ICIC Express Letters
Part B: Applications
Volume **9**, Number **12**, December **2018**

ICIC International ©2018 ISSN 2185-2766
pp. 1257–1263

EXPERIMENTAL STUDY OF PHARYNGEAL TONSIL: A RESONANCE MODEL

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Received May 2018; accepted August 2018

Abstract. *The pharyngeal tonsil of lymphoid tissue becomes hypertrophied as acquired immunity improves during childhood. Generally, pharyngeal tonsil hypertrophy reaches its peak between the ages of 4 to 6, and then the tissue atrophies. However, some cases hypertrophy continues even though the atrophy term has passed have been observed. In these cases, the hypertrophied tissue may lead to sleep and breathing disorders. The many currently available modalities for the detection of pharyngeal hypertrophy are invasive. Therefore, we developed a method for non-invasively detecting pharyngeal tonsil hypertrophy using phonetic sound. In this study, as a fundamental experiment, we verify that the acoustic change due to obstruction of PVC pipes can be detected from the transfer function. There were differences in the frequency response characteristics and impulse responses between PVC pipes with different obstruction rates which indicated that acoustic change due to obstruction can be detected from the transfer function.*

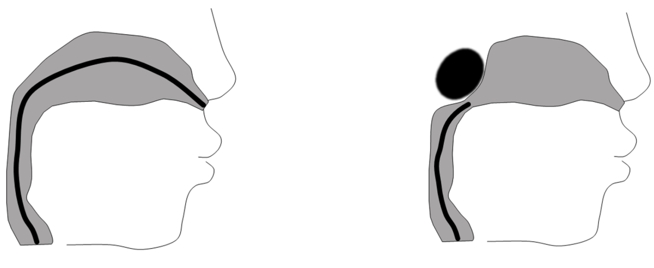
Keywords: Pharyngeal tonsil, Frequency response characteristics, Impulse response, Transfer function

1. **Introduction.** The pharyngeal tonsil of lymphoid tissue sometimes becomes hypertrophied [1]. Generally, pharyngeal tonsil hypertrophy peaks between the ages of 4 to 6, and then, the pharyngeal tonsil atrophies until it reaches size of adult pharyngeal tonsil [2]. However, some cases wherein hypertrophy continues even though the atrophy term has passed have been observed. The hypertrophied pharyngeal tonsil causes stenosis between the nasal cavity and epipharynx. The stenosis inhibits the ability to breathe from the nose, resulting in mouth breathing only. There have also been reports of it leading to sleep apnea syndrome (SAS) [3-5]. Furthermore, long-term mouth breathing during a period of mixed dentition can cause characteristic adenoid facies and may also affect the development of dentition and the facial skeleton. Therefore, early detection of pharyngeal tonsil hypertrophy is important to minimize these effects. At present, invasive modalities such as cone beam computed tomography (CBCT) and roentgenographic cephalogram are primarily used for the detection of pharyngeal tonsil hypertrophy. However, these modalities have risks of radiation exposure [6-8]. Slight radioactivity has a significant influence on children. And parents tend to avoid even a slight radioactivity. Therefore, non-invasive detection is very important, and if this is realized it will be possible to save the children from various risks.

DOI: 10.24507/icicelb.09.12.1257

In previous studies, we developed a non-invasive detection system for pharyngeal tonsil hypertrophy using phonetic sound [9]. In this study, we verify the basic principle used in this system. Specifically, PVC pipes with different obstruction rates were approximated to vocal tracts, and the influence of obstruction was observed from their transfer functions. Finally, we were confirmed that the acoustic change due to obstruction can be detected from the transfer function, and we considered detecting pharyngeal tonsil hypertrophy by frequency analysis of phonetic sound.

2. **Vibrations of Pipes.** Phonetic sound can be expressed by sound source information of the vocal cords and transfer characteristics of articulatory organs. It is radiated from the lips and nasal cavities via oral and nasal articulations. Then formant and anti-formant can be obtained because resonance and antiresonance occur. Pharyngeal tonsil hypertrophy causes stenosis between the nasal cavity and nasopharynx such that an acoustic change in the nasal cavity causes an anti-formant accompanied by closing or opening of the nasal cavity [10]. Generally, for non-nasalized vowels, acoustic characteristics depend on the formant, which is resonance frequency. For nasalized vowels, acoustic characteristics are dependent on the anti-formant, which is anti-resonance frequency. The anti-formant causes a negative peak to appear on the valley of the first and second formants. Therefore, a spectrum shape is different between nasalized and non-nasalized vowels. From the above, we considered that the measured wavelengths of fundamental vibration differ depending on presence or absence of pharyngeal tonsil hypertrophy (Figure 1). However, it is not clear that the frequency response characteristics differ because of obstruction due to pharyngeal tonsil hypertrophy. Therefore, we approximated the vocal tract to a pipe and verified its frequency response characteristics when obstruction rates were changed. Then it is possible to approximate a pipe to a vocal tract without considering the influence of the material [11,12]. As shown in Figure 2, one end opened pipe has a displacement antinode at the open end and a displacement node at the closed end. In its fundamental vibration, the length of the pipe is approximated to a quarter of a wavelength. This is because the reciprocating motion of the air molecules at the open end tends to have a slight streaming effect, and it is therefore necessary to apply an "open end correction". The acoustic length then becomes $l + a$, where l is the physical length and a is approximately $0.6r$, r being the radius. From this, it follows that the lowest resonant frequency of a pipe in which one



(a) Without adenoid (b) With adenoid

Figure 1. Wavelength of fundamental vibration

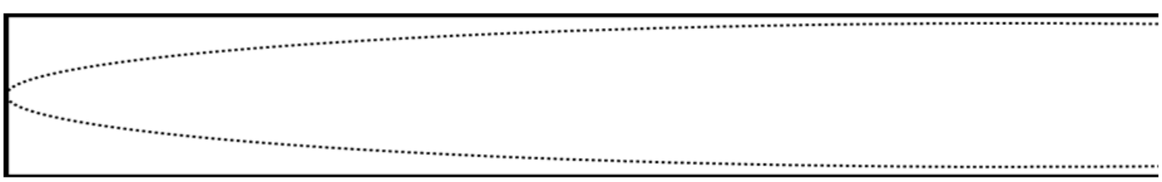


Figure 2. A pipe, open at one end

end opened is

$$f = \frac{c}{4(l + a)} \tag{1}$$

where the f [Hz] is frequency and the c [m/s] is speed of sound. The frequency of the nth harmonic is then

$$f_n = \frac{nc}{4(l + a)} \tag{2}$$

on the pipe in which both ends are opened, as shown in Figure 3, there is a displacement antinode at each open end and length l approximates to a half wavelength. Additionally, there is a correction for both ends so that the acoustic length becomes $l + 2a$. Resonance frequencies are then found from

$$f_n = \frac{nc}{2(l + 2a)} \tag{3}$$

n being 1, 2, 3, etc. [13].

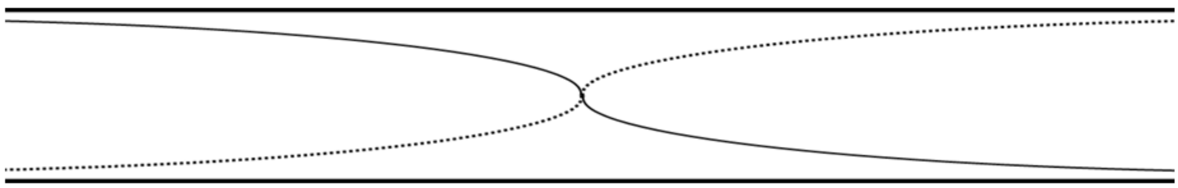


Figure 3. A pipe, open at both ends

3. **Basic Experiment Using a Pipe.** An experiment was conducted to verify that acoustic changes due to obstruction could be detected from the transfer function. First, PVC pipes were prepared with no obstruction, 85% obstruction, and 100% obstruction. Second, a sound was generated from one end of each PVC pipe and recorded at the other end. Using these recorded sounds, we observed the frequency response characteristics, impulse response, and wavelength by applying Chapter 2's principles. In the present study, we did not use a bifurcated pipe, so it was difficult to accurately approximate the PVC pipe to the vocal tract. We used a simple pipe and obstruction as the first stage of verification. The recording was done in an anechoic room to remove ambient noise and echo. Figure 4 shows the experimental system. The PVC pipe with a total length of 15 cm was set about 1 cm from a loudspeaker, and a microphone (Ono Sokki/MI-1432) was set near the boundary between the inside and the outside of the PVC pipe. The audio analyzer (Audio Precision/APx555) generated a sweep sound via the loudspeaker. The sweep sound was recorded through the PVC pipe. Recording was performed with a sampling frequency of 32 kHz and a quantization bit number of 24 bit. The sweep

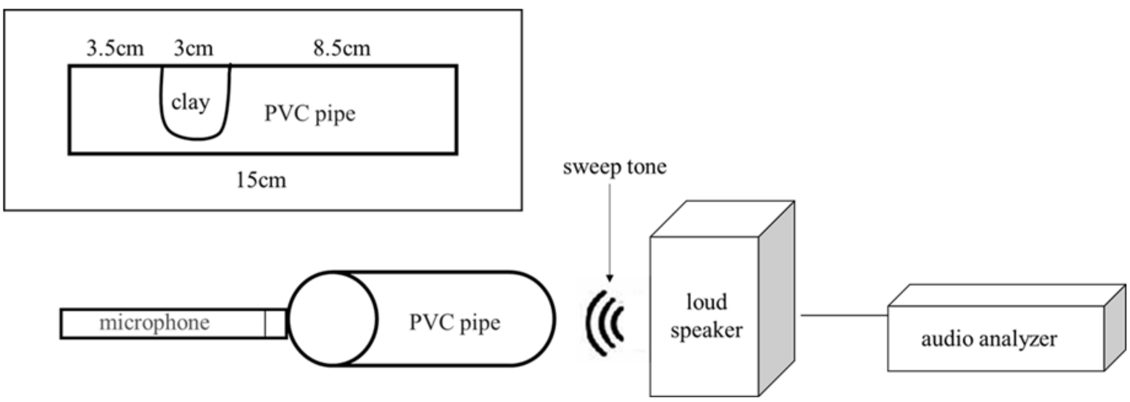
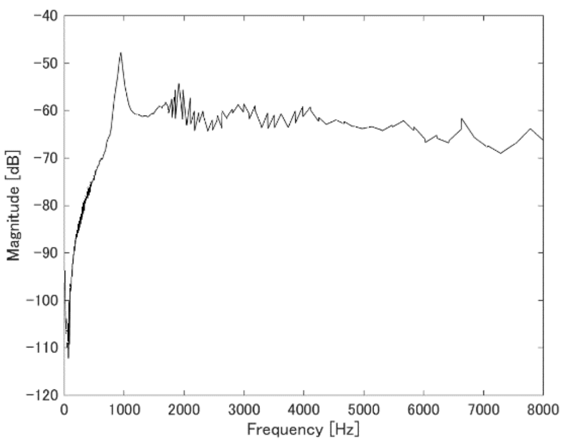


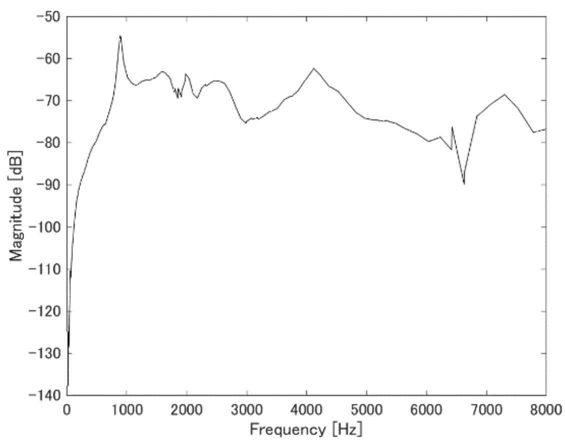
Figure 4. Experimental system

sound was used because the signal to noise ratio is low. The obstruction was made by drilling a 2.5 cm diameter hole on the side of the PVC pipe and filled it with oil clay. The obstruction rate was calculated from the ratio of the cross-sectional area of the oil clay to the cross-sectional area of the PVC pipe.

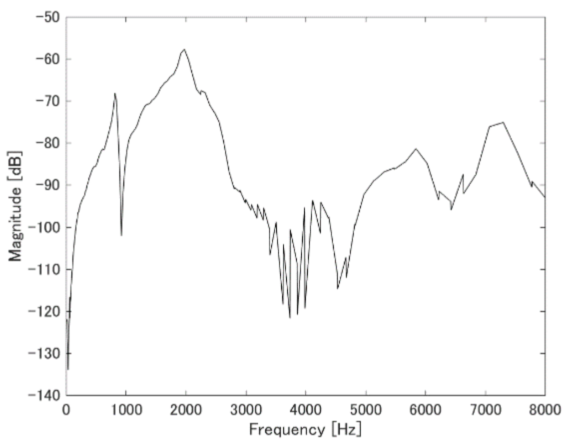
4. **Result and Discussion.** Figure 5 shows the result of the frequency response characteristics, and Figure 6 shows the result of the impulse response obtained from the experiment. Table 1 shows the resonance and anti-resonance frequencies of each PVC pipe and Table 2 shows the wavelength obtained from each frequency. The wavelength was calculated using Equation (1) for 100% obstruction and Equation (3) ($n = 1$) for no obstruction and 85% obstruction. From Table 2, it is confirmed that the wavelength of the first resonance frequency of no obstruction and 85% obstruction is close to 15 cm, which is the total length of the PVC pipe. In other words, it is considered that these are fundamental frequencies of the pipe. Moreover, it is confirmed that the wavelength of the second resonance frequency is close to 8.5 cm, which is the length from one end of the PVC pipe on the sound source side to the obstruction. However, in no obstruction, the same wavelength as that under the condition with 85% obstruction was detected. It is considered that this frequency component has higher harmonics because it is twice the first resonance frequency. Furthermore, it is confirmed that the wavelength of the third



(a) No obstruction

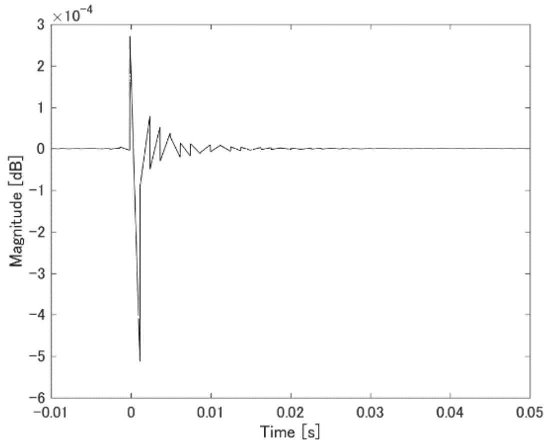


(b) 85% obstruction

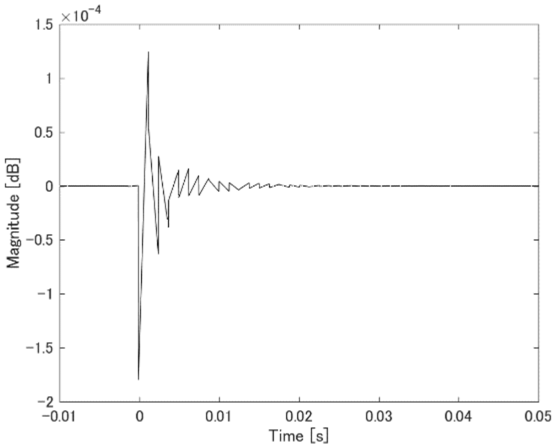


(c) 100% obstruction

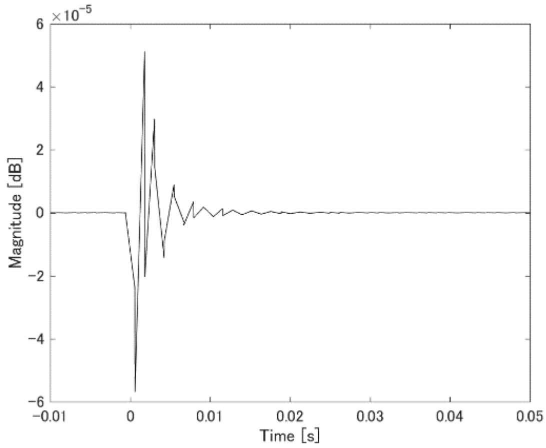
Figure 5. Frequency response characteristics in each pipe with different obstruction rates



(a) No obstruction



(b) 85% obstruction



(c) 100% obstruction

Figure 6. Impulse response in each pipe with different obstruction rates

Table 1. Resonance and anti-resonance frequencies in each pipe with different obstruction rates

Obstruction rate	Frequency [Hz]				
	Resonance			Anti-resonance	
	1st	2nd	3rd	1st	2nd
No obstruction	950	1915	–	–	–
85% obstruction	920	1985	4120	–	–
100% obstruction	815	1980	–	925	3745

Table 2. Wavelength in each pipe with different obstruction rates

Obstruction rate	Wavelength [cm]				
	Resonance			Anti-resonance	
	1st	2nd	3rd	1st	2nd
No obstruction	16.0	7.0	–	–	–
85% obstruction	16.6	6.7	2.3	–	–
100% obstruction	19.0	6.7	–	8.3	1.3

resonance frequency of 85% obstruction is close to 3.5 cm, which is the length from one end of the viper pipe on the microphone side to the obstruction. On the other hand, in 100% obstruction, propagation of sound in a PVC pipe is difficult because it is completely obstructed. Therefore, the resonance information becomes a solid propagation sound and appears as an anti-resonance frequency. Actually, the wavelength of the first anti-resonant frequency is 8.3 cm. This value is close to 8.5 cm, which is the length from one end of the PVC pipe on the sound source side to the obstruction. Additionally, the wavelength of the second anti-resonant frequency is 1.3 cm. This value is close to 3.5 cm, which is the length from one end of the PVC pipe on the microphone side to the obstruction. From Figure 6, it is confirmed that convergence becomes faster as the obstruction ratio becomes higher in the impulse response. Because the resonance frequency is different due to obstruction. Furthermore, it is considered that the convergence becomes faster in 100% obstruction than in 85% obstruction because it is airborne in 85% obstruction and solid-borne in 100% obstruction. As a result, it was confirmed that the acoustic change due to the obstruction can be detected from the transfer function.

5. **Conclusion and Future Work.** In the present study, the basic experiment to detect acoustic changes in the pipe due to obstruction was conducted, and results were analyzed in terms of the frequency response characteristics and impulse response. Outcomes and findings of this study are shown below.

- Frequency analysis was confirmed for PVC pipes with three different obstruction rates as a pharyngeal tonsil hypertrophy.
- The wavelengths of the resonance and anti-resonance frequencies were found to be in agreement with the total length of the PVC pipe and the distance from one end to the obstruction to some extent.
- From the results of the impulse response of each PVC pipe, it was confirmed that the convergence speed is gradually decreasing with the reduction of the obstruction rate.

From these findings, it was confirmed that acoustic change due to obstruction could be detected from the transfer function. By applying these results, we can expect to detect pharyngeal tonsil hypertrophy, focusing on resonance and anti-resonance frequency by comparing wavelengths in frequency analysis. In the future, we plan to verify the effect of the characteristics of microphone and loudspeaker on frequency response characteristics obtained in this study. Further, we plan to compare with actual patients.

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