

Frequency Responses of Conventional and Amplified Stethoscopes for Measuring Heart Sounds

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Abstract

Background: Frequencies of normal and abnormal heart sounds have previously been reported, but the acoustic analyses of the frequency responses of conventional and amplified stethoscopes for different heart sounds have not yet been reported.

Objectives: To compare the acoustic analysis of frequency responses of three stethoscopes (conventional and amplified) for measuring simulated heart sounds.

Materials and Methods: This exploratory study used Starkey SLI-ST3, Cardionics E-Scope II (both electronic) and Littmann Classic S.E. II (conventional) stethoscopes, as they share the same basic design with twin ear tubes coupled to ear tips and chest piece options (bell vs. diaphragm modes). Acoustic analyses using the diaphragm were performed in a soundproof booth and frequency response curves at 85 (the largest), 250, 400, 550 and 1050 Hz were compared for three different digitized heart sound simulations: normal, aortic valvular stenosis (AVS) and pulmonic valvular stenosis.

Results: Amplified stethoscopes provided the most amplification of normal and abnormal heart sounds across all five frequencies compared with the conventional stethoscope. The Starkey SLI-ST3 stethoscope was better at amplifying normal heartbeats than the Cardionics E-Scope II and Littman Classic S.E. II; however, it came last for amplifying normal heartbeats of ~85 Hz. Cardionics E-Scope II had advantages in amplifying abnormal heartbeats (i.e., aortic valvular stenosis and pulmonic valvular stenosis) over the other two stethoscopes.

Conclusion: This study showed that amplified stethoscopes provided better amplification of normal and abnormal heart sounds across the five measured frequencies. Therefore, health professionals should interpret manufacturer claims regarding gain (dB) and frequency (Hz) with caution, and those with hearing loss should carefully investigate the “audio performance” of the stethoscopes. Future research should focus on these effects through coupling with hearing aids.

Keywords: Acoustic, amplification, frequency responses, hearing loss, stethoscopes, valvular stenosis

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Submitted: 19-Apr-2019 **Revised:** 14-Nov-2019 **Accepted:** 02-Mar-2020 **Published:** 17-Apr-2020

Access this article online

Quick Response Code:



Website:

www.sjmms.net

DOI:

10.4103/sjmms.sjmms_118_19

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How to cite this article: Alanazi AA, Atcherson SR, Franklin CA, Bryan MF. Frequency responses of conventional and amplified stethoscopes for measuring heart sounds. Saudi J Med Med Sci 2020;8:112-7.

INTRODUCTION

Hearing loss affects 466 million people globally including health practitioners, who routinely require using stethoscopes for physical examination.^[1] Stethoscopes are acoustic devices used to listen to sounds of the body including those from the lung, heart, gastrointestinal tract and blood flow in arteries and veins. Appropriate diagnosis of diseases, such as cardiovascular disease, using a stethoscope depends on the experience and the hearing threshold of health professionals and the acoustic parameters of the stethoscope.^[2] Stethoscopes can be categorized into two categories: electronic (also called amplified or digital) and conventional (also called nonamplified or acoustic) stethoscopes.^[3]

Amplified stethoscopes were designed to overcome the auditory limitations of nonamplified stethoscopes in terms of amplifying sounds, eradicating background noise and filtering sound frequencies.^[4] Currently, no standards (or parameters) exist for measuring the acoustical characteristics of stethoscopes.^[5] Pasterkamp *et al.*^[6] stated >20 years ago that “stethoscopes are rarely tested, rated, or compared and are often chosen for their appearance, reputation, and inadequately supported claims of performance” (p. 974), and this currently remains the case. Although electronic stethoscopes provide specifications, consumers must rely on the individual claims made by manufacturers regarding gain (dB) and frequency (Hz). Unfortunately, these claims cannot be assumed to be uniformly distributed across frequencies. Moreover, specifications for amplified stethoscopes are affected by factors such as the variability of degree and configurations of unaided hearing loss among health professionals, various coupling methods to personal hearing devices (e.g., hearing aids and auditory implantable devices) and the inability of clinical audiologists to assess calibrated audiometer frequencies <125 Hz (in some cases, 250 Hz).

The literature is replete with studies on stethoscopes (both electronic and conventional) but varies widely in design and analysis methods.^[7-11] Unsurprisingly, the acoustical characteristics of stethoscopes have shown different results, particularly when stethoscopes were measured in an ideal setting without much ambient noise. It should also be noted that each body sound varies widely in terms of frequency range. For example, the frequency range most critical in diagnosing lung sounds is between 200 and 600 Hz but no higher than 2000 Hz.^[12,13] Spencer and Pennington^[14] reported that normal lung sounds range from 100 to 1000 Hz. In terms of heart sounds, Rennert *et al.*^[15] stated that the heart sounds fall between 20 and 650 Hz and

are better detected by the bell of a stethoscope. Noland^[13] showed that the best frequency range for diagnosing the most critical heart sounds is between 70 and 120 Hz. The bandwidth of cardiopulmonary auscultation is between 50 and 1200 Hz.^[16] In fact, heart sounds have multiple components with S1 and S2 being normal, S3 being normal or pathologic and S4 almost always being pathologic. Spencer and Pennington^[14] indicated that S1 and S2 occur between 50 and 500 Hz, while S3 and S4 occur between 20 and 200 Hz and S3 appearing at the lowest frequency. Other cardiac and pulmonary sounds, such as murmurs, ejection clicks and crackles, occur at <300 Hz.^[14] Although frequencies of normal and abnormal heart sounds were previously reported, the acoustic analyses of the frequency responses of conventional and amplified stethoscopes to different heart sounds have not been clearly described.

This study aimed to evaluate the acoustics of three stethoscopes (nonamplified and amplified stethoscopes) for three different digitized heart sounds: normal, aortic valvular stenosis (AVS) and pulmonic valvular stenosis (PVS). This study did not include a newer amplified stethoscope that is popular among health professionals with hearing loss (i.e., Thinklabs One digital stethoscope) because it requires the use of earphones or headphones as the stethoscope tube, and thus differences in the audio quality between earphones/headphones may affect the acoustic measurement of the stethoscope.

MATERIALS AND METHODS

This is an exploratory study of frequency responses of conventional and amplified stethoscopes to digitized heart sounds. This study presents the measurement process and acoustic analysis of these heart sounds.

Stethoscopes

Three popular stethoscopes were used in this study: a nonamplified stethoscope (Littmann Classic S.E. II: 3M™ Littmann® Stethoscopes, USA) and two amplified stethoscopes (Cardionics E-Scope II, Cardionics, Webster, Texas, USA, and Starkey SLI-ST3, Starkey, Eden Prairie, Minnesota, USA). The Littmann Classic S.E. II stethoscope has a two-sided traditional combination chest piece, i.e., tunable diaphragm on one side and traditional bell on the other, and an anatomically designed headset. The Starkey SLI-ST3 stethoscope was in the market for approximately 30 years before its production was stopped in 2010. This amplified stethoscope has two listening modes: “H” for hearing aid and “S” for stethoscope mode. The two listening modes are useful, as they allow health practitioners to listen to the patient in “H” mode and use

stethoscope in “S” mode. Despite its discontinuation, this stethoscope was included in the study because its modes of listening promote sound quality and clarity, specifically for hearing-impaired health professionals, and it is currently still in use, and thus, alternatives for it through comparison need to be provided.^[17] More recently, the Cardionics E-Scope II has been one of the amplified stethoscopes of choice among practicing health professionals with hearing loss.^[4,14] This stethoscope utilizes multiple-style headphones that can be used in conjunction with in-the-ear, completely in-the-canal or behind-the-ear hearing aids. It includes a gain control, an on/off switch and a tone control switch.

Acoustic stimuli

Figure 1 shows the recordings used in this study including simulated heart sounds: a normal heartbeat (“lub dub” or S1–S2) and two abnormal heartbeats, which were obtained from a compact disc (CD) provided with a textbook used for teaching purposes.^[18] The abnormal heartbeats included a recording of AVS (rising–falling crescendo murmur between S1 and S2) and PVS (rising–falling crescendo murmur between S1 and S2 and an ejection click after S1). AVS is the narrowing of the aortic valve in the heart and prevents blood flow from the heart into the aorta for transmission to the rest of the body. Therefore, the heart needs to work harder to push blood to the body.^[18] PVS is an obstruction of blood flow from one or two points of the right ventricle to the pulmonary artery.^[18] Although there are many heart conditions that could have been evaluated, for brevity, two of the most common heart abnormalities were specifically evaluated in this study.

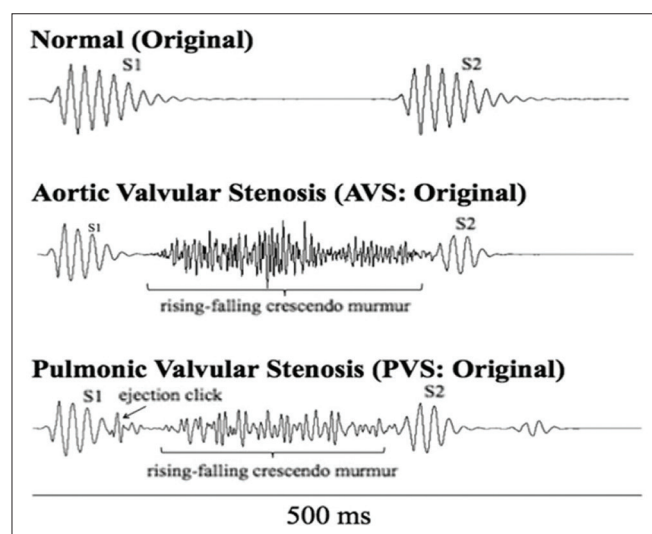


Figure 1: The temporal waveforms for the normal, aortic valvular stenosis and pulmonic valvular stenosis heartbeats

Measurement

The measurement setup of this study involved a laptop presenting these heart sounds obtained from the CD, an amplifier, a headphone loudspeaker for placing the stethoscope bell and diaphragm, a Brüel and Kjaer Type 2250 sound level meter with Type 4157 occluded ear simulator (Brüel and Kjaer – HBK Company, Naerum, Denmark) and a USB Picoscope oscilloscope (Pico Technology, Cambridgeshire, UK) running on a second laptop. The acoustics of all three stethoscopes were measured with A-weighting to mimic the response of the ear. The two amplified stethoscopes (Cardionics E-Scope II and Starkey SLI-ST3) were set at 75% volume to avoid amplifier peak clipping, distortion and saturation before sound level measures. All measurements were taken in a soundproof booth appropriate for testing unoccluded ears.^[19] Heart sounds were presented by a laptop computer, routed to an amplifier, to drive a 10 Ω TDH-39P headphone (Telephonics, Farmingdale, NY, USA). Although Cardionics E-Scope II and Starkey SLI-ST3 stethoscopes were set at 75% volume, the overall dB level of the heart sounds was high enough for adequate detection with the stethoscopes. The amplifier level was kept constant for all heart sounds. According to specifications, the TDH-39P headphone has a frequency range of 100–8000 Hz and a relatively flat frequency response between 100 and 2000 Hz (desirable for auscultation frequencies). Although the specifications do not report the output <100 Hz, there is measurable energy below that cutoff that can be reflected in the acoustical measurements for this study. The diaphragm of the stethoscope bell was placed directly on the MX-41/AR cushions of the TDH-39P headphone. One of the stethoscope binaural earpieces was blocked with putty and the other was coupled using putty to the occluded ear simulator.

Analysis

All oscilloscope measurements were saved and imported into Adobe Audition 2.0 (Adobe Systems Inc., San Jose, CA, USA) for fast Fourier transform analysis (i.e., frequency responses). Spectral analysis of the original normal heartbeat stimulus revealed five maxima at 85 (the largest), 250, 400, 550 and 1050 Hz. The root mean square (RMS) amplitude measures were taken at these frequencies for comparison among the three stethoscopes. Frequency responses for each of the three heartbeat stimuli across stethoscopes were collected in the following manner for spectral comparison: S1 component of the normal heartbeat, the rising–falling crescendo murmur for the AVS heartbeat and the rising–falling crescendo murmur for the PVS heartbeat.

RESULTS

Figure 2 shows the frequency responses for normal and abnormal (i.e., AVS and PVS) heart sound simulations measured by the three stethoscopes. At ~85 Hz, the Cardionics stethoscope amplified the original normal heartbeat stimulus more than other stethoscopes, followed by the Littmann stethoscope and, finally, the Starkey stethoscope. However, at all other frequencies (i.e., 250, 400, 550 and 1050 Hz), the original normal heartbeat stimulus was amplified by the stethoscopes in the following descending order: Starkey, Cardionics and Littmann. Moreover, when the RMS value was taken for all three heartbeat stimuli, the results showed the following: the Starkey stethoscope amplified the normal heartbeat stimulus more than the Cardionics and Littmann stethoscopes.

When evaluating the AVS stimulus, the Cardionics stethoscope amplified more than the Starkey stethoscope, followed by the Littmann stethoscope. The same pattern held true for the PVS stimulus: the Cardionics stethoscope provided the most amplifications followed by the Starkey and Littmann stethoscopes [Table 1]. Although Cardionics and Starkey stethoscopes were set at 75% volume, their sensitivity to normal and abnormal heartbeat sounds

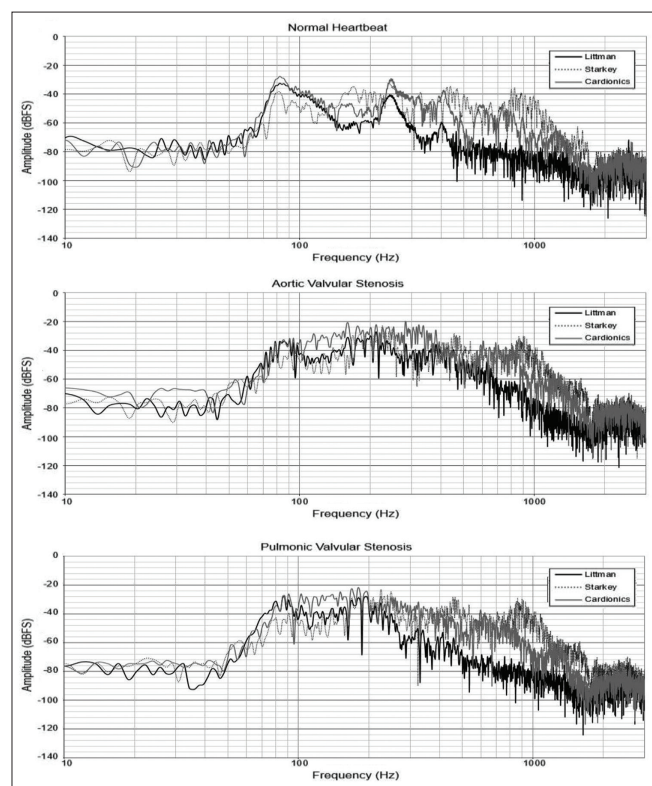


Figure 2: Frequency responses of the three stethoscopes for normal heartbeat (top), aortic valvular stenosis (middle) and pulmonic valvular stenosis (bottom)

was generally better than the nonamplified Littmann stethoscope.

DISCUSSION

Health professionals routinely listen to internal sounds of the body to correctly diagnose health conditions. In addition to clinical skills, the use of appropriate stethoscopes provides optimal listening condition to achieve precise diagnosis and, consequently, increase the safety and quality of patient care. Nonamplified stethoscopes may attenuate the sound transmission related to specific frequencies, while amplified stethoscopes were designed to amplify the acoustic signal and make it easier to even detect sounds below a user’s hearing threshold.^[20] In the current study’s acoustic analyses of the frequency responses of one nonamplified and two amplified stethoscopes to normal, AVS and PVS heart sounds, it was found that all three stethoscopes produced no flat responses with various peaks and nulls in the response frequencies to heart sounds.

The amplified stethoscopes used provided higher amplification of normal and abnormal heart sounds across the studied frequencies (~85, 250, 400, 550 and 1050 Hz) compared with the conventional stethoscope. Previous research indicated similar results.^[7,9,10,20] Kalinauskienė *et al.*^[4] compared an amplified stethoscope with a nonamplified stethoscope in the auscultation of 30 obese patients, and found no significant difference in specificity between the stethoscopes after the combination of all lesions; however, the amplified stethoscope had higher sensitivity.

Because energy is not uniformly distributed across frequencies, claims made by manufacturers of amplified stethoscopes should be interpreted with caution. For example, in the current study, the greatest gain with the normal heartbeat occurred between 550 and 1050 Hz (19–32 dB improvement or 9–43× amplification). However, the most intense component of the heartbeat appeared around 85 Hz. At ~85 Hz, the two amplified stethoscopes offered only a modest 4–10 dB gain or 1.5–3× amplification over the nonamplified stethoscope. RMS levels suggest as little as 1 dB or as much as

Table 1: Summary of the root mean square result for normal and abnormal heartbeats

Stethoscope	Heart sounds			
	Normal at ~85 Hz	Normal*	AVS*	PVS*
Littmann Classic S.E. II	2	3	3	3
Cardionics E-Scope II	1	2	1	1
Starkey SLI-ST3	3	1	2	2

1=The best stethoscope that amplifies normal and abnormal heart sounds.

*The overall heart sounds cross the frequencies ~85, 250, 400, 550 and 1050 Hz. AVS – Aortic valvular stenosis; PVS – Pulmonic valvular stenosis

9 dB of gain over the nonamplified stethoscope or 1.1–2.8× amplification. These results corroborate anecdotal reports on health professionals with hearing loss that some stethoscopes (e.g., Starkey SLI-ST3) are often not loud enough for low-frequency auscultation (i.e., 85 Hz) but work well for higher frequencies.

The Starkey stethoscope has been discontinued by the manufacturer since 2010, but the Cardionics stethoscope is a suitable substitute for acoustic auscultation through the ear tubes and earpiece because of its appropriate amplification across various frequencies. The Cardionics stethoscope was successfully used with several types of hearing aids and cochlear implants.^[21] It includes a filter switch that allows the user to focus on body sounds within a specific range and a volume control.^[21]

Health professionals including those with hearing loss work in settings where noise levels are high. For instance, the average level of noise in neonatal intensive care units is approximately 85 dB.^[22] Therefore, it is important to understand the challenges health professionals face when they listen to certain internal body sounds for differential diagnosis. Moreover, when there is hearing loss, there is a need for more volume (dB). Hearing loss can impact health professionals' ability to perform accurate assessments for internal body sounds (e.g., auscultation). As previously reported, the normal heart and lung sounds range from 20 to 1200 Hz.^[15,16] Heart sounds are in the lower frequencies, and thus generally easier to hear for those with a high-frequency hearing loss. Therefore, health professionals with mild-to-moderate hearing loss in the lower frequencies may miss these sounds at lower volumes, while those with hearing loss in the higher frequencies could miss undetected gasps or other lung sounds. Consequently, patient safety is affected. Even with amplified stethoscopes, professionals with hearing loss may continue to experience difficulties hearing heart, lung and/or bowel sounds.

One of the challenges faced by those using stethoscopes with hearing loss is how to use an amplified stethoscope in conjunction with personal hearing instruments (i.e., hearing aids and auditory implantable devices). One approach is to simply remove the personal hearing instruments and use an amplified stethoscope in its typical fashion, provided that the health professional with hearing loss has enough residual hearing. However, having to remove one's personal hearing instruments could be viewed as unsanitary and effectively creates a barrier to spoken communication with the patient. Alternatively, there may be ways to couple the amplified stethoscope with a personal hearing instrument. The challenge here is that the

amplified signal from the stethoscope will be processed and filtered further by the programming characteristics of the personal hearing instrument. Unfortunately, the programming audiologist will not have equipment to help them “see” the output below 200 Hz. Another component of many personal hearing instruments is the telecoil (or t-coil), which may offer acoustic access delivered electromagnetically for a broad frequency range, but not below 1000 Hz. The telecoil has a progressively lower gain compared with microphones.^[5,18] Needless to say, future research is necessary at more than one level. This study paves the way for the use of the output spectrum and for later investigation of the output levels at various frequencies and degrees of hearing loss.

Based on the preliminary finding of this study, it is recommended that health professionals with and without hearing loss investigate “the audio performance” of the stethoscopes and not only rely on the price, comfort and appearance of the stethoscopes. More importantly, recommendations of a trial period often being helpful remain valid. The present study advocates for a partnership with an audiologist to ensure that any amplified stethoscope coupled with personal hearing instruments should be programmed to meet professional requirements and personal preferences and, consequently, meet clinical competencies. Finally, future research should focus on differences in audio performance of stethoscopes to diagnose different physiologic body sounds when coupling them with hearing aids and auditory implantable devices.

Limitations

Although this is an exploratory study, there are some limitations to this study. The number of stethoscopes and common physiologic sounds used was limited. Other common physiologic sounds that health professionals use stethoscopes to listen to along with different stethoscope brands currently available on the market could be included in future studies. The use of simulated heart sounds is another limitation; actual patients/volunteers' auscultation sounds should have been used. The stethoscopes were tested in a soundproof booth without much ambient noise, which contradicts the real-world scenario where there is plenty of background noises. The study also did not include health professionals with hearing loss to examine the several challenges they encounter.

CONCLUSION

This study showed differences between amplified and nonamplified stethoscopes across all studied frequencies. The Starkey SLI-ST3 stethoscope came first in amplifying

normal heartbeats in A-weighted measurements compared with the Cardionics E-Scope II and Littman Classic S.E. II; however, it came last for amplifying normal heartbeats at ~85 Hz. Cardionics E-Scope II had advantages in amplifying abnormal heartbeats (i.e., AVS and PVS) over the other two stethoscopes. Health professionals with hearing loss may rely on amplified stethoscopes to continue performing their respective job functions, and thus amplified stethoscopes may arguably be considered a form of hearing assistive technology.

Peer review

This article was peer reviewed by two independent and anonymous reviewers.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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