The Chest is a Significant Collector of Ambient Noise in Heart Sound Recordings

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Abstract

Weak murmurs related to coronary artery disease might be masked in ambient noise when heart sounds are recorded in clinical settings. The aim of the current study was to characterize the influx of ambient noise through the chest and through the microphone's coupler house.

To estimate the transmission through the coupler house the coupler was placed in contact with a heavy block of steel in an anechoic chamber while 100 dB(A) SPL pink noise was played as ambient noise.

The transmission through the chest pathway was measured for three males and two females. 45 seconds of heart sounds were recorded in silence in the anechoic chamber and under the presence of 100 dB pink noise. The spectrum of the noise entering the recordings was estimated by subtracting the spectrum of the heart sounds recorded in silence from the spectrum of the heart sounds recorded during 100 dB noise.

In the frequency band of interest (200-1000 Hz) the noise was attenuated 53.5 dB by the coupler house. The chest pathway amplified the noise by 6.6 dB (Std.0.9). In conclusion the ambient noise is conducted via the chest path to the microphone with a slight amplification.

1. Introduction

Auscultation is still a common and essential procedure in clinical cardiology. Computer based methods for automatic analysis of heart sounds and identification of murmurs are becoming more common both in research and in the clinic. These algorithms are often sensitive to ambient noise. The problem becomes especially apparent in algorithms for detection of the weak murmurs related to coronary artery disease (CAD).

A fast and low-cost non-invasive diagnostic method such as heart sound based detection of CAD will provide new diagnostic opportunities, since established diagnostic methods such as coronary angiography, CT and exercise tests, are costly and time consuming.

CAD is reflected in both the low frequency and high frequency (>200 Hz) parts of the heart sounds [1-5]. At higher frequencies CAD cause an increase in energy of the diastolic hearts sound [2,6-8]. This increase is generally associated with weak murmurs caused by post-stenotic turbulence in the coronary arteries. These studies were mostly done in sound proof rooms or in other low noise settings, but in the clinic these murmurs might be submerged in ambient noise [9].

A recent study has demonstrated that ambient noise in clinical settings is a major problem since this noise is included in the heart sound recordings and affects the capability to detect CAD by analysis of high frequency heart sounds [9]. The study identified three main categories of noise: 1) Ambient room noise which is the focus of the current study, 2) physiological noise 3) and recording noise, such as instrumentation noise or noise related to handling of the handheld stethoscopes.

Several studies have developed methods to handle such noise [8,10-14]. The common approach is to identify periods with noise and exclude the noisy periods before final processing.

Despite the different approaches, the pathway of the noise from environment to recording has not been studied in details and open questions still remain. For example, is noise mainly transferred through the walls of the coupler house in which the microphone is situated? Or is noise transmitted through the chest? And how well is the noise damped or otherwise influenced by this transmission?

The aim of the current study was to characterize the influx of ambient noise through the chest and through the microphone's coupler house.

2. Methods

The approach of the current study was to estimate the transfer function of the coupler house and the chest using noise with known characteristics. The transfer functions modelled in the current study describe the whole pathway from air to body, through the chest wall and to the microphone, this is termed the chest partway in the current study.

The recording situation was modelled in the frequency domain as seen in figure 1. When a recording is obtained from the chest wall in noisy surroundings the recorded sound consists of heart sounds, noise transmitted through the chest pathway, and noise transferred through the walls of the coupler house. It is important to note that the model is a simplification since the heart sound is also transferred through the chest wall. However, to lower the complexity of the study we define heart sounds as they occur at the pick-up point.

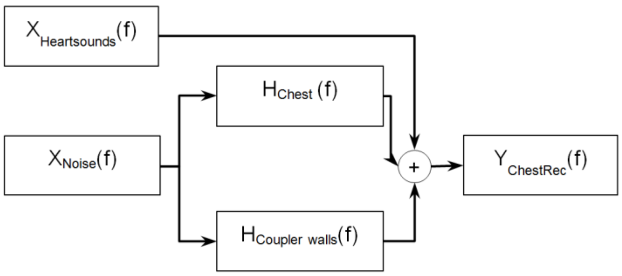

Figure 1. Model of heart sound recordings obtained in ambient noise settings.

2.1. Equipment and setup

The experiment was conducted in an in anechoic room, where the sound field is well controlled. A powerful loudspeaker (Electro-Voice S-200) was mounted above a bed. A measurement point was defined 150 cm below the loudspeaker. The bed was adjusted so that the microphone when placed on the subject's chest wall was in the measurement point, se Figure 2. The noise field was generated by electrical pink noise adjusted to 100 dB(A) SPL in the measurement point using a handheld sound level meter.

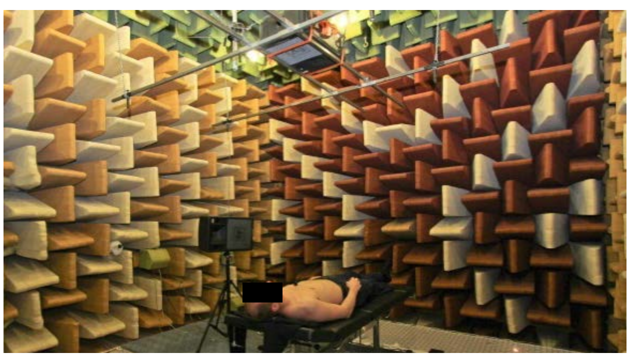

Figure 2. Photograph of the experimental setup.

The sensor used for recording of heart sounds and noise was an air-coupled G.R.A.S 40AD microphone situated into a Polyoxymethylene coupler house as illustrated in Figure 3. The sensor was attached to the skin using a double adhesive patch. Reference [15] includes more details of the transducer. The sounds were recorded using a 24 bit data acquisition system dedicated to recordings of heart sounds[16].

To quantify the spectra of the noise exposure affecting the sensor $|X_{Noi}(f)|$, the sensor was placed upside down in the measurement point with the microphone facing upward to the loudspeaker. 45 seconds of noise were recorded.

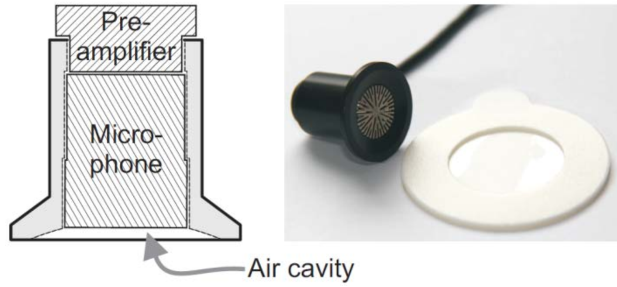

Figure 3. Sectional drawing of the microphone in the coupler house and a photo of the coupler and the patch used to attach the microphone [15].

2.2. The transfer function of the coupler house

To estimate the transmission through the walls of the coupler house the coupler was sealed to a heavy steel block, which was assumed to exclude transmission through it. 45 seconds of sound where recorded while the 100 dB(A) SPL pink noise were played. The amplitude transfer function $|H_{coupler\ walls}(f)|$ of the coupler house walls was then estimated as the ratio between the Fourier spectra of the recording from the metal block $|Y_{SteelRec}(f)|$ and the Fourier spectra of the noise $|X_{Nosie}(f)|$.

$$|H_{coupler\ walls}(f)| = \frac{|Y_{SteelRec}(f)|}{|X_{Noise}(f)|}$$

2.3. The transfer function of the chest

Five subjects, three male and two females, was included in this study. The age was 28-41 years and the BMI was 21-30. The subjects were placed on the bed in a supine position. The coupler was placed at the 4th intercostal room just left to sternum. 45 seconds of heart sounds were recorded in silence in the anechoic chamber to estimate the Fourier spectrum of the heart sounds $X_{Heart\ sound}(f)$. Furthermore 45 seconds were recorded under the presence of the 100 dB(A) SPL exposure noise. The amplitude Fourier spectra of the noise entering the recordings was estimated by subtracting the spectrum of the heart sounds recorded in silence from the spectrum of the heart sounds recorded under noise. The transfer function of the chest pathway was then estimated as

$$|H_{chest}(f)| = \frac{|Y_{Chest\ Rec}(f)| - |X_{Heart\ sound}(f)|}{|X_{Noise}(f)|} - |H_{coupler}(f)|$$

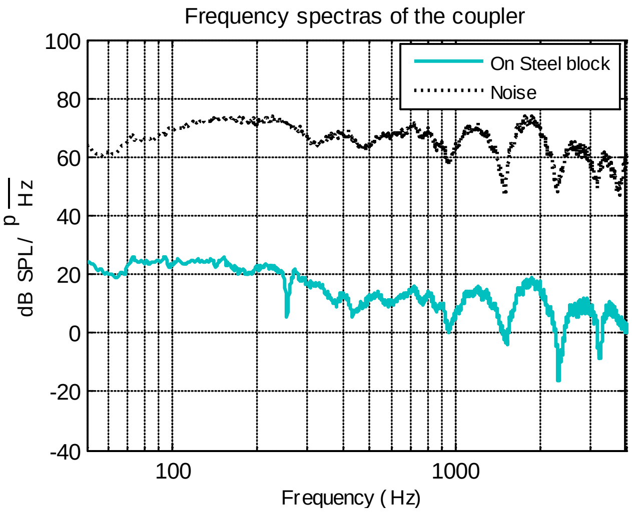

Figure 4. Power density spectrum of noise when the coupler was facing down to the steel block and when it was facing the loudspeaker.

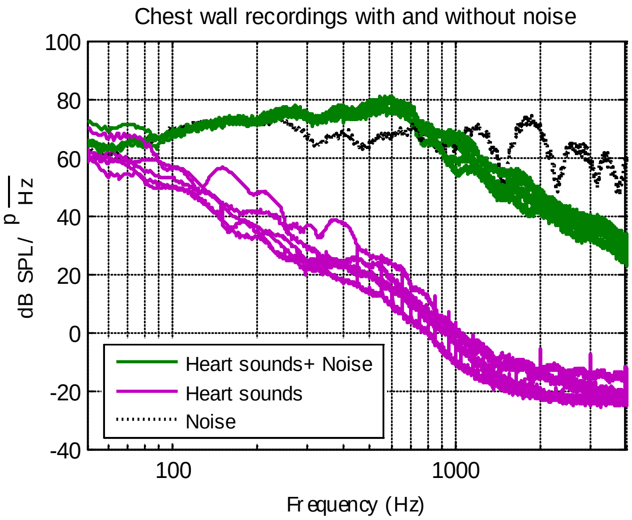

Figure 5. Power density spectrum of the chest wall recordings in silence and under the presence of noise. The spectrum of the noise from figure 4 is also plotted.

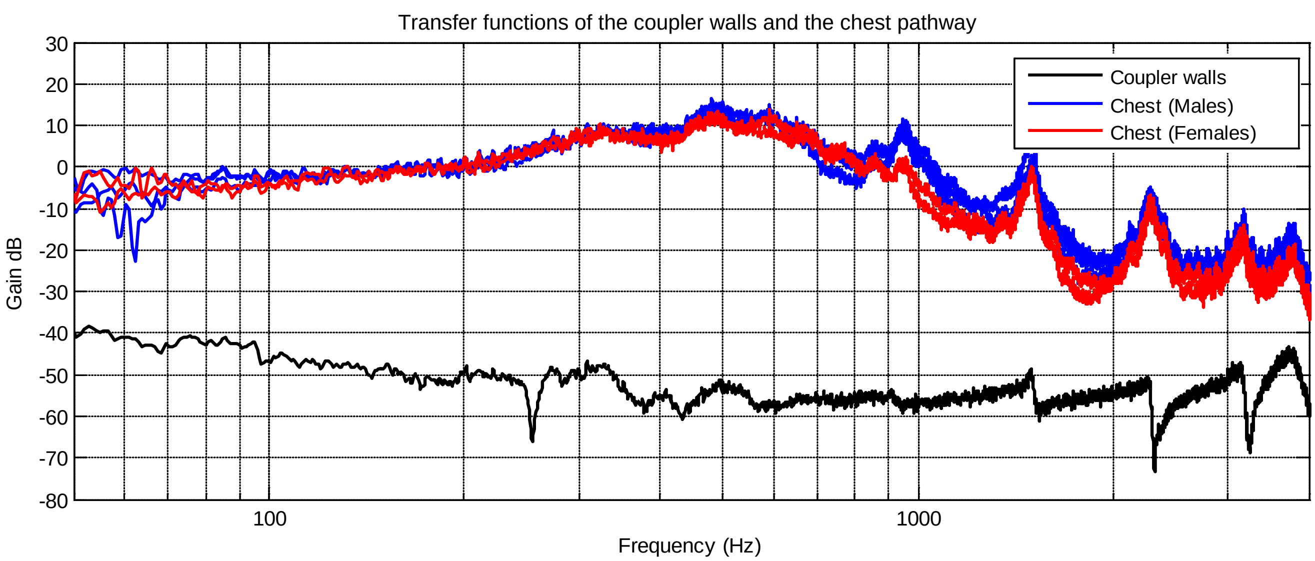

Figure 6. Transfer functions of the Coupler walls and the chest pathway in both male and female subjects.

3. Results

Figure 4 shows the power density spectrum when the microphone is facing downward on the steel block and facing upward to the loudspeaker to measure the noise exposure. In the frequency band of interest (200-1000 Hz) the noise was recorded to 96.8 dB SPL, the noise within the coupler on the steel block was 43.3 dB SPL. This corresponds to an attenuation of 53.5 dB. The powerful attenuation by the coupler walls is also evident in figure 6 where the estimated coupler house transfer function is plotted.

The power density spectra of the unpolluted heart sounds and the heart sounds recorded with noise are seen in Figure 5. In the five subjects the average sound level in the 200-1000 Hz range was 103.4 dB (Std: 0.9) after subtraction of the heart sounds. The noise recorded from the chest wall was therefore amplified with 6.6 dB on average. The same was observed in the estimated transfer functions of the chest, where an amplification of up to 10 dB was observed around 500-600 Hz see figure 6. Figure 6 discloses that the transfer functions show similar morphology across subjects, however above 700 Hz a small variation is seen and a small gender difference can be observed.

4. Discussion

The main findings are that the attenuation by the walls of the coupler house is large, and, in contrast, that the chest pathway slightly amplified the noise.

The attenuation by the coupler house is depending on the design and the material of the coupler house, but the current design is rather simple so it's expected that most designs of airtight coupler houses will result in a significant attenuation of ambient noise. The large attenuation of the coupler house makes the influx of noise through the coupler house insignificant compared to the influx through the chest.

It is surprising that the noise from 200 to 1000 Hz is amplified in the chest pathway. This means that in the air-chamber in front of the recording microphone the ambient noise will be present at a higher level as in the room.

The distinct peaks in the transfer function, was related to the drops in the noise spectrum and was probably due to the measurement setup and not the actual transfer function of the chest pathway.

In the current study the focus was the amount of noise which entered the recordings through the body. Further research should answer questions regarding the partway of noise through the body, like is noise entering through chest wall near the transducer or through the entire body?

The implications of the current findings are that the chest offers no help in suppressing ambient noise and that no performance improvements can be made by only shielding the microphone itself. Any solution for noise reduction must therefore focus on the handling or removal of ambient noise transferred through the chest pathway.

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Conflict of interest

The author Samuel E. Schmidt is a minor shareholder in Acarix A/S. Samuel E. Schmidt works as a part time consultant for Acarix A/S.

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