Radiation Pattern of Classical Singing Style

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ABSTRACT
Musical instruments, and as such the singer’s body is included under this denomination, have a very complicated way of radiating their sounds as they approach our ears. The changing radiation patterns of the “singing voice”, which originates from each adjusting technique, could be a reason why the voice of a classical singing style is perceived differently from other singing styles. For the proposed research one of the largest microphone arrays with 128 microphones is used, and the recorded radiation patterns of the singing voices will be represented visually. This paper shows how two different voices, “chest voice” and “head voice” and the voices from two classical singing techniques “Belcanto” and “German singing technique” radiate from the body. For this research I recorded my own singing voice in three tone pitches of C1, C2 and F2, and results show that radiation patterns of the singing voice change depend on the used voice character and their increase of pitch.

Keywords
Singing voice, classical singing style, acoustical holography

1. INTRODUCTION
Presently a large amount of specialized literature there already exists that analyzes the act of singing from a theoretical and practical (for example physical and phonatory) point of view, but, it most cases, current researches do not refer to cognition. These works try to provide information about singing techniques for singing teachers, voice trainers and singers, such as research of the subglottal pressure, or the position of the larynx and different parts of the body which are responsible for the appropriate timbre and so forth. Besides the “know-how” which can be gained through practical exercises (for example by taking vocal lessons), such a theoretical knowledge should help singers and improve their practical skills. However, from my personal experience as a classical singer and voice trainer, it is very difficult to find out exactly which parts of the body are in fact involved when a singer tries to react to vocal training advice, even if an auditory difference can be recognized. What will be changed concretely? And how does the singing voice radiate audibly when the vocal character or technique is changed?

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2. AIM
As already mentioned in the introduction, I want to find out how the singing voice radiates when it emanates from the vocal folds via vocal tract, and finally from the mouth. Does voice come only from the mouth, in other words only from one of the body parts, or also from other body parts? Further, it is also a purpose of this research to find out whether (and/or how) the radiation pattern of a singing voice as a musical instrument can be changed, similarly to other musical instruments (see 3.2. “Analysis techniques”). For example a research on guitar showed that the radiation changes according to the tone pitch. Finally, it is expected that this examination will contribute to a better understanding about the physiology and function of the singer’s body in order to enable its use more efficiently in achieving an ideal sound level.
3. METHODS
Firstly I will briefly introduce the used research objects and their definition for a better understanding. Secondly I will present which methods were used in order to analyze the questions of this research.

3.1. Research Objects
Currently, I have been researching the differences of radiation pattern of two voices “head voice” and “chest voice”: the head voice is the voice which is often used for classical singing and the chest voice could be comparable with “speaking voice”. In addition I also explore two different classical vocal techniques “Belcanto” and “German singing technique”. The word “Belcanto” is not clearly defined and used with wide interpretations, but Belcanto is mostly known by classical singers as the most popular classical (mainly operatic) singing technique in the world and most classical singers will be trained in this singing method at several music educational institutions. For the Belcanto it should be important to have “sensations of openness in the nasopharynx” in order to open the throat area widely [1] and the technique of “singing in the mask” is known as the most essential term for the Belcanto. What the „singing in the mask“ means in practice is singing toward the paranasal sinuses [2] and the brilliant voice of the Belcanto should occur through this italian singing method. The “German singing technique” also attaches value to opening the throat area, but what differentiates the German singing technique differs from the Belcanto is the principle of singing toward the rear, and one of the known pedagogical methods for this german technique is “up the throat wall into the dome of the skull” [1]. For the research on the above-named two voices “head voice” and “chest voice” I chose tone C1, and for other one on two different singing techniques “Belcanto” and “German singing technique” I used tone C2 and F2. For each research I recorded my own singing voice and always sang on vowel “a”.

3.2. Analysis Techniques
In order to explore the above-mentioned scenario I would like to illustrate the radiation patterns of the singing voices. However, measuring these radiation patterns is quite complicated since radiation comes from different sources and materials. For this sake an acoustic camera using 128 microphones, which was developed for the Institute of Musicology at the University of Hamburg, is employed in an anechoic room. Those microphones record the sound field simultaneously with a sampling frequency of 48 kHz differentiating. The array spacing is in a regular grid with a grid constant of 3.9 cm. Researchers of the institute have applied this method successfully on different instruments, for example on guitars. The research on guitars showed that the radiation of guitar sounds spread on the top plate and that the radiation pattern changes depending on the character and quality of a guitar. Through this technical device it will be determined whether the radiation of a singing voice comes only from the mouth, or from other parts of the body. Furthermore, it is intended to measure if the radiation patterns of a singing voice changes corresponding to the singing style, similarly as the results of the above mentioned research on the changes of radiation guitar patterns showed.

For the visualization technique of the radiation patterns Mathematica was applied and thereby it was possible to show energy values of the voice radiation as well as radiated areas from the body on the picture.

4. RESULTS
In the following, the radiation patterns of each recorded voice from two different kind of voices and techniques will be shown. When the radiation comes not only from one body part but also from other body parts, the fields will be also presented. Before the result presentation I would like to indicate that there are some areas shown on the pictures where radiation does not come directly from the body, instead from nearby the body. At present it is not clear yet if such radiation is a room reflection or a refraction from any body part, but I hope that it will be clarified in the near future. Furthermore, each method was repeated five times in order to get an authentification and here only the findings will be presented which yielded the same or similar results in the fives time repeated research.

4.1. Radiation Patterns of the Chest Voice and Head Voice in Tone C1
Although a sound difference was perceived by a supporter and myself at the recording, the picture of the fundamental from both voices shows no difference, as it is shown in Fig.1. But it was measured that energy value from the chest voice is stronger than from the head voice: Although the fundamental at 257 Hz of the head voice achieves a maximum 0.14, in the case of the chest voice at 252 Hz it shows maximum energy of 0.03, almost a fifth from the head voice.
But at the 2. partial, the energy value of the chest voice increases to 0.29 and it is almost five times stronger as the head voice (0.06). The radiation pattern, for example its size from both voices changes at each partial, depending on the pitch. However, the radiation from the 1. partials to 18. partials still comes only from the mouth. But on the 19. partial it is shown that which could be an answer to two of my questions for this research, i.e. whether there is a difference between voice characters and if radiation also comes from other body parts. As it is shown in Fig. 2, for example on the 19. partial of the chest voice, the radiation also comes from the nose part and it differs from the radiation of the head voice. Furthermore, on the 23. and 28. partial it is shown that many body parts operate to radiate at the same time: When both 23. partials will be compared, you can see that the radiation of both voices comes from the mouth and head part, but using the chest voice it is also radiated from the chest, and using the head voice from the large area, or rather from the eye to chin area. As I already mentioned, the reason for some radiations near by the body on the picture cannot be explained, but the outside radiation on the 23. partial of the chest voice could be a refraction from any part because they are symmetrical. In any case, what is very remarkable is that the radiation from the mouth (at the using chest voice) and nose (at the using head voice) is just as strong as from the mouth. On the 28. partials the radiated areas become smaller than with the 23. partials, but at the head voice the throat appears as a new radiated part.
4.2. Radiation Patterns of the Belcanto and German Singing Technique
Because I researched the Belcanto and German singing technique on two different heights (C2 and F2), in the following their results will be presented separately.

4.2.1. In the Case of Tone C2
Already on the fundamentals (1st partials) there are two differences between Belcanto and German singing technique: one of them is the radiation size and area. As it is shown in Fig. 3, the radiation of the Belcanto technique originates not only from the mouth but also from the chin area. The other one is energy value, because the energy value of the fundamental from the Belcanto is recognized stronger than from the German.
singing technique. It shows that the fundamental of the Belcanto technique in tone C2 radiates the maximum energy of 0.16 and the fundamental of the German singing technique produces only the maximum of 0.11. But their maximum energy values changes on the 2. partial: With the Belcanto increases to 0.63 and at the German singing technique to 0.39. However, with the Belcanto the singing voice is still radiates stronger than with the German singing technique.

![Image](image1)

1. Partial: 521 Hz  
1. Partial: 520 Hz

Figure 3. Radiation of the fundamental from the Belcanto (left) and German singing technique (right) in tone C2

At first, a pattern will be shown here which does not originate from the mouth. As it is shown in Fig. 4, on the 6. partial a radiation from the mouth can be seen which neither the Belcanto nor the German singing technique produce. Both techniques have the radiation only in the chin area. Even on the 11. partials the radiation not only from the mouth but also from other body parts is significant: On the 11. partial of the German singing technique the radiation is located in the mouth and chest area. In the case of the Belcanto the radiation is not located directly in the mouth, but rather in the chin and throat area. In addition it is also in the chest area, more precisely, almost near by the shoulder. Remarkably the strongest radiation does not come from where it usually arises, namely the oral area, but from the left chest (near by the shoulder). Similarly it seems to radiate on the 14. partials in both techniques: The radiations of three parts from the chest area (Belcanto) and the throat and shoulders (German singing technique) are measured stronger than from the oral area. Even the radiation from the throat is 2.5 times as much as from the mouth.

![Image](image2)

6. Partial: 3115 Hz  
6. Partial: 3113 Hz
4.2.2. In the case of tone F2
On the fundamentals of both techniques in tone F2 the radiations look similar, although in tone C2 both fundamentals radiated differently. However, energy values are already reached on the fundamentals and its power subsequently decreases then. The maximum of each technique measures 0.82 (Belcanto) and 0.69 (German singing technique), hence my research on the Belcanto and German singing technique showed that in general the voice from the Belcanto technique radiates stronger energy then the voice from the German singing
Here in Fig. 6, I will show the radiation patterns of the 8. partials and compare not only both ways of the radiation in tone F2 but also the 8. partials of F2 and 11. partials of the mentioned C2, because its partials all are in a similar frequency area: The 8. partial of the Belcanto radiates from the mouth again, although on the 11. partial in tone C2 it was not the case. But at the 8. partial it radiates from the throat instead of the nose area (compare with 11. partial of the Belcanto in Fig. 4). The radiation pattern of the 8. partial from the German singing technique shows an enormous finding: With the exception of a few parts of the face (e.g. under the forehead), most of the facial area – from the head to clavicle – radiates energy and the energy value from the head is just like from the mouth. As I already mentioned, I repeated every experiment five times and of course this result was also compared with four other results. The results of the 8. partial from the German singing technique was not always the same, but the fact that the radiation comes from most of the facial area remains unchanged.
5. CONCLUSION
The Results of this research show that the radiation of singing voice changes depends on the used voice character, singing technique and their increase of pitch, just as in the case of the research on other instruments. A changed vocal folds configuration, i.e. a register change, is certainly a reason for the different radiation patterns between chest voice and head voice. Also the difference in radiation patterns from the research on Belcanto and German singing technique could originate because of similarly reason, namely from the change of spatial configuration between vocal folds and opening mouth, since the geometrical change of this space, called vocal tract, determines the timbre of the radiated sound [3]. Furthermore, I will research on the singing voice on other vowels, different registers and various singing techniques like Belt (musical singing technique), sprechgesang (e.g. Rap) and overtone singing.

6. REFERENCES