Polygonola, a polygonal plate musical instrument

Polygonola is a flat polygonal musical instrument and made from bronze (see below). The size and shape varies and depends on the pitch of the original scale based on a vibration theory of the plate. The shapes are triangle, square, pentagon, hexagon and disc. There are also a pentagram and hexagram Polygonola. It is played by hitting with any type of mallets.

Disk Triangle Pentagon Supporting system

Figure 1 Various shapes of Polygonola and its supporting system

The pitch of Polygonola is defined by the size. Large Polygonola gives you a low pitch, and small one a high pitch. Thick Polygonola gives you a high pitch and thin one a lower pitch. The size ranges from 50 to 300 mm and the thickness from 1.5 to 3.0 mm.

When you play the Polygonola, it generates sounds of overtones that are completely different from those from a string with which most of the ordinary musical instruments are equipped.

The tones or timbre depends on the shape of Polygonola. When you hit a disc Polygonola, it generates a set of overtones that are different from those of the other shapes of Polygonola. The different set of overtones makes different tones or timbre. Therefore the tone and timbre of a disk Polygonola is different from those of triangular, square, pentagonal or hexagonal Polygonola.

Polygonola is a unique musical instrument which generates a sound that you have not heard before. Polygonola has a musical scale and tone that are different from do, re, me with which we are familiar.

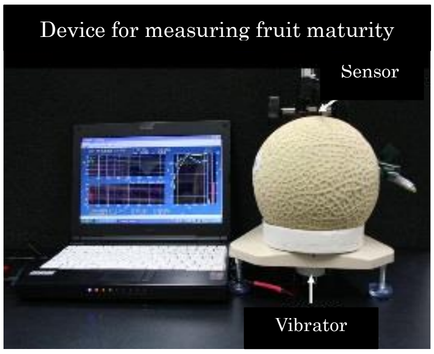
How does Polygonola differ from a drum? The drum and tympani have a membrane that is fixed to the rim. A cymbal is fixed at the center.

When you hit Polygonola, it has a free vibration of the entire plate including the edge. A special supporting system allows the instrument to freely vibrate the center as well as the edge (right in Figure 1). A gong is an instrument most similar to Polygonola. The gong, however, doesn’t have an fixed, defined musical scale. Furthermore, a typical Polygonola generates pitches much higher than the gong.

One of the most prominent characteristics of Polygonola is that it generates two completely different timbres when you hit the center or edge. When you hit the center, you can hear a clear, deep sound similar to a Japanese temple bell. However, when you hit the edge, you can hear a brilliant sound similar to a western style chapel bell. You may completely separate these two sounds by attaching two piezo microphones to the center and edge. Then you can switch the input signal from center to edge or vice versa through an amplifier connected to a speaker.

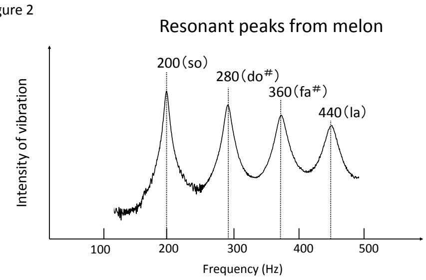
Extensive study of the Polygonola tones and its overtones lead to another prominent discovery. It creates a new musical scale based on the 2nd dimensional vibration. This scale is totally different from the 12 tone equal temperament (12-tet) scale. Polygonola may create new music that we have never experienced before.

This discovery was not made by a professional musicologist or musician. Polygonola originated from plant physiology. Resonant peak from the fruit tells us the maturity. When the fruit resonates with a higher frequency, the fruit may be immature. When it resonates with a lower frequency, it may be over-ripe. Mature fruit resonates with an appropriate sound pitch.



A device for measuring the resonance of the fruit is shown on the left. The melon in this figure is placed on a stand. The bottom part of the fruit is slightly vibrated, and the resonance at the top surface is detected by a sensor.

Figure 2



When the melon is vibrated, we observe many resonant peaks as shown in Figure 2. The abscissa (horizontal) is frequency in Hertz (vibration frequency in cycles per second), and ordinate (vertical) is the vibration intensity of melon. The first resonant peak is very low and is not shown in the figure. The second resonant peak (200 Hz in Figure 2) is used for determining maturity.

When you hit the melon, you may hear a rather complex sound. The sound corresponds to each of the peaks with a designated frequency as shown in Figure 2. In this figure, the left peak corresponds 200 Hz that is roughly equivalent to 'so' in 12-tet (12-tone equal temperament). The second peak with 280 Hz corresponds to 'do#', and third (360 Hz) to 'fa#' and forth to 'la' (440 Hz). If you play these four notes on the piano at the same time, the sound is dissonant or not harmonious according to 12-tet.

When you hit the melon, you can hear the sounds exactly shown in Figure 2. One should note that the melon sound is different from that played by the piano because the piano sound is generated by a string vibration and the melon generates sound from its spheroidal (ball shaped) body.

Table 1 shows the reason. The order of resonant peaks from melon from the lowest peak (200 Hz in this case) is 200, 280, 360, and 440 Hz. When the lowest peak (200 Hz) is defined as the fundamental resonance, the second peak (280 Hz) is 1.4 times higher than the fundamental 200 Hz. The third peak (360 Hz) is 1.8 times higher and the forth is 2.2 times higher. The numerical order is 1.0, 1.4, 1.8 and 2.2. These sounds are the overtones of melon.

Table 1 Non-integer overtones of melon and integer overtones of a string

Resonant peaks of melon Hz	Ratio	String overtones Hz	Ratio	Overtones of melon generated by a string instrument (piano)				
200 (so)	1.0	200 (so)	1.0	200	280	360	440	…
280 (do#)	1.4	400 (so)	2.0	400	560	720	880	…
360 (fa#)	1.8	600 (re)	3.0	600	840	1224	1320	…
440 (la)	2.2	800 (so)	4.0	800	1120	1440	1760	…
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	
Non-integer		Integer		Complex sounds by piano				

When you generate 200 Hz by plunking a string, the 200 Hz corresponds roughly to ‘so’ in 12-tet. When you tune a string as a pitch, ‘so’, and plunk the string, you vibrate the string that makes ‘so’ with one octave higher (400 Hz), ‘re’ with 3 times higher frequency (600 Hz), and again ‘so’ with two octaves higher (800 Hz). These are known as integer (whole or non-decimal number) overtones. When the pitch of the fundamental sound, ‘so’, is defined as 1.0, the second overtone, ‘so’, is exactly twice the frequency of the fundamental sound, the third is 3 times higher, and the fourth is 4 times higher. The numerical order is as follows, 1.0, 2.0, 3.0, and 4.0.

If you play the second note of melon overtones, do# (280 Hz), on the piano, the piano automatically generates second (560 Hz), third (840 Hz) and fourth (1120 Hz) integer overtones. These series of notes made by the piano are quite different from that of the original non-integer (fractional or decimal number) overtones found in the melon. If you play four notes (so, do#, fa#, la) using four piano keys, the resultant sound is very complex. This is the reason why the sound produced when hitting a melon is different from the sound played by piano with strings.

When you compare the series of overtones of a string with those of melon overtones as shown in Table 1, the numerical order for a string is integer, while the order for melon is non-integer. The melon generates non-integer overtones because its shape is not a string, but spheroidal. The sound produced when you strike the melon is different from the sound produced when you play the melon overtone notes on the piano because a melon generates a different set of overtones than those played by piano.

The theory of Polygonola is based on these non-integer overtones.

A musical instrument that generates non-integer overtone should not have a string for making sound. All the instruments equipped with strings such as piano, violin, cello, or harp generate a sound with integer overtones. Therefore they are not able to mimic melon sound. Even a wind instrument, such as flute, oboe, and clarinet generate a set of integer overtones because the air column in the tube works as a one-dimensional string.

It is not easy to make a spheroidal musical instrument. If it is made from wood, you will need a wood ball more than 1m (3.28 feet) in diameter. The physical calculation tells us that the 1m diameter wood ball makes a sound pitch as high as 4000 Hz that corresponds to the highest piano key (C8). When you want to make a wood spheroidal instrument that generates a pitch lower than 4000 Hz, the diameter exceeds 1 m.

You may artificially create melon sound with non-integer overtones by using a synthesizer. When you make a melon sound by a synthesizer and taking special care to make non-integer overtones, the sound is very similar to the Bonang used in Indonesian gamelan. The Bonang is a musical instrument with a 3 dimensional scale. It is a small gong shaped like an inverted cooking pot. It also has a round dome shaped projection on the top and is played dome side up. The Bonang is suspended by two strings within a wooden frame. Gamelan music uses its inherent musical scales which are different from 12-tet. The different scale used in gamelan is very complex and will be described later.

The wooden balls with diameters wider than 1m are not practical for the usual concert hall. Therefore, a two dimensional musical instrument, Polygonola, was born. Why does a melon generate a sound with 200 Hz that we can easily hear? Because the melon is very soft.

One may come up with the idea to use a melon or other fruit as a musical instrument. But this is impractical because the fruit changes over time. Musical instrument must be made from solid material.

Polygonola is a two- dimensional or flat plate musical instrument made from bronze. As mentioned before, the size ranges from 50 to 300 mm, the thickness from 1.5 to 3.0 mm. The ratio of size to thickness affects the timber. Among the metal materials, bronze is the best in that it is durable, not damaged by striking hard and sustains a lingering tone.

The size and thickness contribute to the fundamental pitch as described before. When you hit a Polygonola, it generates non-integer overtones like a spheroidal body. Of course, the order and number of overtones from two dimensional Polygonola is different from that from three dimensional body, but both make non-integer overtones when they are hit.

Table 2 Order of overtones from different shapes of Polygonola

	Disk (ϕ, 233 mm)		Triangle (height, 180 mm)		Square (side, 180 mm)		Pentagon (height, 221 mm)	
	Pitch (Hz)	Ratio	Pitch (Hz)	Ratio	Pitch (Hz)	Ratio	Pitch (Hz)	Ratio
1	248	1.000	296	1.000	277	1.000	316	1.000
2	549	2.214	738	2.493	380	1.372	640	2.025
3	938	3.782	1009	3.409	667	2.408	730	2.310
4	1026	4.137	1313	4.436	688	2.484	1036	3.278
5	1415	5.706	1400	4.730	695	2.509	1216	3.848
6	1599	6.448	1446	4.885	1136	4.101	1369	4.332
7	1949	7.859	1837	6.206	1283	4.632	1531	4.845
8	2241	9.036	1860	6.284	1380	4.982	1801	5.699
9	2348	9.468	2021	6.828	1423	5.137	2476	7.835
10	2552	10.290	2268	7.662	1472	5.314	2491	7.883
11			2297	7.760	1653	5.968	3034	9.601
12			2331	7.875	1749	6.314	3070	9.715
13			2682	9.061	1857	6.704	4204	13.304
14			2992	10.108	2155	7.780		
15					2232	8.058		
16					2348	8.477		
17					2630	9.495		
18					2693	9.722		
19					3037	10.964		

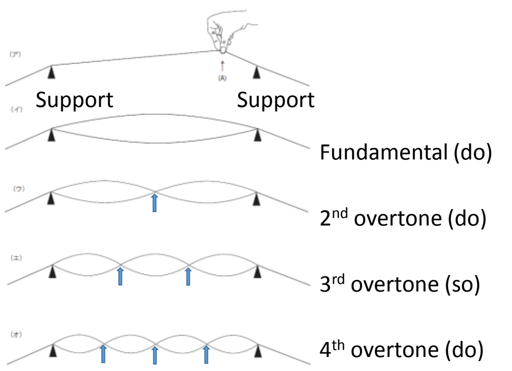
Table 2 (above) shows the orders of overtones of various shapes of Polygonola. Numerical figures in the table are overtone frequencies and the ratio to corresponding fundamental pitch. All shapes of Polygonola exhibit non-integer overtones. Non-integer overtones are expressed as “Ratio” in the table. Ratios are shown over 10. They are different from overtones of a melon as shown in Table 1.

Note that square Polygonola has more overtones than the others up to 10 time’s higher overtone than the fundamental. If one carefully looks at the figures for the square in the table, one notices that there are pairs of overtones that are very close each other, such as 667 and 688 Hz, 3% difference, 688 and 695 Hz, 1% difference, 1380 and 1423 Hz, 3% difference, and 2630 and 2693 Hz, 2% difference. These pairs of overtones which are very close to each other characterize the timbre of the square Polygonola, that is, a brilliant sound. The reason is unknown. On the other hand, Polygonola with fewer overtones such as the disk type, emits a clear and deep tone. They also have a soft vibration sound. The vibration mechanism is unknown.

Table 3 New scales for different shapes of Polygonola

Scale No.	Triangle	Square	Pentagon	Hexagon	Disk	12tet
1	1.000	1.000	1.000	1.000	1.000	1.000
2	1.114	1.274	1.178	1.136	1.163	1.060
3	1.243	1.360	1.384	1.216	1.229	1.122
4	1.315	1.422	1.554	1.381	1.270	1.189
5	1.384	1.527	1.689	1.573	1.308	1.260
6	1.465	1.620	1.811	1.770	1.384	1.335
7	1.619	1.671	2.137	1.770	1.384	1.335
8	1.827	1.731	**2.636**	1.912	1.696	1.498
9	1.916	1.873	3.105	2.053	1.811	1.587
10	2.130	2.001	3.648	**2.223**	1.931	1.682
11	2.274	2.207	4.096	2.525	2.066	1.782
12	**2.464**	**2.516**	4.452	2.703	**2.254**	1.888
13	2.745	3.205	4.774	2.879	2.621	**2.000**
14	3.063	3.422	5.633	3.070	2.770	2.119
15	3.240	3.578	**6.948**	3.497	2.863	2.245
16	3.410	3.842		3.935	2.948	2.378
17	3.610	4.076		4.250	3.120	2.520
18	3.989	4.204		4.564	3.363	2.670
19	4.502	4.355		**4.942**	3.823	2.828
20	4.721	4.712			4.082	2.997
21	5.248	5.035			4.352	3.175
22	5.603	5.553			5.081	3.664
23	**6.071**	**6.330**			**5.081**	3.564
24						3.775
25						**4.000**

Figure 3 Overtones from a string



↑, the node points where the string doesn’t vibrate.

Integer overtones found in a string vibration lead to 12 tone equal temperament scale (12-tet). For example, the third overtone of ‘do’ is ‘so’. Fifth overtone is ‘mi’. To make a long story short, the scale is based on the integer overtone of a string. Using the example of “do”, one can see it includes several integer overtones when the tone is made by a string (Figure 3).

When you plunk a string to make ‘do’, the vibrating string generates several overtones including the second overtone, ‘do’ as one octave higher, the third overtone equivalent of ‘so’, fourth overtone of ‘do’ with two octaves higher, fifth over tone equivalent of ‘mi’, sixth overtone equivalent of ‘so’, and so on. Comparing the ‘do’ (designated as fundamental ‘do’ in Figure 3) with one octave higher ‘do’ (designated as 2^{nd} overtone ‘do’), the frequency of the 2^{nd} ‘do’ is double the fundamental ‘do’. In other words, the 2^{nd} overtone ‘do’ has a frequency that is twice that of the fundamental ‘do’. When two notes are played by piano together at the same time, we feel two tones are combined into one tone because some overtones of the fundamental 'do' are the same as those of the octave high 'do'.

Four times higher frequency of the fundamental 'do' (4th overtone) is the same as the double frequency of the 2nd overtone, 'do'. Furthermore, six times higher frequency of the fundamental do (6th overtone, not shown in the figure) is the same as the triple frequency of the 2nd overtone, 'so'. Therefore, the 2nd, 4th and 6th overtones of the fundamental "do" are the same as the 1st, 2nd and 3rd overtones of the 2nd overtone (one octave high), "do".

When you plunk a string tuned the fundamental pitch as 'do', the string generates several overtones shown in Figure 3. When you plunk two strings at the same time with one tuned as fundamental do and the other tuned as second overtone of the fundamental, three overtones (2nd, 4th and 6th) out of 6 of the fundamental 'do' are the same as three out of three overtones (fundamental, 2nd and 3rd) of the one octave high 2nd overtone, 'do'. That is the reason why we feel that two do's with octave different pitch are combined together to make one tone.

Sethares (2005), however, demonstrated that this is a kind of illusion of human auditory sense. If we hear two do's with octave different pitch, and only when these two do's concurrently generate several integer overtones, these two tones are blended into one tone. But, if each 'do' does not have any overtone, one feels these two tones are different. Only after the second higher tone is tuned to be 2.10 times higher the fundamental frequency, one feels two tones are consonant, that is two are the same. Therefore he declared that the octave is dead.

In other words, when you make two tones an octave different by two strings, you feel that two tones are the same, because the tone made by a string always includes several integer overtones.

A tone without any overtones is made only by a synthesizer. Therefore, such an experiment was performed only with the aid of a synthesizer. At any rate, the octave is not originally imprinted in our brain, rather the octave feeling is a kind of musical learning and historical custom.

The equal temperament scale was originated from the integer overtones from string vibration. This hypothesis was established by a German physicist, Hermann Helmholtz (1877). His hypothesis was further strengthened by Promp and Levelt (1965). They gave an equation that automatically creates the musical scale, when you input the numerical figures of overtones to the equation.

Non-integer overtone data of a disk or any shape of Polygonola (Table 2) were input into the equation. It made new scales completely different from the musical scale with which we are familiar (Table 3). A new octave of Polygonola scale was set for the sound of the second overtone of the 1st scale, since the scale always includes the second overtone of the 1st scale within the scale. The new octave is 2.254 for disk Polygonola. It is not 2.0 as found in the conventional 12-tet scale as shown in Table 3.

Other new scales were made for the different shapes of plate. They have octaves of 2.464 for triangle, 2.516 for square, 2.636 for pentagon, and 2.223 for hexagon.

Table 3 shows the two new octave scales for each Polygonola. The triangle Polygonola has 11 scale tones between 1st and 12th scale, the latter is 2.464 higher than the 1st scale. The 2nd overtone for triangle Polygonola is 2.464 as shown in Table 2. You may create the next octave scale in the following way; the 13th scale tone is made by multiplying 2.464 and 1.114 that is 2nd scale in Table 3 for Triangle, and 14th sound by multiplying 2.464 and 1.243 that is 3rd scale in Table 3. Then, the 23rd scale tone was made by multiplying 2.464 and 2.464. When scale No. 1, 12, and 23 were hit together, three sounds are melted into one tone.

As mentioned before, the pitch of the Polygonola depends on the size. The size or diameter of the Polygonola is able to be calculated by a vibration equation to generate each defined scale pitch shown in Table 3. Therefore, one can make 12 triangle Polygonola instruments or other shape of Polygonola that generates the scale pitches designated in Table 3.

Polygonola was coined by linking two words, “polygon” as Greek and “ola” as Spanish word meaning “wave”. Polygonola with a polygonal shape generates a sound wave. If the number of side of polygon is increasing to an infinite number, it becomes a disk.

The 12-tet scale was established in the middle of the 17th century. The scale is based on the vibration of a string. Most environmental sounds, however, are not born from the string vibration. The sounds of tree leaves by wind, insect or bird chirping, river water and sea waves are not generated from a string vibration but from vibrations of 2nd or 3rd dimensional body. Mimicking these sounds by 12-tet has its limitation.

Twelve tet scale music might have been developed, because the sound generated from a string is unusual and rare in nature and that may be why it intrigued people. The music that was developed in the western world and used for religious hymns probably made people feel like they were in heaven.

There are, however, a lot of music styles in the world that do not follow the 12-tet scale. Although many non-western musical instruments have strings, the sound timber is not at all similar to those of familiar instruments used in a traditional classical orchestra. The sounds includes non-integer overtones as well as integer overtones. One may compare such sound with noise.

Even a western style instrument, the saxophone, creates more non-integer overtones than horn, flute, oboe or clarinet in orchestra. It may be a reason why the saxophone is not included in a western orchestra but rather played in Jazz.

The typical musical instrument that generates a lot of non-integer overtones is the percussion. Jazz and Rock are always played with such percussion.

Electric guitar often creates a lot of non-integer overtones. The sound is artificially distorted intentionally (by effects boxes) and unintentionally (particularly by a vacuum tube amplifier).

The distortion sounds especially contains a lot of non-integer overtones.

Even Japanese traditional musical instruments create non-integer overtones. “Biwa” and “Shamisen” have several strings, but a small and not so obvious structure is made to generate non-integer overtones. The name of this structure is “Sawari”, meaning “touching”. The fret of the “Biwa” is flat to make complicated noise between the string and flat fret. One string of “Shamisen” is also supported by a flat saddle to make non-integer overtones. Such construction is also found in an Indian instrument, the Tambura, which has a flat bridge to make non-integer overtones.

Another example of Japanese instrument is “Shaku-hachi”, a wind instrument made from bamboo. It may generate a clear sound with integer overtones. But when the player changes the way they blow into the instrument, it generates a sound rich in non-integer overtones. Tuning of an ancient or original “Shaku-hachi” is thought to be different from that of the modern instrument. Modern instruments are tuned to 12-tet.

Not only the musical instruments, but also Japanese traditional singing contains a sound rich in non-integer overtones. “Gidayu” sang in a Japanese puppet play, “Joruri”, with “Shamisen” contains a full of non-integer overtones, especially when the play is going to a very emotional scene. It is a bit strange because the singer is a single male, but he plays many roles including female or even an infant girl. No one laughs, but is moved by the play.

Why were these music containing non-integer overtones inherited? One hypothesis may be that these music was made to express natural voice from human emotion or nature sound with which we are surrounded. Bonang in the gamelan also generates non-integer overtones and is played in forest. Quick and right recognition of dangerous sounds like a wild animal voice or even a car behind you must be very important. These sounds aren’t generated from a string vibration, but contain a lump of non-integer overtones. Any consonants in daily conversation also contains a complex of non-integer overtones. We are able to recognize these sounds.

Polygonola is a flat musical instrument without strings and with a defined musical scale different from 12-tet scale. It generates non-integer overtones that may be consonant with natural sounds that may not be regenerated by music using 12-tet scale. (November 2, 2016)

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