The quality and reliability of the mechanical stethoscopes and Laser Doppler Vibrometer (LDV) to record tracheal sounds

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Abstract

The sound of breathing activity can be used to assess the state of the lungs and detect adverse problems involving respiratory failure. Traditionally, mechanical stethoscopes are used for respiratory auscultation to analyse the lung sounds. Firstly, measurements are carried out on the five different standard stethoscopes to assess their reliability for detecting respiratory sounds in people. Secondly, three human subjects were used for tracheal sound experiments using the five stethoscopes. Thirdly, a Laser Doppler Vibrometer was used to detect tracheal sounds from three human subjects. The five stethoscopes used for measurements give different results, especially above 150 Hz. Experimental results show that mechanical stethoscopes are not reliable tools for assessing lungs sounds in people.

1. Introduction

Breathing is vital for human life. Respiratory-related diseases cause more than one million deaths each year. Pneumonia annually kills over 1.8 million children throughout the world. The vast majority of these deaths occur in resource poor regions such as sub-Saharan Africa and remote parts of Asia. Prompt diagnosis and proper treatment are essential to prevent these unnecessary deaths [1, 2]. The sound of breathing activity can be used to assess the state of the lungs and detect adverse problems involving respiratory failure (respiratory auscultation). Clinical practitioners use mechanical stethoscopes to listen to breath sounds and analyse the sounds they hear. Their analysis is based on their own observation, experience, and auditory capabilities. This procedure is subjective, time consuming and not always accurate and does not lend itself to a quantitative analysis of the sounds heard from the patients [3]. Computerised monitoring of breathing activity has overcome some limitations of subjective human observation and inconsistency of stethoscope contact [4, 5, 6].

Traditionally, stethoscopes are used for respiratory auscultation to analyse the sounds from lungs. However, they are unreliable for assessing respiratory sounds in people, especially in infants. This has important implications for their use as diagnostic tools for lung disorders in infants, and it confirms that stethoscopes cannot be used as the “gold standard” [7]. Because of the unreliability of the stethoscope, the validity of acoustic analysis cannot be demonstrated. In principle it could discriminate between sounds well and has shown good within-observer reliability. The amplitude variations of spectral components of lung sound signals is sufficient to have sensitivity to the louder sounds produced by breathing. The further development of smart pattern recognition systems may improve the reliability of acoustic observations so that it can be used in clinical practice [8, 9, 10].

The aim of this work is to investigate the reliability and the quality of the mechanical stethoscopes and Laser Doppler Vibrometer to detect tracheal sounds. The five stethoscopes are calibrated using a shaker system and a Head-And-Torso Simulator (HATS). Measurements are carried out on three human subjects in a semi-anechoic chamber to record their tracheal sounds. The results are compared with the data obtained from three human subjects using a Laser Doppler Vibrometer, which is a non-contact technique.

2. Determining the performance of the stethoscopes

The stethoscope consists of the ear-tips, ear-tubes, tubing, stem, diaphragm and bell. A diagram showing the structure of a typical stethoscope is given in Figure 1. The diaphragm and/or bell end of the stethoscope is used to detect the sounds created from lungs. The diaphragm of the stethoscope will vibrate due to the lung sound when it is placed on the body. The vibrating diaphragm creates sound pressure waves that propagate through the tubing and stem, up to the practitioner's ears. The diaphragm transmits higher frequency acoustic waves while the bell part of it transmits low frequency acoustic waves. The procedure given by Davison [11] was followed for determination of the stethoscope performance. A fixed repeatable vibration level is induced into the diaphragm of each stethoscope, and then the sound pressure levels are detected using microphone at the earpiece.

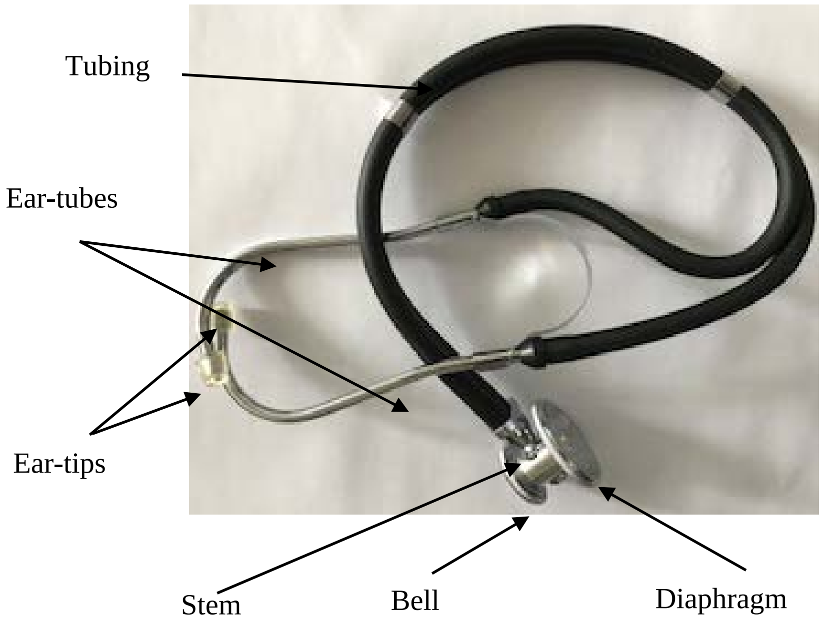

Figure 1: The structure of a mechanical stethoscope (KT-102 Rapaport Stethoscope)

2.1. Calibrating and testing the stethoscopes

The five mechanical stethoscopes were calibrated and tested using a shaker system and the Head-And-Torso Simulator (HATS) as shown in Figure 2. The details of stethoscopes are given in Table1. HATS is designed to represent the dimensions of an average human head. It has a pair of realistic simulation pinnae which can flex and compress like real human ears. The large diaphragm of each stethoscope was placed on a 10 mm thick porous circular plate of an open cell material and fabricated from particles of plastic foam obtained from recycled car dashboards. The circular porous plate is attached onto a metal circular plate to reduce unwanted noise and vibration generated by decoupling. The circular porous plate is mounted on a force transducer that is connected to a shaker. The porous plate which is placed between the stethoscope head and vibrating metal plate, attenuate vibration and unwanted noise. A Lab Gruppen LAB300 amplifier, which is connected to a NTi Minirator MR-pro signal generator, is used to power the shaker. A clamping force of 5 N is used as weight to control the pressure of the stethoscope head onto the shake so that the clamping force is repeatable and same for every measurement. Each stethoscope was connected to the Head-And-Torso Simulator (HATS) for binaural recording of the stethoscope performance. The earbuds of the stethoscope were placed in the anterior notches of the outer ears of the HATS. Built in microphones were used to detect the stethoscope's response. The microphones were placed in the ear of the HATS and then connected to two Bruel & Kjaer signal conditioning units, type 2829, into an M-Audio Profire 610 sound card which was connected to a laptop. Pink noise is applied to the shaker to generate vibration. The sounds resulting from the five stethoscopes were each recorded for 10 seconds using two microphones in the ear of the HATS. The recorded audio (24bit 44.1kHz) was analysed using Audacity software and the Plot Spectrum Function. The samples were analysed using FFT with a Hanning window of size 65536 samples to get a better frequency resolution for vibration/stethoscope measurements, and to reduce spectral leakage.

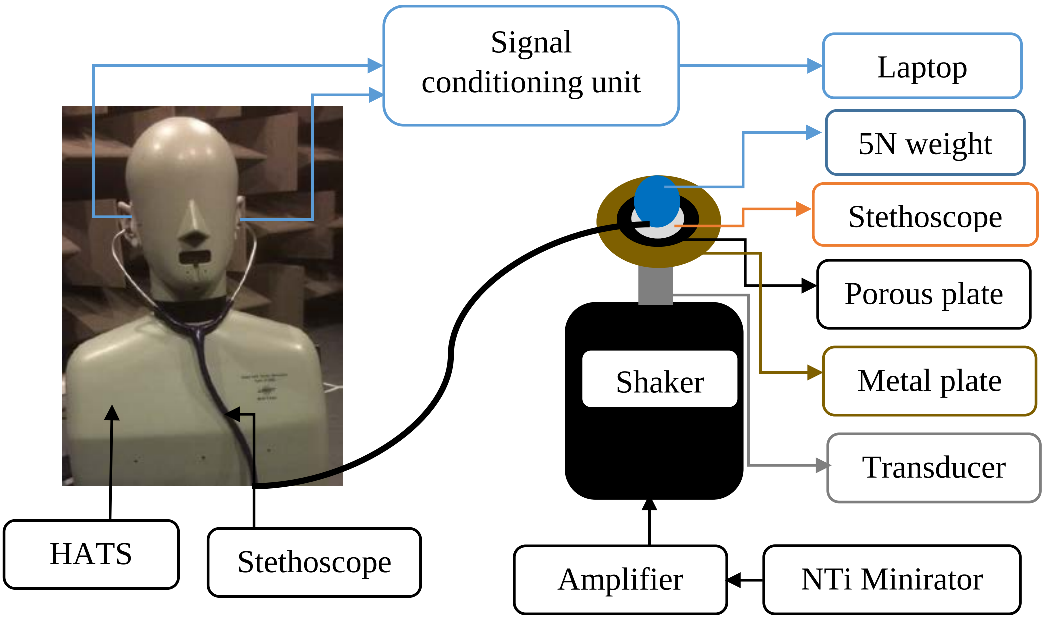

Figure 2: Measurement set-up for the shaker and the Head-And-Torso Simulator system.

Table 1: Five mechanical stethoscopes used for measurements

Red	Red Stethoscope
Teach.	3M Littmann Classic II S.E. Teaching Stethoscope [12]
Rapaport	KT-102 Rapaport Stethoscope [13]
Select	3M Littmann Select Stethoscope [12]
Classic	Littman Classic III Stethoscope [12]

2.2. Results

Background noise in busy hospitals and in local surgeries has a significant effect on diagnoses made by the mechanical stethoscopes. Previous work carried out at Johns Hopkins Hospital in 2005 [14] showed that the sound pressure level measured in a hospital is in the range of 50-60 dB(A).

In this present study, firstly, measurements were performed on the five stethoscopes in an anechoic chamber to determine their background noise levels without any specific noise or vibration sources in operation. The HATS was used for the background noise measurements of the stethoscopes. One-third octave band frequency responses were detected using ½ inch microphones connected to the signal conditioning unit. The amplitudes of the stethoscopes were determined from recorded signals and they are similar below 500 Hz, especially at lower frequencies. Initial resonance peaks were observed around 100 Hz as shown in Figure 3. The difference between amplitudes of the mechanical stethoscopes increases significantly with frequency above 500 Hz while the amplitudes are very similar below 500 Hz. The amplitudes of the stethoscopes are close to the mean at 100 Hz with a standard deviation value around 1.14. The maximum standard deviation, which is around 13.25, was observed at 2500 Hz.

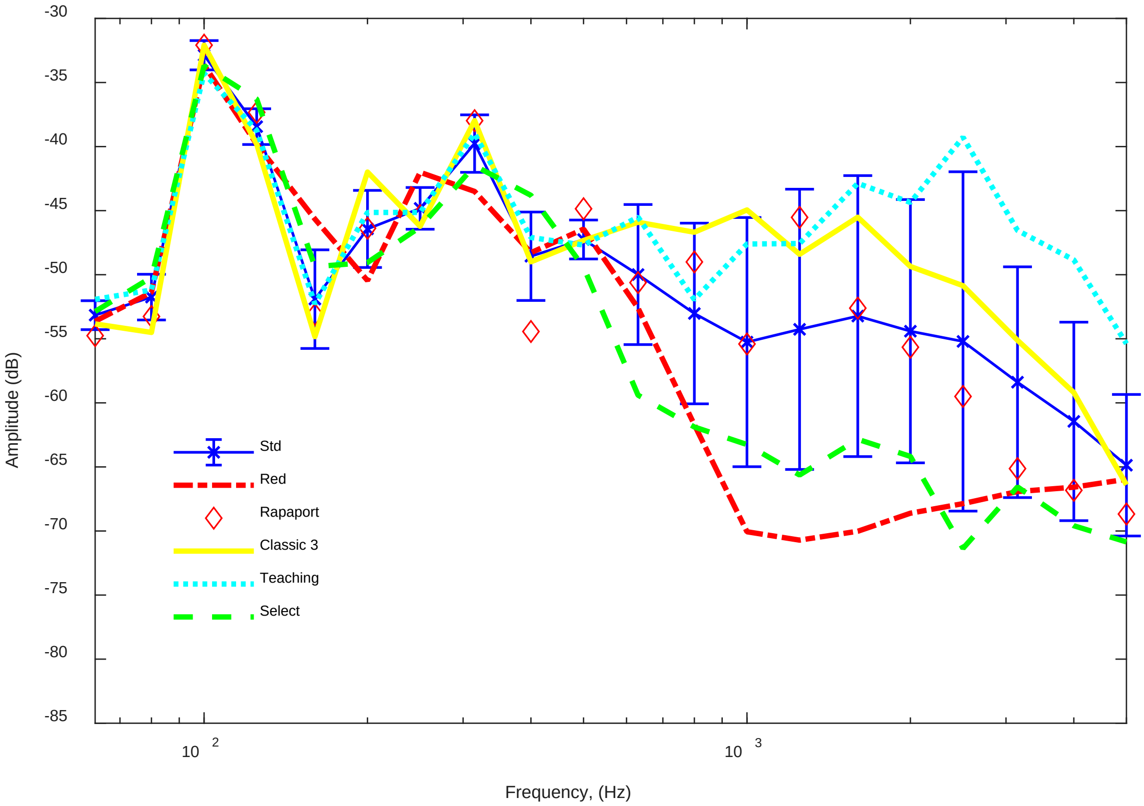

Figure 3: The amplitude of the five stethoscopes, including the mean values with the standard deviation values (Std), presented in the frequency domain.

Secondly, performance of the five stethoscopes was measured in the anechoic chamber when they were connected to a source of vibration. A force generated by a shaker was applied to the stethoscopes through the transducer and plates as shown in Figure 2. The resulting responses were recorded using the microphones placed in the ears of the HATS. Same vibrational force was applied to the stethoscopes during all measurements carried out in the anechoic chamber. Measurements were repeated three times for each stethoscope. The frequency response of Red, Teach, Select, Classic, and Rapaport stethoscopes are shown in Figures 4a, 4b, 4c, 4d, and 4e respectively with their standard deviations. It can be said that the measured amplitudes of the five stethoscope are repeatable, since they are very similar between the three trials throughout the frequency range.

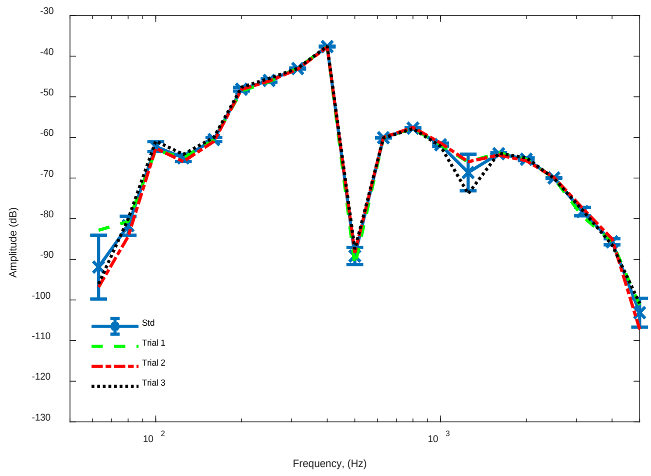

Figure 4a: The amplitude (performance level) of Red Stethoscope over the frequency domain, including the mean with the standard deviation values (Std).

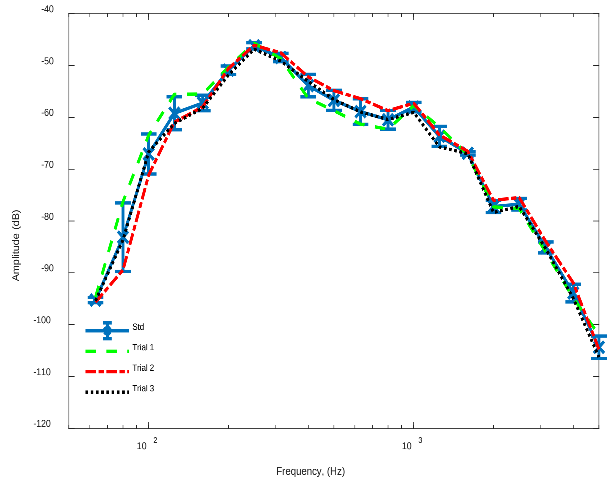

Figure 4b: The amplitude (performance level) of Teaching Stethoscope over the frequency domain, including the mean with the standard deviation values (Std).

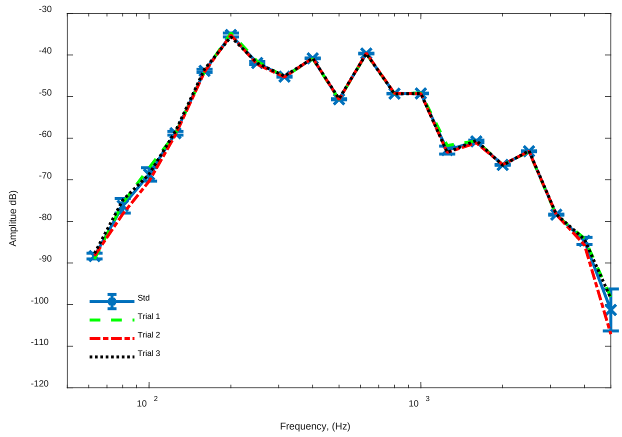

Figure 4c: The amplitude (performance level) of Select Stethoscope over the frequency domain, including the mean with the standard deviation values (Std).

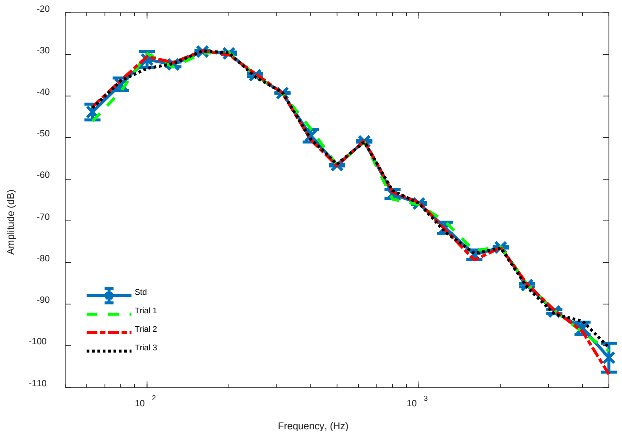

Figure 4d: The amplitude (performance levels) of Classic Stethoscope over the frequency domain, including the mean with the standard deviation values (Std).

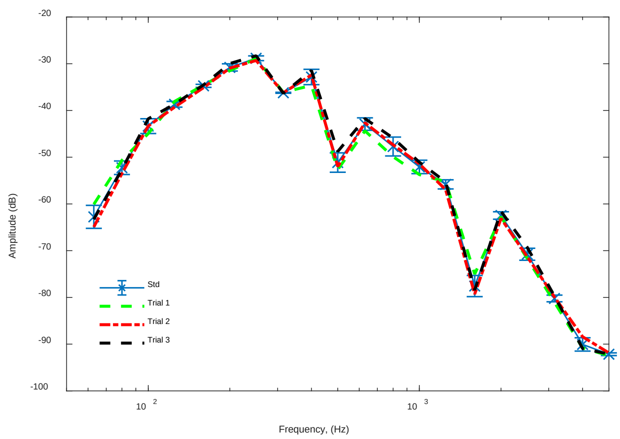

Figure 4e: The amplitude (performance level) of KT-102 Rapaport Stethoscope over the frequency domain, including the mean with the standard deviation values (Std).

The frequency responses of the five different stethoscopes are given in Figure 5. The responses of the various stethoscopes to the same vibration force are very different throughout the frequency range, especially below 250 Hz. Differences between them reduce at higher frequencies. Select, Teaching, and Red stethoscopes have similar responses below 400 Hz while the Classic 3 has a higher amplitude level than others at lower frequencies. The Red stethoscope has a sharp “coincidence deep” at 500 Hz. The standard deviation interval is between 4.34 and 20.1. It can be said that when a clinical practitioner examines a patient who has lung problems, the practitioner may hear different lung sounds from the lungs if s/he uses different stethoscopes. Now, the question is which stethoscope represents the true response of the lung sounds. There is not an established answer for this question. It can be said that the stethoscopes might detect the same sound energy, but the determined amplitudes will be different from one stethoscope to another, because some of the acoustic energy might be lost while it travels through the stem and tubing parts of the stethoscopes.

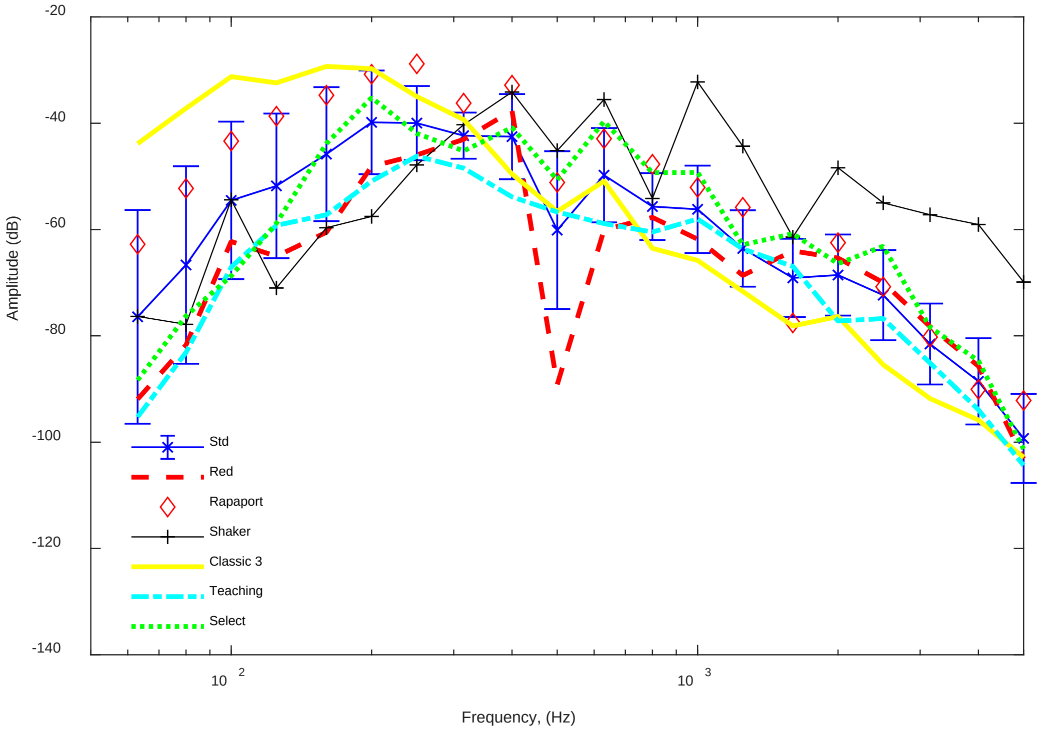

Figure 5: The amplitudes of the five stethoscopes, including the mean values with the standard deviation values (Std), given in frequency domain.

3. Tracheal sound detection

Two tracheal sound recording techniques were used for experiments; a Laser Doppler Vibrometer and the stethoscopes.

3.1. Using a Laser Doppler Vibrometer

A Laser Doppler Vibrometer (A Polytec PDV-100 portable digital vibrometer) contactlessly measures vibrational velocities in the 0 to 22 kHz frequency range and allows digital signal processing. A Laser Doppler Vibrometer (LDV) was used to record tracheal sounds during inhalation and exhalation. The LDV measurements were carried out on three human subjects (three volunteers) to detect tracheal sounds in a hemi anechoic chamber. The LDV was pointed to the anterior cervical triangle on the throat. The responses were recorded three times for each human subject using the LDV that works based on the optical interference whereby essentially two coherent light beams are required to overlap. The LDV was connected to a Bruel & Kjaer signal conditioning unit, type 2829, that is feeding into an M-Audio Profire 610 sound card which was connected to a laptop as shown in Figure 6. The recorded tracheal sounds were processed using Adobe Audition CC 2015. The "Noise Print" of unwanted audio data was captured and then eliminated using a process of Noise Reduction in Adobe Audition. The unwanted noise appeared due to the interaction of the laser with the throat of each of the participants was removed. Moreover, artefacts such as clicks, and pops were "cleaned" by the Click/Pop Eliminator. Parameters for each noise removal tool were adjusted individually in order to obtain the cleanest signal possible [15].

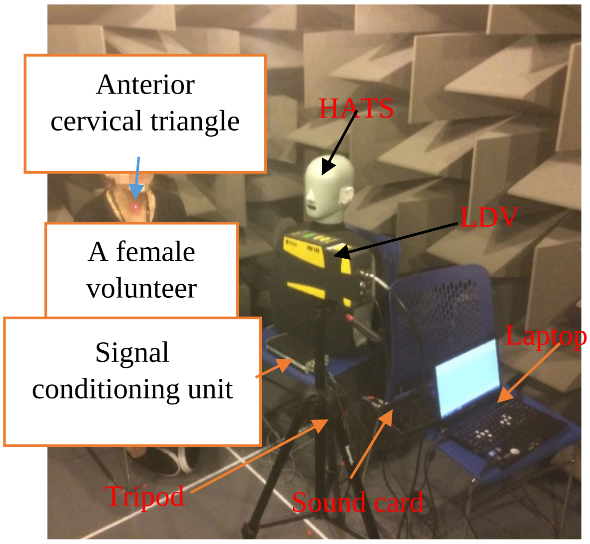

Figure 6: Measurement set-up for the laser Doppler Vibrometer.

3.2. Using the stethoscopes

The five stethoscopes given in Table 1 were used for measuring tracheal sounds. The large diaphragm of the stethoscope was placed on anterior cervical triangle of three volunteering human subjects (same participants as the for LDV experiments). The stethoscope earbuds were placed in the anterior notch of the outer ear of the HATS. The breathing activity of three human subjects was recorded for 10 seconds when they were inhaling and exhaling. The procedure was repeated for the five mechanical stethoscopes on three human subjects in the semi-anechoic chamber. Measurements were repeated three times for each stethoscope on each participant. It was ensured that the breathing sound was consistent during the different measurements for all stethoscopes. A sheet of 100 mm thick sound absorptive material was placed in between the participants and the HATS to minimize the effects of the breath sounds on the recording.

4. Analysis of tracheal sounds

Tracheal sounds measured using Laser Doppler Vibrometer are compared with the sound detected from three human subjects using the five different mechanical stethoscopes. Detected responses from participants 1, 2, and 3 are presented as a function of frequency in Figures 7, 8, and 9 respectfully. Results from the five different stethoscopes given in Figure 7 have similar patterns but different amplitudes. The maximum and minimum standard deviations of the sound obtained from participant 1 using LDV and the five stethoscopes are 10.9315 dB and 4.6932 dB at 63 Hz and 1600 Hz respectively. The reasons for the observed discrepancy between results obtained from the stethoscopes might be because of different diaphragms and/or characteristics of stethoscopes. Another reason might be the acoustic energy being attenuated while it travels through the stem and tubing parts of stethoscopes. The quality of the materials that are used to make the parts of the stethoscopes might be considered as one of the reasons for the discrepancies observed in the amplitudes of the signals detected. There are not any international standards suggesting what the parts of the stethoscope should be made of. The stethoscope manufacturers do not provide detailed information about the materials used for making the parts. The materials that are used to make the parts should be categorised based on their sound transmission quality.

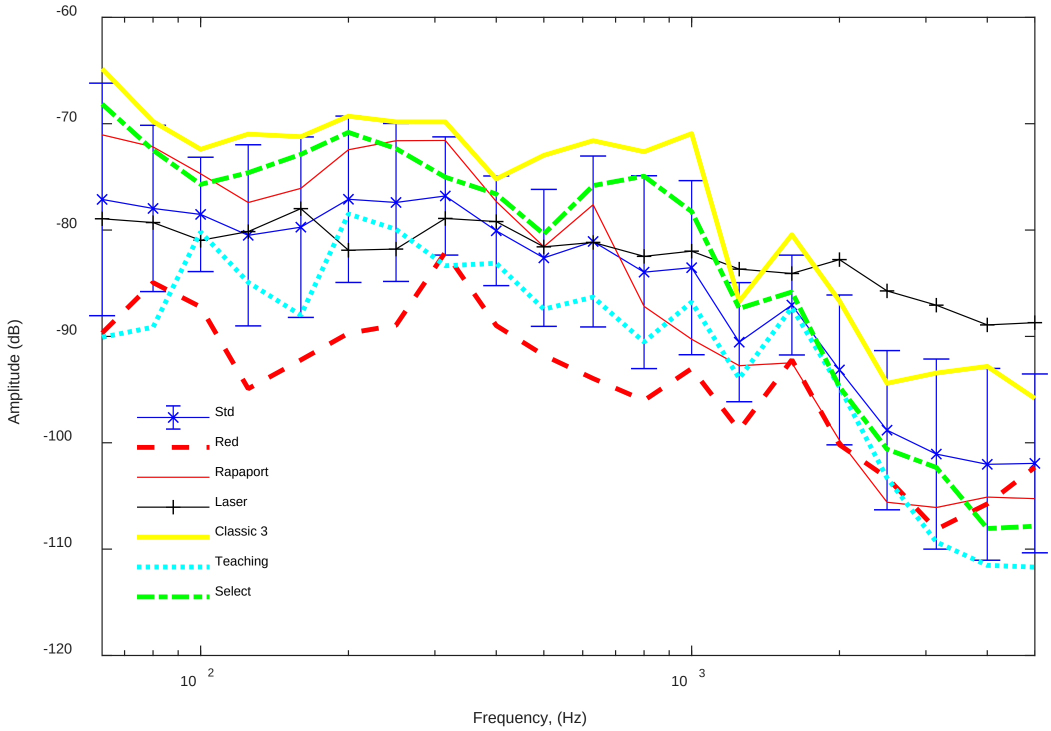

Figure 7. The averaged amplitudes of the responses from the five mechanical stethoscopes and a laser Doppler Vibrometer, including the mean values with the standard deviation values (Std), given as a function of frequency for participant 1.

Furthermore, tracheal sounds produced on different occasions might have similar wave patterns, but their amplitudes would be different. The Laser Doppler Vibrometer results are comparable with the ones obtained from the five mechanical stethoscopes, especially below 1000 Hz where they are in a good agreement. The tracheal sounds measured on participant 2 using Laser Doppler Vibrometer and the stethoscopes are following similar patterns except for the cheap Red stethoscope which has higher amplitude below 1000 Hz and the Laser Doppler Vibrometer producing lower amplitude above 1000 Hz as shown in Figure 8. This might be caused by weak breathing performance of the human subject. The standard deviation for participant 2 is very good at lower frequencies below 1000 Hz and then it increases up to 18 dB at higher frequencies. The amplitudes of the LDV and the five mechanical stethoscopes measured on participant 1 and participant 3 are in a better agreement as shown in Figure 7 and Figure 9. The performance of the LDV is comparable with those of the stethoscopes performance below 1000 Hz and it is a promising non-contact technique to measure tracheal sound. The maximum and minimum standard deviation of the sound obtained from participant 3 using LDV and the five stethoscopes is 16.0949 dB and 7.3943 dB at 125 Hz and 500 Hz.

The main issue with using Laser Doppler Vibrometer was making the human subjects to stand still during the inhalation and exhalation. A thin sticker, placed on the skin of the participant, can help to reduce the laser-hair-skin interaction, and reduce number of the artefacts such as clicks and pops.

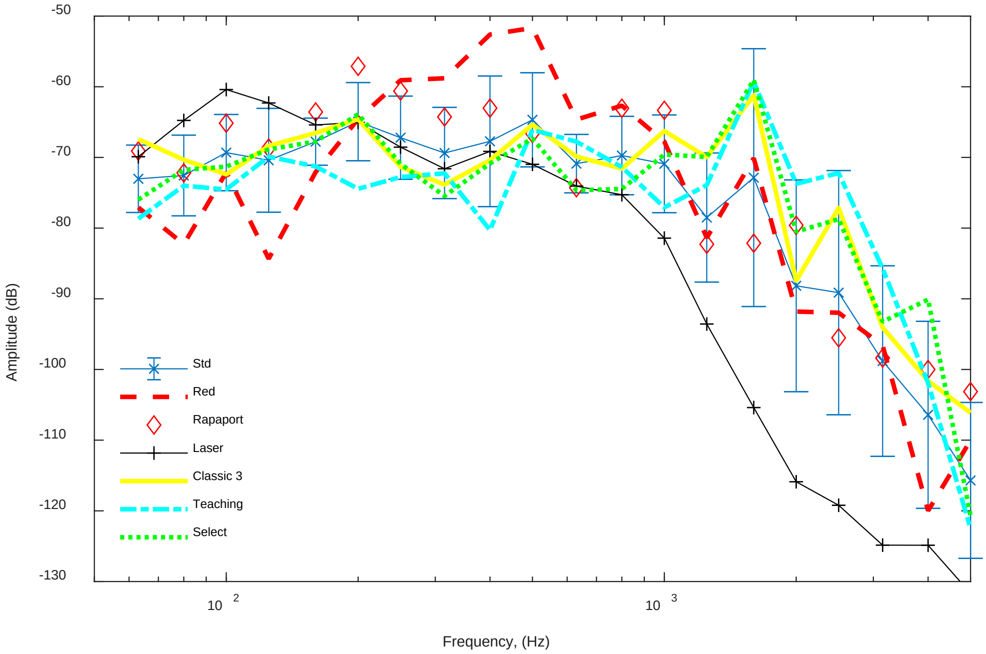

Figure 8. The averaged amplitudes of the measured responses from the five mechanical stethoscopes and laser Doppler Vibrometer, including the mean values with the standard deviation values (Std), given as a function of frequency for participant 2.

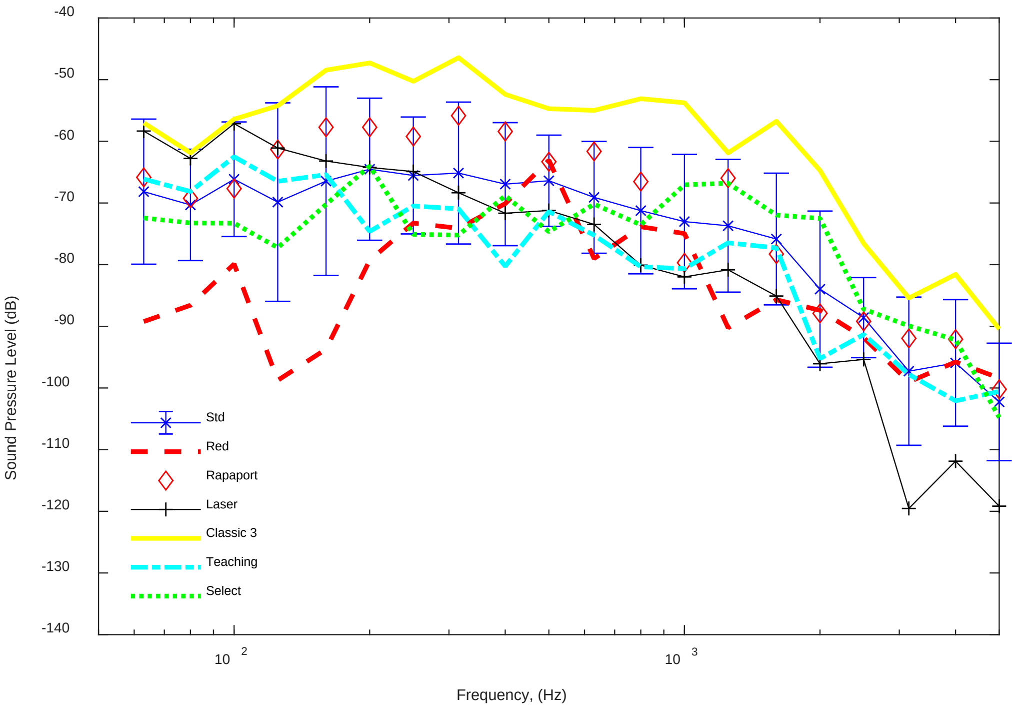

Figure 9. The averaged amplitudes of the measured responses from the five mechanical stethoscopes and laser Doppler Vibrometer, including the mean values with the standard deviation values (Std), given as a function of frequency for participant 3.

5. Conclusion and further work

An investigation has been carried out to analyse tracheal sounds detected using both a variety of stethoscopes and a Laser Doppler Vibrometer. The results show that mechanical stethoscopes are not reliable tools to monitor lungs sounds consistently. The sounds detected with stethoscopes are very different in terms of amplitude and wave shape over the frequency range of interest. The analysis of lung sounds by clinical practitioners is limited to their experience and auditory capabilities. The LDV is a new and non-contact technique for monitoring appropriate lung sounds, but it needs to be improved to be suitable for use in a clinical environment.

The quality of the materials used for making the parts of the stethoscopes effects the sound signals detected from the lungs. There are not any international standards suggesting what the parts of the stethoscope should be made of. Materials that are used to make the parts should be categorised based on their sound transmission quality. If the stethoscopes are standardised, then they could give same response to a fixed force that is applied to them.

There is a need for low-cost, small, and non-contact smart devices to provide clinical practitioners with much more detailed information than traditional stethoscopes but without the need for cumbersome and expensive sensor deployment. Smartphone-based systems to detect and analyse complex lung sounds with the aim of providing early diagnosis of respiratory diseases should be investigated and developed. Early diagnosis of lung conditions could significantly reduce the overall long-term treatment costs by reducing admissions to hospital or urgent treatment. The low anticipated costs of such a smartphone-based system compared to other technologies [5, 8, 9, 16, 17] should enable increased overall take up of this approach by clinics.

6. Acknowledgements

This work was supported by Southampton Solent University Research Internship Scheme (SURIS), and Acoustic Group of London South Bank University.

7. References

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