – happiness, joy, excitement, sorrow, fear, … to us humans. Why/how?

Some fraction of the higher-order processing centers of auditory information are wired into various the emotional centers of our brain – directly affecting our emotional state – happy/sad/fear/exhuberance/anticipation…. Why???

The human voice {along with visual information – *e.g*. body language} convey emotional information in speech/music communication from one person to another – enabling other humans to better understand the state of that person at that time.

Interestingly enough – the intervals and harmonic content of sad and/or stressed/subdued speech contains an ***<u>excess</u>*** of intervals/harmonics which are ***<u>minor</u>*** and/or more dissonant-sounding than happy/exhuberant and/or excited speech, which contains an ***<u>excess</u>*** of intervals/harmonics which are ***<u>major</u>*** and/or more consonant-sounding:



B Single Words

Intervals	Excited	Subdued	p-value
Unison/Octave	25.5 %	13.7 %	< .0001
Minor Second	0.0 %	3.5 %	< .0001
Major Second	2.7 %	5.8 %	< .001
Minor Third	0.0 %	1.1 %	< .001
Major Third	22.7 %	5.3 %	< .0001
Perfect Fourth	8.6 %	3.6 %	< .0001
Tritone	0.0 %	4.1 %	< .0001
Perfect Fifth	16.0 %	10.2 %	< .0005
Minor Sixth	0.0 %	1.5 %	< .0001
Major Sixth	10.1 %	6.4 %	< .01
Minor Seventh	0.0 %	3.7 %	< .0001
Major Seventh	0.0 %	2.3 %	< .0001
Non-Chromatic	14.4 %	38.7 %	< .0001

D Monologues

Intervals	Excited	Sudbued	p-value
Unison/Octave	17.6 %	14.1 %	< .0001
Minor Second	1.0%	2.1 %	< .0001
Major Second	6.6 %	5.4 %	< .0001
Minor Third	0.7 %	1.4 %	< .0001
Major Third	12.0 %	7.6 %	< .0001
Perfect Fourth	5.5 %	5.4 %	= .82
Tritone	0.8 %	1.3 %	<. 0001
Perfect Fifth	15.4 %	11.5 %	< .0001
Minor Sixth	1.0 %	1.5 %	< .0001
Major Sixth	5.6 %	4.8 %	< .0001
Minor Seventh	0.9 %	1.6 %	< .0001
Major Seventh	1.4 %	2.7 %	< .0001
Non-Chromatic	31.6 %	40.7 %	< .0001

FIG. 5. Comparison of the ratios of the first two formants in excited and subdued speech derived from analyses of the single word and monologue databases. Ratios have been collapsed into a single octave such that they range from 1 to 2. (A) The distribution of formant ratios in excited and subdued speech from the single word database; green bars indicate ratios within 1% of chromatic interval ratios (see Table IA); gray bars indicate ratios that did not meet this criterion. (B) The percentage of formant ratios corresponding to each chromatic interval in (A) for excited and subdued speech. (C) The same as (A), but for the monolog data. (D) The same as (B), but for the monolog data in (C). *p*-values for each interval were calculated using the chi-squared test for independence, with expected values equal to the mean number of occurrences of an interval ratio across excited and subdued speech. Intervals empirically determined to distinguish major and minor music are underlined (dashed-lines indicate intervals with less marked contributions).

TABLE IV. Frequency of occurrence of chromatic intervals in major and minor Western classical and Finnish folk music. (A) Tonic intervals; defined as the number of semitones between a melody note and its tonic. (B) Melodic intervals; defined as the number of semitones between adjacent melody notes. The preponderance of small intervals in (B) is in agreement with previous studies (Vos and Troost, 1989). The intervals that distinguish major and minor music are underlined (dashed-lines indicate intervals with less marked contributions).

Major melodies			Minor melodies		
Intervals	Classical (%)	Folk (%)	Intervals	Classical (%)	Folk (%)
		(A) Tonic intervals			
Unison/octave	19.9	20.4	Unison/octave	19.4	19.1
Minor second	0.4	0.1	Minor second	0.6	0.2
Major second	12.8	15.9	Major second	13.0	19.6
Minor third	0.8	0.0	Minor third	15.8	15.6
Major third	18.2	16.8	Major third	0.7	0.2
Perfect fourth	10.6	9.5	Perfect fourth	10.5	10.1
Tritone	1.1	0.4	Tritone	1.7	0.2
Perfect fifth	19.1	19.6	Perfect fifth	20.3	19.9
Minor sixth	0.4	0.0	Minor sixth	7.9	1.6
Major sixth	8.4	8.9	Major sixth	1.3	2.9
Minor seventh	0.6	0.2	Minor seventh	3.4	7.5
Major seventh	7.7	8.1	Major seventh	5.4	3.1
		(B) Melodic intervals			
Unison	10.7	24.9	Unison	11.4	24.0
Minor second	20.8	13.3	Minor second	28.2	19.1
Major second	36.1	29.9	Major second	27.6	27.6
Minor third	9.4	11.6	Minor third	10.4	12.1
Major third	6.9	8.6	Major third	5.4	6.2
Perfect fourth	7.6	7.4	Perfect fourth	7.2	7.1
Tritone	0.4	0.2	Tritone	1.1	0.0
Perfect fifth	2.7	2.0	Perfect fifth	3.2	2.5
Minor sixth	1.1	0.6	Minor sixth	1.8	0.8
Major sixth	1.3	0.9	Major sixth	1.2	0.1
Minor seventh	0.4	0.3	Minor seventh	0.4	0.1
Major seventh	0.1	0.0	Major seventh	0.2	0.0
Octave	1.3	0.3	Octave	1.2	0.2
Larger	1.0	0.0	Larger	0.9	0.0

TABLE I. Western musical scales (also called modes). (A) The 12 intervals of the chromatic scale showing the abbreviations used, the corresponding number of semitones, and the ratio of the fundamental frequency of the upper tone to the fundamental frequency of the lower tone in just intonation tuning. (B) The seven diatonic scales/modes. As a result of their relative popularity, the Ionian and the Aeolian modes are typically referred to today as the major and minor scales, respectively. Although the Ionian and Aeolian modes and the scales they represent have been preeminent in Western music since the late 16th century, some of the other scales/modes continue to be used today. For example, the Dorian mode is used in plainchant and some folk music, the Phrygian mode is used in flamenco music, and the Mixolydian mode is used in some jazz. The Locrian and Lydian are rarely used because the dissonant tritone takes the place of the fifth and fourth scale degrees, respectively.

(A) Chromatic scale			(B) Diatonic scales						
Interval Name	Semitones	Frequency ratio	"MAJOR" Ionian	Dorian	Phrygian	Lydian	Mixolydian	"MINOR" Aeolian	Locrian
Unison (Uni)	0	1:1	M2	M2	m2	M2	M2	M2	m2
Minor second (m2)	1	16:15	M3	m3	m3	M3	M3	m3	m3
Major second (M2)	2	9:8	P4	P4	P4	tt	P4	P4	P4
Minor third (m3)	3	6:5	P5	P5	P5	P5	P5	P5	tt
Major third (M3)	4	5:4	M6	M6	m6	M6	M6	m6	m6
Perfect fourth (P4)	5	4:3	M7	m7	m7	M7	m7	m7	m7
Tritone (tt)	6	7:5	Oct	Oct	Oct	Oct	Oct	Oct	Oct
Perfect fifth (P5)	7	3:2							
Minor sixth (m6)	8	8:5							
Major sixth (M6)	9	5:3							
Minor seventh (m7)	10	9:5							
Major seventh (M7)	11	15:8							
Octave (Oct)	12	2:1							

Above figure & tables from "Major and Minor Music Compared to Excited and Subdued Speech", D. Bowling, *et al*., J. Acoust. Soc. Am. 127, *p*. 491-503, 2010.

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