An Acoustic Analysis of Formants between Frequently Smoking Subjects and Non-smoking Subjects

G R F Suwandi¹², M A Mustajab², M Haekal³⁴, S N Khotimah¹³, F Haryanto¹³

¹ Nuclear Physics and Biophysics Research Division, Department of Physics, Faculty of Mathematics and Natural Sciences, Institut Teknologi Bandung, Bandung, Indonesia
² Material Electronics Physics Research Division, Department of Physics, Faculty of Mathematics and Natural Sciences, Institut Teknologi Bandung, Bandung, Indonesia
³ Biophysics Laboratory, Department of Physics, Faculty of Mathematics and Natural Sciences, Institut Teknologi Bandung, Bandung, Indonesia
⁴ Department of Physics, Faculty of Science and Data Analytics, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

E-mail: galih@fi.itb.ac.id

Abstract. Smoking is one of the factors that affect the respiratory health of human. A system of respiratory health indicators is needed to prevent the negative effects of smoking at an early stage. The relation between respiratory and vocal coordination can be analysed by measuring the formant frequencies, which indicate the spectral shaping of the human vocal tract. In this study, two groups of subjects with and without smoking habits were studied in terms of their formant frequencies. The results showed that there were statistical significance differences in the four formant frequencies between the two groups. The differences might be due to the changes in the elasticity of the oral cavity, which were affected by the smoke produced from cigarettes. Therefore, we conclude that a smoking person can be identified by the characteristics of their formant frequencies.

1. Introduction
In 2018, Southeast Asia Tobacco Control Alliance (SEATCA) found that 66% of adult male in Indonesia were smoking frequently. This became the highest percentage among other country in ASEAN [1]. The condition is made worse by the increase of prevalence adult with smoking habit every year [2]. Tobacco smoking contributes to 14.7 % death annually, causing cardiovascular and chronic respiratory diseases [3]. Efforts to prevent people from making smoking a habit and help current smoking person to quit is urgently needed. Generally, people who smokes realize their respiratory health condition is getting worse far too late. Therefore, early detection of respiratory health is required to prevent smoking and help frequent smoking person to quit.

Respiratory and vocal coordination is related as the initiation of sound and voice begins with inhalation and exhalation. Vocal changes often described and studied in relation to smoking, because the accumulation of toxic substances across respiratory system can lead to a change in conformation of the larynx and vocal cord [4]. The change in larynx and vocal cord can be identified from the changes
in the fundamental frequency, pitch, amplitude, and sound quality [5,6]. These changes can be measured from the physical quantities of the voice such as volume, fundamental and formant frequency. Formant frequency is a spectral shaping that results from an acoustic resonance of the human vocal tract [7]. Formant frequency may be used as one of the indicators of vocal changes due to smoking [8].

This study aims to characterize and verify the difference between formant frequency of people with frequent smoking habits and non-smoking people. The formant frequency is studied from the first four formant frequencies (F1, F2, F3, and F4) from the vowel sounds.

2. Method
The subjects of this study were male within age of 20-35 years old which consisted of two groups: 40 males who smoke daily (DS) and has been smoking for more than 5 years. The second group was 40 males of without smoking habits (NS). Each subject recorded the sound of five type of vowels in 2-3 seconds using a voice recorder from smartphones or notebook PC. These five types of vowels are listed in Table 1.

| Vowels | Pronunciation |
|--------|---------------|
| A      | like “a” in “father” |
| E      | like “e” in “step” |
| I      | like “i” in “will” |
| O      | like “a” in “fall” |
| U      | like “oo” in “moon” |

Voice recorded files was analyzed using Praat 6.0.25 software to extract four formant frequencies. The raw data files were spectrogram of vowels records, which then converted using Fast Fourier Transform (FFT) into spectra of frequency to get its formant data. The four formant frequencies were compared for daily smokers subject and non-smokers subject to characterize the differences. The block diagram of the experimental method is shown in the Figure 1.

3. Results and Discussion
The formant frequency (F1, F2, F3 and F4) were obtained from smoking and non-smoking subjects. The t-test (two-tailed) was used to compare the formant frequency that was obtained from smoking and non-smoking subjects. Table 2 shows the means and standard deviations of the first formant (F1). In general, the formant frequency parameter was clearly affected by smoking.

| Table 2. Comparison of F1 values from smoking and non-smoking subjects. |
|------------------------|----------------------|---------------------|-------------------------|
| F1/vowels             | Non-smoking          | Daily smoking       | Significance level      |
|                       | Mean | SD   | Mean | SD   |                     |
| F1/a (Hz)             | 696.75 | 110.57 | 681.77 | 110.68 | 0.001               |
| F1/e (Hz)             | 490.24 | 66.85 | 510.35 | 143.18 | 0.001               |
| F1/i (Hz)             | 340.08 | 70.19 | 316.28 | 36.21 | 0.02-0.01           |
| F1/o (Hz)             | 506.00 | 62.98 | 543.38 | 77.39 | 0.01-0.002          |
| F1/u (Hz)             | 394.46 | 68.19 | 428.55 | 83.26 | 0.01-0.002          |

The frequencies of F1 in “e”, “o”, and “u” vowels for non-smokers were smaller than those of smokers'. The frequencies of F1 in “a” and “i”, however, were found to be smaller in smokers’ subjects. The largest difference in mean F1 value between subject groups was obtained in the vowel “o” with statistical significance level ranged from 0.01-0.002. F1 value is related with the shape of the vocal tract when the subject made vowels sound [9]. The “o” letter requires the vocal tract to be more open and enlarged compared with the other vocal letters.

| Table 3. Comparison of F2 values from smoking and non-smoking subjects. |
|------------------------|----------------------|---------------------|-------------------------|
| F2/vowels             | Non-smoking          | Daily smoking       | Significance level      |
|                       | Mean | SD   | Mean | SD   |                     |
| F2/a (Hz)             | 1286.30 | 86.46 | 1340.60 | 148.81 | 0.001               |
| F2/e (Hz)             | 1882.79 | 240.88 | 1928.25 | 143.18 | 0.001               |
| F2/i (Hz)             | 2312.89 | 193.21 | 2112.51 | 207.64 | 0.001               |
| F2/o (Hz)             | 988.49 | 91.77 | 1046.43 | 190.17 | 0.001               |
| F2/u (Hz)             | 905.16 | 174.25 | 1215.29 | 466.01 | 0.001               |

Table 3 shows the comparison of F2 values between vocal sound frequencies produced by smoking and non-smoking subjects. The F2 values of the five vocal letters in non-smoking subjects were lower than those of smoking subjects, except in “i”. The F2 is related with the production of sound in pharynx cavity [10]. The shape of the pharynx cavity is more open when producing the “i” sound than other vocal letters.

| Table 4. Comparison of F3 values from smoking and non-smoking subjects. |
|------------------------|----------------------|---------------------|-------------------------|
| F3/vowels             | Non-smoking          | Daily smoking       | Significance level      |
|                       | Mean | SD   | Mean | SD   |                     |
| F3/a (Hz)             | 2740.91 | 302.82 | 2576.03 | 340.36 | 0.001               |
| F3/e (Hz)             | 2535.89 | 300.17 | 2637.84 | 362.44 | 0.001               |
| F3/i (Hz)             | 2894.07 | 276.68 | 2937.92 | 345.72 | 0.001               |
| F3/o (Hz)             | 2721.54 | 316.43 | 2662.75 | 275.29 | 0.001               |
| F3/u (Hz)             | 2728.39 | 257.83 | 2819.33 | 305.96 | 0.001               |

Table 4 shows that non-smoking subjects have higher F3 mean value than smoking subjects in “a” and “o” sounds and vice versa on “e”, “i”, and “u” sounds. The F3 value is related with the front cavity and lip spreading when producing the vocal sound [11]. The largest difference in F3 value between smoking and non-smoking subjects was obtained in producing “a” sound with statistical significance level of 0.001.
The comparison of F4 mean values can be observed in Table 4. The mean values of F4 for all vocal sounds in non-smoking subjects were higher than those of smoking subjects. The largest difference was observed in producing “u” sounds with a statistical significance level of 0.001. The F4 values is affected by lip-protrusion [11].

The smoke produced when smoking could cause plaque in the oral cavity. This is indicated by the darker color of lips and oral cavity in smoking subjects than those of non-smoking subjects. This would affect the elasticity of the oral cavity, which responsible for the process of sound production and causing a change in formant frequencies produced by the subjects [12].

4. Conclusions
This study discusses on the differences of formant frequencies (F1,F2,F3 and F4) from non-smoking and frequent-smoking subjects when pronouncing the vowels “a”, “e”, “i”, “o”, and “u”. Our results indicate there are differences of formant frequency between non-smokers and smokers with significance level within 0.001-0.01. The difference most likely affected by the change in the elasticity of the oral cavity in the subjects with smoking habits, which was caused by the smoke produced by the cigarettes.

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References
[1] Lian, T.Y , Dorotheo, U. The Tobacco Control Atlas ASEAN Region Fourth Edition. Southeast Asia Tobacco Control Alliance. 2018. pp. 19 – 22
[2] Badan Penelitian dan Pengembangan Kesehatan. Hasil Utama Riset Kesehatan Dasar 2018. Kementrian Kesehatan Republik Indonesia. 2018. pp. 124
[3] World Health Organization – Regional Office for South-east Asia. Tobacco Factsheet Indonesia 2018. World Health Organization. 2018. pp. 1-2
[4] Mohamed E. E., El-magrabhy, R. A. Voice changes in patients with chronic obstructive pulmonary disease. Egyptian Journal of Chest Diseases and Tuberculosis. 2018. Vol. 63. Issue 3. pp. 562-565
[5] Gonzales, J. , Capri A. Early effects of smoking on the voice: A multidimensional study. Med Sci Monit. 2004. Vol. 10. Issue 12. pp. 649-656
[6] Verdonck-de Leeuw, I. M., Mahieu, H.F. Vocal aging and the impact on daily life: a longitudinal study. Journal of Voice. 2004. Volume 18. Issue 2. Pp. 193 – 195
[7] Dos Santos, K. W., Echeveste, S. S., Marques Vidor, D. C. G., Association between Lung Function and Vocal Affections Arising from Tobacco Consumption. International Archives of Otorhinolaryngology. 2014. Volume 18. Issue 1. pp. 11 – 15
[8] Zealouk, O., Satori, H., Hamidi, M., Laaidi, N., Satori, K. Vocal parameters analysis of smoker using Amazigh language. International Journal of Speech Technology. 2018. Volume 21. Issue 1. pp. 85–91

[9] Story, B. H., Bunton, K., Relation of vocal tract shape, formant transitions, and stop consonant identification. J Speech Lang Hear Res. 2010 Dec; 53(6): 1514–1528.

[10] Korkmaz, Y., Boyaci, A. Examining Vowels' Formant Frequency Shifts Caused by Preceding Consonants for Turkish Language. Journal of Engineering and Technology. 2018. Volume 2. Issue 2. pp. 38–47.

[11] Isei-Jaakkola, T., Naka, T., Hiroshi, K. Comparison of the formant frequencies F3 and F4 on a three-dimensional vowel chart. 2010. Volume 127. Issue 3. p. 2019.

[12] Gilbert, H.R., and Weismer, G.G. The effects of smoking on the speaking fundamental frequency of adult women. J. Psycholing. Res 1974. Volume 3. pp. 225–231.