Aerodynamic and Acoustic Correlates of Vocal Register and Vibrato in the Singing Voice

Haruhito Saida, Satoshi Imaizumi and Hajime Hirose

Introduction

In studies of the singing voice, "vocal register" is a well-known term used to describe different voice qualities possibly due to different laryngeal adjustments. There still seem to be a controversy over how many registers should be defined based on what definitions or physiological/aerodynamic/acoustic/perceptual properties of voicing.

Based on electromyographic studies, Hirano[1)] classified vocal register into three major categories: "Vocal fry", "Heavy register", and "Light register (Falsetto)". Furthermore, they classified "Heavy register" into three subcategories: the "Chest", "Mid" and "Head" registers. They also reported that the intinsic laryngeal musculature plays a significant role in regulating the vocal registers. However, the acoustic and aerodynamic properties of each register have not yet been clarified.

On the other hand, vibrato[2-18)] is also a well-known phenomenon whose regulatory mechanisms are not completely clarified yet. If laryngeal adjustments play a significant role in controlling both vocal register and vibrato, then vibrato may depend on vocal register.

This paper describes the aerodynamic and acoustic properties characterizing the "Chest" and "Mid" registers in a soprano singer, and the possible effects of laryngeal adjustments on register changes in the acoustic characteristics of vibrato.

Method

Aerodynamic Observation

The flow rate, the sound intensity level and the fundamental frequency were observed using SH01 (RION) for the speech and singing voices produced by non-professional speakers and professional soprano singers.

Each speaker or singer produced the vowel /a/ in singing mode or speech mode. There were no strict rules used to classify the two modes, which were subjectively defined by each subject.

In Experiment I (Crescendo), each subject produced /a/ while slowly increasing the sound intensity level and keeping the fundamental frequency constant (about 220Hz, 350Hz and 460Hz). In Experiment II (Scaling), each subject produced /a/ while increasing and decreasing the fundamental frequency by one octave from c^1 to c^2 keeping the sound intensity level.

Acoustic Analysis

The details of the analysis method used here is reported by Imaizumi et al (1992).

The singing voice was recorded simultaneously with the electroglottogram (EGG) from one soprano singer and analyzed. The voice and EGG signals were recorded while the singer produced the Japanese five vowels. For each vowel, the singer increased the fundamental frequency from c^1 to c^2 and then decreased it. The voice and EGG signals were digitized through a 12 bit A/D converter at a sampling rate of 40 kHz.

At first, using a peak picking method[19,20], the local maximum points of voice signal, s(sample number:j), which could correspond to vocal excitation epochs were detected successively. Here, we write $L(i)$ for the i-th pitch location, $p(i)=L(i)-L(i-1)$ for the i-th pitch period, $F_0(i)=1/p(i)$ for the i-th fundamental frequency; and $e(i)$ for the amplitude at $L(i)$; for $i=0, 1, ..., I$, where I was the total number of pitch periods extracted. $SPH(i)$ was defined as the peak-to-peak value of $s(j)$ for each i-th pitch period.

To estimate the degree of abduction or adduction of the glottis[5], $EGGOQ(i)$ and $EGGH(i)$ were estimated as shown in Figure 1. In this figure, "A" was defined as the duration between the local maximum and the local minimum peaks of the differentiated EGG in a pitch period, and "B" the duration between a local maximum peak and the next local maximum peak. $EGGOQ$ was defined as $B/(A+B)$. Since $EGGOQ$ tends to increase when the duration of the opened glottis in a pitch period increases, thus it is possible to consider that it represents the ratio of the duration of the opened glottis to the pitch period. The $EGGH$ was defined as the peak-to-peak amplitude of the EGG in a pitch period. The $EGGH$ was measured, because it is possible to consider that a greater amplitude in the EGG signal represents less electrical impedance through the larynx and a greater contact area between the vocal folds.

Results and Discussion

Aerodynamic Measurements

Figures 2 (a)-(c) show the results of the aerodynamic measurements for the vowel /a/ produced by a professional singer. She produced /a/ while slowly increasing the sound intensity level and keeping the fundamental frequency constant about 220Hz (a), 350Hz (b) and 465Hz (c). The left panels in Figures 2 (a)-(c) were produced in the speech mode, and those in the right panels in the singing mode. For the singing voice, the vowel at a F_0 of 220Hz was produced as "Chest" register, and vowels at 350Hz and 465Hz were in the "Mid" register.

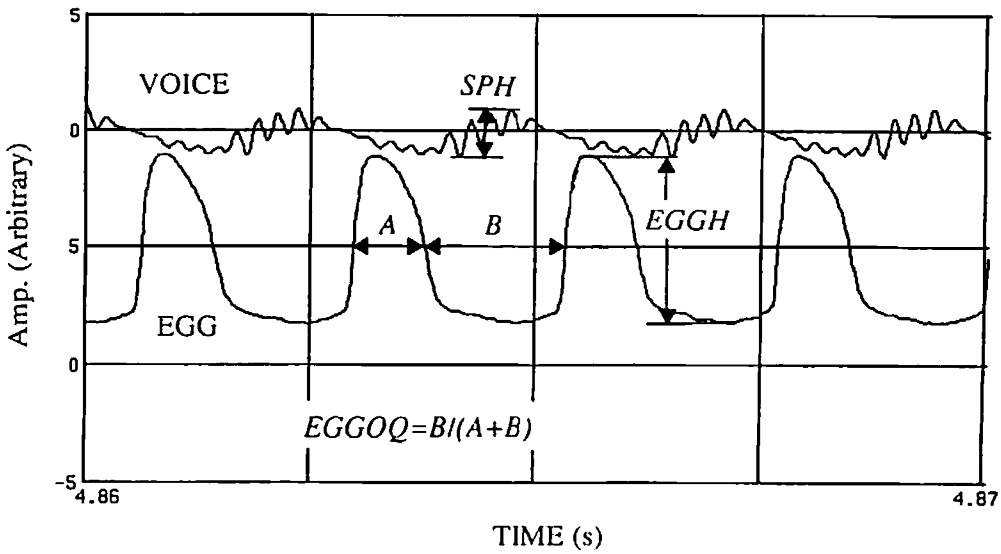


Figure 1. Definitions of *EGGOQ* and *EGGH*. "*A*" was defined as the duration between the local maximum and local minimum peaks of the differentiated EGG in a pitch period. and "*B*" the duration between a local maximum peak and the next local maximum peak. The *EGGOQ* was defined as $B/(A+B)$. The *EGGH* was defined as a peak-to-peak amplitude of the EGG in a pitch period.

For the vowels in the speech mode, the flow rate increased when the intensity increased, but became saturated at a rate of 220ml/s, 150ml/s and 100ml/s when the fundamental frequency was 220Hz, 350Hz and 465Hz respectively.

On the other hand, for the vowels in the singing mode at "Mid" register, the flow rate increased beyond 150ml/s to 500ml/s when the intensity increased. For the vowels in the singing mode at "Chest" register, however, the flow rate became saturated at a low rate of 150ml/s, which was lower than the rate for the speech mode.

Figure 3 shows the results of Experiment II (Scaling). In this figure, for the singing mode, the flow rate increased to 250ml/s when the fundamental frequency was higher than 350Hz. For the speech mode, the flow rate increased slightly when F_0 increased, but it became saturated at a low rate of 105ml/s.

The results shown in Figures 2 and 3 indicate that the register change from "Chest" to "Mid" occurred at a F_0 of 350Hz, and that at this point the flow rate increased significantly even though the intensity level did not change greatly. These results may indicate that laryngeal adjustments changed at this point, and that eventually the flow rate was increased in the singing mode but not in the speech mode.

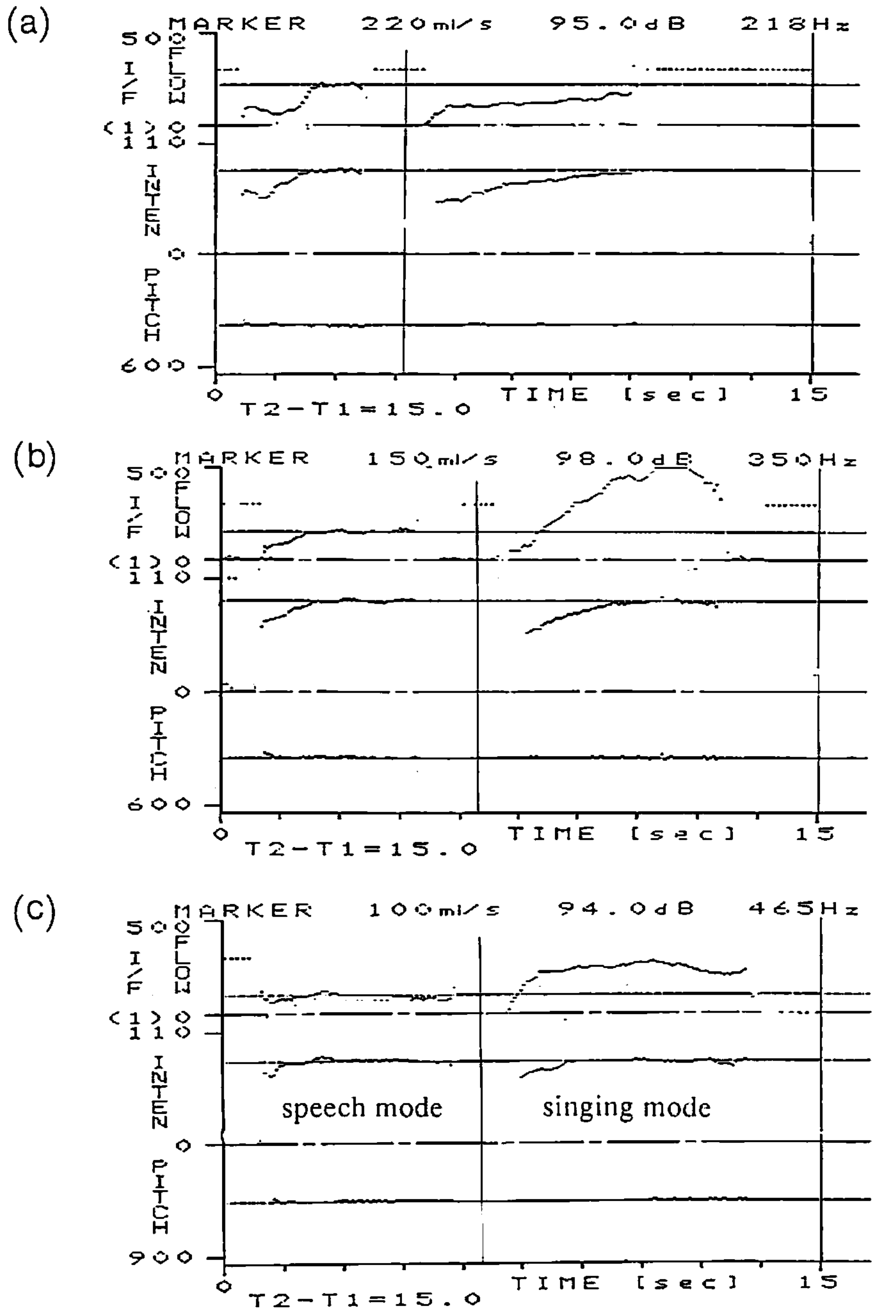


Figure 2. The results of aerodynamic measurements for a crescendo of the vowel /a/ produced while slowly increasing the sound intensity level and keeping the fundamental frequency constant about 220Hz (a), 350Hz (b) and 465Hz (c). Left panel:speech mode; Right panel: singing mode--"Chest" (a) vs. "Mid" (b) and (c).

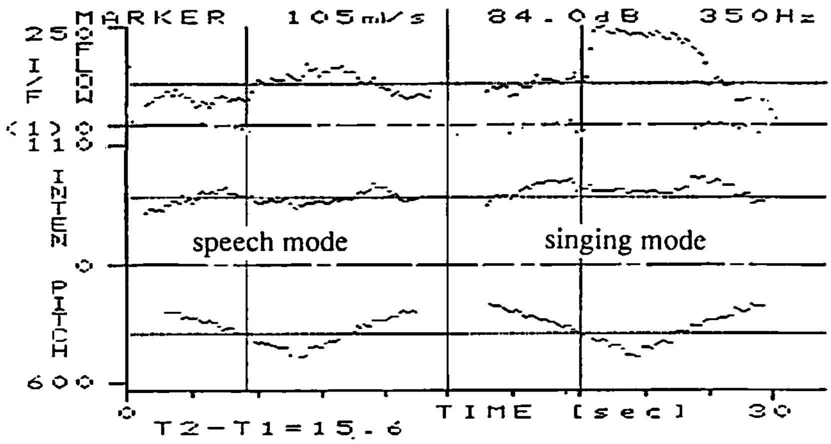


Figure 3. The results of aerodynamic measurements for scaling of the vowel /a/ produced while increasing the fundamental frequency (F_0) from c[1] to c[2]. The F_0 axis ("PITCH" in Figures 2 and 3) is displayed upside down. "INTEN" represents the sound pressure level (dBSPL), and "FLOW" the flow rate (ml/s) in Figures 2 and 3.

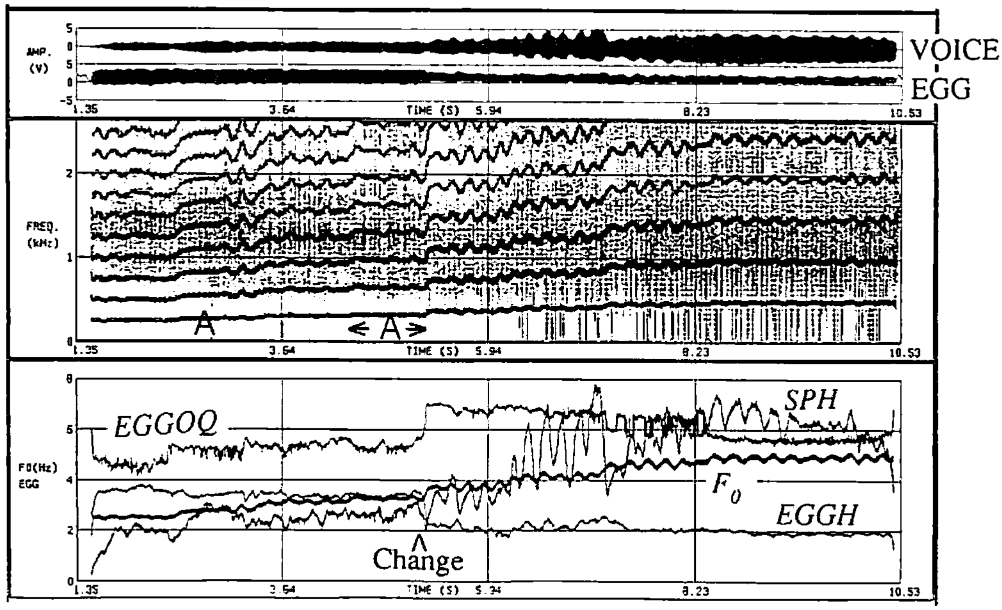
Acoustic Measurements

Figures 4 (a) and (b) show the results of the EGG analysis for the voice sample sung by a soprano singer. She sung the vowels /a/ and /i/ with ascending pitch from c[1] to c[2]. The point "Change" indicates the point where the singer changed vocal register from "Chest" to "Mid". Before the register change occurred, during the "Chest" register, *EGGOQ* was around 63%, and then it jumped to 85% to produce her "Mid" register voice. The *SPH* increased at this point, but on the other hand, the *EGGH* decreased from 350 to 200. These tendencies were common for the five vowels.

These results indicate that the open quotient of the glottis increased when the vocal register changed from "Chest" to "Mid" for all the five vowels.

At the changing point, the vibrato tended to be suppressed. This suppression of vibrato was sometimes observed when the fundamental frequency was increased (for instance, at Point A). The vibrato suppression was of long duration (more than 4 vibrato cycles) before the register change for the open and low vowels (/a/, /o/). On the other

(a)



(b)

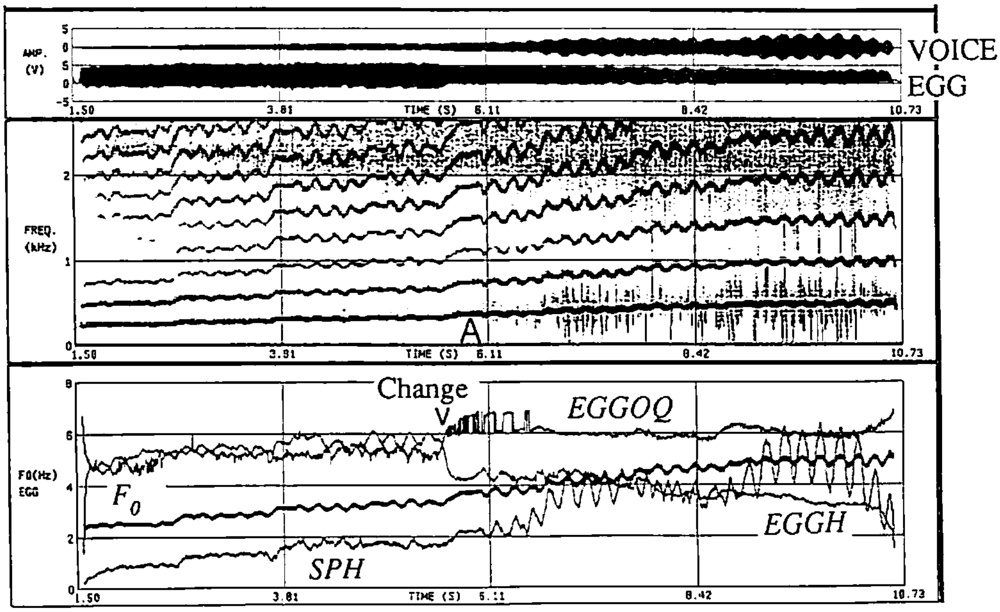


Figure 4. Voice signal, EGG signal, the sound spectrogram of the voice signal, and some results of the EGG analysis. (a) /a/, (b) /i/.

hand, the vibrato suppression was of a short duration (about 2 vibrato cycles) after the register change for the close and high vowels (/i/, /u/).

This result may suggest that the laryngeal adjustments for the register change from "Chest" to "Mid" may require suppressing of the vibrato for the open and low vowels. This tendency might be accounted for by possible interactions between the tongue and larynx positioning, and might indicate that laryngeal adjustments are important for changing the vocal register and to control the vibrato.

This paper reports only small number of examples. Obviously, we need more detailed analyses from a large number of singers. Further results on formant estimation and vibrato analyses for sung vowels will be reported in the future.

Conclusions

This paper presented the aerodynamic and acoustic properties characterizing the "Chest" and "Mid" registers for a soprano singer, and possible effects of laryngeal adjustments on register changes in the acoustic characteristics of vibrato. Aerodynamic results indicated that the register change from "Chest" to "Mid" occurred at a F_0 of 350Hz, and that at this point the flow rate increased significantly even though the intensity level did not change greatly. Acoustic results indicated that the open quotient of the glottis increased when the vocal register changed from "Chest" to "Mid." At the register changeing point, the vibrato tended to be suppressed. The vibrato suppression was of a long duration (more than 4 vibrato cycles) before the register change for the open and low vowels (/a/, /o/). These results suggest that laryngeal adjustments may play an important role in controlling both vocal register and vibrato.

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