Buenos Aires – 5 to 9 September, 2016
Acoustics for the 21st Century…

PROCEEDINGS of the 22nd International Congress on Acoustics

Biomedical Acoustics: Paper ICA2016-405

On the relation between pressure applied to the chest piece of a stethoscope and parameters of the transmitted bioacoustic signals

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Abstract

The force with which the chest piece of a stethoscope is pressed against the body of a patient during an auscultation examination introduces the initial stress and deformation to the diaphragm and the underlying tissues, thus altering the acoustic parameters of the sound transmission path. If the examination is performed by an experienced physician, he will intuitively adjust the amount of the force in order to achieve the optimal quality of the heard sound. However, in case of becoming increasingly popular auto-diagnosis and telemedicine auscultation devices with no instant feedback mechanisms which could perform such an adjustment procedure, the question arises regarding the influence of the possible force mismatch on the parameters of the recorded signal. The present study describes the results of the experimental investigations on the relation between pressure applied to the chestpiece of a stethoscope and parameters of the transmitted bioacoustic signals. The experiments were carried out using acoustic and electronic stethoscopes connected to the developed and constructed force measurement system, which allowed to maintain a given value of the applied pressure during auscultation examinations. The signals were recorded during examinations of different volunteers, at various auscultation sites. The obtained results reveal strong individual and auscultation-site variability. It is concluded that the underlying tissue deformation is the primary factor that alters the parameters of the recorded signals. It is shown, that in certain cases applying too light or too firm pressure to the chest piece may result in significant decrease of specific frequency components. Possibilities of developing universal force control algorithms without feedback mechanisms are discussed.

Keywords: stethoscope, auscultation, chestpiece

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1 Introduction

The auscultation is one of the most important part of medical examination. Pressure applied to the patient's body by a chest piece of a stethoscope causes the initial stress and deformation to the diaphragm and underlying tissues. In consequence it leads to altering the acoustic parameters of the sound transmission path. The diaphragms of the stethoscopes are claimed to introduce high-pass filtering effects ("the diaphragm mode") when pressed more firmly to the body of a patient. This feature is supposed to be achieved with a thin, round inset below the diaphragm, close to the edge of the chest piece. When more pressure is applied, the diaphragm becomes in contact with the inset, and its acoustic properties are altered [1]. If the chest piece of a stethoscope is pressed lightly against the body of a patient the low-pass filtering effect ("the bell mode") is claimed to occur. Such technology is referred to as the "tunable diaphragm" or "dual-frequency diaphragm" and it is often encountered in many stethoscope models. The manufacturers of the stethoscopes often call it as switching between bell and diaphragm modes. The "tunable diaphragm effect" was tested in two healthy volunteers (male and female) [2]. The mentioned effect was found only in female volunteer but impaired acoustic coupling was shown at the same time. Occurring of "tunable effect" only in females may be due to the fact that deformation of the underlying tissues play a more important role than deformation of the diaphragm itself. According to the study performed by Zimmermann a high pressure applied to the skin will stretch it similar to a drum skin and as a result lower frequencies will be attenuated [3]. In contrast the frequency range can be broadened by a lighter pressure [3]. Although in electronic stethoscopes there is no "tunable effect" described, the pressure applied to the chest piece during the patient's auscultation may also influence the quality of the acoustic signal.

The number of the auto-diagnosis and the telemedicine auscultation devices are increasing every year [4,5]. On the market there are available tele-auscultation systems without earpieces. During an auscultation examination a physician instinctively adjusts the pressure of a chest piece in order to achieve the optimal quality of the heard sound. However performing an auscultation by unqualified person without instant feedback mechanisms which could perform such an adjustment procedure, the parameters of the recorded signal may not be efficient enough for a remote doctor to analyse and to identify a disease. The present study describes the results of the experimental investigations on the relation between pressure applied to the chestpiece of a stethoscope and parameters of the transmitted bioacoustic signals. Both acoustic and electronic stethoscopes were tested in healthy volunteers for different auscultation sites of heart and lungs.

2 Methods

The experiments conducted within the framework of the present study involved the auscultation examinations of different, healthy volunteers (men and women), performed using a various kinds of stethoscopes. Three popular acoustic stethoscopes (Littmann Classic II SE, Master Classic and Littmann Select) and one electronic stethoscope (Littmann 3200) were used. The acoustic stethoscopes were equipped with an electret microphone capsule (Panasonic WM-61) placed either inside the earpiece or in the hollow tube, close to chest piece. The microphone was connected to the audio recorder (ZOOM H2N) in order to record the auscultation signals. The sounds from the electronic stethoscope were recorded to its internal memory.

All the auscultation examinations were performed by an experienced physician. The pressure applied to the chest piece during the examinations was measured either subjectively or objectively. In the first case, the physician was asked to press the chest piece either with light or firm pressure. Such procedure is consistent with instructions provided by the stethoscope manufacturers. In the latter case, a custom built force measurement system was used. The system used a strain gauge sensor attached to the chest piece and electrically connected to the meter with a display. The display allowed the physician to continuously control the applied pressure. The sensitivity and resolution of the measurement system was equal 1 g, however, due to the fact that the stethoscope was operated manually under the conditions typical to the true auscultation procedure, the actual accuracy achievable to maintain was approx. +- 50 g related to the setpoint.

The constructed measurement system used for some of the experimental investigations described in the present study is presented in Fig.1. All the key components of the system are clearly visible: the chestpiece of an acoustic stethoscope (eg. Littmann Select) with attached strain gauge sensor and electret microphone capsule inside its hollow tube; acoustic recorder; force meter with a display and headphones for acoustic feedback during the auscultation.

The analysis of the recorded auscultation signals was performed in several subsequent steps. First, from each of the audio files recorded during the single auscultation procedure parts defined as “acoustic events” were extracted and saved in separate audio files. In case of heart auscultation, a single acoustic event was defined as a 0,7 second long sequence including both S1 and S2 tones. In case of lung auscultation, the acoustic event was a 1. second long audio fragment containing breath sounds – alternately inhale and exhale sounds. Fragments containing noise or other, unwanted sounds were rejected at this stage of the procedure. Afterwards, for each fragment a number of FFT transforms were computed, using 8192 samples long rectangular windows, with 75% overlap. The computed spectra were averaged over every single acoustic event, and – eventually – over all the acoustic events consisting the considered auscultation signal.

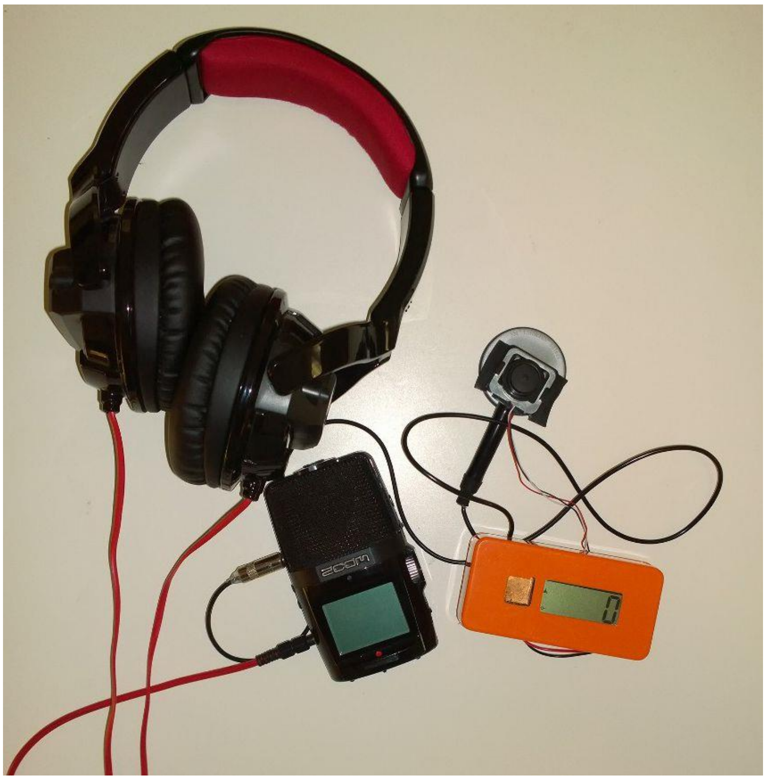

Figure 1: The measurement equipment used for some of the experimental investigations described in the present study: headphones, recorder, stethoscope chestpiece with force sensor and part of a hollow tube with installed electret microphone inside, and a meter with a display

The auscultation of heart was performed in two locations: aortic valve area (second right intercostal space, right sternal border) and Erb's Point (third left intercostal space, left sternal border). The lower posterior site was chosen for auscultation of breath sounds.

3 Results

Figs. 2 and 3 present the comparison of the spectra of the heart and lung auscultation signals recorded in different, healthy volunteers using the Littmann Master Classic acoustic stethoscope (with the large diaphragm chestpiece, implementing the "tunable diaphragm" technology), for different pressures applied to the chestpiece during the auscultation. The examination was performed by an experienced physician, who was asked to apply "light" or "firm" pressure.

Figs. 4 and 5 present the comparison of spectra of the heart auscultation signals (recorded at aortic and Erb's sites) of a single male and female volunteers. The signals were recorded using the Littmann Select stethoscope chestpiece with strain gauge sensor attached and electret microphone capsule placed inside the 55 mm section of a hollow tube. Three different force values were assumed – 300 g, 1500 g and 4000 g.

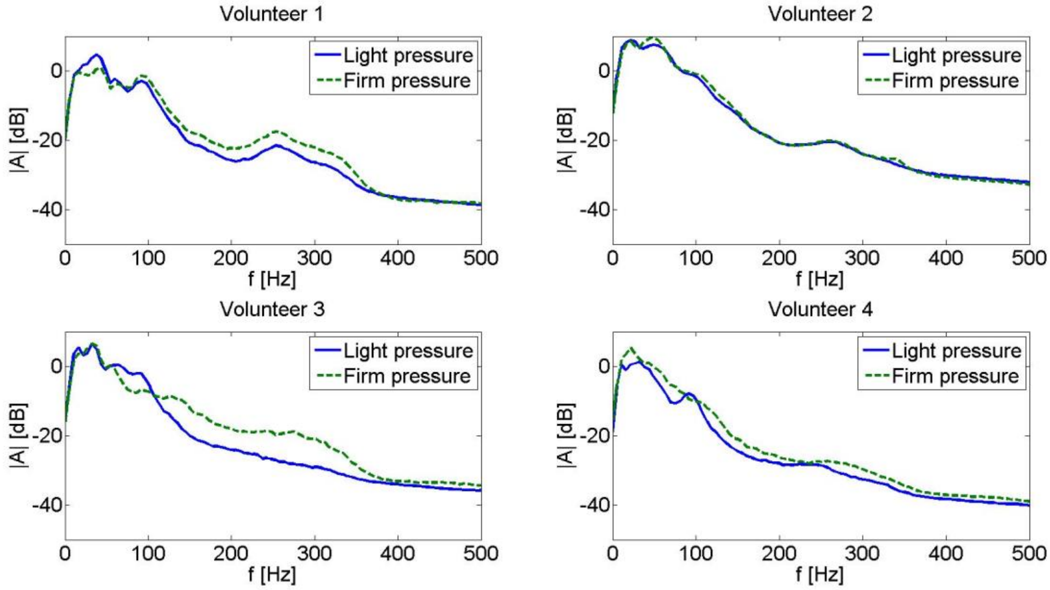

Figure 2: Comparison of the spectra of the heart auscultation signals depending on the force applied to the chest piece of the acoustic stethoscope during the examination of different volunteers (Littmann Master Classic)

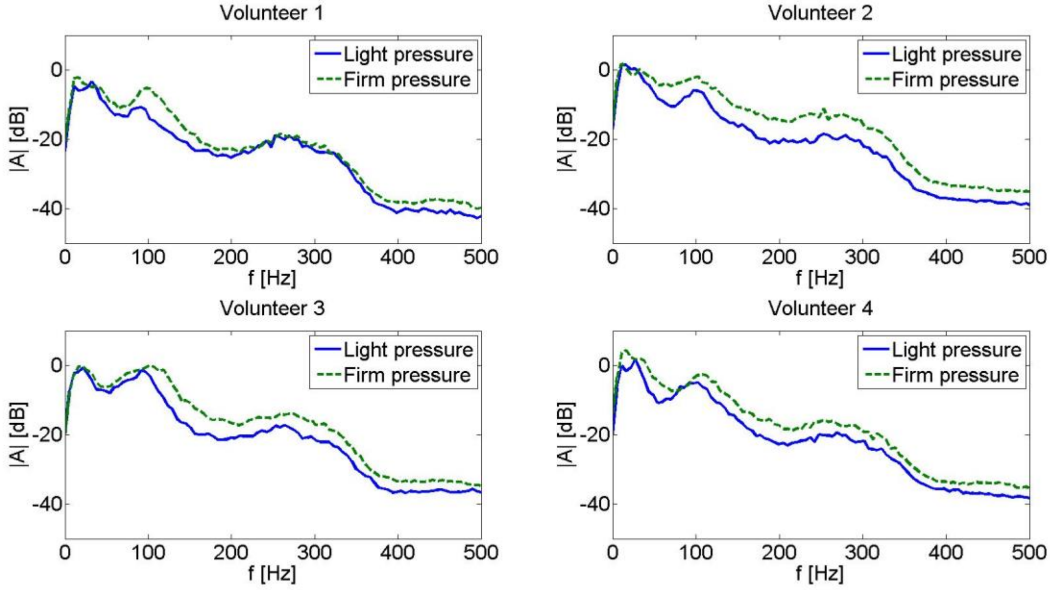

Figure 3: Comparison of the spectra of the lung auscultation signals depending on the force applied to the chest piece of the acoustic stethoscope during the examination of different volunteers (Littmann Master Classic)

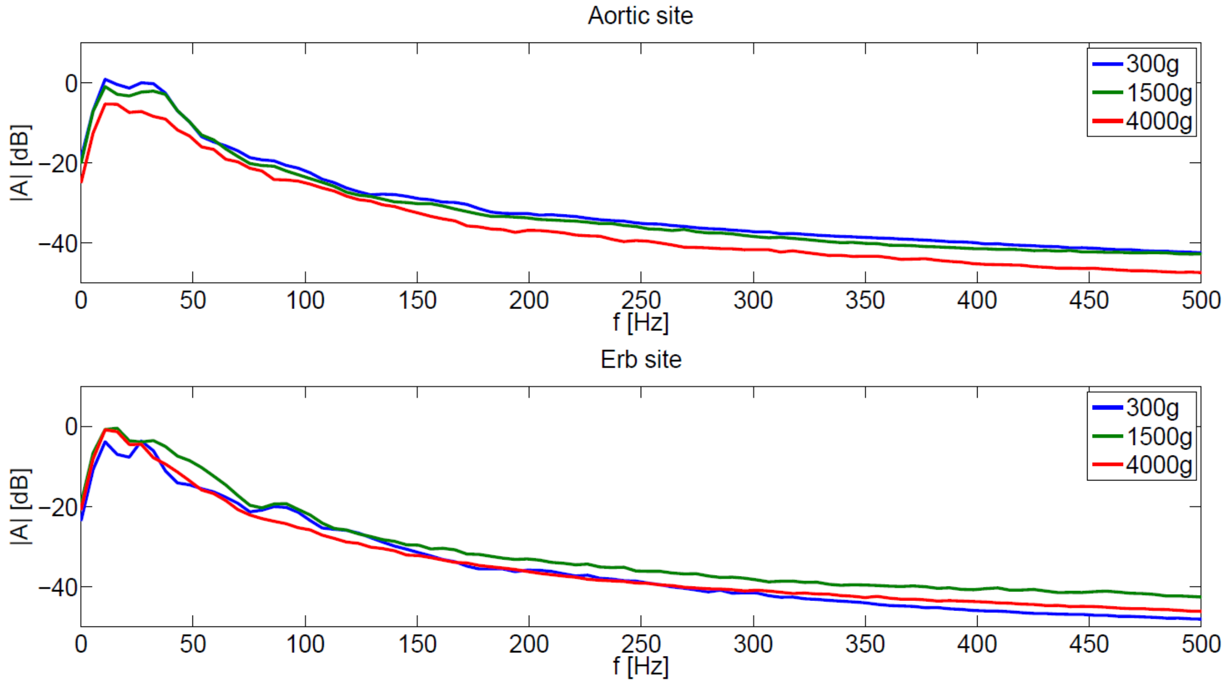

Figure 4: Comparison of the spectra of the heart auscultation signals depending on the force applied to the chest piece during the examination of a single male volunteer, at two different heart auscultation sites (Littmann Select)

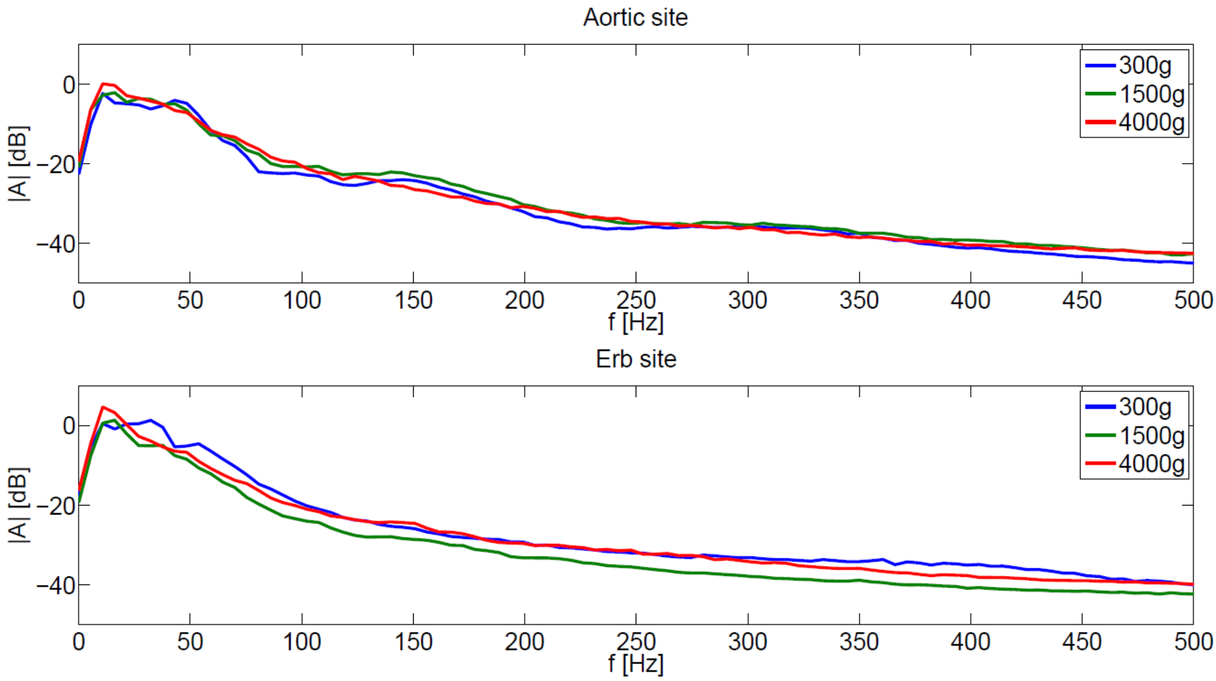

Figure 5: Comparison of the spectra of the heart auscultation signals depending on the force applied to the chest piece of the acoustic stethoscope during the examination of a single female volunteer, at two different heart auscultation sites (Littmann Select)

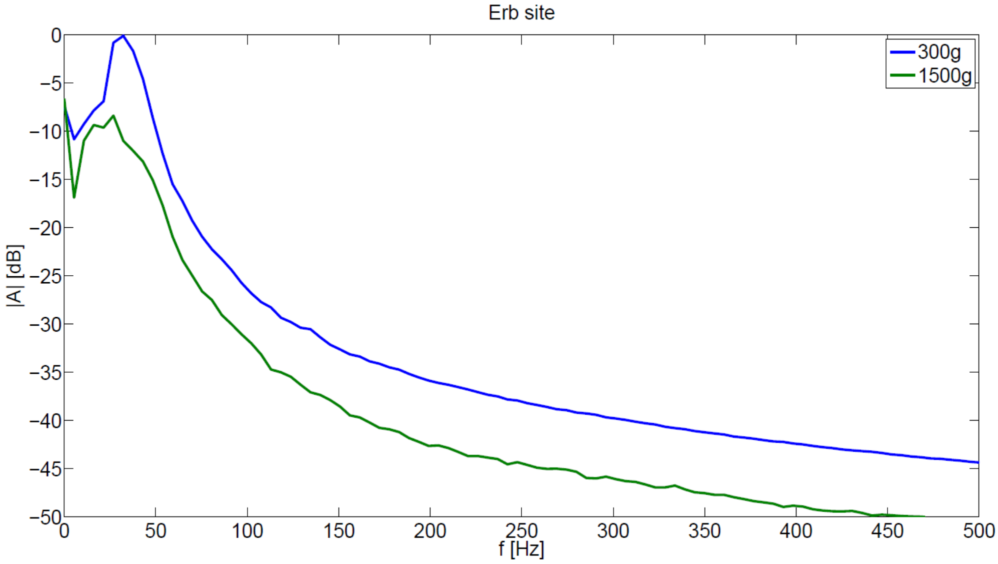

Figure 6: Comparison of the spectra of the heart auscultation signals (Erb site) depending on the force applied to the chest piece of the electronic stethoscope during the examination of a single female volunteer using electronic stethoscope with piezoelectric ceramic transducer (Littmann 3200).

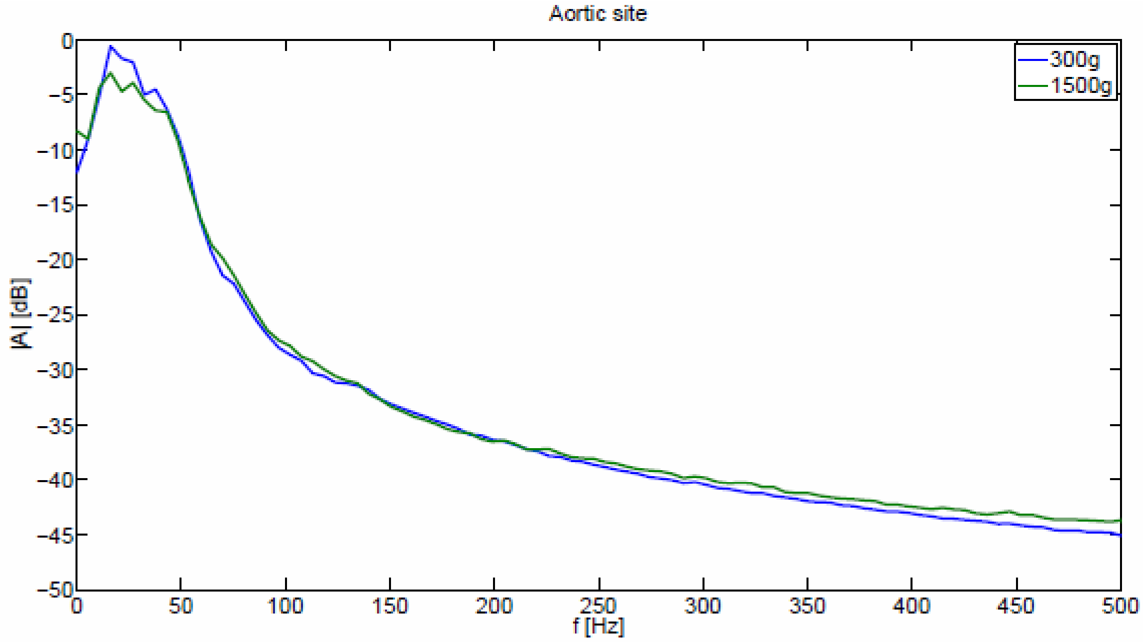

Figure 7: Comparison of the spectra of the heart auscultation signals (aortic site) depending on the force applied to the chest piece of the electronic stethoscope during the examination of a single female volunteer using electronic stethoscope with piezoelectric ceramic transducer (Littmann 3200).

The graphs presented in Fig. 6 and 7 show the spectra of signals obtained for the heart auscultation (Erb's and aortic site) of the same female volunteer, using Littmann 3200 electronic stethoscope. The construction of this stethoscope differs significantly from the construction of acoustic stethoscopes used in the previously described experiments, as instead of a diaphragm it involves a piezoceramic transducer to convert the vibrations of the surface of the skin to the electric signal. Due to fact that there is no diaphragm, there can be no "tunable effect" in electronic stethoscope used for the study. In Fig. 6 there is a noticeable difference in the amplitude spectra depending on force applied to the chest piece. This difference is no longer observable for another auscultation site.

4 Discussion

The amplitude spectra presented in Figs. 2 and Fig. 3 reveal some noticeable differences related to the applied pressure in volunteer 3 and volunteers 2, 3 and 4, respectivelly. In general, the amplitudes of the components of the recorded bioacoustic signals increased when the chest piece was pressed more firmly to the body. In most cases, this effect is emphasised in the high frequency range (above 50—100 Hz). This observation seems to confirm the "tunable diaphragm" mechanism, however, one should notice that when the pressure applied to the chest piece increases, not only the geometry and the boundary conditions of the diaphragm are altered, but the same counts for the underlying tissues.

Comparing the amplitude spectra in Figs. 4 and Fig. 5 it is clearly noticeable that amplitude and character of changes in the acoustic parameters in the function of pressure applied to the chest piece are dependent on auscultation site. They are also differently shaped in each volunteer. These observations support the hypothesis that the most impact on altering the amplitude spectra during auscultation is not dependent only on the deformation of the diaphragm itself but rather to the tissue deformation under the chest piece of the stethoscope. It can be presumed that the latter phenomenon contributes significantly to the observed effect, as the changes in the spectral component ratios with frequency vary significantly not only between different volunteers, but also between the auscultation sites.

The results for electronic stethoscope (Fig. 6) and two different force applied to the chest piece strongly reveals the differences between the amplitude spectra of the recorded signal. The light pressure of the chest piece provides a significantly higher level of all frequency components in the entire spectrum. However for another auscultation site (Fig. 7) the differences were not present. The electronic stethoscope used for the research has no diaphragm so there can be no „tunable effect". Due to the character of the piezoelectric transducer it is hypothesized that the noticeable effects result mostly from the deformation of tissues under the chest piece and their potentially better acoustic coupling.

5 Conclusions

Concerning the pressure applied to the chest piece of the stethoscope the obtained results reveal strong individual and auscultation-site variability. This phenomenon is complex in which probably the major role in altering the parameters of the recorded signals plays the deformation of underlying tissues rather than the diaphragm itself. In the presented study authors did not observe any effects that can confirm the "tunable effect" of the diaphragm declared by the stethoscopes manufacturers. The differences in amplitude spectrum was also noticeable in the electronic stethoscope (without diaphragm) what seem to confirm the mentioned hypothesis. In certain cases applying too light or too firm pressure to the chest piece may result in significant decrease of specific frequency components.

The observed effect may be crucial in telemedicine and auto-diagnostic systems when a patient does self-auscultation. Without experience or instant feedback mechanisms about the amount of force applied to the chest piece the quality of the heard sound may be too poor for a remote doctor to identify a disease.

The solution for such systems cannot be universal force measurement algorithms because as was shown it the presented study, the acoustic parameters of obtained signals present variability between individuals and auscultation sites. It seems necessary to implement the algorithms for analyzing the collected real-time signal and providing feedback for user, enabling him to maintain a stethoscope chest piece in a proper manner during auscultation. These algorithms can be based, for example, on the characteristic parts of the signal, e.g. heart or respiratory sounds. In any case an adjustment procedure for the pressure of a chest piece would be helpful and in order to achieve the optimal quality of the heard sounds.

Acknowledgments

The authors would like to acknowledge the financial support from the Polish National Centre for Research and Development (NCBiR), grant no. LIDER/034/037/L-5/13/NCBR/2014

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