A PILOT STUDY OF VIBRATION PATTERN MEASUREMENT FOR FACIAL SURFACE DURING SINGING BY USING SCANNING VIBROMETER

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ABSTRACT

We attempted to measure the vibration velocity patterns of the facial surface during sustained singing using a scanning laser Doppler vibrometer. The measurement system used allowed laser-based, noncontact, and multipoint measurements of the vibration of objects. Three Japanese female professional singers (A, B, and C) participated in three experiments. In the first experiment, the vibration velocity patterns for the Japanese vowels /a/ and /i/ were obtained for the singers. The patterns for the vowels demonstrated a clear contrast, especially around the nose and cheek. In the second experiment, the differences in the vibration velocity patterns due to the pitch frequency were compared for Singer A. The results show that the amplitude of the vibration velocity of the forehead for a higher pitch frequency (F5=698.5 Hz) is larger than that for a lower pitch frequency (A4=440 Hz). In the third experiment, the effects of methods of vocalization on the vibration velocity pattern were measured while Singer A sang in falsetto and modal voice. A significant difference in the amplitude of the volume velocity of the cheek was observed.

1. INTRODUCTION

Expert singers can express their somesthesis during singing in their unique expressions. For example, one of the authors once heard of a singer who sings by expanding her skull – of course, we cannot expand our own skull by ourselves. If the causal relationship between these expressions and various physical phenomena on the body surface and inside the body is clarified, it could lead to the understanding of the singing mechanism and the improvement of methods of singing exercise. To this end, in the present study, we conducted a pilot study measuring one of such physical phenomena, the vibration velocity pattern of the facial surface during singing for expert singers.

The vibration patterns of skin surfaces during phonation and singing have been measured by contact and noncontact methods [1]. In their pioneering work, Kirikae *et al.* [2] used vibrometers to measure phonatory body vibrations at more than forty points. Suzuki *et al.* [3] employed acceleration pickups and measured the acceleration of the nasal wall, the neck wall, and the cheek during speech production. Toyoda and Fujinami [4] utilized an optical fiber sensor to measure the vibration at nine different locations on the body during singing. It is, however, undeniable that the sensors used in contact with the measurement objects affect their vibration, although the acceleration pickup used by Suzuki *et al.* [3] is very light and small.

Noncontact methods, on the other hand, have a clear advantage in that they allow measurements without affecting the vibration of objects. Pawluczyk and Kraska [5] developed a laser-based method that can show equal-vibration-amplitude contours of objects and measured the nodal patterns of the facial and neck surfaces during singing.

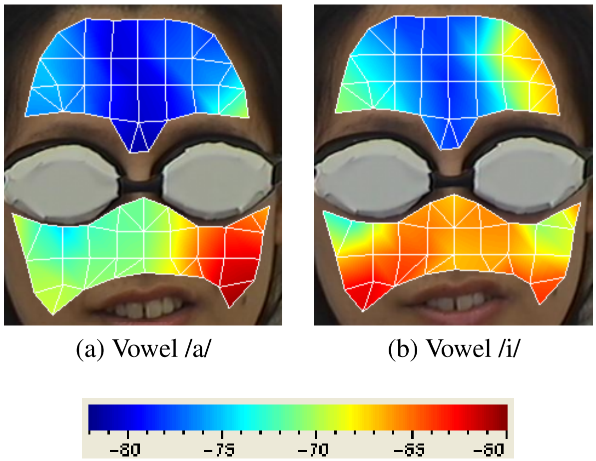
Recently, laser Doppler vibrometers (LDVs) have been utilized to measure the skin surface vibration during phonation. Avargel and Cohen [6] attempted to obtain speech information from the vibration of the surface of the larynx using a single-point LDV. Kitamura [7] reported the vibration velocity pattern of the facial surface during phonation using a scanning LDV. The scanning vibrometer permits multipoint measurements of the vibration of targets.

In this research, we conducted a preliminary study to obtain the vibration velocity pattern of the facial surface during singing using the scanning LDV.

2. METHODS

2.1 Scanning laser Doppler vibrometer

The vibration velocity of the facial surface was obtained with a scanning LDV system, Polytec PSV-400-M4. The LDV is an optical transducer that senses the frequency shift of the light reflected from a vibrating surface on the basis of the Doppler effect and can determine the vibration velocity and displacement at a certain point [8]. The scanning LDV can scan and probe multiple points of a vibrating surface automatically.



(a) Vowel /a/ (b) Vowel /i/

Figure 1. Vibration velocity of facial surface of Singer A during singing of Japanese vowels (a) /a/ and (b) /i/ in falsetto at her most comfortable pitch frequency (A4=440 Hz). The unit is m/s [dB] and 0 dB is equal to 1 m/s.

2.2 Participants

Three Japanese female expert singers, who are faculty members of Showa College of Music, participated in the measurements. Two of them (Singers A and B) are classical singers and the other one (Singer C) is a musical singer.

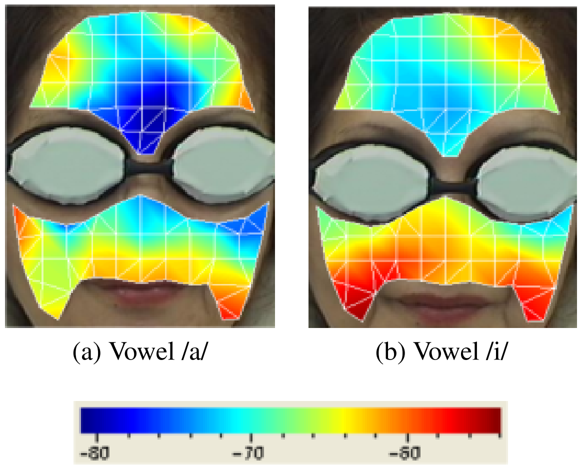
2.3 Data acquisition

We measured the vibration velocity pattern of the facial surface from the frontal direction, which is perpendicular to the forehead. The scanning head of the vibrometer was mounted on a tripod approximately 2 m away from the head of the participant. The participant sat on a high-back chair. Her head was held from either side by two steel poles covered with polyurethane foam that were clamped to the back of the chair. Her neck was also stabilized by a vacuum cushion. She wore protective goggles to protect her eyes from the laser emission.

In the experiment, scanning points on the facial surface were first determined using system control software. During the measurement, the vibrometer scanned each point and obtained the vibration velocity of the point. One measurement point was probed within 1 s. The vibration velocity and singing voices were measured from 100 Hz to 10 kHz.

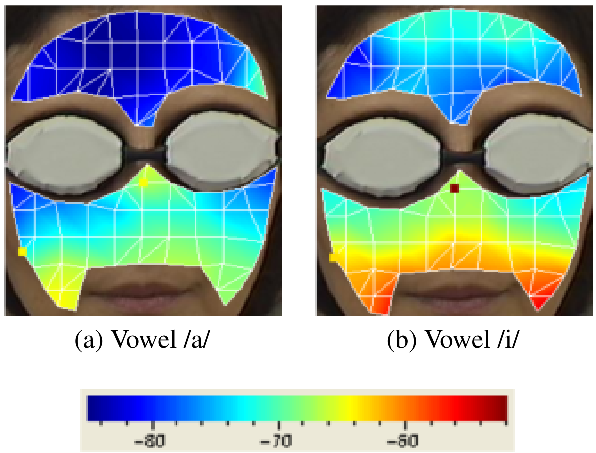
Data were acquired during sustained singing of a Japanese vowel. The participants were asked to sing repeatedly while keeping their head immobile during the measurements. Singing voices were recorded through a microphone (PCB PIEZOTRONICS 130E20).

Written informed consent was obtained from the participants prior to the measurement. The experimental protocol was approved by the ethical and safety committees of Konan University.



(a) Vowel /a/ (b) Vowel /i/

Figure 2. Vibration velocity of facial surface of Singer B during singing of Japanese vowels (a) /a/ and (b) /i/ in falsetto at her most comfortable pitch frequency (?=??? Hz). The unit is m/s [dB] and 0 dB is equal to 1 m/s.



(a) Vowel /a/ (b) Vowel /i/

Figure 3. Vibration velocity of facial surface of Singer C during singing of Japanese vowels (a) /a/ and (b) /i/ in falsetto at her most comfortable pitch frequency (?=??? Hz). The unit is m/s [dB] and 0 dB is equal to 1 m/s.

2.4 Experiments

Three experiments were carried out in this study. In the first experiment, we compared the vibration velocity patterns of the facial surface during sustained falsetto singing of the Japanese vowels /a/ and /i/, back and front vowels. The three singers sang in their most comfortable pitch frequencies (A4=440 Hz for Singer A, G4=392 Hz for Singer B, and A4=440 Hz for Singer C).

The second experiment was conducted to investigate the differences in the vibration velocity pattern due to the pitch frequency. Singer A sang in her higher comfortable pitch frequency (F5=698.5 Hz) during the measurement.

The third experiment aims to reveal the differences between falsetto singing and modal singing. The vibration velocity pattern was measured while Singer A sang the vowel /i/ sustainedly in her modal voice and compared it with the patterns measured in the first experiment. The pitch frequency of the modal voice of Singer A was the same as her comfortable pitch frequency in experiment 1.

3. RESULTS AND DISCUSSION

3.1 Experiment 1

Figures 1, 2, and 3 show the root mean square (RMS) values of the vibration velocitiesq of the facial surfaces of the three singers. The grid points in the figures are measurement points and the RMS values of the other colored points were interpolated from the RMS values of adjacent measurement points. The cold and warm colors of the patterns indicate low and high vibration velocities, respectively.

The results show that the amplitude of the vibration velocity for the vowel /i/ is larger than that for the vowel /a/ around the nose and cheek for all the participants. This is probably because the variation in intraoral pressure during the production of the vowel /i/ is higher than that during the production of the vowel /a/.

The vibrometer utilized in this study can visualize the vibration velocity pattern for a specific vibration frequency band of interest. Figure 4 shows the vibration velocity pattern during sustained singing of the vowel /a/ for the harmonic frequencies (438 Hz and 875 Hz) and the frequencies intermediate between the harmonic frequencies (291 Hz, 657 Hz, and 1,094 Hz). This figure illustrates that the amplitude of the vibration velocity of the facial surface at the harmonic frequencies is significantly larger (approximately 20 dB) than that at the other frequencies.

3.2 Experiment 2

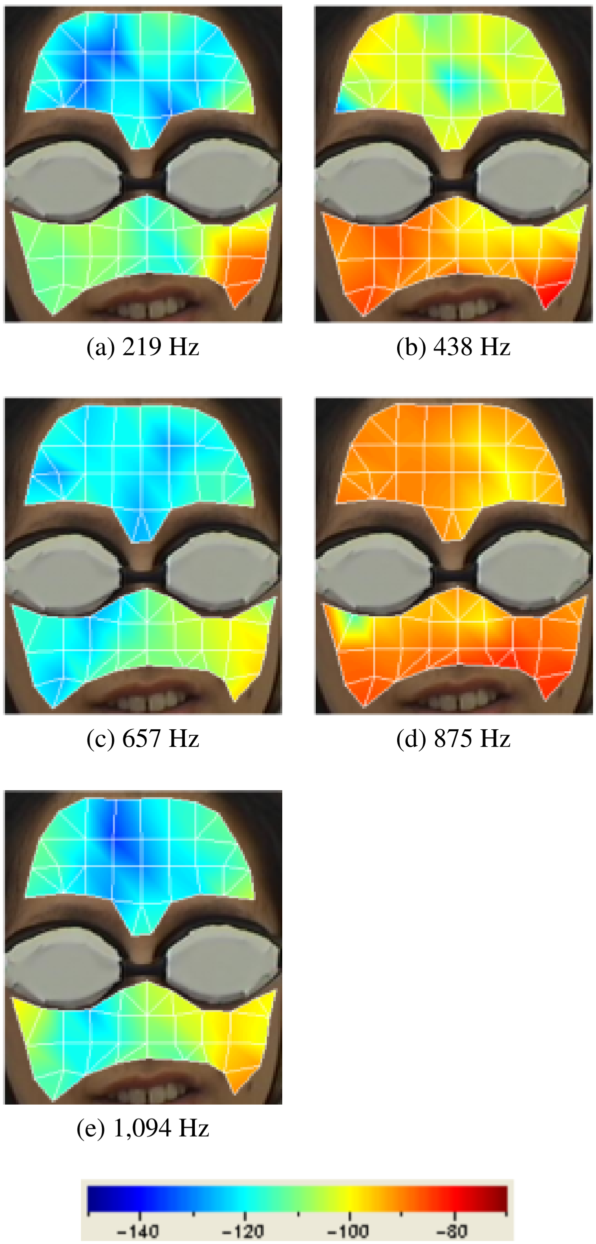
The vibration velocity pattern of the facial surface of Singer A for her higher comfortable pitch frequency is shown in Fig. 5. The vibration velocity of the forehead increased compared with that for the pitch frequency of A4 (Fig. 1). For the vowel /i/, the vibration velocity of the bilateral cheeks also increased, whereas that around the nose decreased.

Singer A reported that she vocalized so that the voice went through the top of her head when she sang in a high pitch frequency. Her introspection might correspond to the results for F5, that is, the vibration of the forehead increased probably because the singing voice radiated from there.

3.3 Experiment 3

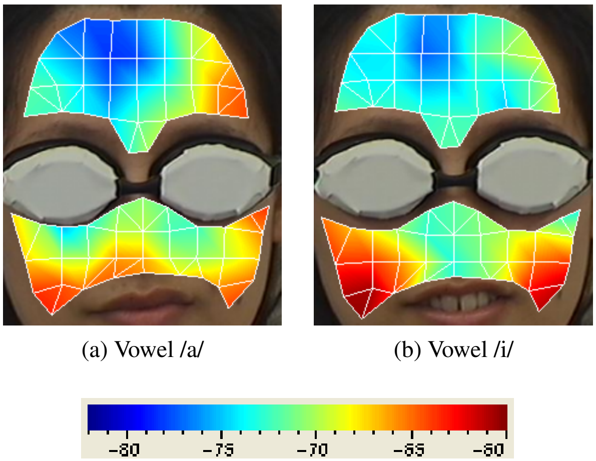
The vibration velocity patterns of the facial surface of Singer A for her falsetto singing and modal singing are shown in Fig. 6, indicating that the vibration velocity patterns of the cheeks notably decreased for the modal singing even though the vowel and the pitch frequency were the same. Note that the result for the falsetto singing (Fig. 6(a)) is the same as that shown in Fig. 1(b).

Singer A has an image that the modal singing voice propagates inward of the body. Her introspection is possibly linked to the differences between Figs. 6(a) and 6(b).



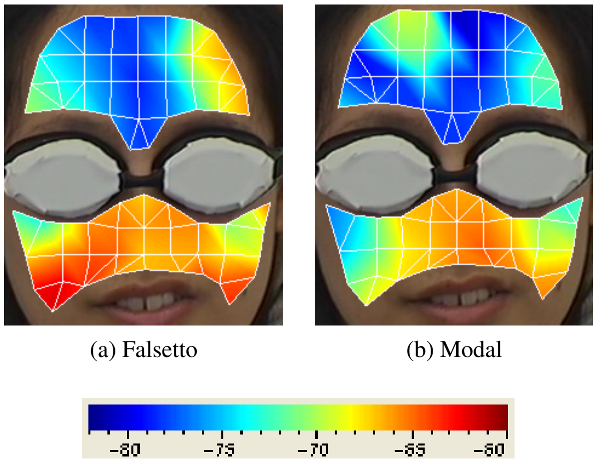
(a) 219 Hz (b) 438 Hz (c) 657 Hz (d) 875 Hz (e) 1,094 Hz

Figure 4. Vibration velocity of facial surface of Singer A during singing of Japanese vowel /a/ in falsetto at her most comfortable pitch (A4=440 Hz). The figures show the vibration velocity patterns at frequencies of (a) 219 Hz, (b) 438 Hz, (c) 657 Hz, (d) 875 Hz, and (e) 1,094 Hz. The unit is m/s [dB] and 0 dB is equal to 1 m/s.



(a) Vowel /a/ (b) Vowel /i/

Figure 5. Vibration velocity patterns of facial surface of Singer A during singing of Japanese vowels (a) /a/ and (b) /i/ in falsetto at her higher comfortable pitch frequency (F5=698.5 Hz). The unit is m/s [dB] and 0 dB is equal to 1 m/s.



(a) Falsetto (b) Modal

Figure 6. Vibration velocity patterns of facial surface of Singer A during singing of Japanese vowel /i/ in (a) falsetto and (b) modal voice at her most comfortable pitch frequency (A4=440 Hz). The unit is m/s [dB] and 0 dB is equal to 1 m/s.

4. CONCLUSIONS

In this study, we reported the results of a pilot study of measuring the vibration velocity patterns of the facial surface during singing. The obtained results show clear contrasts between the patterns for the vowels, pitch frequencies, and vocalization methods. A scanning LDV proved to be extremely useful for measuring the vibration velocity patterns during singing, even though we need to confirm the reproducibility of the measurement.

The proposed method enables us to evaluate singing voices. The vibration patterns may be helpful as a visual feedback of a singing exercise. The vibration patterns may be easier to relate to the somesthesis than the spectra of the speech sounds or trainer's comments.

Acknowledgments

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