FRONTLINE

Phonocardiography with a smartphone

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When a stethoscope is placed on the chest over the heart, sounds coming from the heart can be directly heard. These sound vibrations can be captured through a microphone and the electrical signals from the transducer can be processed and plotted in a phonocardiogram. Students can easily use a microphone and smartphone to capture and analyse characteristic heart sounds. Since smartphones are commonplace and require only inexpensive supplementary equipment, the experiments can be carried out by the students themselves. This allows for the separation of the class into small groups and into experimental homework assignments, so that the students can carry out measurements with less ambient noise.

1. Heart sounds
During the cardiac cycle, the heart produces rhythmic sounds. The major components of cardiac sounds are associated with the abrupt acceleration or deceleration of blood in the cardiovascular system [1]. The most fundamental and easily recognized heart sounds are defined as the first heart sound $S_1$ and the second heart sound $S_2$ (see figure 1). The first heart sound occurs at the beginning of ventricular contraction in the frequency range of 10–180 Hz, with duration: 0.12–0.15 s. The shorter second heart sound arises at the end of the ejection phase of the systole and is related to the closure of the aortic and pulmonary valves; this sound occurs in the frequency range of 50–250 Hz, with duration: 0.08–0.12 s [2, 3].

In figure 1, the first and the second sounds appear clearly in the phonocardiogram of a healthy heart, but it is difficult to identify them in the second graph, which charts abnormal cardiac sounds, because they are partly obscured by an additional signal.
2. Stethoscope acoustics

Common stethoscopes have a dual-head chest piece consisting of a diaphragm (plastic disc) and a bell (hollow cup), see figure 2. If the diaphragm is placed on the patient, bodily sounds cause vibrations of the diaphragm, leading to acoustic pressure waves that propagate along a hollow tube to the listener’s ears. If the bell is used, the skin functions as a membrane and the vibrations of the skin directly produce acoustic pressure waves. The two attachments differ in the frequency range over which they efficiently transmit sound along the tube: while the diaphragm transmits higher pitched sounds more efficiently, the bell is better suited to the transmission of lower-pitched sounds [5, 6].

The choice of tube length and internal diameter of a stethoscope (ca. 60 cm and 3 mm respectively) involves a compromise of several characteristics: first, the volume of the tubes should be small, to ensure large pressure changes with the motion of the membrane or the skin, when the bell is used). On the other hand, small tube diameters also increase air friction, which reduces the range of pressure modulation.

Figure 2. A traditional stethoscope along with the five main areas for heart auscultation. For simultaneous observation of S1 and S2 sounds, position 2 is the best choice [4].

Figure 3. Three detection methods: heart sounds are captured (a) after transmission through the tube or (b) by a microphone that is placed close to the bell. In either of these cases, the bell is made from a piece of bicycle inner tube with the valve hole covered by a union nut of ca. 3 cm diameter and 1 cm depth. Finally, (c) a headset microphone is covered with double-sided adhesive tape.
3. Low-cost phonocardiography

Electronic stethoscopes convert sound into electrical signals. This permits a great deal of functionality, including amplification, storage, analysis and visual representation of heart sounds. Electronic filters and noise reduction make the tube obsolete as an acoustic apparatus. Thus, sound can be detected most easily by simply placing a microphone in the chest piece [7]. The bell and the microphone work together to capture sound waves and to convert them into an electrical signal. The microphone is situated inside the flexible tubing at the end of the acoustic pathway, or close to the bell. The microphone must be compatible with the device used and should have good response characteristics for low frequency sounds, preferably from as low as 20 Hz upwards.

When using usual headsets, the microphone can easily be attached to the bell, by means of a piece of double-sided adhesive tape with a hole at the centre (see figure 3(c)).

Figure 4. Phonocardiogram and corresponding spectrogram obtained with an iPhone 5, a microphone at the end of a tube, and the Stethoscope app\(^1\) as displayed on screen and (b) as exported for further analysis. The green curve (1) shows the sound amplitude over a 3 second interval. Additionally, the frequency spectrum in the range from 0 Hz to 500 Hz is shown in false colours (2); red implies high intensity of a distinct frequency. In class, special attention should be paid to the lack of axes in both representations and to the lack of scale inscriptions in the screen representation.

\(^1\) The stethoscope app may be obtained for free at itunes.apple.com/\~gb/app/id346239083.
4. Results

The first and second heart sounds appear clearly in the phonocardiogram shown in figure 4. The amplitudes of these sounds depend on the position of the chest piece. The heart rate can be determined and probable arrhythmia can be detected. In general, several factors complicate sound collection. Varying heart rhythms, background noise, respiratory sounds, and noises produced by shifting the stethoscope head on the skin all contribute to the difficulty in isolating cardiac sounds, which are generally low-intensity signals. For this reason, all efforts should be made to maximize the signal and minimize acoustic and electrical noise. Furthermore, improving and testing different options for stethoscopes promotes greater understanding of acoustics.

Note that the devices presented here are only for understanding the underlying physics concepts, and should not be used for medical diagnosis. Noise signals make it difficult for an inexperienced user to distinguish between normal and abnormal cardiac sounds. Nevertheless, the use of new intelligent mobile devices in the field of auscultation is actually a current research topic in several European research projects [8–10]. A thorough review of state-of-the-art products and smartphone stethoscope apps can be found in the literature [7].

References


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