ACOUSTIC ANALYSIS OF OVERTONE SINGING

M. Kob and C. Neuschaef-Rube
Dep. of Phoniatrics, Pedaudiology, and Communication Disorders
Aachen University (RWTH), D-52074 Aachen

Abstract: The articulatory configuration of an overtone singer is analysed with frequency analysis of the voice signal, sonographic visualisation of the tongue position, and analysis of the vocal tract impedance at the mouth. The biphonic character of the signal is observed in the spectrum plot. The sonographic analysis reveals a highly variable tongue position during production of a rising overtone. The high pitch of the produced biphonic sound is further analysed using the impedance technique. The extraordinary amplification of the melody pitch seems to be caused by the coincidence in frequency of two resonances. This findings support the theory that the overtone sound in sygyt style is a result of the filter effect of the vocal tract.

Keywords: Overtone singing, articulation, sonography, acoustic impedance

I INTRODUCTION

The production of overtone singing has been a fascinating field of research since many decades. Trần Quang Hai gives an overview of the broad variety of different overtone styles [1, 2, 3]. The study of S. Adachi and M. Yamada [4] presents measurements and simulation of Xõõmij singing in the sygyt style where a low pitch sound (drone) is accompanied by a high melody pitch. Adachi supports the “resonance” theory, which considers the source for the melody tone to be a separated harmonic of the lower tone. F. Klingholz describes aspects of the voice source in [5]. Recent work of K. Sakakibara focuses on synthesis and analysis of the kargyraa style that is characterised by a very low fundamental frequency, probably due to vibrations of the ventricular folds, and a melody pitch [6].

Measured data of overtone singers are relatively rare. This might be caused by the fact that insight into the function of biphonic singing is of minor interest to most artists. Furthermore, the determination of voice physiology is rather invasive or very costly (laryngoscopy, MRI). However, completely noninvasive sonographic and acoustic measurements are possible [7].

This contribution shall contribute to the understanding of the physical principle of the biphonic sound generation in the sygyt style. In a recent work [8, 9] a new method for analysis of the vocal tract configuration during overtone singing in the sygyt style has been developed. The method determines the acoustic impedance of the vocal tract at the mouth. These measurements are complemented by sonographic measurements of the tongue position and spectrum analyses of the voice signal.

II METHODOLOGY

2.1 Voice signal analysis

The voice of an overtone singer has been recorded during sustained phonation of a distinct overtone sound in sygyt style. In Fig. 1 the spectra of the voice signal at the mouth is shown for two cases. In the first (black line) the overtone singer did not yet amplify the melody pitch, in the second (gray/green line) the melody pitch was “switched” on. For a comparison to western phonation, in Fig. 2 the spectrum of the voice signal at the mouth is shown for the vowel /a/.

From a comparison between Fig. 1 and Fig. 2 it is obvious that the production of the overtone is different from the production of regular vowels. The amplification of the melody pitch over the amplitude of the fundamental is surprising since the vowel acoustics describes the vocal tract function mostly as a damping transmission line. Since the partials between the lowest few partials and the amplified partial are strongly damped, the latter is perceived as a separate sound.

1 Sound examples from overtone recordings recorded at various occasions can be found at the Internet address URL: www.akustik.rwth-aachen.de/~malte/overtone
2.2 Sonographic analysis

The tongue movement of an overtone singer singing a rising sequence in sygyt style has been analysed with a sonograph using a 90°–3.5/5 MHz ultrasound probe. Within the same plane, the central submental position of the probe was not varied during the recorded performance of the overtone sequence.

In Fig. 3 and Fig. 4 the tongue position is shown as a sonographic image in the coronal respective mediosagittal plane. The image has been delineated by a marking procedure (white lines) that represents the interface between the dorsal tongue tissue and the oral air within the selected plane.

With rising pitch both, the images in the mediosagittal and in the coronal plane, exhibit a continuous change of the tongue position. In the mediosagittal plane the increasing backwards location of the dorsal tongue tissue can be observed, which forms a constriction in the vocal tract. In the coronal plane the forming of a channel with increasing depth can be observed.

2.3 Impedance analysis

The impedance analysis uses a method that determines the impedance spectrum of the vocal tract resonances. A sweep signal is generated, amplified, and emitted at the end of a horn. The horn is placed in such a way that the sound is emitted into the vocal tract. At the horn exit two sensors record the sound pressure $p$ and the sound velocity $v$ simultane-
ouslly. After a reference procedure and windowing the spectrum of the acoustic impedance $Z$ is calculated from the Fourier spectra of both signals (Equation 1).

$$Z = \frac{\text{FFT}(p)}{\text{FFT}(v)}$$

(1)

The prototype of the measurement set-up is shown in Fig. 5. The signal flow is described in detail in [9].

Due to the sensor and loudspeaker specifications used in this set-up a frequency range from 500 Hz to 5 kHz could be evaluated.

In Fig. 6 the impedance spectrum of the voice signal at the mouth divided by the free-field impedance $Z_0$ is shown for an overtone sequence similar to that described in section 2.2. The curves are shifted (from bottom to top) to visualise the course of time during the phonation of the rising overtone. With rising sequence the resonance structure of the vocal tract exhibits a strong resonance between 500 Hz and 2 kHz. In some cases, at higher frequencies of the melody pitch, a double resonance can be observed. Resonances apart from the one that corresponds to the melody pitch are not present.

In Figure 7 another impedance analysis is shown: the singer was asked to articulate the sound /a/ and then successively change the articulation towards an overtone sound. The sequence of shifted curves demonstrates the “morphing” from vowel /a:/ (bottom) to the configuration of an overtone (top).

III DISCUSSION

The sonographic analysis of the vocal tract configuration change with rising melody pitch indicates a change of the resonator structure.

The impedance plot in Figure 6 illustrates that, apart from the overtone resonances, only relatively weak resonances are excited between 3 kHz and 4 kHz. At higher resonances in the upper part of the plot a double resonance can be observed. This indicates that the overtone singer does not form a single resonance at the frequency of the melody tone but rather two closely neighboured resonances. This finding seems to be supported by the result from the morphing experiment shown in Fig. 7.

It is interesting to note that the second formant around 1300 Hz does not move significantly during the course of the sequence whereas the 3rd formant moves from 2500 Hz downwards until it merges with the second one. The first formant of /a:/ cannot be resolved either because the lower frequency limit of the measurement set-up does not allow the visualisation or because first and second formant have the same frequency. All other frequencies are increasingly damped.
towards the overtone configuration. However, a weak resonance can be observed at 4 kHz.

Even if two formants can be observed in the impedance spectrum, it is not clear how they are generated. Due to damping mechanisms in the vocal tract the longitudinal vocal tract resonances are not capable of producing very high quality formants.

One approach is to look for a different mechanism for the focalisation effect. The Helmholtz resonator is a well known resonator type that works as a main resonator in numerous musical instruments and — in the human voice organ — during whistling [10]. It could be possible that a combined longitudinal resonator and Helmholtz resonator could achieve a high quality formant when the resonance frequencies of both resonators coincide.

A numerical approach to verify this hypothesis is described in [8]. The calculation was based upon the equivalent area data published in [4]. A longitudinal resonator was assumed between glottis and constriction, and a Helmholtz resonator was supposed for the mouth cavity between constriction and mouth opening. The calculations confirm that the resonance frequencies of both resonators are of the same order of magnitude and that they are quite close for some overtones.

IV CONCLUSION

Within this contribution we could demonstrate that the simultaneous application of ultrasonography of the tongue, spectrum analysis of the overtone sound and impedance analysis of the vocal tract resonances during overtone singing support the filter theory. It could further be shown that in the case of sygyt style two resonances coincide at the frequency of the melody pitch.

In future investigations, the same procedure could be applied to the investigation of other singing styles, of both western and eastern cultures. Another current application of the impedance technique is the analysis of articulation disorders. With the help of this technique a mapping of acoustic resonances and dysfunction of the articulatory organs should be established.

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REFERENCES


