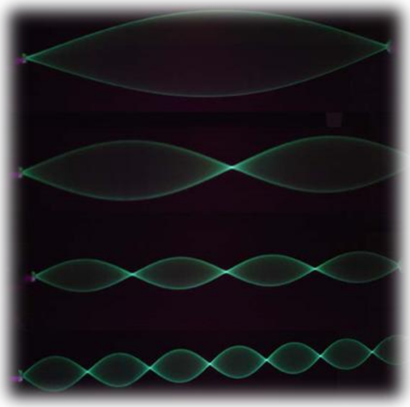
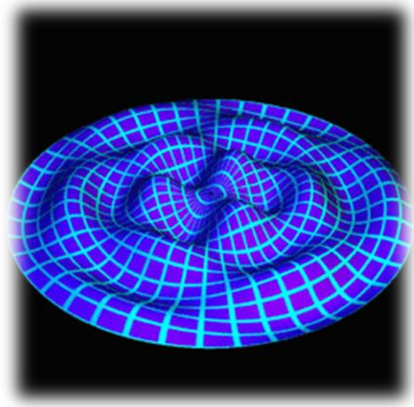
A Look at How A Different Evolution Would Have Changed Music





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PHYS 406 – Acoustical Physics of Music
Professor Steven Errede

Introduction:

Music has long been essential in human culture for bringing beauty to the ordinary. From Gregorian chant to smooth jazz, baroque to dubstep, and so many other incredible (and often puzzling) genres, music has followed humanity's evolution and brought meaning to sometimes trivial matters. The origin of music is a complex tale, one perhaps too complex to ever understand in entirety. What began as an animal hide drum transformed into cellos, French horns, saxophones, synthesizers… the list is endless, and ever-growing. The origin of music is what I delve into with this project, though with respect to a very particular area.

It is no secret that animals are most interested in their species, and humans are no exception. Our anatomy has evolved to best perceive the sounds we make—our ears hear the frequency range of sounds we produce, and our brains process "human" sounds in a very special way [3]. Human sounds are sounds that mimic the harmonic content of the human voice. Since humans evolved with vocal cords that vibrate like strings, that means that humans sounds are sounds that have integer-related harmonics and form standing waves. When the brain hears a human sound, it processes it as *consonant*; that is, the signal gets sent to a part in the human brain that makes the listener enjoy the sound. When a sound is not human, it gets sent to the processing center for *dissonant* sounds, and humans tend to feel uneasy. This is actually the basis of the musical scale—it is formed from ratios of sounds that are consonant, which are sounds that are made up of integer harmonics [3]. See **Figure 1** for a visualization of what the integer harmonics are.

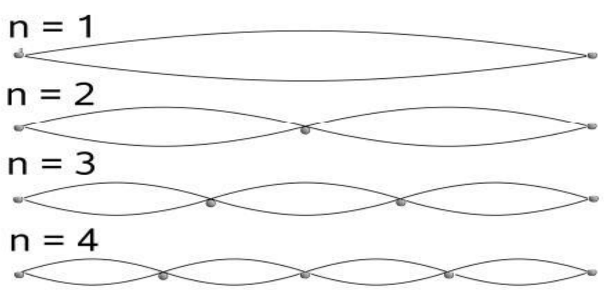


Figure 1
Normal mode vibrations of a string, from first harmonic (n=1) to fourth (n=4) [1]

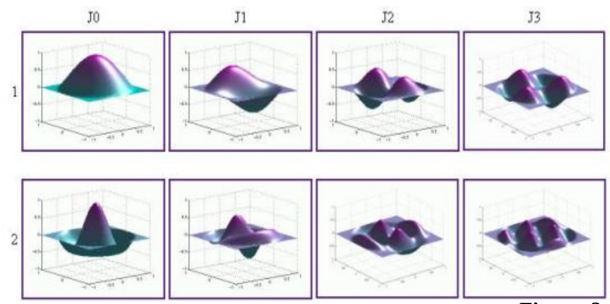


Figure 2
Normal mode vibrations of a circular membrane, from first harmonic (J0,1) to eighth (J3,2) [2]

The project I constructed in PHYS 406 was intended to explore how music today would sound if humans had evolved differently—specifically, if they had evolved with a circular vocal membrane that vibrates two-dimensionally instead of one-dimensionally vibrating vocal cords. See **Figure 2** for a visualization of the harmonics of a circular membrane. Vocal membranes are an alternative adaptation some animals, such as bats and primates, utilize to improve vocal efficiency and assist in making high-pitched sounds [4]. This membrane is usually rectangular [4], but could (theoretically) be any shape. Because of its presence in primates, it is entirely feasible that it could have become the primary tool of communication for humans. If this occurred, I believe that the membrane would take on a more circular shape to mimic the shape of the larynx, and so it is this shape that I primarily study, though my experimental data can be used for other shapes.

The Design:

To determine how music would sound if humans evolved differently, I first needed to go to the root of music: the musical scale. While there are a variety of musical scales, all of them are built off of the idea of the consonant ratios of string harmonics. For example, the ratio of the 3rd harmonic to the 2nd harmonic (3/2 or 1.5 for a string) dictates a perfect fifth. Because of this, the logical project design was to create musical scales based on the ratios of circular membrane harmonics. Professor Errede and I decided the best way to go about this was to write a program in MATLAB that would take the harmonic ratios of the vibrating system and perform the calculations to create a musical scale. This approach would make it very easy to generalize to *any* vibrating system, rather than just a vibrating circular membrane. It would also allow the musical scale to be played as audio, which is primarily what I was interested in.

The next step was to determine a basis from which to build the new musical scale. The best candidate for this was the modern musical scale: the *tempered scale* (see **Figure 3**). This scale separates the space between two harmonics into twelve equal steps, each of which is a musical note. For a string, this system maintains the consonant ratios almost perfectly; for example, the perfect fifth is 1.498 instead of 1.5 [3]. While this was the perfect candidate for a new musical scale, I also decided to include the *just diatonic scale* (see **Figure 4**) as the basis for a second version of the scale. The just diatonic scale is composed entirely of the ideal consonant ratios of strings, and so it would be a good comparison to see just how different the new vibrating system is.

C	C♯ / D♭	D	D♯ / E♭	E	F	F♯ / G♭	G	G♯ / A♭	A	A♯ / B♭	B	C
1	a	a^2	a^3	a^4	a^5	a^6	a^7	a^8	a^9	a^{10}	a^{11}	a^{12}
1.000	1.059	1.122	1.189	1.260	1.335	1.414	1.498	1.587	1.682	1.782	1.888	2.000

Figure 3
The Tempered Scale [3]

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:		$\frac{9}{8}$	$\frac{10}{9}$	$\frac{16}{15}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{9}{8}$	$\frac{16}{15}$

Figure 4
The Just Diatonic Scale [3]

The Program:

The program I designed as fairly straightforward. It takes the first nine relative harmonic frequencies of any vibrational system (i.e. 1, 2, 3, 4, etc. for a string, see **Figure 5** for a circular membrane) and uses them to calculate two different musical scales—the tempered and just diatonic versions of the new scale. It can also take just the first four relative harmonic frequencies if the first eight are unknown and it will produce only the tempered version.

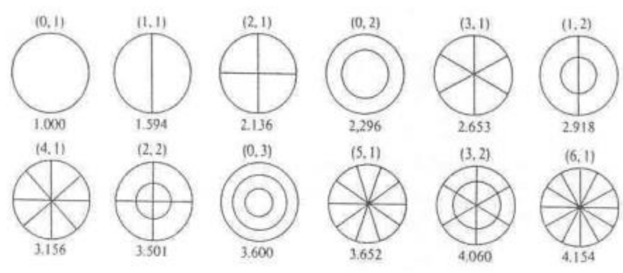


Figure 5
The relative harmonic frequencies of a circular membrane [2]

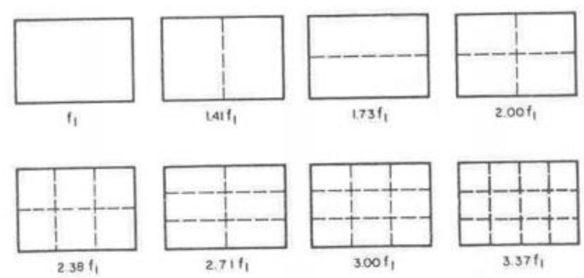


Figure 6
The relative harmonic frequencies of a rectangular plate [2]

To calculate the tempered variant, the program calculates twelve equal intervals between the first two harmonics, and twelve equal intervals between the third and fourth harmonics. This creates the first and second octaves the scale, respectively. Since vibrational systems other than strings often have unequal harmonic spacing, I felt it was necessary to make the scale follow this unequal spacing (if it is present) as the scale progresses through octaves. For example, while a string's harmonics are 1, 2, 3, and 4, the harmonics of an ideal circular membrane are 1, 1.59, 2.13, and 2.29; the steps between the harmonics are quite different, and so a single calculated interval between the first and second harmonics would not be representative of the system as a whole. Ideally, my scale would also change for the third, fourth, and further octaves—however, I only calculate two in the program I wrote, as it sufficient to get an idea of the sound.

To calculate the just diatonic variant, the program uses the consonant ratios of a string for a basis. These ratios can be seen in the frequency row of **Figure 4**. So for the perfect fifth, instead of 1.5, my program takes the third harmonic of the system and divides it by the second harmonic to create the new interval—for a circular membrane, that is 1.34. This is then done for all seven notes of the octave, and then repeats for a new octave.

As the scales are calculated, the program outputs each note frequency as both text and audio, starting with 440 Hz for the first note. This was chosen because it is the standard for current music—440 Hz for an A note is the standard for most tunings. After the scale is generated, the program will then play a transposition of the popular tune "Twinkle Twinkle Little Star" in the new musical scale. This is the ultimate comparison for just how music would change, for it takes a (relatively) modern tune and reconstructs how it would sound in a musical scale based off of a different vibrational system. The data will focus on the tempered scale data, as the just diatonic data is designed for a quick, audible comparison of how changing the vibrational system changes the fundamental tones present. The tempered scale variant is what I am proposing to be the theoretical scale of an alternative evolution.

The Data:

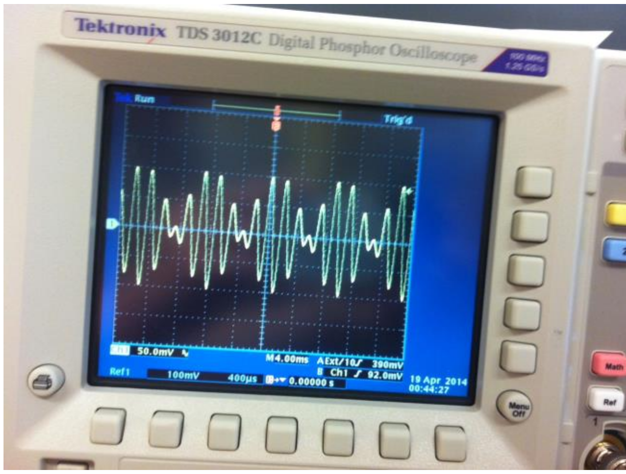
Calculated Scale Comparison

Note (Single Octave)	**String** (Modern Tempered Scale)	**Circular Membrane** (Tempered Variant)
A	440 Hz	440 Hz
A♯	466.16 Hz	457.43 Hz
B	493.88 Hz	475.56 Hz
C	523.25 Hz	494.40 Hz
C♯	554.37 Hz	513.98 Hz
D	587.33 Hz	534.35 Hz
D♯	622.25 Hz	555.52 Hz
E	659.25 Hz	577.52 Hz
F	698.46 Hz	600.41 Hz
F♯	739.99 Hz	624.19 Hz
G	783.99 Hz	648.92 Hz
G♯	830.61 Hz	674.63 Hz
A	880 Hz	701.36 Hz

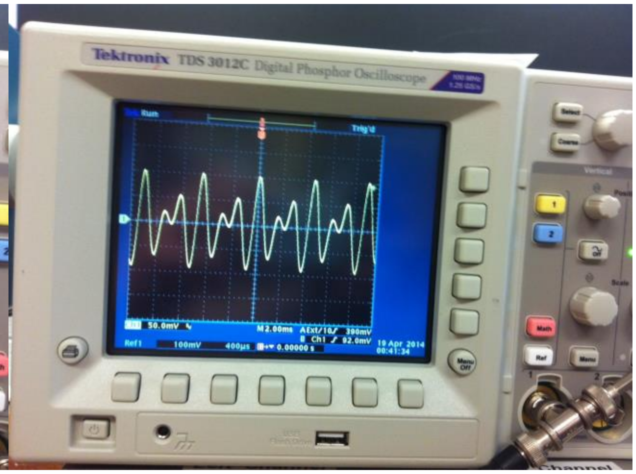
The data shows a correlation with the relative harmonics of a circular membrane; the note spacing is condensed, creating a scale that spans roughly half of its starting frequency (220 Hz in this case) instead of the entire starting frequency, as the modern scale does (440 Hz here). This creates tones that are much closer together than ones humans are used to, and so, if we had evolved with this particular vocal media, perhaps humans would be better at distinguishing similar pitches from one another. This condensed scale creates a rather haunting sound when a song is transposed with it. The similar notes create slightly vague pitch slides, rather than immediately noticeable changes in pitch. It is a rather alien sound, as one might expect from a different evolution of humanity.

Waveform Comparison

Vibrating String Harmonics:

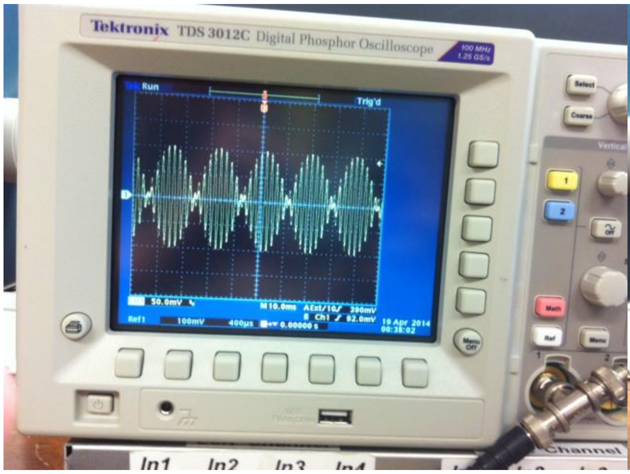


Standing wave formed by a perfect third interval

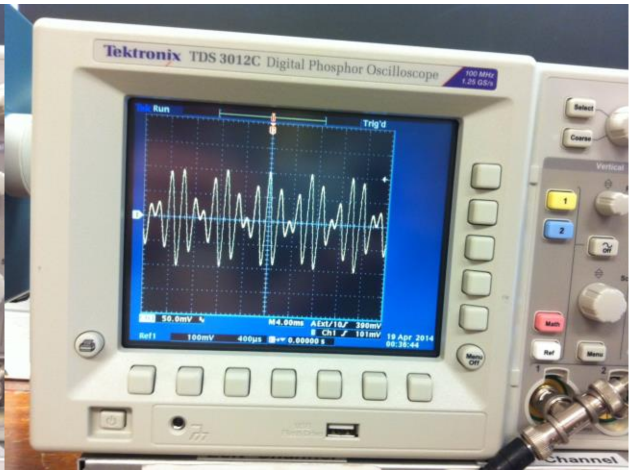


Standing wave formed by a perfect fifth interval

Vibrating Circular Membrane Harmonics:



Waveform of a modified third interval (not standing!)



Waveform of a modified fifth interval (not standing!)

The vibrating string harmonics data is representative of the modern notes A and C played in unison, creating a perfect third, and A and E playing in unison, creating a perfect fifth. Both intervals create standing waves with the above waveforms. For the vibrating circular membrane harmonics data, the pictures are showing the third and fifth interval designated by the scale on **Page 5**, so 440 & 494.4 Hz and 440 & 577.52 Hz respectively. These intervals create very distinct beats patterns, and they do *not* create standing waves, i.e. the waveform is time dependent. If humans had evolved with a circular membrane for vocal transmission, I believe that they would be far more sensitive to beats information and the phase relation between waves—indeed, perhaps they would utilize beats effects and phase relationships as a part of communication.

The Conclusion:

The results of this project are very promising—the musical scale generator can create a scale for any vibrational system where the relative harmonics are known, and it outputs a scale for audible comparison as well as numerical comparison. The data for a circular membrane shows quite clearly how humans may have perceived sound differently had evolution been slightly altered. While it is not a perfect depiction of what may have occurred, it is a fair estimation. Real results could vary in any number of ways—after all, there are hundreds of different music scales used around the world today. It is safe to say that that would be true had humans evolved with vocal membranes instead, and so the created scale is more of a best guess approach. This means there is plenty of room for expansion upon this project, as alternate scales could be created with more notes, different interval calculations, and different scale bases. This particular project could be expanded on by creating an instrument capable of playing the circular membrane scale, or by calculating how modern day instruments would be different. Another topic of interest would be how actual modern day music would sound in this format, such as classic rock or electronic dance music. This was an altogether enlightening project with relatively few obstacles and a seemingly endless amount of different ways to approach it. It will be interesting to see what future results hold.

Works Cited

[1] Errede, Steven. “Lecture IV: Complex Vibrations & Resonance.” *Physics 406 Acoustical Physics of Music Lecture Notes*. University of Illinois at Urbana-Champaign. May 2014.

[2] Errede, Steven. “Lecture IV Part 2: Vibrations of 2- and 3-Dimensional Systems.” *Physics 406 Acoustical Physics of Music Lecture Notes*. University of Illinois at Urbana-Champaign. May 2014.

[3] Errede, Steven. “Lecture VIII: Consonance and Dissonance, Musical Scales….” *Physics 406 Acoustical Physics of Music Lecture Notes*. University of Illinois at Urbana-Champaign. May 2014.

[4] Mergell, P., W. T. Fitch, and H. Herzel. "Modeling the Role of Nonhuman Vocal Membranes in Phonation." *Acoustical Society of America* 105.3 (1999): 2020-028.