Sound Energy Measurement of Singing Voice on upper Parts of the Body: A Research in Classical, Pop, Soul and Musical Theatre Singing

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Most musical instruments exhibit complex patterns of sound radiation, which change with materials, pitches played and other factors. The same holds true for the body of a singer (regarded as an instrument) singing with her or his voice but activating also parts of the neck, face, etc. A topic addressed in this paper is whether there are differences of sound radiation energy between Classical and Popular including Soul and Musical Theatre singing. Five vowels /a/e/i/o/u/ at 250 Hz (approx. tone B3) were sung by seven trained singers (five females and two males of the four singing styles) and measured with a microphone array comprising 121 microphones. This method allows to measure in which body parts the energy of the singing voice is generally produced and its extent and strength. For this research, the energy of the singing voice was analyzed at fifteen body parts. The results show that the energy of singing voices is not only produced in the mouth but also in other body parts that can even become stronger in a higher frequency range than from the mouth and the corners of the mouth. This phenomenon depends not only on frequency range but also on the vocal technique and the vowel.

1 Introduction

For a long time, motor control as related to cognition has been of interest since any singer must learn in lessons and through exercises to control and coordinate those parts of the body relevant to sound production in singing. This implies that the singer knows which muscles, tendons, etc. must be activated, and to which degree, in order to shape the sound of the singing voice according to a certain style of music as well as to certain expressive features. In regard to measurable differences, it can be expected that the radiated sound energy changes if a singer adopts a different vocal technique or sings a different vowel. Also, singers at times remark that certain parts of her or his body tend to vibrate while singing, and that the degree of such vibrations varies in line with vocal technique employed. Hence there are indications that sound radiation from singers must not be restricted to the mouth (though maximum of energy is expected from there). According to Sundberg, generally phonatory vibration occurs from vocal fold collisions of opening and closing of the glottis, and such collisions must generate shock waves in the tissue (i.e. body tissue vibrations) [1]. But he described in his research report that vibration on the sternum cannot be generated by such vocal fold collisions. In the past, the topic, whether the sound energy of singing is restricted only to the mouth or not, was already repeatedly researched [2,3,4,5,6,7]. In a book published in 1912, German doctor Hermann Gutzmann sen, the founder of the medical research field "phoniatrics", already described that the vibration of vowels /i/ and /u/ produced in the whole vocal tract, the nape (behind the vocal tract) and the skull area, is much stronger than that of the vowel /a/. It´s noteworthy that the vibration of the vowel /a/ covers just a smaller area [8]. Kirikae et al. did a vibration measurement by means of an accelerometer on the forehead, the cheek, the lower mandible, the larynx as well as the sternum at 125 Hz. They also showed that the vibrations on the forehead, the cheek and the lower mandible are greatest for the vowels /i/ and /u/, lowest for the vowel /a/, while intermediate values were measured for the vowels /e/ and /o/ [2]. But the vibrations on the larynx and the sternum were greatest for all vowels. Also using an accelerometer, Fant et al. recorded vibration at vocal tract walls by means of low frequency sine tone induced through a thin tube. They determined that the vibration is greatest near vocal tract ends, the lips and the larynx at very low frequency [3]. Pawlowski et al. showed by means of a laser technique the same result from measurement for the vowel /a/. They found that the larynx vibrates rather vigorously for the low tone while the greatest amplitudes appear in the lip region for the highest pitch [5]. Concerning the comparison of the singing voice between in the chest register and in the head register, Kirikae et al. demonstrated that singing in chest register vibrates clearly stronger than singing in head register [2]. They measured vibration levels of five vowels /a/e/i/o/u/ on the skull, the nasal dorsum, the mandible, the larynx and the sternum by means of an accelerometer at 250 Hz (in chest register) and 500 Hz (in head register), and, as already mentioned, they found that generally the singing voice in the chest register vibrates stronger than in the head voice, but this tendency is more clearly shown on the nasal dorsum and the sternum. Recently, I myself also researched on this topic by means of an microphone array, called 'acoustic camera', to find out the difference between radiation from the upper parts of the body in both registers of Classical singing voice [7]. For the study, the singing voice of a professional classical soprano singer was measured on three tones (B3, B4, F5) at the vowel /a/ and it showed that the singing voice in both registers radiates not only from the mouth but also from other parts like the forehead, the nasal bone or the throat, and that the radiation patterns change depending on frequencies. But such dependence of radiation or vibration level on frequency range was already confirmed by Sakakura and Takahashi [6]. They also used the vowel /a/ for their measurement at five body parts (forehead, cheek, right and left clavicles and sternum) and found that the vibration level on the forehead, on the clavicles and on the sternum become higher near 3 kHz, although that on the forehead showed low level at the fundamentals. They thus asserted a connection with singer´s formant, which occurs in around 3kHz. As shown here, the topic was already researched for a long time, mostly by means of an accelerometer but also by means of a laser technique. As an expansion of previous works, this study shows results by means of a microphone array investigating the voice energy of various trained singers from different musical genres.

2 Materials and Methods

2.1 Objects of Research

Seven trained singers - three Classical (bass, alto and soprano), two Musical Theatre (tenor and mezzo soprano) and two Popular singers (both mezzo soprano) - participated in this study. Five of them finished their study in vocal music at a music educational institute, and there were two singers who did not study singing, but had had singing lessons for a long time and various experiences on stage. In addition, one popular singer's voice (female) was recorded twice by means of Popular singing technique and by means of Soul singing technique, because she claimed that she uses her voice to adapt musical genre in her performance. For the study, after a short warming-up vocal exercise, each subject sung five vowels a/e/i/o/u in tone B3 (approx. 250 Hz) and each vowel was recorded separately. In order to get good data, the vowels were repeatedly measured two or three times in the order of a-e-i-o-u, respective. Before recording, all singers were asked which vocal technique they learned and usually use for their singing, but it was not indicated that they must apply that. For this study, the objects were normally dressed for the measurement, because the ultimate goal of this research project is a better understanding about the production of sound energy from the singer´s body which is finally perceived as total sound energy by listeners.

2.2 Analysis Technique

An ‘acoustic camera’ comprising an array of 121 microphones (developed by Rolf Bader, University of Hamburg) was employed for this study. The array spacing is a regular grid with a grid constant of 3.9 cm. All microphones record the sound emitted from a source placed in front of the array in an anechoic room. Microphone signals are digitized at 24 bit/48 kHz and are fed into a computer where special software permits to calculate as well as to display in a graphic format the radiation patterns of sources that have been recorded [9,10]. For the recording, the microphone array was attached to the front of a stand and adjusted for the height of singers, so that their mouth is positioned in the front of the center microphone (No. 61). The center microphone was placed 3 cm in front of the mouth and the singing voice was measured from max. 2 seconds of phonation. For the analysis, code written in Mathematica was applied to the data and by means of this the vibrations were analyzed on a total of fifteen upper parts of the body (mouth, chin, throat, left and right clavicles, sternum, nose, nasal bone, left and right corners of the mouth, left and right cheeks, forehead, left and right lower eyelids). This setting made it possible to show energy values of the voice radiation from the singer’s upper body.

3 Results

3.1 Measurement with all Singers

First, results of measurements on the vowels /a/e/i/o/u/ at 250 Hz in which all subjects took part are discussed. The results of the vowel /a/ are shown in Figure 1. This figure demonstrates the radiated sound energy from the mouth and fourteen other parts from the upper body analyzed up to the 20th partials (ca. 5 kHz), respectively. In order to compare the sound level of the mouth to that of the other parts, all radiations are shown in relation to mouth radiation set to 0 dB. The results of all five vowels reveal that the energy comes the strongest from the mouth, as expected, but sufficiently loud sound pressures from other body parts were also observed: the chin and the left corner of the mouth were the strongest sound sources for all vowels and their sound level was shown in around -10 dB or lower at the fundamentals, but rides up to around -5 dB in higher frequency range, so that the distinction between the sound power level of the mouth and the sound power level of both upper body parts will be smaller in ascending frequency range. But in fact, this holds true for all the measured parts. For all the vowels, the increase of energy was shown in the frequency range from about 1 kHz up to 5 kHz, which is the highest range that was analyzed in this study. This slightly increase for the vowels /a/e/i/, while a rapidly rising energy is observed for the vowels /o/ and /u/. As shown in Figure 1, measured on the vowel /a/, there is a remarkable increase of the body parts between the fundamental (250 Hz) and the 20th partial (5000 Hz). Just like for this vowel, such increase between the both partials was also observed for other vowels. In addition, the result reveals a remarkable increase up to 23 dB in the sound power between the fundamentals and the 20th partials for many parts (see the marked values in Table 1), while the sound levels for the chin and the corners of the mouth seem to remain almost unchanged because both parts are the strongest energy sources from the beginning. But in fact, most of the body parts including the chin and the corners of the mouth radiate stronger at the 20th partials than at the fundamentals.

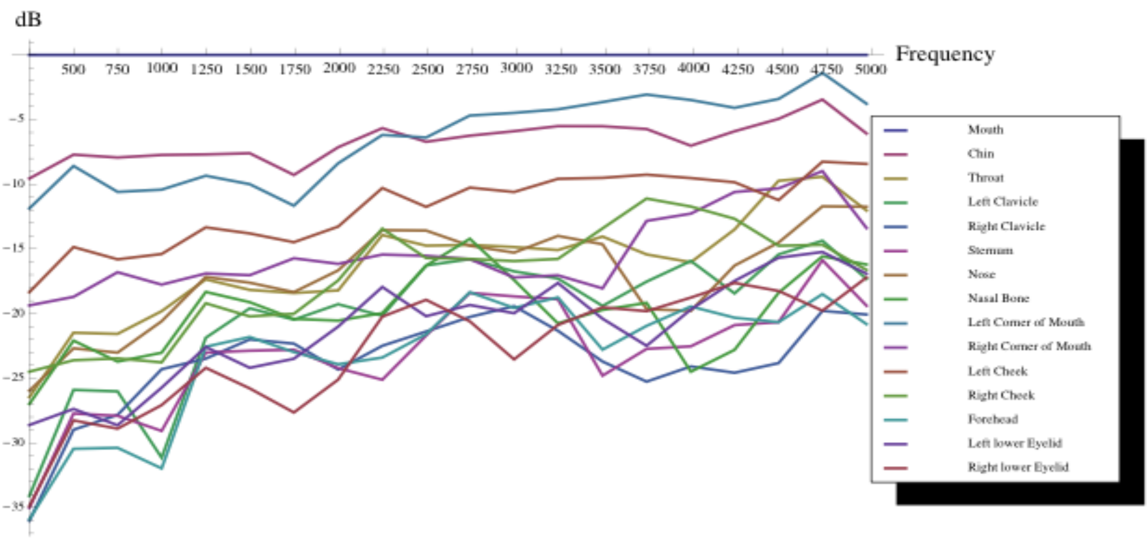

Figure 1. Sound levels of fourteen measured upper body parts on the vowel /a/ at 250 Hz, compared to the sound level of the mouth. The energy from the mouth is shown in zero on the x-axis (dark blue line).

Table 1. Sound levels of fourteen upper body parts measured on the vowels /a/e/i/o/u/ at the fundamentals (250 Hz, above) and the 20th partials (5 kHz, middle), and the differences between the both values (below). The marked values show the energy value that increased more than 15 dB between the fundamentals and the 20th partials. The following names of the body parts are abbreviated in the list: the left corner of the mouth (L. C. of M.), the right corner of the mouth (R. C. of M.), the left lower eyelid (L. L. Eyelid) and the right lower eyelid (R. L. Eyelid).

Vowel/Part	Chin	Throat	L.Clavicle	R.Clavicle	Sternum	Nose	Nasel Bone	L. C. of M.	R. C. of M.	L. Cheek	R. Cheek	Forehead	L. L. Eyelid	R. L. Eyelid
Vowel /a/	-9	-26	-34	-36	-35	-25	-26	-11	-19	-18	-24	-35	-28	-34
	-6	-12	-17	-20	-19	-11	-16	-3	-13	-8	-16	-20	-16	-17
Difference	3	14	17	16	16	14	10	8	6	10	8	15	12	17
Vowel /e/	-10	-27	-34	-36	-34	-26	-27	-13	-16	-19	-24	-35	-28	-34
	-5	-11	-17	-18	-18	-13	-12	-5	-12	-9	-15	-20	-14	-17
Difference	5	16	17	18	16	13	15	8	4	10	11	15	14	17
Vowel /i/	-13	-29	-32	-36	-35	-27	-27	-16	-18	-23	-23	-34	-30	-35
	-5	-11	-18	-21	-19	-11	-13	-4	-7	-7	-9	-20	-14	-19
Difference	8	18	14	15	16	16	14	12	11	16	14	14	16	16
Vowel /o/	-15	-35	-37	-39	-38	-30	-31	-12	-20	-25	-31	-39	-31	-37
	-7	-12	-16	-19	-18	-13	-15	-3	-11	-8	-14	-20	-14	-17
Difference	8	23	21	20	20	17	16	9	9	17	17	19	17	20
Vowel /u/	-16	-35	-35	-41	-36	-29	-30	-12	-21	-24	-30	-38	-33	-37
	-9	-16	-16	-20	-21	-16	-15	-8	-12	-10	-17	-21	-17	-20
Difference	7	19	19	21	15	13	15	4	9	14	13	17	16	17

By focusing on the vowels, slightly higher sound levels on the chin, the cheeks and the throat were measured for the vowels /a/ and /e/ than for the vowels /o/ and /u/ (the vowel /i/ is middle value of them) at the fundamentals, while at the 20th partials there was no wider difference in relation to the value of all body parts between the five vowels. This means that the vowels /o/ and /u/ were dramatically rising in a higher frequency range, as mentioned before. However the results in Table 1 also show a decrease of the distinction between the body parts in radiation energy: compare the values of the weakest and strongest at the fundamentals as well as at the 20th partials, that were measured at the body parts for each vowel, shows that all the energy values are equalized due to dramatically increasing energy from the parts which showed first low sound energy level at the fundamentals. For example in the case of the vowel /u/, the lowest value is -41 dB (right clavicle) and the strongest value displays sound level of -12 dB (left corner of the mouth) at the fundamental, therefore the difference between both values will consist of 29 dB at the fundamental. Calculated using the same method, it arises a difference of 13dB at the 20th partial (strongest value -8 dB of the left corner of the mouth from the weakest value -21 dB of the forehead/sternum), and the difference of energy values between the fundamental (29 dB) and the 20th partial (13 dB) thus amounts 16 dB. This implies that the difference of energy between the measured body parts gets smaller in the high frequency range. This also reveals that sound radiation from singers is not restricted to the mouth. Sound energy from all measured body parts are present increase with ascending frequency, so that the difference of sound level between the mouth and all the other parts become smaller for higher frequencies. In Figure 2, it will be shown in the case of the vowel /a/, how strongly the energy from the measured body parts is, by totalized the energy values from all non-mouth parts (measured parts except the mouth) and compare them with that from the mouth. The results reveal that the other parts radiate slightly more energy than the mouth at the fundamentals but its power become dominant in higher frequency range, so that at the frequency of the maximum energy, this will be more than 10 dB stronger compared to the mouth. This clearly indicates origination of strong sound energy from non-mouth parts. This clearly indicates origination of strong sound energy from non-mouth parts.

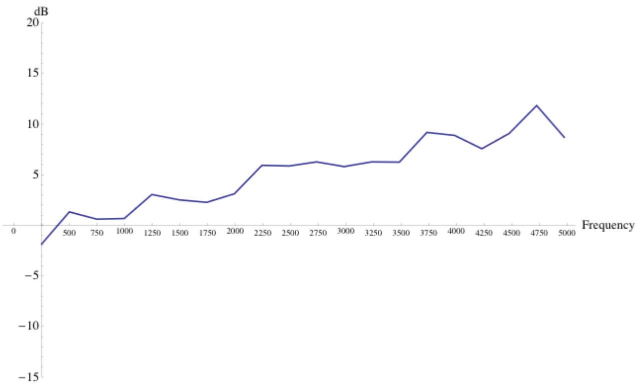

Figure 2. Progress of the sound energy from all fourteen measured body parts for the vowel /a/ at 250 Hz, compared to that from the mouth (set to 0 dB).

At this point, one question arises: how is sound level of the radiation power without the corners of the mouth? Can that be still stronger than from the mouth? As shown above, it is sure that the mouth emits the strongest power, if the body parts will be compared separately with the radiation from the mouth. But also the corners of the mouth showed great energy values. Therefore, totalized the energy value from the body parts except the corners of the mouth is presented in Figure 3 (here the results of the vowel /a/ only). The results indicate that sound power from the corners of the mouth has also great influence on the total radiated sound energy level, as expected. Therefore, a considerable decrease of sound level is shown for the vowels /a/ and /i/. However the total energy except from the corners of the mouth can still surpass the others in the higher frequency range. For example, such a finding is shown from 2250 Hz for the vowel /a/. The findings for the vowels /e/ and /i/ exhibit that the energy value constantly remains over the level from the mouth, although it appears just in high frequency range, from around 4500 Hz. Therefore the sound power of these vowels seems to be dominated by the surroundings of the mouth. On the other hand, the vowels /o/ and /u/ yielded remarkable results, so that their energy from the body parts without the corners of the mouth already reaches its maximum energy at 2000 Hz. However, the sound energy from 2750 to 4250 Hz is dominated by the surroundings of the mouth again and then a next increase appears from around 4500 Hz, as for the vowels /i/ and /e/. There is a clear indication that the vowels /o/ and /u/ are affected at least by the energy from the corners of the mouth.

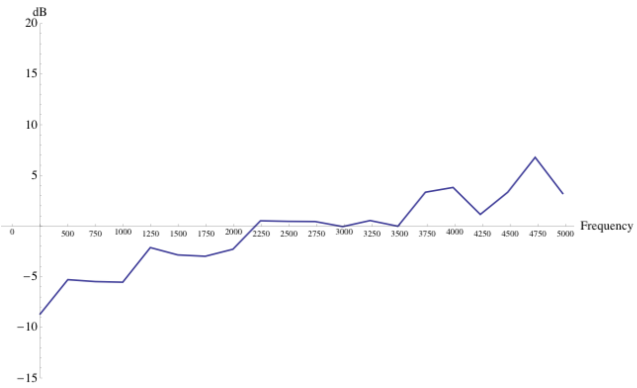

Figure 3. Progress of the sound energy from the measured body parts except the corners of the mouth for the vowel /a/ at 250 Hz, compared to that from the mouth (set to 0 dB).

3.2 Analysis of Radiation Energy by Musical Genre

So far in this case study, general information about energy radiation from upper body parts was presented without differentiation of musical genres. In the following, the results will be shown segmented according to the musical genre of participating singers, Classical, Musical Theatre and Pop/Soul singing. Again, the results of all vowels were analyzed with and without the corners of the mouth and are displayed in Table 2. In order to compare the results from both analyses as well as to recognize the difference between musical genres clearly, the energy value of the fundamental, the minimum and the maximum energy from each vowel are shown according to musical genre. As shown in Table 2, the minimum energy is mostly measured at the fundamentals, so that there is no wider difference between the values of the fundamentals and the minimum energy. By analysis of sound energy including the corners of the mouth, Classical singing reveals the strongest energy at the fundamentals in comparison to all the others, however there are no wider differences among the musical genres for the vowels /a/ and /e/ at the frequencies of the maximum energy. This implies that the energy value of Popular and Soul singing would be strongly grown in the increasing frequency range. Unlike this results from the analysis with the corners of the mouth, the results without them shows that the voice of the Classical singing has clearly more power at the fundamentals, i.e. less depending on the surroundings of the mouth than that of the Musical Theatre and Pop/Soul singing. Furthermore, the Classical singing radiates the strongest energy for the vowels /a/e/i/ at the frequencies of the maximum energy. Moreover, some considerable distinctions between the musical genres for the vowels /o/ and /u/ are observed in both results: firstly, by comparison of the vowel /o/, the Musical Theatre and Pop/Soul singing show a dramatic jump from the partial measured the minimum energy to the partial measured maximum energy in the frequency range (e.g. case of the analysis without the corners of the mouth: from -28 dB to +12 dB for the Musical Theatre singing and from -13 dB to +25 dB for the Pop/Soul singing), and ultimately, these great cumulativeness surpassed the maximum energy value of the Classical singing. Secondly, the dramatic rise for the vowels /o/ and /u/ of the Pop/Soul singing shows almost the same value of maximum energy in both results, with and without the corners of the mouth, although at the fundamental the value without the corners of the mouth was obviously weaker than another. But the Classical singing also presents a similar result. As already mentioned, in most instances, the power of the singing voices, independent of genre, seems to radiate strongly from the surroundings of the mouth (see also Figure 2 and 3). But these findings in Table 2 reveal that energy of the vowels /o/ (for the Musical Theatre and Pop/Soul singing) and /u/ (for the Classical, the Pop/Soul and the Musical Theatre singing) is influenced by surroundings of the mouth just at the beginning, because in higher frequency range, where occurred the maximum energy, the sound power in both cases reaches almost the same value. For the Classical singing, its sound energy seems to be least dependent on radiation from the surroundings of the mouth. The reason may be caused of the classical singing technique: classical trained singers must use their body as an instrument in order to produce loudness of the singing voice, by means of adjusted spatial configuration between the vocal folds and mouth opening, according to the space size of a concert hall or opera house. Thus, it seems that the strong involvement of body parts (except for the corners of the mouth) that allows the singers to keep more stability in emitted singing voice is necessary for producing the loudness for Classical singing.

Finally, it will be shown in Table 3 which body part is involved in the ascending sound energy related to the intensity of the energy increases between the fundamentals and the 20th partials (by the analysis including the corners of the mouth). A similar comparison was already numerically presented in Table 1 as total result from all objects, but this list displays an individual comparison by musical genre. As shown in Table 3, regardless of the musical genre, there is a great increase of energy in the frequency range at all parts except the chin, the corners of the mouth and the cheeks. In particular, the progress for the Musical Theatre singing is enormous and can be clearly recognized almost everywhere, except for some exceptions. The measurement on the Pop/Soul singing also reveals a similar result, but with somewhat smaller body progress. On the other hand, for the Classical singing such a increase is verifiable almost just for the vowels /i/, /o/ and /u/. However it can be assumed that the total energy increase of the vowels for the Classical singing is general strongly supported by the enhanced energy values from certain parts recorded in Table 3, because the values at a few parts, such as the chin, the corners of the mouth and the cheeks, did not change so much.

Table 2. Comparison of the sound energy between from the mouth and from all measured body parts (left) and comparison of the sound energy between from the mouth and from the body parts except the corners of the mouth (right). The energy values of the fundamentals, minimum and maximum energy for all vowels are shown there by musical genre.

All body parts				**Body parts except the corners of the mouth**			
Tone & Genre	**Fundamental**	**Min. Energy**	**Max. Energy**	**Tone & Genre**	**Fundamental**	**Min. Energy**	**Max. Energy**
Classical				Classical			
B3a	0	0	13	B3a	-5	-5	8
B3e	0	0	13	B3e	-5	-5	9
B3i	0	-1	15	B3i	-7	-7	12
B3o	-2	-2	10	B3o	-8	-8	6
B3u	0	-1	20	B3u	-6	-6	19
Musical				Musical			
B3a	-6	-6	11	B3a	-12	-12	5
B3e	-5	-5	10	B3e	-14	-14	6
B3i	-12	-12	6	B3i	-21	-21	0
B3o	-15	-16	15	B3o	-28	-28	12
B3u	-12	-12	8	B3u	-27	-27	-1
Pop & Soul				Pop & Soul			
B3a	-1	-1	13	B3a	-9	-9	7
B3e	-1	-3	14	B3e	-10	-10	9
B3i	-4	-4	10	B3i	-11	-11	5
B3o	-2	-2	24	B3o	-13	-13	25
B3u	-8	-9	30	B3u	-21	-22	31

Table 3. List of increase of energy values at the measured body parts displayed by musical genre (x = 10-19 dB, xx = 20-29 dB, xxx = 30-39 dB)

	Chin	**Throat**	**L.Clavicle**	**R.Clavicle**	**Sternum**	**Nose**	**Nasel Bone**	**L.C. Mouth**	**R.C. Mouth**	**L.Cheek**	**R.Cheek**	**Forehead**	**LL. Eyelid**	**R.L. Eyelid**
/a/														
Classical					x	x				x			x	
Musical		xx	xx	xx	x	xx	x	x	x	x	x	xx	x	xx
Pop/Soul		x	x	x	x	x	x			x		x	x	x
/e/														
Classical			x		x							x	x	x
Musical	x	xx	xx	xx	xx	xx	x	x	x	xx	x	xx	x	xx
Pop/Soul		xx	xx	x	x	x	x				x	x	x	x
/i/														
Classical		x			x	x	x		x		x	x	x	x
Musical	x	xx	xx	xx	xx	xx	x	x		x	x	x	x	x
Pop/Soul		xx	x	x	x	x	x	x		x	x	x	x	x
/o/														
Classical		x	x	x	xx	x	x	x	x	x	x	x	x	x
Musical	x	xx	xx	xx	xx	x	xx	x		xx	xx	xxx	x	xxx
Pop/Soul		xx	x	x	x	x	x			x	x	x	x	x
/u/														
Classical			x	x	x	x	x		x		x	x	x	x
Musical		xx	xx	xx	xx		x			x	xx	xx	x	xx
Pop/Soul		xx	xx	x		x	x			x	x	x	x	x

4 Conclusion

The study reveals that the sound energy of the singing voice generally arises not only from the mouth but also from other fourteen measured upper body parts. In addition, the non-mouth body parts showed relatively weak radiation at the fundamentals, but that will be stronger in the higher frequency range, so that the total energy from the non-mouth parts can surpass not only the energy value from the mouth, but also that from the surroundings of the mouth (i.e. the mouth and the corners of the mouth). However, the result seems strongly dependent on frequency and differs according to the musical genre and vowel. As shown in Table 2, the Classical singing case revealed the strongest energy production at the fundamentals including the corners of the mouth, although the difference between Pop/Soul and Classical singing was relatively small there. But a clear difference between the Classical singing and other musical genres was demonstrated by the analysis without the corners of the mouth, especially at the fundamental: the Classical singing radiates stronger from the non-mouth parts. In addition, at the fundamentals in both analyses, the radiation of the Classical singing is equal for all the vowels, although for others there are wide differences of the radiated sound levels among the vowels. However, for the maximum energy in both cases, no wide difference between musical genres appeared for the vowels /a/ and /e/, while there were considerable distinction for the vowels /i/, /o/ and /u/. The maximum energy of the Pop/Soul singing was partly over twice as strong as that of others for the vowels /o/ and /u/. All the results are caused of geometrical change of vocal tract including lip opening which influences on vocal sound pressure. Furthermore, according to Sundberg, very strong sound pressures in the vocal tract and in the trachea generate the phonatory vibrations in the skull, neck and chest region [1]. This will be the cause for the great energy radiations of the throat, the clavicles, the sternum and the forehead that were shown in Table 3.

References

[1] J. Sundberg, "Phonatory Vibrations in Singers. A critical Review", Q. Prog. Status Rep. STL-QPSR 1, 37-51 (1991).

[2] J. Kirikae, T. Sato, H. Oshima and K. Nomoto, "Vibration of the Body during Phonation of Vowels", Revue de Laryngologie, Otologie, Rhinologie 85, 317-345 (1964).

[3] G. Fant, L. Nord and P. Branderud, "A Note on the Vocal Tract Wall Impedance", Q. Prog. Status Rep. STL-QPSR 4, 13-20 (1976).

[4] J. Sundberg, "Chest Wall Vibrations in Singers", J. Speech and Hearing Research 26, 329-340 (1983).

[5] Z. Pawlowski, R. Pawloczyk, Z. Kraska, "Epiphysic Vibrations of Singers studied by holographic Interferometry", Proc. of SMAC (1983), the Royal Swedish Academy of Music, Stockholm, 37-60 (1985).

[6] A. Sakakura, H. Takahashi, "Body Wall Vibration in trained and untrained Voices", In O. Fujimura (ed.), Vocal Physiology: Voice Production, Mechanisms and Functions, Raven Press, New York, 391-401 (1988).

[7] O. Takada, "Sound Radiation Patterns in Classical Singing Styles", In A. Schneider and A. v. Ruschkowski (ed.), Systematic Musicology: Empirical and Theoretical Studies, Peter Lang, Frankfurt am Main, 163-173 (2011).

[8] H. Gutzmann (sen.), "Stimmbildung und Stimmpflege: Gemeinverständliche Vorlesungen", Bergmann, Wiesbaden (1912).

[9] R. Bader, M. Münster, J. Richter and H. Timm, "Microphone Array Measurements of Drums and Flutes", In R. Bader (ed.), Musical Acoustics, Neurocognition and Psychology of Music, Peter Lang, Frankfurt am Main, 15-55 (2009).

[10] R. Bader, "Reconstruction of Radiating Sound Fields using minimum Energy Method", JASA, Vol. 127, 300-308 (2010).