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DIAGNOSIS OF LUNG RELATED DISEASES BY ASSESSING VIBRATION PATTERNS OF STRUCTURES AT THE THORACIC CAVITY

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Abstract

This paper aims to investigate the vibration measurements of the human chest wall of non-smokers, cigarette smokers, and electrical cigarette smokers in conducting human health diagnosis. Measurements were taken from 6 non-smokers, 5 cigarette smokers, and 5 electrical cigarette smokers using an accelerometer, a Data Acquisition (DAQ) hardware, a LabVIEW software for collecting data and a Matlab software for spectral analysis. The accelerometer was secured directly below the left nipple of chest wall. Time-domain signals were then converted into frequency-domain through spectral analyses, which include Fast Fourier Transform (FFT) analysis and Power Spectral Density (PSD) analysis. Based on the FFT spectrum results, 90% of smokers show A_{max} values of less than 1 x 10^{-5} G^2, whereas 50% of non-smokers show A_{max} values of more than 1 x 10^{-5} G^2. The PSD graphs show 100% of non-smokers show no noticeable frequency contents above 14 Hz, whereas 80% of smokers show noticeable frequency contents after this point. There is definitely a correlation between smokers and other respiratory diseases in terms of chest wall intensity and frequency of vibration using spectral analyses.

Keywords: Chest wall, vibration, human health diagnosis, FFT, PSD.

1. Introduction

Vibration is known to be a dynamic phenomenon where it moves to-and-fro about equilibrium position. When taking vibration measurements, it can either be represented in the time domain or the frequency domain; the former shows the change in amplitude of vibration with time, whereas the latter describes it with the

Nomenclatures

A_{max}	Amplitude reading of the highest frequency peak, G^2
F_{max}	Maximum frequency value with an amplitude reading of at least 5% of A_{max}, Hz

Abbreviations

AP	Anterior-Posterior
DAQ	Data Acquisition
DFT	Discrete Fourier Transform
FFT	Fast Fourier Transform
PC	Personal Computer
PSD	Power Spectral Density

frequency spectrum [1]. These two domains are mathematically related via the Fourier Transform.

In the engineering field, machine fault diagnosis and health monitoring is one of the main reasons vibration is measured. By conducting frequency analysis through measuring a machine's vibration, it can be tested to determine its lifespan as well as predicting any impending problems [1]. For instance, an evaluation of vehicle vibration on different types of roads was done to determine the ride comfort of the passenger [2]. The vibration readings can show indications of possible problems, if any, thus allowing preventive steps to be taken.

By taking that same principle, theoretically, it can be applied in the human health diagnosis whereby chest wall vibration measurements of smoking and non-smoking subjects are obtained. The frequency content in the smoking subjects might show some sort of an indicator of impending problems. The vibrational energy of these test subjects is to be studied to perform an educated human health diagnosis.

The human chest wall, which consists of structures such as the diaphragm, the ribcage and the abdomen, undergoes a vibrational energy during respiration [3]. Data on the chest wall vibration between different types of people have not yet been greatly quantified, especially between smoking and non-smoking subjects.

Looking at it from a medical point of view, assessing the chest wall motion and its behaviour is a common medical practice. Medical students were taught to evaluate the chest wall expansion by placing their hands on the back of the patient; the thumb being on the midline section [4]. However, it is crucial to quantify these chest wall motions. Konno and Mead [5] were the firsts who attempted a measurement and mathematical analysis of chest wall motion by demonstrating that it is possible to obtain accurate volume changes by measuring anterior-posterior (AP) diameter changes at the abdomen and ribcage. Another study was done to determine the effects of smoking on the heart rate of people between the age of 20 - 29 years old when they were at rest and during exercise [6].

It is said that a more solid structure has higher pitch (higher frequency) and a softer intensity (lower amplitude), whereas a more air-filled structure has lower pitch (lower frequency) and a louder intensity (higher amplitude) [7]. Therefore, the frequency content and amplitude depend on the air content and nature of the structures present at the location of percussion.

The main objective of this study is to investigate the frequency content of the human chest wall vibration in non-smokers, cigarette smokers and electrical cigarette smokers, and use the frequency component of measuring signals for health diagnosis. Malaysia is currently facing challenges due to long waiting time for radiological diagnostic services. The conventional approach for detecting lung related diseases is to capture the x-ray image of chest and examine for lungs deformations. This research is proposing a new technique for preliminary diagnosis of lung related diseases based on processing the vibration patterns of structures from the thoracic cavity. It is worth highlighting that the source of vibration from the outer chest wall are from both heart and lungs, even though the preliminary assessment is for lung related disease.

2. Research Methodology

2.1. Design of experiment

The experiment aims to measure the chest wall vibration of smoking and non-smoking subjects using a physical device. Note that the smoking subjects will further consist of normal cigarette smokers and electrical cigarette smokers. The physical device used is called the DAQ system, which includes the accelerometer, the data acquisition (DAQ) measurement hardware, and the LabVIEW software installed on a Personal Computer (PC). The accelerometer acts as a sensor, which is generally known to convert a physical phenomenon (eg. vibration) into electrical signals [1]. These electrical signals will then be sent to the DAQ measurement hardware for signal conditioning and analog-to-digital conversion before they are sent to the PC for visualization of data.

There were 16 test subjects that volunteered in this experiment; 6 non-smokers, 5 cigarette smokers, and 5 electrical cigarette smokers. It should be taken into consideration that there was only one female test subject under the cigarette-smoking category. The other 15 test subjects were all males. All test subjects were aged between 22 - 27 years old. A short survey was conducted at the end of every experiment to find out about the test subject smoking habits and whether they have any other health issues, allowing the author to observe any correlation with the experimental results. It is noted that all test subjects were considered “healthy” and did not have any other health issues. Also, 2 out of 10 of the smokers have only been smoking for only 2-4 years, whereas the rest of them have been smoking for 5 years or more.

The experiment was conducted at the Clinical Theatre, Taylor’s University. The accelerometer was attached on the patient’s chest, below the left nipple, with a double sided medical tape, designed to be gentle as well as secure enough on human skin. Typically, doctors are trained to assess the heart beat sounds by placing the stethoscope at four primary areas [7]; the second rib of the left and right sternum, left sternum of the fourth rib, and at the fifth rib level right below the left nipple line.

These four primary areas are all located below the two nipples, more so on the left nipple, proving that they are the optimal places to listen to heart sounds because both lung and heart movements can clearly be detected. Based on this, the point of detecting vibration for this study was below the left nipple area. The placement of the accelerometer was done by a trained lecturer from School of Medicine. Fig. 1 shows one of the test subjects in supine position while vibration measurements were taken.

Fig. 1. Taking of measurements of a test subject in a supine position.

Referring to Fig. 2, the sensor used was a Bruel & Kjaer DeltaTron Accelerometer Type 4507 B with a frequency range of 0.3 Hz - 6 kHz. The DAQ measurement hardware used for this study is NI 9234 Module with 1-slot NI CompactDAQ Chassis with a maximum bandwidth of 23 kHz, which would be sufficient for the study of the human chest wall vibration. LabVIEW and Matlab will be used for data collection and data analysis respectively.

(a) **(b)**

Fig. 2. (a) Bruel & Kjaer DeltaTron Accelerometer Type 4507 B,
(b) DAQ Hardware used in the experiment.

This accelerometer was connected to the DAQ measurement hardware which is connected to the PC. During the collection of data, the patient will be in supine position in a relaxed state, while making no sudden movement as that might affect the data. Data collected from each patient will be stored into the PC.

2.2. Data collection parameters

Fekr et al. used a sampling rate of 50 Hz to measure respiration rate [8], Kikhia et al. [9] used 10 Hz to measure body movement, and Dehkordi et al. used 500 Hz to record upper-body acceleration and the movement of chest and abdomen wall [10]. The author decided to use 500 Hz as a sampling rate to be safe, as too low of a sampling rate will cause aliasing. The signals were collected at 15000 samples with a sampling frequency of 500 Hz. The amplitude unit was set as G, which equates to approximately 9.81 m/s^2. It is noted that results and discussions will be expressed in terms of the unit G.

2.3. Pre-processing of Data

Before conducting the data analysis, a pre-processing stage was added. This pre-processing stage was necessary because it was seen that the time-domain signals were rather noisy, which might bury the desired frequency contents after signal processing. Therefore, a filter was needed to minimize or even eliminate this unwanted noise, thus achieving clearer results for the post-processing stage. A 2^{nd} order Butterworth low-pass filter was used with a cut-off frequency of 20 Hz.

2.4. Post-Processing & Analysis of Data

Figure 3 shows the signal analysis and measurement workflow of this study. After obtaining the results in LabVIEW, the data will be presented in the time domain. Data will then be converted into frequency domain through spectral analyses used in this experiment; Fast Fourier Transform (FFT) spectrum and Power Spectral Density (PSD) analyses. This conversion can be done using Matlab software. To do this, the raw signals in time-domain collected in LabVIEW must first be imported into Matlab software in the form of excel files.

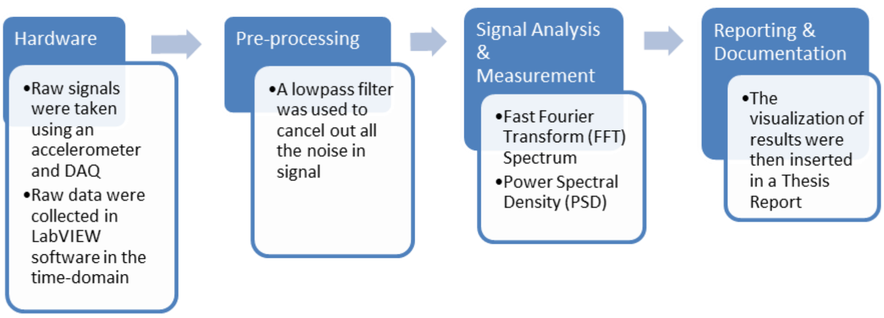


Fig. 3. Signal analysis and measurement workflow.

3. Results

The graphs for FFT and PSD were all obtained using Matlab Signal Processing Toolbox. The results were first visually analyzed by observing any difference or repeating patterns between the non-smokers, cigarette smokers, and electrical cigarette smokers. The main points to look for would be the amplitude readings, the frequency contents, as well as the shape of the graph. Note that the amplitude units for FFT and PSD graphs are G^2 and G^2/Hz respectively; whereas the frequency unit for all graphs is in Hz.

Referring to Fig. 4, the FFT graphs were analyzed by observing the amplitude reading (A_{max}) of the highest frequency peak. In addition, the frequency content is observed by determining the F_{max} value based on the PSD graphs; whereby F_{max} is the maximum frequency value with an amplitude reading of at least 5% of A_{max} (as shown in Fig. 5). Moreover, the area under the curve of the PSD graphs were obtained by using the Matlab function Trapz to obtain more information about the power content of the graphs between the test subjects. All these results were then tabulated.

The first thing to note is that the all of the signals seem to be harmonic signals. In other words, the frequency components that were obtained in the graphs were multiples of the fundamental frequency. These frequency components are known to be harmonics. Considering that the signals are heartbeat signals, this would make sense as a heartbeat motion consists of a highly repeatable series of sine and cosine waveform. It is known that all harmonic signals are periodic as well.

First and foremost, the A_{max}, F_{max}, and area under the curve readings between the cigarette and electrical cigarette smokers showed no difference during the research. This can be explained with the fact that all electrical cigarette smokers started with the conventional cigarette before switching to electrical cigarette. Moreover, the market of electrical cigarette is rather new, so there might not be enough time for it to show any significant effects towards the human body. For ease of discussion, the author will refer to both categories cigarette and electrical cigarette smokers as "smokers". Referring to the FFT spectrum graphs in Figs. 6 and 7, it can be seen visually that the A_{max} values of non-smokers are higher than that of smokers. PSD analyses in Figs. 8 and 9 reveal that most of non-smokers show F_{max} of no more than 14 Hz whereas most smokers do show F_{max} reading of more than 14 Hz. It is also seen that the frequency peak with highest amplitude for both smokers and non-smokers range between of 1 - 6 Hz. The data is tabulated in Table 1 to have a better overview of the findings.

It is important to take note of the exception cases in the data obtained from the 16 test subjects. Based on all the FFT spectrum results, 90% of the smokers show A_{max} values of less than 1×10^{-5} G^2, whereas 50% of non-smokers show A_{max} values of more than 1×10^{-5} G^2. However, this low percentage of non-smokers might be contributed to two things; the number of non-smoker test subjects are much less than that of smokers, and that 2 out of the 6 non-smokers have a BMI of more than 30, which by the standards equate to being obese [11]. The thicker layer of the chest wall due to the fat causes the sound transmission to be diminished, thus resulting in lower amplitude.

Based on the PSD graphs, 90% of smokers show area under the curve of less than 5 x 10^{-5} G^2, whereas 67% of non-smokers show area under the curve of more than 5 x 10^{-5} G^2. The remaining 33% of non-smokers represent the same 2 out of 6 people who have a BMI of more than 30, as mentioned previously. Therefore, there is a consistency in the results based on A_{max} readings from the FFT graphs and the area under the curve readings from the PSD graphs since both of these readings represent the power of the signal, which has a unit of G^2. In other words, a unit of $(\text{amplitude})^2$.

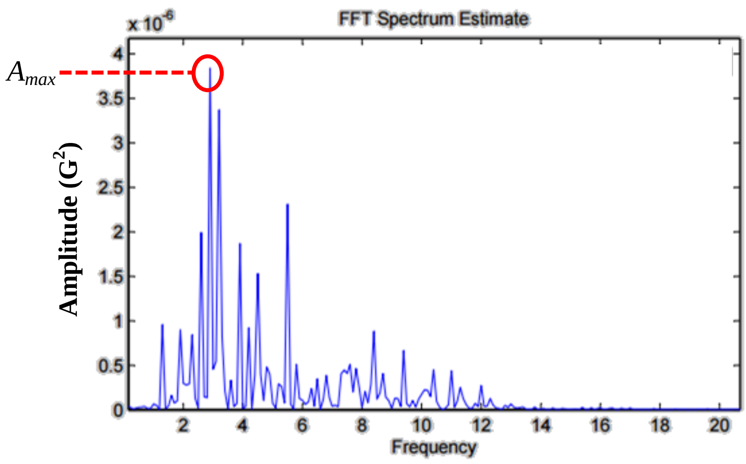


Fig. 4. Example of FFT spectrum.

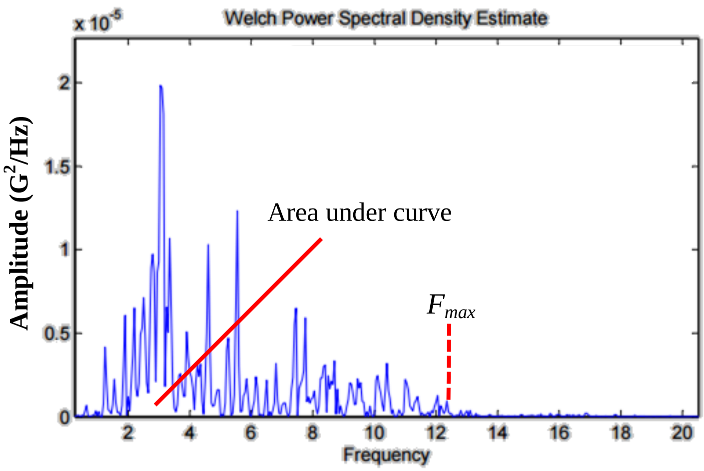
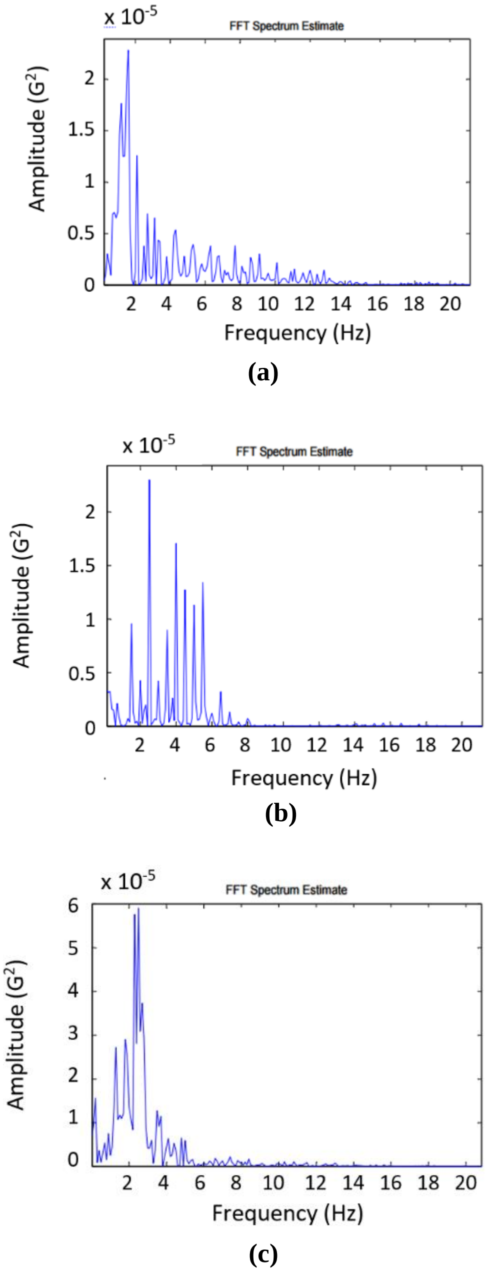


Fig. 5. Example of PSD estimate.



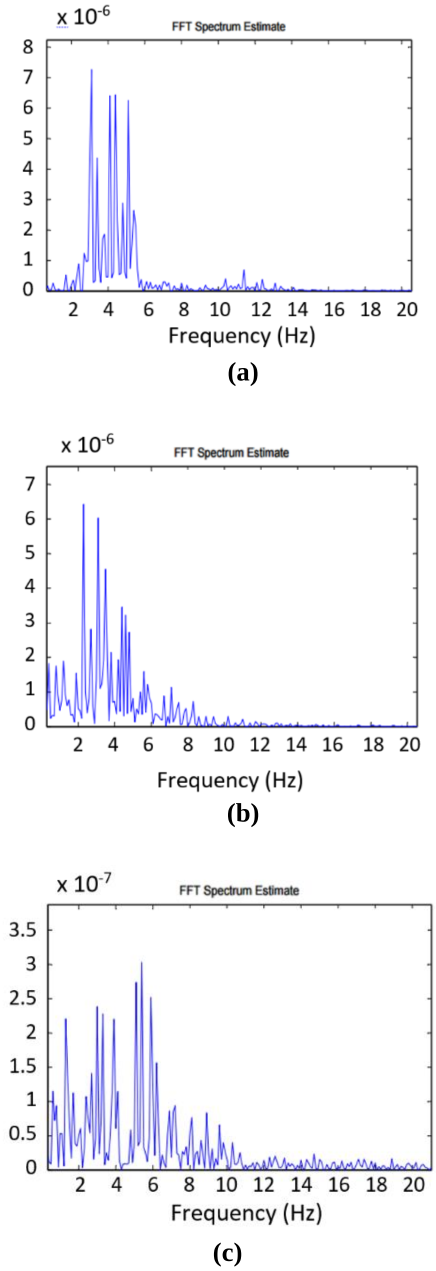


Fig. 6. FFT spectrum for non-smokers.

Fig. 7. FFT spectrum for smokers.

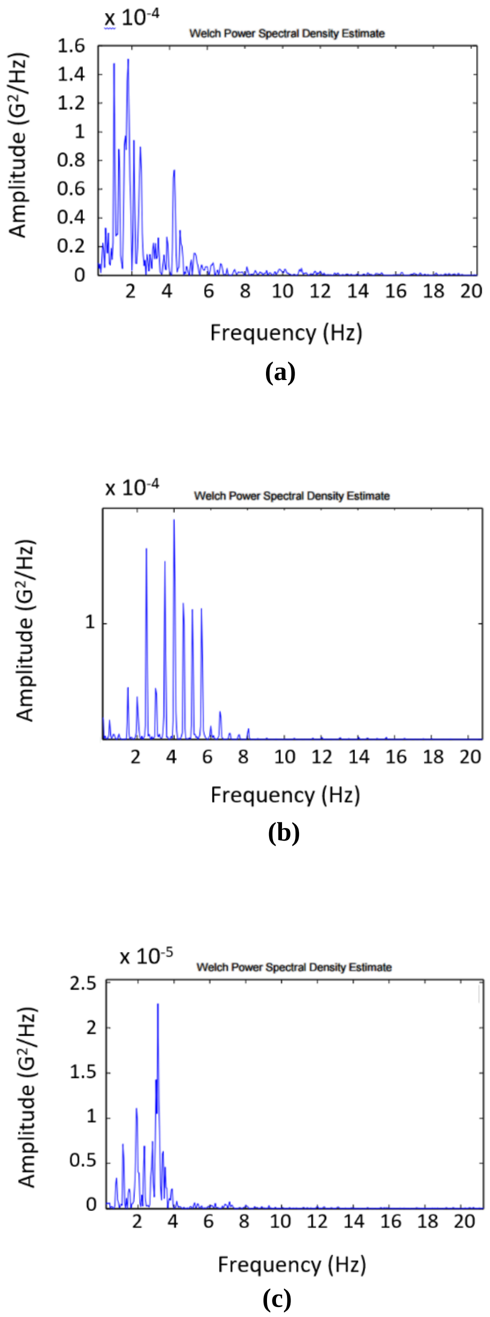


Fig. 8. PSD estimate for non-smokers.

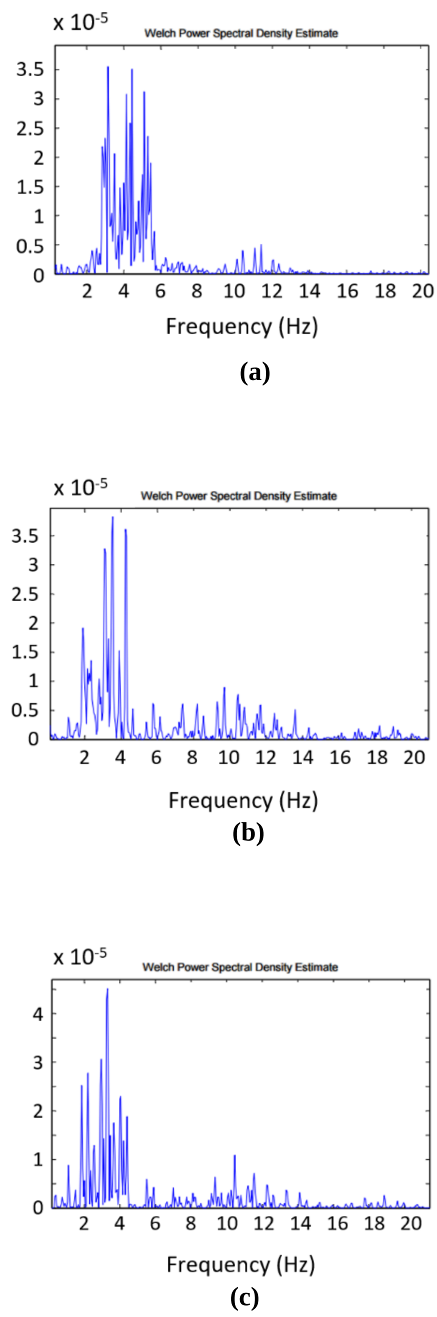


Fig. 9. PSD estimate for smokers.

Table 1. Data on all test subjects.

Type	Age	BMI	Health	A_{max} (G^2)	Area Under Curve (G^2)	F_{max} (Hz)
Non-Smoker	23	32.1	Obese	1.8497E-6	1.2119E-5	12.0
Non-Smoker	24	24.2	Normal	2.2804E-5	9.9112E-5	12.0
Non-Smoker	23	26.5	Overweight	2.2997E-5	1.0594E-4	8.0
Non-Smoker	23	35.1	Obese	3.0519E-6	1.1772E-5	8.0
Non-Smoker	25	19.3	Normal	5.9019E-5	1.28E-4	14.0
Non-Smoker	27	23.1	Normal	7.4016E-6	9.1816E-5	14.0
Cigarette Smoker	22	26.6	Overweight	3.5080E-6	1.9653E-5	20.0
Cigarette Smoker	23	29.8	Overweight	7.2635E-6	4.6328E-5	12.2
Cigarette Smoker	24	24.5	Normal	5.0531E-6	4.7289E-5	21.0
Cigarette Smoker	25	25.9	Overweight	6.3290E-6	4.662E-5	20.0
Cigarette Smoker	25	19.7	Normal	3.2736E-5	1.2246E-4	16.0
Electrical Cigarette Smoker	23	21.5	Normal	4.0804E-6	2.0644E-5	18.0
Electrical Cigarette Smoker	23	19.0	Normal	4.4767E-6	2.7298E-5	18.0
Electrical Cigarette Smoker	25	26.1	Overweight	6.4281E-6	4.8181E-5	12.0
Electrical Cigarette Smoker	23	23.6	Normal	8.9689E-6	3.9817E-5	18.0
Electrical Cigarette Smoker	23	25.0	Overweight	3.0279E-7	6.5602E-6	21.0

Based on these same PSD graphs, 100% of non-smokers show no noticeable frequency contents above 14 Hz, whereas 80% of smokers show noticeable frequency contents after this point. It is important to take note of the exceptions, as it may be correlated to any health issues. The other 20% of smokers showed little to no frequency content above 14 Hz, possibly due to the fact that these test subjects have only smoked for only 2 - 4 years.

4. Discussions

It is said that a more solid structure has higher pitch (higher frequency) and a softer intensity (lower amplitude), whereas a more air-filled structure has lower pitch (lower frequency) and a louder intensity (higher amplitude) [7]. Therefore, the frequency content and amplitude depend on the air content and nature of the structures present at the location of percussion. Following this same concept, this would suggest that non-smokers have a more air-filled chest wall structure when compared to smokers, and smokers have a more solid chest wall structure. Moreover, the higher frequency readings in smokers would suggest a more rapid breathing.

In a smoker, some lung tissue would be loss [12]. Lung tissues referred here would be the air sac and tubular structures that carry the air to the air sacs (alveoli). The loss of these lung tissues will cause a block in the bronchiole, or may even cause the alveoli to lose its elastic recoiling capacity, which is needed for gas exchange to happen. Even though smokers can inhale well, the air may not reach the terminal air sacs due to the blockage at the bronchiole. When compared to this, non-smokers seem to have better ventilated lungs, which explain why the results suggest they have more air-filled lung structure.

The inability of air reaching the terminal air sacs for smokers results in no gas exchange to occur. Consequently, there is more carbon dioxide present than oxygen. The brain detects this lack of oxygen, which in turn triggers the respiration action, thus increasing the breathing rate. This would explain why smokers have higher frequency content. Severe cases would cause the person to start panting.

The increase in breathing rate in smokers would also mean a higher heart rate. Papathanasiou et al. conducted a study which proved that smokers have higher heart rate values than non-smokers [6] at rest among young adults, thus supporting the results of this experiment. A high resting heart rate may be a sign of any manifestations of cardiovascular disease and might help in identifying a person with any risk of this disease.

A study was done to determine the spectral characteristic of sound transmission of the typical human chest wall [13]. It showed that the sound vibration of the chest surface is loudest at low frequencies and there is a decrement in amplitude with increasing frequency, which is a clear pattern among all of the graphs obtained in this experiment.

The higher amplitude readings (at low frequency) and area under the curve of the non-smokers suggest higher vibration intensity, which agrees with a study done by Yigla et al. [14] using a Vibration Response Imaging (VRI) device. VRI is a technology used to measure the intensity of vibration by producing a grey-scale image. Darker images represent a higher intensity in vibration whereas lighter images represent a lower intensity [15]. It was found by Yigla et al. that non-smokers show a darker and symmetrical images of the lungs, which suggest they have higher vibration intensity throughout the entire lungs. In contrast, smokers have a slight inconsistency in vibration intensity throughout the lungs.

Inhaling cigarette smoke has shown to cause changes in respiratory function that includes coughing, irritation of airways and alterations in resistance to airflow. There are other studies on the human respiratory systems with people that have respiratory problems which might have some correlation with the findings obtained in this experiment. It was found that patients with emphysema, which is a condition of damaged air sacs of the lungs, showed a lower amplitude readings at low frequencies [16]. In addition, Yonemaru et al. [17] found that patients with tracheal stenosis display a rise in power (amplitude reading) at higher frequencies through frequency analysis. Tracheal stenosis is a condition whereby the trachea is narrowed, causing difficulty in breathing. These studies show a similar pattern among the smokers of this experiment.

It is known that there is a strong relationship between lung sound amplitude and its ventilation, whereby lung sounds were the loudest with best ventilated lung units [18]. This can be seen in the current study whereby non-smokers show higher vibration intensity, thus suggesting having a better ventilated lung unit. Moreover, studies using bronchoprovocation challenge testing have shown that high frequency breathing sounds were obtained in lung analysis as the bronchial airways get narrowed [19]. This would suggest that smokers might show signs of having narrower airways.

However, there are no clinical evidences among the smokers of having any lung abnormalities, apart from them being smokers. Nevertheless, smooth-muscle hypertrophy, increased fibrosis, inflammation, and goblet cells can be found in the lungs of smokers that have no clinical evidence of respiratory diseases [20]. These histologic changes may slightly alter the sound vibration transmission through the lungs and its airways. Our findings show that spectral analysis does in fact show a promise in detecting these subtle disease changes.

There is definitely a correlation between smokers and other respiratory diseases in terms of chest wall intensity and frequency of vibration using spectral analyses. The results obtained throughout this experiment suggest that smokers experience a decrease in lung function and may have a higher risk of having respiratory problems in the future. This information may be used to encourage young people to quit smoking. A medical health screening should be performed among heavy smokers to monitor how bad it is.

Accelerometers are built into smart phones and there are various possibilities to use this to our advantage. Even though a microphone is typically used to measure the human lung vibration, an accelerometer is proven to work just as well. An app could be built by including algorithms which would display the PSD and FFT graphs for consumers to visualize their heartbeat reading, using this experiment as a guideline to distinguish a non-smoker’s and a smoker’s heartbeat.

5. Conclusions

The results showed that the type of smokers (cigarette and electrical cigarette smokers) does not affect the A_{max}, F_{max} or the area under the curve of the FFT and PSD graphs. Based on results, there is a significant effect between smokers and non-smokers on A_{max}, F_{max} or the area under the curve of the FFT and PSD graphs. Non-smokers show higher A_{max}, higher area under the curve, and lower F_{max}; whereas smokers show lower A_{max}, lower area under the curve and higher F_{max}.

Based on the FFT spectrum results, 90% of smokers show A_{max} values of less than 1×10^{-5} G^2, whereas 50% of non-smokers show A_{max} values of more than 1×10^{-5} G^2. The PSD graphs show 100% of non-smokers show no noticeable frequency contents above 14 Hz, whereas 80% of smokers show noticeable frequency contents after this point.

These results have definitely shown a correlation between people who smoke and people with respiratory diseases, which suggest that smokers would have higher risk of having respiratory problems in the future. This information should be used to encourage young people to quit smoking.

Moreover, it can be said that an accelerometer is as good as a microphone to measure the chest wall vibration, thus creating a potential of measuring the chest wall vibration with our smartphones since there are built in accelerometers in them already.

Smokers can monitor their breathing rate through this app and take preventive precautions accordingly, such as minimizing the amount of cigarettes smoked within the day, using a nicotine replacement therapy or even to quit cold turkey.

This experiment has achieved both project objectives which were to conduct frequency analysis of chest wall vibration between smokers and non-smokers, as well as to conduct a human health diagnosis based on the results.

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