Acoustic analysis on the voice of choir singers using *Spectroid*

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Abstract. This study was conducted based on interdisciplinary approach, physics and vocal music science, it could be used as an alternative activity to support student learning about sound wave. The aim of this study was to analyse the voices of the school choir singers using android App namely *Spectroid*..The result showed that 16 of 18 singers had been in the right position based on their type of voice. There are two singers had not been in the right position because they positioned in bass group which their voice could not reach the minimum limit of Bass frequency. The Soprano group which had the frequency range *148.6 Hz-1045.6 Hz*, 6 of 8 singers could be in mezzo-soprano and 4 of them could be in Alto. The Tenor group (*96.4 Hz-697.0 Hz),* 1 of 2 singer could be in Baritone but both of them could not be in Bass. The Bass group *(81.4 Hz – 493.8 Hz),* 2 of 4 singers are true Bass but all of them could be in Baritone and 1 of them could be in tenor. All of 4 singers in Alto group (*171.2 Hz-702.0Hz),* only positioned in Alto.

1. Introduction

School choir is one of extra-curricular activities that has been favoured by students, although they sing in a group, each of them has own sounds characteristic. The sounds are produced by the physical system, the vocal human track, which modulates the pitch of the voice[1], so that every people, include the choir singers, have different characteristic of the sounds.

There are several studies related both to acoustic analysis of human voice and musical instruments, such as the Acoustical characteristics study that conducted on the voice of school teachers in Iran [2], also there are studies to compare the experimental results of *Bonang Barung* waves superposition simultaneously and mixing using Audacity and MATLAB[3] and to measure the sound intensity produced angklung using a sound level meter[4].

The study of acoustic has both physic and vocal science side. Acoustic is a part of physics science that related to sound study. The acoustic waves, also known as sound waves, are longitudinal waves since the elements of their medium move in a direction that parallel to the direction of the wave propagation [5]. The propagation of the sounds is affected by the laws of mechanics and the properties of the medium [6]. Harmonic sound waves occur when air molecules oscillate with simple harmonic motion around their equilibrium due to the vibrational sound sourcesuch as a person's vocal folds in the larynx[7]and have sinusoidal pattern of displacement[8]. The sinusoidal waves are characterized by their amplitude, frequency and phase as shown by the harmonic sound wave function (1) [9].

$$s(x,t) = s_{\max} \sin(\frac{2\pi}{\lambda}\mathrm{x} - 2\pi ft) = s_{\max} \sin(\mathrm{kx} - \omega \mathrm{t}) \quad (1)$$

where $s(x,t)$ is the displacement of the molecules from equilibrium that cause the change of density and pressure of the air (*m*), λ is the wavelength (*m*),f is the wave frequency (*Hz*) that corresponds to the pitch of sound and this is the main parameter to classify the voice, $s_{\max}$ is amplitude (*m*) that affects to the loudness of the sound as described in equation (2)[10].

$$I = \frac{E}{A} = \frac{1}{2}\rho v\left(\omega s_{\max}\right)^2 \quad (2)$$

where I is the intensity of the sound (W/m^2) that correspond to the sound level in decibel (dB), E is the energy of the wave, A is unit area that passed by the energy. ρ is the density of the medium and v is the speed of the sound in the air. Thus, the intensity of the sound wave is proportional to the amplitude and the energy, also inverse to the wide of area. The greater amplitude, the bigger intensity of the sound wave, so that the sound is louder.

In the vocal science side,the voice of choir singers is classified into the vocal types based on the vocal range frequencies [11], as shownintable 1. Likeother studies on acoustic analysis, this study compared those required pitch range with maximum frequency range that can be reached by participants, respect to the fundamental frequency(F0) [12].

Table 1. Vocal group based on Its Frequency

Types of Sound	Gender (M/F)	Range Vocal	Frequency (*Hz*)
Soprano	F	C4-C6	261.626– 1046.50
Mezzo-Soprano	F	A3-A5	220.000 – 880.000
Alto	F	F3-F5	174.614 – 698.456
Tenor	M	C3-C5	130.813 – 523.251
Baritone	M	F2-F4	87.3071 – 349.228
Bass	M	E2-E4	82.4069 – 329.628

The very now students are part of the digital generation and very open to technology such as smartphonealthough most of them just use it for both communication tools and social-network media purposes[13], therefore, using smartphone as learning media is an interesting thing to do[14]. Current smartphones have offered many utilities such as GPS, light sensor, and sound measurement application that draw attentions from people such as educators, acoustic and environmental researchers [15]. Some educators even developed their own apps that help the student engaging with sound wave in the physics classroom [16]. *Spectroid*is one of Android apps and a real-time audio spectrum analyser with reasonable frequency resolution across the entire frequency spectrum. It is able to capture the frequency of sound with the greatest intensity.The aim of this study is to analyse and classify thevoice types of the school choir singers. The procedure also has a potential to be develop as a physics student activity.

2. Method

This study used repeated data retrieval method. The participants consisted of 18singers of the senior high school choir inMojoagung,Jombang. The research participants were asked to sound vowels within the lower threshold of the type of their voice (such as soprano, etc) assisted with *MIDI* piano-keyboard app to find the intended sound. For example, if the participant was asoprano singer, shewas asked to sound vowel /a/for five times within the lower threshold frequencyof soprano typewhich isaround 261 *Hz*(C4 tone frequency), then they sounded it within frequencies that arelower and higher than the threshold to get the lowest and highest frequencies they could reach.This data was taken from the vowels only because they are produced due to vibrations in the vocal cords without constriction of the vocal tract and sounded with the open mouth[17]. The vowels sounds have a longer duration pronunciation than consonant and clearer so that they are easier to recognize and analyze [18].

The sounds frequenciesgenerated by the participantswere monitored by*Spectroid* to ensure the participants were at the right tone frequency and captured. The distance between smartphonespeakerand the mouth of the participant should have been constant and not been too far (± 8 cm) because *Spectroid* displayed the frequencyof the loudest sound automatically.The procedure was repeated on other vowels /i/, /u/, /e/, /o/. From the data, the mean of frequency $\overline{f}$ is given as the sum of frequency f_i divided by the number of repetitions N as shown at equation (3)[19].

$$\overline{f} = \frac{1}{N}\sum_{i=1}^{N} f_i \qquad (3)$$

3. Results and Discussions

The coach classified the choir members into 4 groups of voice types, namely soprano, alto, tenor and bass. To test whether *Spectroid*is feasible to be used as a frequency measurement instrument, it had been compared to the *Audacity* software (installed on laptop) since it is well-known as sound measurement tool. The result showed that *Spectroid* can read the sound frequencies as good as the *Audacity* software.

3.1. Group of Soprano (consisting of eight participants)

Soprano is a type of female voice with a high tone frequency (261.626 – 1046.50*Hz)*. The results of the measurement of the sound frequency of the soprano group aredelivered in table 2.

Table 2. Frequencies of voices of Soprano singers (*Hz*)

Participant	Vowel /a/			Vowel /i/			Vowel /u/			Vowel /e/			Vowel /o/		
	L	**T**	**H**	**L**	**T**	**H**	**L**	**T**	**H**	**L**	**T**	**H**	**L**	**T**	**H**
S1	246.4	266.0	697	246.4	260	698.6	247.8	263	696.2	244.4	264.6	705.4	247	261.6	705
S2	175.2	256.6	1034	175.8	261	1045	175.2	258.8	1042	175	260	1043	175.8	260.2	1043
S3	222.8	260.4	781.4	219.2	257.6	788	218.2	262.2	785	218	257.2	779.4	218.6	260.6	787
S4	148.6	262	986.2	150.4	263.8	976.4	150.2	263.8	986.2	148.8	262	988.4	148.8	260	989.8
S5	177.8	266	870.6	175.8	269	820.2	176.2	272	851.8	172.4	266.6	841.4	175.6	264	822.4
S6	194.4	261.4	787.2	194.6	261	787.2	189.8	262.4	783	195.6	264.6	785	195.8	259.6	782.8
S7	218	263	700.8	220.4	262.4	693.2	222.4	260.4	697.4	223	263.8	700.8	224	263.8	705.2
S8	263.6	263.6	696.4	263.4	263.4	704	264	264	694	263.4	263.4	696.6	262.8	262.8	705

The data explains the frequency distribution of the participants namely S1-S8. There are three frequencies measured, the lowest (L) frequency, threshold (T) and highest (H). The lowest data (L) shows the lowest frequency that can be achieved by soprano. The threshold data (T) is the frequency that had been sounded by the participants around the lower threshold of soprano. When a soprano singer can reach the sound at this frequency, it shows that she has met the criteria for the type of soprano voice.

The highest data (H) shows the highest sound frequency that can be achieved by a singer. The lowest and highest frequency is different among the soprano singers because this occurs due to various factors such as the amount of training and talent[20].Comparing the frequency data in tableof each vowels, it is known that the soprano singers have a stable frequency on the measured frequency, for example, the lowest frequency of participant 1 (S1) on /a/,/i/, /u/, /e/, and /o/ are 246.4 *Hz*, 246.4 *Hz*, 247.8 *Hz*, 244.4 *Hz* and 247.0 *Hz*. From table 2, we can analyze that S1 had the shortest vowel range, so she would not comfortably sing songs on very high notes.Otherwise, S2 had the greatest tone range.

The lowest frequency that could be reached by her was on the lower threshold of the alto so she was also able sing well as a mezzo soprano and altosinger. Judging from the criteria for the frequency threshold of each type of sound, the result of the soprano group analysis issimply described in table 3.

Table 3. Results of the analysis on soprano singers

	Position on the choir group		
Participant	Soprano	Mezzo Soprano	Alto
S1	√	-	-
S2	√	√	√
S3	√	√	-
S4	√	√	√
S5	√	√	√
S6	√	√	√
S7	√	√	-
S8	√	-	-

3.2. *Group of Tenor (consisting of two participants)*

Tenor is a type of male voice with a high tone frequency (130.813 – 523.251*Hz*). Data from the measurements of vowel tenor singers are shown in table 4.

Table 4. Frequencies of voices of Tenor singers (*Hz*)

Participant	Vowel /a/			Vowel /i/			Vowel /u/			Vowel /e/			Vowel /o/		
	L	**T**	**H**	**L**	**T**	**H**	**L**	**T**	**H**	**L**	**T**	**H**	**L**	**T**	**H**
T1	107.6	128.2	693	108.2	129.2	694.0	107.0	132	697	108.2	129.8	696.6	108.4	130	130
T2	96.8	131.8	440.4	96.4	131.6	445.6	96.8	131	446	96.8	129.8	450	97.2	132.2	444.6

All participants could meet the lowest threshold tenor. We can see that T1 has the longest vowel range. For a tenor, the highest frequency is important, because he sing all kinds of high pitch song. T1 could not sing comfortablyas a baritone singer because he only reached a few frequencies below the tenor threshold. Thatwas different from T2, although the highest frequency that could be achieved was not as high as participant 1, but he hada minimum frequency that was lower than T1. T2 could be a baritone singer if needed and sang more comfortably than T1 within the note.Judging from the criteria for the frequency threshold of each type of sound, the results of the analysis of the tenor group can be seen simply in table 5.

Table 5. Results of the analysis on Tenor singers

	Position on the choir group		
Participant	Tenor	Baritone	Bass
T1	√	-	-
T2	√	√	-

3.3. Group of Bass (consisting of four participants)

Bass is a type of male voice with a low tone frequency (82.4069 – 329.628*Hz)*. Data from the measurement of the voices of bass singers are shown in table 6.Thus, we see that only two of the four bass singers, B1 and B2,were able to reach the lower bass threshold.The measurement of the sound frequency in the bass group was only repeated bytwo times because the lower bass threshold was also the lowest tone that could be reached by the participants.The highest frequency of B2 reachedthe tenor zone, he could be a fine tenor singer. B3 and B4 were actually baritone singers because their lowest voice frequencywas at the threshold of baritone instead of bass.

Table 6. Frequencies of voices of Bass singers (*Hz*)

Participant	Vowel /a/			Vowel /i/			Vowel /u/			Vowel /e/			Vowel /o/		
	L	**T**	**H**	**L**	**T**	**H**	**L**	**T**	**H**	**L**	**T**	**H**	**L**	**T**	**H**
B1	81.6	81.6	217	81.4	81.4	218.6	82	82	215.6	81.6	81.6	215.2	82.2	82.2	217.6
B2	82.6	82.6	191.4	82.8	82.8	197.2	83.6	83.6	193.2	83	83	192.8	83.4	83.4	193.2
B3	87.8	87.8	491.2	89.2	89.2	490.6	88,2	88.2	492.8	89.8	89.8	492.2	87.4	87.4	492.8
B4	94.4	94.4	176	96.2	96.2	176.6	97	97	175.2	95.6	95.6	177.4	97	97	174.6

The school choir was only divided into 4 groups namely soprano, alto, tenor and bass, therefore those two baritone singers were included in the bass group. B3 has a very large voice range so he can sing as a tenor very well. B4 was a true baritone because his voice was not able to reach the lowest bass threshold. Judging from the threshold criteria for the frequency of each type of voice, the results of the bass group analysis is delivered in table 7.

Table 7. Results of the analysis on Bass singers

Participant	Position on the choir group		
	Tenor	Baritone	Bass
B1	-	√	√
B2	√	√	√
B3	-	√	-
B4	-	√	-

3.4. Group of Alto (consisting of four participants)

Alto is a voice type of female singer which has a frequency range from 174.614 – 698.456Hz. The Data of frequency measurement results of alto's voice is displayed in table 8. All of theparticipants had the lowest sound frequency at the lower threshold so that thetwo measurements were taken.A1, A2 and A4 hadsound frequency rangesthat was exactly same as frequency range of alto voice. Those participants were alto singers with a consistent low tone. A3 had a wider range than others and she could sing above the maximum frequency but all of the alto singer remained alto.

Table 8. Frequencies of voices of Alto singers (*Hz*)

Participant	Vowel /a/			Vowel /i/			Vowel /u/			Vowel /e/			Vowel /o/		
	L	**T**	**H**	**L**	**T**	**H**	**L**	**T**	**H**	**L**	**T**	**H**	**L**	**T**	**H**
A1	178	178	700.8	178	178	695.2	176.8	176.8	697.6	176.6	176.6	702	176.2	176.2	698.6
A2	171.4	171,4	702	173.6	173.6	697.6	173.4	173.4	699.6	171.2	171.2	701	174.2	174.2	698.4
A3	175.8	175.8	787	173.2	173.2	786	174.2	174.2	787	175.2	175.2	784	174.8	174.8	783
A4	175	175	689.4	175.4	175.4	691.4	177.2	177.2	688.2	174.8	174.8	689.4	175.6	175.6	694.8

4. Conclusion

Based on the analysis, it confirms that 16 of 18 research participants had been in the correct type of voice group based on the threshold frequency limit rule. However, two participants from the bass group whose sound frequency could not reach the lower threshold of the bass because there was no baritone group in school. The two participants were then included in the group of bass. From eight participants in the soprano group, there were six participants who could be in mezzo soprano position and four people in alto position. One of participants in tenor group could be in both bass and baritone. Two of fourparticipants in the bass group, only two singers were actually in the bass position, one in the tenor position butall of them could be in baritone position. All of alto singers can only sing as alto singers.

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