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Discovering new facts and revealing existing myths about the acoustic stethoscope 200 years after its invention

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Abstract

Acoustic stethoscope, invented exactly 200 years ago by French physician, Rene Laennec, is the most widespread medical diagnostic device, and also the icon of the medical profession. Hence, it might seem strange, that the mechanisms and physical phenomena underlying the auscultation examination are still not well understood, and some of the commonly repeated statements – such as those regarding high- or low-pass filtering effects supposedly introduced by specific kinds of chestpieces – have no scientific justification. The present study introduces results of the experimental investigations on the different factors influencing the acoustic properties of a stethoscope. Unlike other studies which were based either on subjective evaluation of sound quality or on measurements of the transfer functions performed using loudspeakers as the primary sound source, the investigations described herein were based on original experimental and data analysis schemes, which allowed to quantitatively evaluate the parameters of signals recorded during the actual auscultation examinations. Results obtained using various kinds of chestpieces and different lengths of the hollow tubes are compared in order to expose the factors which have the greatest impact on the perceived sound quality. It is shown, that the parameters and the construction of the chestpiece determine the achievable sound level, while the hollow tubes act as an acoustic filter. This contradicts the statements repeated in the literature for over 50. years, about the highly frequency-selective behaviour of the diaphragms of the stethoscopes.

Keywords: stethoscope, auscultation

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1 Introduction

The basic assumptions concerning the construction and theory of operation of modern acoustic stethoscopes were formulated by an American cardiologist and researcher, David Littmann, in 1960s and 1970s [1]-[5]. His theses were in many points based on the ideas and results presented earlier by other investigators (see, for instance, [6]-[10]). Littmann postulated, among other things, that the head of a stethoscope should include a smaller, open chestpiece (referred to as the "bell") and a larger one, closed with a diaphragm. Both elements should have minimum possible internal volume, in order to minimize the acoustic damping. He concluded, that the open chestpiece should better transmit lower frequencies, due to the lower natural resonances. He also stated, that the stiff or stretched membrane will attenuate lower-pitched sounds and thus better transmit higher frequencies[1]. These statements are commonly repeated in the literature ever since.

The acoustic stethoscopes are still the most commonly used diagnostic equipment in medical practice, thanks to their low cost, high mobility, ease of use and maintenance-free operation. And even though the giant leap in diagnostic technology since the 60s and availability of various types of electronic stethoscopes, nothing indicates that the current state of affairs was subject to change in the nearest future. Various modifications were proposed and implemented since the days of Littmann (see, for instance, [11]-[13]), but none of them were comparably revolutionary. In many models of modern acoustic stethoscopes the head is no longer divided into two separate parts, leaving only a single chestpiece with a diaphragm. Such an approach is consistent with results presented by Welsby et al.[14], which undermine the use of the bell chestpiece in auscultation. Different manufacturers are using various kinds of diaphragms. Information about the advances of the specific solutions can be found in the advertising materials, however, due to the fact that no objective, supporting data are presented, it is unclear, how reliable they are.

Many different studies on sound quality provided by various models of acoustic stethoscopes are available in the literature. However, none of the experimental schemes presented so far allow to obtain objective and quantitative data that could be used to evaluate the actual role and function of the diaphragm on the parameters of acoustic signal during auscultation of a patient. Most of the described studies are based either on subjective evaluation of acoustic properties of the stethoscopes or on laboratory measurements of the acoustic transfer function. The chestpiece in such measurements is coupled with an artificial sound source via an air- or water-filled coupling chamber, and the data are obtained with microphones placed in the earpieces[14]-[16]. The former case does not provide any objective information regarding the stethoscope, while the results of the latter cannot be in fact extrapolated to the case of actual patient auscultation. The mechanical behaviour (and, consequently, acoustic properties) of a diaphragm placed in a coupling chamber do not have anything in common with behaviour of the same diaphragm in contact with a body of a patient. Some of the data available in the literature, based on the measurements of the transfer function of a stethoscope with the chestpiece placed over a speaker and a microphone placed in the earpiece, indicate that the diaphragm introduces damping of over 30 dB to the low frequency signal components (of frequencies below 100 Hz) compared to the bell-type chestpiece[17]. Even despite the fact that such a conclusion stands in clear contradiction to the everyday clinical observations, it is widely repeated in the literature ever since without any proper experimental validation[18][19].

The aim of the present study is to introduce the methods for objective evaluation of the acoustic properties of the chestpieces in the modern acoustic stethoscopes, as well as the exemplary results of such an evaluation concerning several different chestpieces. The introduced methods include both the experimental and data analysis schemes. All the measurements involve the actual auscultation examinations performed by a trained physician. Thus, the obtained results reflect the true acoustic behaviour of the considered patient-stethoscope system..

2 Methods

The measurements concerning the acoustic influence of the different types of chestpieces were carried out using the 3M Littmann Classic II S.E. acoustic stethoscope. It is equipped with a dual chestpiece comprising a large, 44 mm diaphragm and a 33 mm bell. The bell can also be closed with a smaller, 33 mm diaphragm. Thus, the selected stethoscope model allowed to investigate three different, representative cases. The acoustic signal from the stethoscope was recorded using a Panasonic WM-61A electret microphone capsule placed in the one of the earpieces. The second earpiece was closed with a plug. The microphone was connected to the input of a ZOOM H2N audio recorder. The gain of the recorder was held constant during all the measurements performed on a single volunteer at a single auscultation site.

The influence of the length of the hollow tubes on the parameters of the acoustic signal transmitted through the stethoscope was investigated using two Littmann Select stethoscopes. This model is equipped with a single chestpiece in the form of a 44 mm diaphragm. In one of the stethoscopes the hollow tube was cut approx. 55 mm after the chestpiece, and the electret microphone capsule was placed inside. In the second stethoscope, the microphone was placed in the ear piece

The acoustic signals were recorded during the heart and lungs auscultation examinations of the healthy volunteers. All the examinations were carried out by an experienced physician. For each volunteer and each auscultation site four different measurements were taken, using various investigated types of the chestpieces: the large diaphragm, the bell, the small diaphragm and the large diaphragm pressed firmly to the body. All the signals were recorded with 44,1 kHz sampling rate and 16. bit resolution.

A dedicated data analysis procedure was developed in order to evaluate the acoustic properties of the investigated chestpieces. A number of 30 to 50 acoustic events were extracted from each of the recordings. In case of the heart auscultation an acoustic event was assumed to be a 0,7 second long sequence containing a single heartbeat signal. In case of the lung auscultation the acoustic event was defined as a 1 second long respiratory sound. All the signals with noise (which could be the result of, for instance, other unwanted body sounds) were removed at this stage.

The spectral analysis was performed independently for each of the acoustic events and the results were averaged for each of the recordings, corresponding to the specific volunteer and the auscultation site.

3 Results

Figs. 1 and 2 present the comparison of the spectra of the heart and lung auscultation signals recorded in different volunteers using the three different types of chestpieces. Figs. 3 and 4 present the analogous spectra comparison obtained using the two Littmann Select stethocopes with different lengths of the hollow tubes.

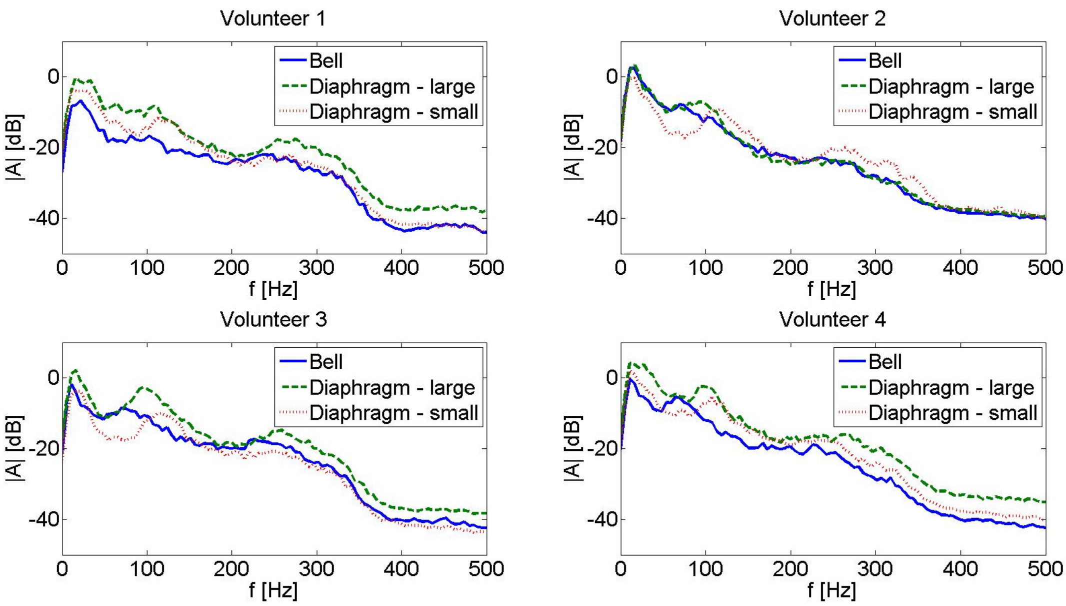

Figure 1: Comparison of the spectra of the lung auscultation signals obtained with various chestpieces in different volunteers.

The differences in the obtained spectra are clearly visible, as well as some features common to all the presented cases. Maximum acoustic energy of the recorded signals is concentrated in the low frequency band (below approx. 200 Hz). Above approx. 500 Hz the amplitude of the frequency components decreases at a rate of about 6 dB per octave (Figs. 3 and 4).

One of the aims of the present study was to determine, whether different types of chest pieces actually act as low- or high-pass filters, as stated by the stethoscope manufacturers. The results presented in Figs. 1 and 2 clearly indicate, that such a statement is far from the truth under the conditions of the actual auscultation examinations. If the specific types of the chest pieces would actually act as acoustic filters, the significant differences in ratios of the amplitudes of the spectral components obtained for different chest pieces in low- and high-frequency range

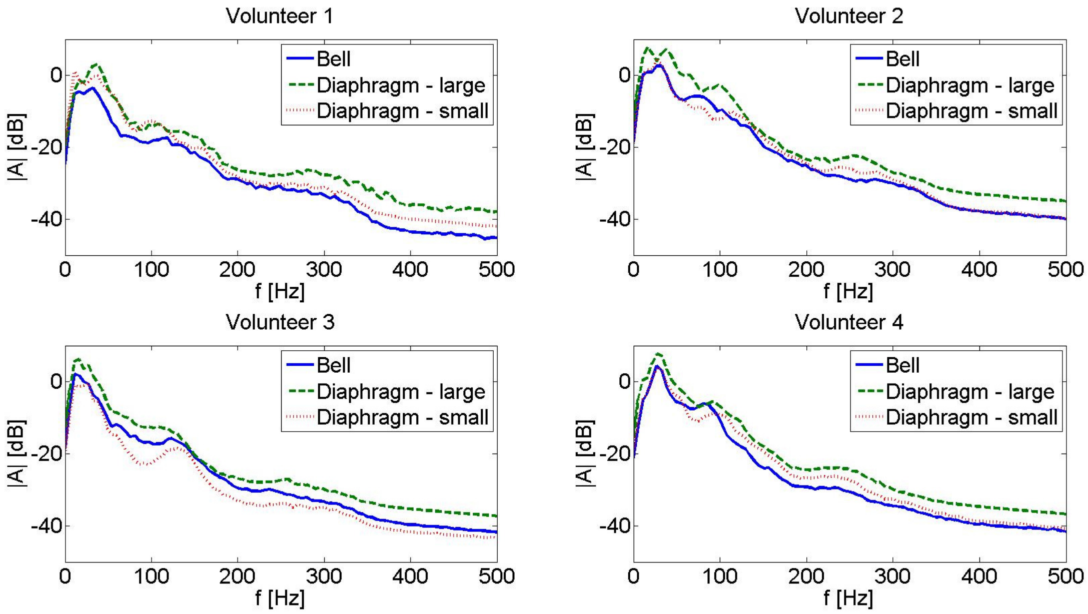

Figure 2: Comparison of the spectra of the heart auscultation signals obtained with various chestpieces in different volunteers.

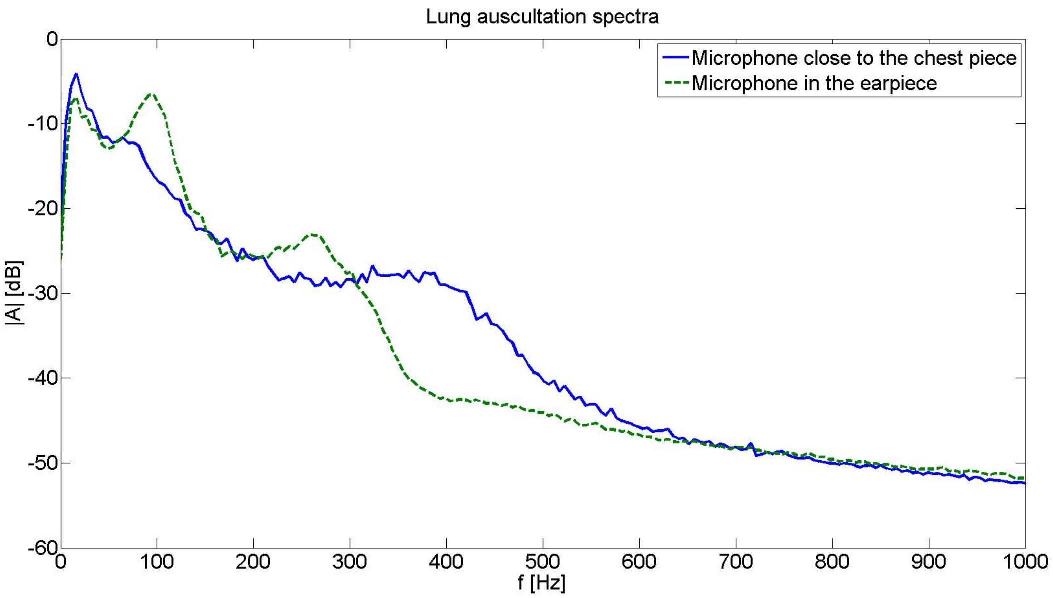

Figure 3: Comparison of the spectra of the lung auscultation signals obtained with various lengths of the hollow tubes.

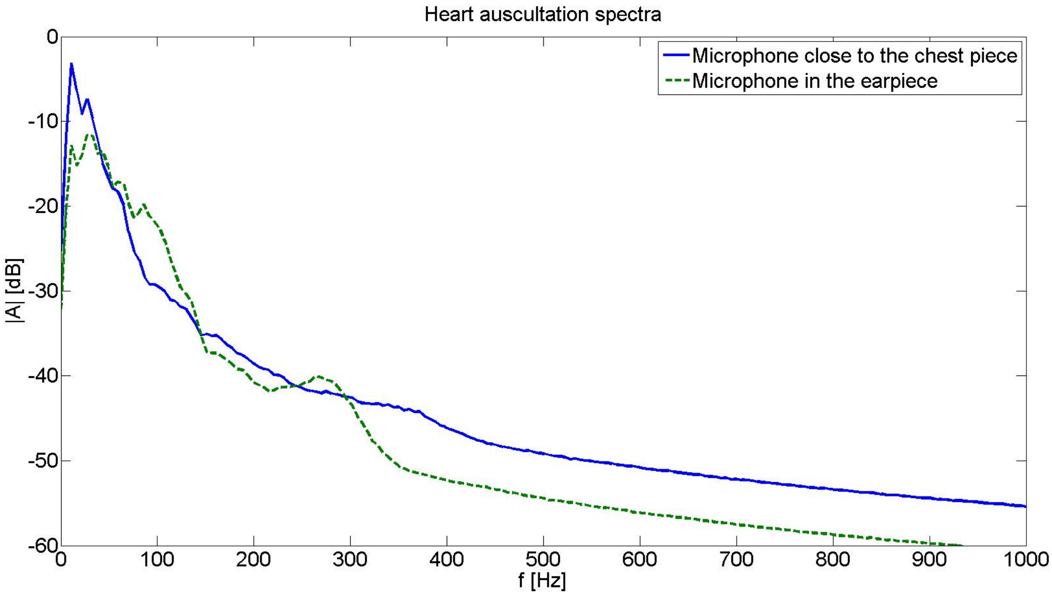

Figure 4: Comparison of the spectra of the heart auscultation signals obtained with various lengths of the hollow tubes.

should be observed. Specifically, accordingly to the data available in the literature[1],[15]-[17], the amplitudes of the spectral components of the signals recorded using the bell chest piece should be greater than the corresponding amplitudes of the signals obtained using the diaphragms in the low frequency range, and lower than them in the high-frequency range. Such effects are not observed. In general, the large diaphragm ensures the highest amplitude levels, which is due to the fact, that it has significantly larger surface than the bell/small diaphragm chest piece. The results obtained using the bell chest peace reveal in fact the worst overall acoustic performance. The presented results are representative and consistent, with some minor differences resulting from the individual anatomical variation in the examined volunteers.

The comparison of spectral components of the signals recorded close to the chestpiece and in the earpiece of the stethoscope during heart and lung auscultation (Figs. 3 and 4) allows to notice some important differences. The signal recorded close to the chestpiece has slightly higher overall level, with exception of several specific frequency regions, namely close to about 90 Hz and 270 Hz. Those would correspond to the resonant frequencies of a closed cylinder with a length of about 1 meter. The length of the hollow tubes in the considered stethoscope is equal approx. 71 cm, which is significantly less. Thus, the influence of the length of the hollow tubes on the parameters of the recorded signal is clearly visible, however the observed resonant frequencies cannot be simply computed from the basic cylinder resonator model. Those differences probably result from the introduced damping and more complex internal structure of the signal path in an acoustic stethoscope.

4 Conclusions

The analysis of the bioacoustic signals recorded using various types of chest pieces attached to the same stethoscope model did not confirmed neither low-frequency amplification introduced by the bell, nor the high-pass filtering effects introduced by the diaphragms. It has been shown, that the chest piece with a large diaphragm ensures the best acoustic performance in the whole frequency band, regardless of the auscultation site, and that its frequency response might be slightly altered by changing the applied pressure. Thus, from an objective, acoustical point of view, there are no arguments for using the bell type chest pieces in the auscultation examinations. It has also been shown, that the hollow tubes of an acoustic stethoscope introduce selective boost to the specific frequency regions, connected with its resonant frequencies. Thus, the length of the hollow tubes of a stethoscope has significant influence on the acoustic parameters of the whole device.

Acknowledgments

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