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Abstract

Introduction: Electronic stethoscopes are medical devices that can collect, store and transmit physiologic sounds, as heart beats, of acoustic auscultation in a digital format. These can then be replayed, sent to a colleague for a second opinion, studied in detail after an auscultation, used for training or, as we envision it, can be used as a cheap powerful tool for screening cardiac pathologies. Despite having several electronic stethoscopes available on the market nowadays, there are no published studies about the recording quality of auscultation.

Objectives:

• Develop a ranking in order to the quality of the sound, based on experts opinion, of the 6 most relevant electronic stethoscopes on the market, according to its popularity, attendance at scientific studies and market penetration - Littmann, Cardionics, Jabes, Welch Allyn, Wise, Thinklabs;

• Check if the sound recording has enough quality to be reproduced for education and telemedicine.

Methodology: Based on similar studies, was created two study groups made up of different observers: a first group consisting of 10 cardiologists and cardiology house officers, our gold standard, and a second consisting of 15 medical students or general practitioners. Using a database of sounds recorded in hospitals, questionnaires were made to observers from each group, through Moodle. The questionnaire of the first group consisted of a sound of a particular stethoscope and the observer to infer the condition of the patient. The questionnaire of the second group consisted of the presentation of two sounds from stethoscopes, where the observer gave his opinion about the best.

Results: For Group 1, the expert group, a total of 120 evaluations were performed, while in Group 2, the normal group, were performed 240 evaluations. The results of Group 1, indicate no statistically differences between the evaluated stethoscopes. However, Wise was the stethoscope that obtained the higher proportion of success, while Cardionics obtained the low proportion of success. The results of Group 2, indicate that Thinklabs was the stethoscope more chosen (66%), following by Jabes (65%), Wise (48%), Cardionics (44%), Littmann (41%) and, at least, Welch Allyn (35%). There was statistically significant differences between Thinklabs [55; 76] and Cardioncs [33; 55]; Thinklabs [55; 76] and Littmann [31; 53]; Thinklabs [55; 76] and Welch Allyn [25; 47]. Also show a statistically significant difference between Jabes [53; 75] and Littmann [31; 53] and Jabes [53; 75] and Welch Allyn [25; 47].

Conclusions: The main conclusion of this study is that in fact the Jabes is the best stethoscope to record cardiac auscultation, according to Group 2. Furthermore, we find that the electronic stethoscopes is a good instrument to record heart sounds in order to use in teaching or telemedicine.

Keywords: electronic stethoscopes, cardiac auscultation, comparative study.

Resumo

Introdução: Os estetoscópios eletrónicos são aparelhos médicos que podem coletar, armazenar e transmitir sons fisiológicos, tal como os batimentos cardíacos, de uma auscultação acústica num formato digital. O som coletado pode ser reproduzido, enviado para um colega para uma segunda opinião, estudado ao pormenor depois de uma auscultação, usado para ensino ou, tal como encaramos isso, pode ser utilizado como uma ferramenta barata e poderosa para triagem de patologias cardíacas. Hoje em dia, existem vários estetoscópios eletrónicos disponíveis no mercado, contudo, não há estudos publicados sobre a qualidade da gravação da auscultação destes.

Objetivos:

- Elaborar um ranking, quanto à qualidade do som, segundo a opinião de peritos, dos 6 estetoscópios eletrónicos mais relevantes no mercado, baseado na sua popularidade, presença em estudos científicos e penetração no mercado – Littmann, Cardionics, Jabes, Welch Allyn, Wise, Thinklabs;
- Averiguar se a gravação do som tem qualidade suficiente para ser reproduzida para fins de educação e telemedicina.

Metodologia: Tendo por base estudos semelhantes, foram criados dois grupos de estudos constituídos por observadores distintos: um primeiro grupo constituído por 10 cardiologistas ou internos de cardiologia, o nosso *gold standard*, e um segundo constituído por 15 estudantes de medicina ou médicos de medicina geral e familiar. Recorrendo a uma base de dados de sons gravados em ambiente hospitalar, foram feitos questionários aos observadores de cada grupo, através do Moodle. O questionário do primeiro grupo consistiu num som de um determinado estetoscópio e o observador inferir sobre a patologia do paciente. O questionário do segundo grupo consistiu na apresentação de dois sons provenientes de estetoscópios diferentes, em que o observador deu a sua opinião sobre o melhor.

Resultados: No Grupo 1, o nosso grupo *gold standard*, foram realizadas 120 avaliações, enquanto no Grupo 2, o grupo normal, foram realizadas 240.

Os resultados do Grupo 1 indicam que não existem diferenças estatisticamente significativas entre os estetoscópios. Contudo, o estetoscópio com maior percentagem de acertos foi o Wise, enquanto que o Cardionics foi o estetoscópio que obteve a percentagem de acertos mais baixa. Os resultados do Grupo 2, indicam que o Thinklabs foi o estetoscópio mais escolhido como sendo o melhor (66%), seguido pelo Jabes (65%), Wise (48%), Cardionics (44%), Littmann (41%) e por fim o Welch Allyn (35%). Os resultados revelaram diferenças estatisticamente significativas entre Thinklabs [55; 76] e Cardionics [33; 55]; Thinklabs [55; 76] e Littmann [31; 53]; Thinklabs [55; 76] e Welch Allyn [25; 47]. Também mostraram uma diferença estatisticamente significativa entre o Jabes [53; 75] e Littmann [31; 53] e entre o Jabes [53; 75] e Welch Allyn [25; 47].

Conclusões: A principal conclusão deste estudo assenta no facto de o Thinklabs assumir-se como o melhor estetoscópio para gravação de auscultação cardíaca. Para além disso, obtemos confirmação do estetoscópio eletrónico como bom método de gravação de som cardíaco para ensino ou telemedicina.

Palavras-chave: estetoscópios eletrónicos, auscultação cardíaca, estudo comparativo.

Abbreviations and Acronyms

ECO	Echocardiography
G1	Group 1
G2	Group 2
Hz	Hertz
WHO	World Human Health

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1. Introduction

In recent years, Portugal has been observing an increase in the number of sick people as well as in the European Union. Factors such as physical inactivity, obesity and poor dietary practices lead to an increase in diseases in general. Cardiovascular diseases are among the most common. According to the PORDATA, in 1960 the proportion of deaths due to cardiovascular diseases in Portugal was 29, 5%, while in 2012 was 30, 4% (PORDATA, 2015). The same happens around the world. In 2008, an estimated 17.3 million people died from cardiovascular disease, and is expected that over years the number of deaths continues increasing. By 2030 more than 23 million of people will die annually from this type of disease (WHO, 2013).

By the other hand, the ageing population has been steadily growing over the past few years. According to World Health Organization," the proportion of population over 60 years in the WHO European Region is growing faster than any age, as a result of both longer life expectancy and declining fertility rates" (WHO, 2011).

Therefore, with a high number of deaths caused by cardiovascular diseases, with an ageing population with increasing health problems and with healthcare costs augmenting around the world, there is the need for inexpensive healthcare solutions. Cardiac auscultation is a very old technique used by healthcare professionals on their daily routines. Auscultatory findings provides a cheap and quick initial assessment of a patient's clinical condition and allows health care professionals to choose better treatments and possible complementary exams, and despite is becoming a lost art because there is a shortage of available experienced clinician teachers skilled in the art of auscultation and more sophisticated tests are available, is still one of the most powerful cost-effective solutions available.

In 1816, Laennec invented the first stethoscope, which depends solely on acoustics to amplify and transmit the heart sounds to the physicians (Fayssoil, 2009). Since it was invented, the stethoscope has been constantly in evolution. The concept of electronic stethoscopes arrived in the late of XX century when electronic components were first used essentially to amplify, filter and record the sound (Durand & Pibarot, 1995). The use of a digital stethoscope, adequate for training inexperienced physicians, or as a tool for worldwide screening of specifics cardiac diseases, are just some examples where advanced technology can be used to benefit society.

1.1. Research problem

There are several types of electronic stethoscopes available on the market today, however, no published studies have previously investigated their effectiveness, as a recorder of heart sounds that may be used for education or telemedicine.

The motivation for this work arose from the need for an urgent response to these issues, raised by either biomedical engineering or by healthcare professionals.

1.2. Objetives

The main objectives of this thesis are as follows:

- Evaluate whether the electronic stethoscopes have enough quality to record cardiac sounds and that this recording can be reproduced for education and telemedicine;
- Define the ranking of stethoscopes, within a set of six, at the level of their performance in the recording of cardiac auscultation.

1.3. Thesis structure

The present thesis is organized in 8 chapters and outlined as follows: Chapter 2 presents the context: the invention, the evolution and the anatomy of stethoscope as well as a revision about electronic stethoscopes. Also the basic concepts of heart sounds and cardiac auscultation are reviewed; In Chapter 3 the state of the art is presented: a literature review of studies that compare stethoscopes and the features of various electronic stethoscopes available on the market; Chapter 4 presents the study design like the dataset characterization, participants recruited, the questionnaire and the calculation of sample size and The methodology is described in Chapter 5; Chapter 6 reports the results of the implementation; Chapter 7 discusses the results obtained and the problems occurred throughout the project progress; Finally, in Chapter 8 main findings and some recommendations and directions of future work are presented.

2. Context

2.1. The history of stethoscope

2.1.1. The invention

The stethoscope as we know it, is the one instrument common to all doctors. No other symbol identifies so strongly a doctor than a stethoscope dangling around his neck.

The stethoscope, from two Greek words "stethos", meaning chest, and "skopein", meaning to see (Roguin, 2006), is used to listen to the internal sounds of the body, from the cardiovascular, pulmonary, and gastrointestinal systems. The act of listening to the sounds produced by organs within these systems is called auscultation (Dolan, Oliver, & Maurer, 1816). Auscultation is a technique used by physicians in their daily routines since auscultation is a key diagnostic tool providing a cheap and quick initial assessment of a patient's clinical condition.

In 1816, René Théophile Hyacinthe Laënnec, a French physician, invented the stethoscope. Laënnec was born at Quimper, in Brittany, on 17 February of 1781. When he was 5 years old, his mother died with tuberculosis, and René was sent to live with his grand-uncle Guillaume, dean of the Faculty of Medicine at Nantes. At the age of 20, he studied at the *École de Médecine* in Paris. At the time, Paris was considered the leading center of medicine in the world with such great clinicians, teachers and researchers as Xavier Bichat, Gaspard Laurent Bayle, Guillaume Dupuytren, and Jean-Nicholas Corvisart. Laennec received his medical degree in 1804, having already published papers on peritonitis, amenorrhea, and establishing that phthisis was due to pulmonary tuberculosis (Roguin, 2006) .He received his medical degree in 1804 (Fayssoil, 2009). Laënnec influenced by his teachers, mainly Corvisart, had interest in autopsy studies and sounds, however thought that immediate auscultation, the method of auscultation used by physicians at that time, pressing the ear to the chest wall "…was as uncomfortable for the doctor as it was for the patient, disgust in itself making it impracticable in hospitals. It was hardly suitable where most women were concerned and, with some, the very size of their breasts was an obstacle to the employment of this method" (Sakula, 1981), refers Laënnec.

With this requirement, the stethoscope has emerged. Despite it is well established that it was René Laënnec the inventor, how he discovered this great instrument for medicine has been the subject of many stories. The most frequently quoted story was that Laennec, in 1816, was called to examine a young lady but was embarrassed because it was necessary to place his ear against her bosom to listen to the heart sounds. Another version of the story indicates that this patient was obese and the sound was not good and Laennec which may had observed two children playing with a long piece of solid wood and, remembered that and used a sheaf of paper rolled into a cylinder to auscultate the heart. By applying one end of the cylinder to her chest and the other to his ear, he heard sounds such as he had never before been able to hear with such clarity. Describes Laënnec: "Then I remembered a well-known acoustic fact, that if the ear be applied to one end of a plank it is easy to hear a pin's scratching at the other end. I conceived the possibility of employing this property of matter in the present case. I took a quire of paper, rolled it very tight, and applied one end of the roll to the precordium; then inclining my ear to the other end, I was surprised and pleased to hear the beating of the heart much more clearly than if I had applied my ear directly to the chest" (Cheng, 2007).

The French physician had, therefore, the instrument to stand between him and the patient: the stethoscope. He used the first primitive stethoscope between September 1816 and August 1819, and has investigated the sounds made by heart and lungs with his new tool. In the same year, 1819, Laennec found that his diagnoses were supported by observations made in autopsies and he published the first seminal work on the use of listening to body sounds entitled *"De l'auscultation mediate ou traité du diagnostic des maladies du poumons et du Coeur"* (Sakula, 1981), through which he achieved widespread recognition. At the same time, he carried out extensive investigations in order to test various types of materials to make tubes and perfecting the design. The first real stethoscope, after the version constructed from paper journal, consisted in a monaural stethoscope, made in wood with a cylinder 25 cm in length and a channel full of air, with a 3.5 of diameter, which transmitted sound (Roguin, 2006) - Figure 1(A). The stethoscope allowed Laennec make extensively studies about chest diseases, especially tuberculosis. In 1826, he published the second edition of his book and died after a shortly time. This new instrument was not accepted immediately by medical community but, over time, began to understand that it was a valuable tool for physical diagnoses ("Monaural stethoscope," n.d.).

2.1.2. Evolution of stethoscope

Since the invention of the stethoscope, several modifications have been introduced. In 1828, Pierre Adolphe Piorry incorporated another diagnostic instrument, the pleximeter, into the stethoscope – Figure 1(B). This improvement in the sound made the Piorry's stethoscope the standard for doctors to use for auscultation in the middle of 19th century. After a few years, in 1843, Charles Williams also introduced new improvements to the design of the stethoscope. He added a trumpet shaped chest end that fit more comfortably and snugly against the chest wall. In addition, his stethoscope had a removable ear piece. Flexible tubes were introduced in stethoscopes around 1832 – Figure 1(C). These were tubes of coiled spring covered with woven silk, usually 35.6 to 45.7 centimeters long, with a chest piece at one end and usually a very short, straight earpiece at the other. Stethoscopes were also developed for obstetrical and pediatric auscultation. A Laennec's friend named Kergaradec was the first doctor to use the stethoscope for fetal auscultation and this technique was discussed by Laennec in his second edition text on auscultation. The stethoscopes were adapted for these circumstances. While for children tended to be shorter than those for adults, the fetal stethoscopes had a very wide bell and a wide ear plate. The monaural stethoscope was used exclusively for about 30 years, and was used into the late 19th and early 20th centuries. In fact, they are still used today in a minority of countries. After changes to the appearance and the introduction of rubber, some physicians decided to find out if an instrument using both ears would be better than the simple monaural ("Monaural stethoscope," n.d.)

In 1852, the stethoscope had its next major improvement – Figure 1 (E). George Cammann of New York designed a stethoscope that used the both ears, what would be the chosen design. However, the first commercially available binaural stethoscope was created by Marsh and patented in 1851 - Figure 1 (D). His model was made of India rubber with a long stem to which a flaring bell made of wood could be attached, but it proved cumbersome, very fragile and quickly faded. The Cammann's model was made with ivory earpieces, a wooden chest piece and woven tubing held together by a broad rubber band ("The binaural stethoscope," n.d.) – Figure 1 (F). The models proposed by Cammann usually came in a carrying case and were designed with different types of tension mechanisms in order to hold the binaural ear pieces together so they would be firm against the listener's ears. The original tension mechanism designed by Dr. Cammann was an elastic band stretched between the two earpieces. As was the case with Laennec's model, Cammann's models were initially met with some skepticism. Doctors worried about hearing imbalances caused by using both ears instead of one. However, there was a doctor named Austin Flint, who had previously spoken against the binaural in 1856, but finally endorsed it in 1866, and helped this model become more accepted by the scientific community. Nevertheless, many doctors continued to use monaural stethoscopes into the early 1900's.

During the late half of the 19th century, well-educated physicians used advances in medical technology to aid their ability to diagnose diseases in their patients. The stethoscope had become one of the doctor's vital tools. Learning to listen and diagnose the sounds from the chest became an important part of a doctor's training. Henceforth, several physicians came up with their own ideas for stethoscopes for different purposes, using materials that were commonly found in a physician's office. In 1884, Aydon Smith, for example, described a stethoscope that was invented by himself: "…the chest-piece of which is formed by a pair of ear-specula, the tubes are Jaques' India-rubber catheters, and the ear-pieces those of an otoscope." Another modification was made by George Cammann's son, which incorporated a chest piece with a rubber ball, which was used as a suction cup, when apply to the chest. This would leave the hands free to percuss to chest. It was not very helpful for an untrained ear. After this, new improvements to the stethoscope focused on the tension mechanism to hold the earpieces to the head of the physician. The main change is in the form of the spring, in spiral, acting on two levers in the form of a toggle joint. There was still a desire to improve the sound conduction through the tubes. Around 1882, Bartlett designed a stethoscope that used metal ear-tubes with silk covered rubber tubes leading to a wooden chest piece. This model was also called "Bartlett's Laennec" stethoscope. There were also other types stethoscopes designed to enhance the quality of auscultatory sounds. The most notable and widely copied stethoscope had a diaphragm membrane and was known as a phonendoscope. It was developed by Bazzi and Bianchi, in 1894. The idea was that the small chest piece could fit between the ribs and convey better sounds. Throughout the 20th century many minor improvements were made to these iconic devices to reduce weight, improve acoustic quality, and filter out external noise to aid in the process of auscultation, and also in other situations. In 1901, Bowles patented a version of his stethoscope with a combination of a bell and a rigid diaphragm chest piece, as used today. Around 1931, a stethoscope which has combined the binaural ear piece with a very long tube and wide bell, enabled the patient to read or speak to himself stimulating the dormant auditory center by natural means of the voice in order to treat middle ear deafness – Figure 1(G). Between 1945 and 1946 Rappaport, Sprague and Groom experimented various designs to determine ideal properties for the modern binaural stethoscope ("The binaural stethoscope," n.d.) – Figure 1 (H).

Doctor David Littmann was a Harvard Medical School professor, a distinguished cardiologist and a very famous expert in electrocardiography. In 1963 he patented a stethoscope which was lighter than previous models and had improved acoustics. The stethoscope proposed by David had a single short tube connected to a two sided stethoscope which bifurcated into the ear pieces ("Antiquemed - 20th Century," 2015) – Figure 1 (I). The physics seem to be based on vibrations which the chest and other noises produce. The bell receives the skin vibrations which produce acoustic pressure waves which are transmitted to the listener's ears. The diaphragm reduces the low pitched vibrations. There were two models, the doctor's stethoscope and the nurse's stethoscope. The Littmann Stethoscope rapidly became the stethoscope of choice in America and was therefore created the benchmark of stethoscopes industry the Littmann Stethoscopes. This simple design is still the basis for most stethoscopes used in medical practice today (3M Littmann, 2015).

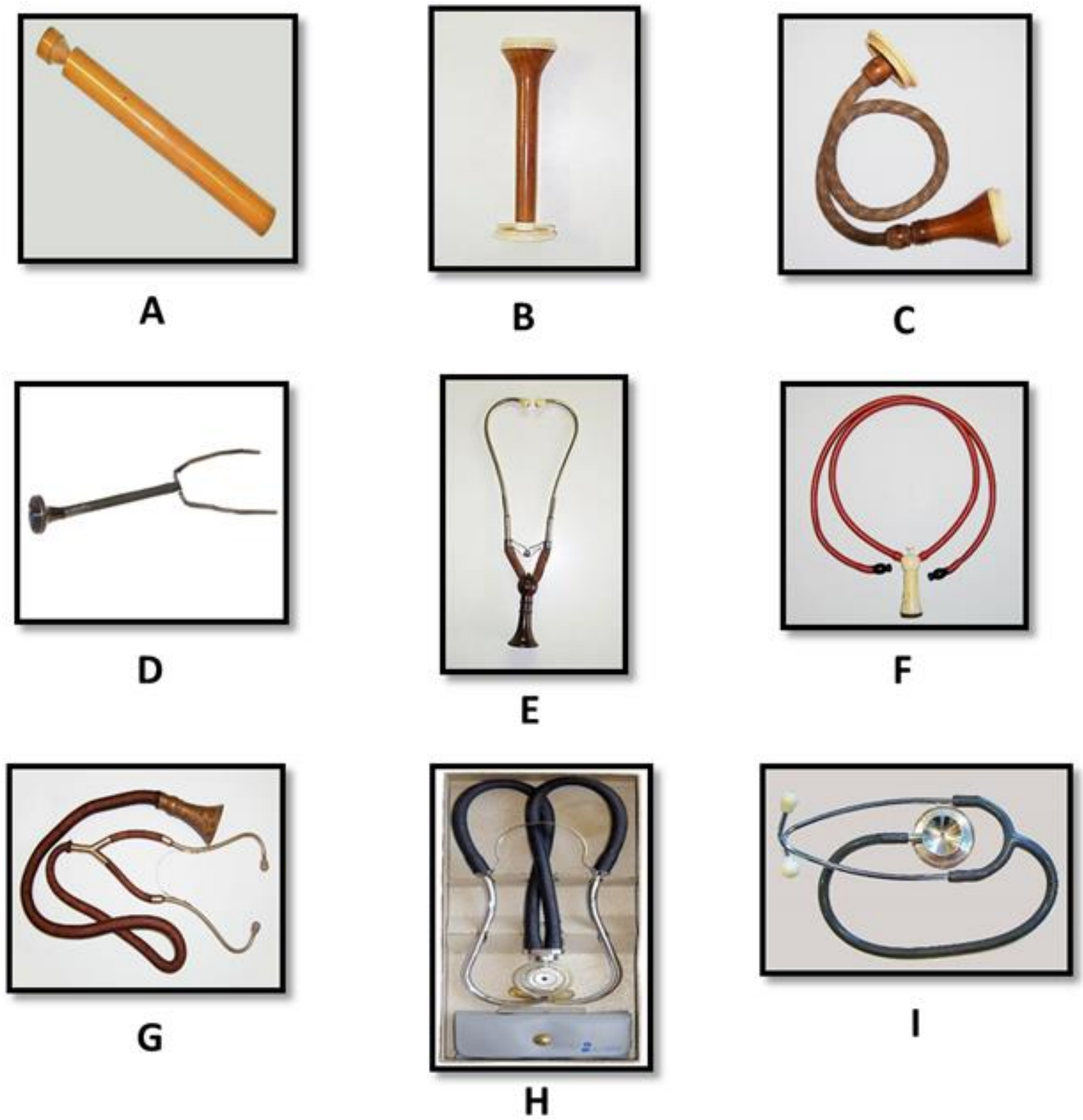


Figure 1: The evolution of the acoustic stethoscope (Med, 2015):

A – Original version of Laennec's stethoscope, 1816; B – Piorry's stethoscope, 1830; C – Piorry's stethoscope with flexible tube, 1835; D – The first original binaural stethoscope by Marsh, 1851; E – Cammann's stethoscope, 1852; F – Stethoscope used in 1880 with ivory earpieces; G – Stethoscope used in 1931 to enable the patient to read or speak to himself in order to treat ear deafness; H – The stethoscope present by Rappaport – Sprague, in 1960; I – The Littmann's stethoscope, 1961.

Although to this day the majority of medical professionals continues to use the generation of acoustic stethoscopes, there has been a perceived need to amplify sounds that cannot be detected otherwise. With this need, another big modification was invented: the electronic stethoscopes. We can thus think of digital stethoscopes as an evolution of the later, since we exploit the advantages of converting the audio signal to the digital domain, whether these are storage, transmission, analysis or simply visualization.

The electronic stethoscope was first described as a 'magnoscope' by Sato e Nukuyama, in 1926 (Bishop, 1980). In 1995, Durand & Pibarot described an electronic stethoscope, which allowed users to amplify, filter and transmit the sound (Durand & Pibarot, 1995). Bredesen and Schmerle, in 1993, have patented an intelligent stethoscope designed for performing auscultation and for automatically diagnosing abnormalities by comparing digitized sounds to reference templates using a signature analysis technique (Mark S. Bredesen, 1993). Several other electronic stethoscopes have been developed and described in the literature: In 1994 a study proposed by Tavel et al. described a portable system with a new graphic display (Tavel, Brown, & Shander, 1994); In 2006, Brusco & Nazeran, presented a system which has been able to record and display the heart sounds, but also apply signal processing and statistical techniques (Brusco & Nazeran, 2005); In 2007 Hedayioglu, Mattos, Moser, & de Lima, developed a tele-stethoscope to be applied on pediatric cardiology (Hedayioglu, Mattos, Moser, & de Lima, 2007).

Beyond these articles, there is very little published data about the evolution and validation of electronic stethoscopes. Over time, physicians had knowledge of electronic stethoscopes through essentially of Littmann. Littmann was always the benchmark of acoustic stethoscopes, and, the main inventor of electronic stethoscopes. The doctors knew the brand and the divulgation to scientific community of this new technology, was more accessible. Furthermore, at the time, was very common physicians exchanged ideas with colleagues about new discoveries, and it may have contributed to the acceptance of electronic stethoscope. Until today, the electronic stethoscopes have been constantly in evolution, improving not only their usability but also the technical features.

2.1.3. Anatomy of the stethoscope

Acoustic stethoscopes are nowadays available in an array of colors and models, but the function of all of them is attributed to the components as shown in Figure 2, presented below

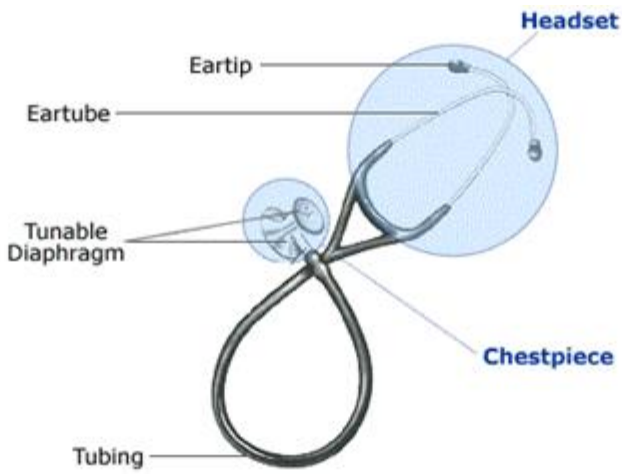


Figure 2: Anatomy of acoustic stethoscope (Standris, 2015)

- **Ear tips**

The eartips and the ear tube form the headset. The ear tips, usually made in rubber, are the pieces that fit on ear listener canal and allows us to hear the vibrations of the body as sounds. The seal created by earpieces is very important and allows improving the acoustic function of the stethoscope. Furthermore, the insertion pressure, and ear tip insertion angle are variables that can affect the connection between earpieces and human ear. Some manufactures offer various sizes of ear tips, which give the user the ability to accommodate on ear canal size, adjust the insertion pressure and angle by manually manipulating the head set (T. T. Center, 2015)

- **Tubing**

When a clinician places the stethoscope chest piece on a patient, they are closing a circuit that allows sound energy to travel internally from the patient, through the tubes and to the listener ear's. These tubes are air-filled hollow and can vary both in material, length and diameter. The flexible tubes can be neoprene, plastic or latex. As with the material, the length, normally about 25 to 30 cm, and the internal width of the tubing will affect the frequency response of acoustic transmission from the body surface to the ears too (Northrop, 2001). An increase in the length of the tubing will decrease the pressure at the end of the tubing as a result of frictional and other internal forces. In other words, resonant frequency decreases and sounds have greater potential to be attenuated. Thin tubing have worse insulation than thicker tubing, which enable sound to be transmitted with smaller distortion and noise from external sources (Linehan & Jaques, 2011).

Regarding the tube disposition, the stethoscopes can be single lumen or double lumen. The single lumen has one tube connected to the chest piece, and then that tube splits via a 'Y' junction into two tubes, with each one going into one ear. Double lumen has two tubes attached to the chest piece, and each tube or lumen goes directly into one of the listener's ears. Double lumen stethoscopes are more sensitive and create more ambient noise, so the single lumen stethoscopes are more common.

- **Chest piece**

The chest piece is the part of the stethoscope that when placed on the skin directs sound energy generated from the body into the tubes. The chest piece comprises a diaphragm and a bell, which can be combined. This piece is available in a couple different designs and can be made from different materials. To selectively pick up certain frequency ranges, the appropriate bell size and diaphragm tension must be chosen. The diaphragm side (plastic disk) is larger and is used to listen the higher frequency sounds and the physician should press more firmly the skin of the patient. The bell side (hollow cup) is the smaller part and is for listening to medium and lower frequency sounds and the user should press lightly on the skin of the patient. When the bell is used, the vibrations of the skin directly produce acoustic pressure waves, instead of the diaphragm. Some stethoscopes use only one of these designs, but some two-sided stethoscopes incorporate both designs so that listeners can reverse the stethoscope to listen to either high frequency sounds or low frequency sounds. Despite the sound with bell or diaphragm side be different and involve new training about that, the majority of physicians learns auscultation with diaphragm side because it adapts to all circumstances and, therefore, they use this side in their clinical routines. The bell is only used by cardiologists to detect very specific pathologies.

2.1.4. Electronic stethoscope

Electronic stethoscopes offer potential advantages compared to conventional stethoscopes and several of these unique features could influence the performance of cardiac auscultation. These new stethoscopes utilize advanced technology to amplify the body sounds, filter sound frequencies and eliminate background noise. Each electronic chest piece contains a broadband microphone, amplifier power supply, and frequency bandwidth and volume controls (T. T. Center, 2015). Additionally, electronic stethoscopes have dry cells or a battery.

They convert acoustic sound waves into electronic signals which are then transmitted through uniquely designed circuitry and processed for optimal listening. The circuitry allows the energy to be digitized, encoded and decoded, to have the ambient noise reduced or eliminated, and sent through speakers or headphones.

The fact that sounds are transmitted electronically brings advantages, not only on the quality of the sounds, but also allows offer particular features:

- **Wireless transmission:** Some electronic stethoscopes allow transmission of data through a wireless or Bluetooth interface to other devices, which must have Bluetooth too. Other stethoscopes allow transmission with a cable provided by the manufacturer;

- **Sound recording**: These devices should be able to store audio recordings in a non-volatile memory, which permits to create a record of the exam;

- **Visual data presentation**: Some electronic models provide visual information to be shown to the physician.

Introducing an electronic stethoscope that allows the replay and the transmission of sounds in clinical practice can bring several advantages. With these stethoscopes it is possible to make a medical consultation at a distance, sending the sound to a colleague for a second opinion. According to WHO, this process is called Telemedicine (WHO-Global Observatory for eHealth, 2010). On the other hand, auscultation is a hard skill to master and, like most clinical skills, requires repetition. The recorded sounds can be used as a teaching tool. Listening to real sounds, the medicine students or even physicians can train the art of auscultation, by associating signs and pathologies to sounds. Furthermore, researchers have recently explored the information contained in the sounds in order to create reproducible systems that may aid in the detection of alarming events in the signals, and in the quantification of these events in terms of severity.

More technical characteristics about electronic stethoscopes will be presented on Chapter 3.

2.2. Cardiac auscultation

We now live in the digital era, and despite having much more sophisticated and reliable methods like the ultrasonic imaging and Doppler techniques, cardiac auscultation is still taught and used in modern cardiology, because its simplicity, quickness, efficiency and its excellent relation between cost and benefit.

According to *Diário da República* (Agroambientais, Integradas, Rural, & Dom, 2014), an echocardiography can cost between 110 and 278€, and the money can be wasted with false positives, while a routine consultation, which cardiac auscultation is included, can cost around the 30€ and establish the same previous diagnosis.

The comparison of electronic stethoscopes described in this thesis is based on heart auscultation so it's important to understand not only its essentials but also all the physiological phenomena that occurs in the heart.

2.2.1. Heart Sounds

It is possible, that the existence of heart sounds was known to Hippocrates (460 to 370 BC), the father of medicine. He used his knowledge for diagnostic purposes, described a noise heard when a body cavity containing air and water is shaken briskly. However, it was only in 1628 that William Harvey, an English physician, made the first specific reference to them «... with each movement of the heart, when there is the delivery of a quantity of blood from the veins to the arteries, a pulse take place and can be heard within the chest» (Hanna & Silverman, 2002). Two centuries later, Laënnec, with his own invention, gave the first precise description of the character of sounds in normal and pathologic conditions and founded the art of auscultation, which developed considerably during the nineteenth century. Henceforth and over the years, various works have studied the source of heart sounds, a better understanding of the physiology of the heart and the knowledge about some less frequent sounds like some types of murmurs correlated with heart disease.

The heart, as we know it today, is one of the most important organs of human body. It is a muscular organ, located slightly to the left of the chest, between lungs, which pumps blood through the blood vessels of the circulatory system to every part of the human body (see Figure 3).

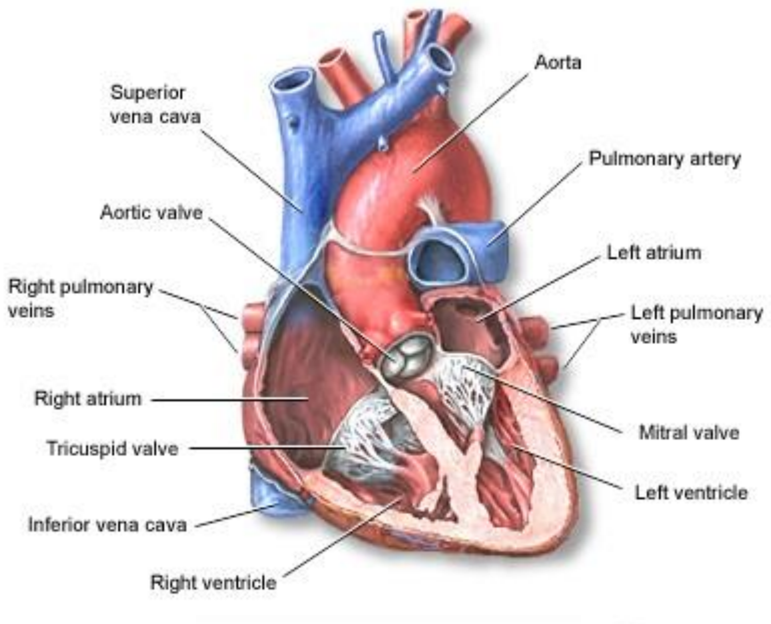


Figure 3: Anatomy of heart. (Image, 2014)

It has four chambers: the left and right atriums and the left and right ventricles. The muscle which separates the left side from the right side is called the septum. The heart has four types of valves: aortic, pulmonic, tricuspid, and mitral. De-oxygenated blood from the superior and inferior vena cavae enters the heart through the right atrium which is pumped through the tricuspid valve into the right ventricle and then to the lungs where carbon dioxide is exchanged for oxygen. The pulmonary valve controls blood flow from the right ventricle into the pulmonary arteries, which carry blood to the lungs to pick up oxygen. The mitral valve, separates left ventricle and left atrium, and opens the way for oxygen-rich blood from the lungs to pass from the left atrium into the left ventricle. The aortic valve lets oxygen-rich blood to pass from the left ventricle into the aorta (T. H. I. H. I. Center, 2015)

This process produces sounds. The generation of heart sounds is essentially related to cardiac muscle contraction, the closing of the valves and turbulence generated by blood flow. Listening with a stethoscope to a normal heart, one hears two types of sounds: the "lub" is the first sound (S1) and the "dub" represents the second heart sound (S2). The time period between S1 and S2 are due to the contraction phase, called systole. S1 is related with the closing of the mitral and tricuspid valves (called atrioventricular valves) that causes vibration of the adjacent walls of the heart and major vessels around the heart. The time period between S2 and S1 is due to the expansion of the heart, named as the diastole. S2 results from the sudden closure of the aortic valve with the pulmonic valve at the end of systole. As S1, the vibrations travel through the adjacent tissues to the chest wall, where they can be heard as sounds by using a stethoscope. In some heart disease scenarios, there are some extra sounds like the S3 and S4. The third heart sound (S3) and the fourth heart sound (S4) correspond to the cessation of ventricular filling and the atrial contraction, respectively. They appear at very low amplitudes with low frequency components and are difficult to be caught in usual auscultation (Willacy, 2011)

The perception of sounds by a listener is dependent of its physical properties: intensity, frequency, duration, and the listener's own perception of sound, among others. The intensity of sounds is related with the magnitude of sound waves (loudness) which is directly dependent of the amount of energy that goes into sound production and the efficiency of the sound generator. Thus, the intensity of a sound at a given location is determined by the intensity at the source, the distance of the listening position from the source, and the density and homogeneity of the media, through which the sound must travel to reach the listener. Another important factor to perceive a sound is related with the threshold sensitivity of the human ear. While children can hear from 20 to 20.000 Hz, an adult hearing ability ranges from 50 to 12.000 Hz, but it is most efficient in the frequency range from 1000 Hz to 5000 Hz. The cardiovascular sounds are characterized by having lower frequencies, when compared with optimal human hearing. Almost all of them occur in the frequency range of 20 Hz - 500 Hz, and occasionally up to 1000 HZ. This frequency range is determined by the number of vibrations or cycles per second and is represented by Hertz (Hz). For example, an intense cardiovascular sound in this low frequency range may be perceived as a soft sound that is difficult to hear. The duration between the first beat and the second beat is also important. Normally, the duration of S1 is about 0.14 seconds, while the duration of S2 is about 0.11. This little difference is due to the fact that the aortic and pulmonic valves (semilunar valves) are more stretched and strained so they vibrate in a short time. Furthermore, the pressure in these valves is higher comparing with atrioventricular valves, thus they close faster than others and the cycle duration is shorter. The human ear can normally identify two sounds separated by between 0.02 and 0.03 seconds as two distinct sounds. When, this difference is smaller, the human ear typically interprets them as a single sound. In turn, the perception of sound, which improves with training, is influenced by the sensory and integrative mechanisms involved in listener's hearing (Heart, 2015)[21

When a human listens to a sound, he engages statistical learning mechanisms to passively and tacitly get rules and regularities about musical and linguistic structures. Studies have revealed that there is evidence that musical training changes brain structure, brain function, and performance of auditory tasks. For example, the brains of non-musicians compared with brains of musicians with a lifetime of intensively musical training are substantially different. They have, between other curious capabilities, enhanced sensitivity to acoustic stimuli presented within a noisy background.(Ellis, 2015)

2.2.2. Auscultation

Cardiac auscultation is a physical examination that allows the listening of cardiovascular sounds, in order to evaluate the frequency, intensity, duration, number and quality of them to deduce possible diseases. As seen in the subchapter presented above, these sound characteristics are affected by their location of origin and the relative amplitudes in the different auscultation areas have important clinical value for the diagnosis of heart disease. Thus, there is a need of listening to different auscultation areas.

Inspection of the thorax allows the definition of some important anatomical references that are useful for the adequate placement of the stethoscope: the sternum, the claviculae and the axillary lines. Auscultation should be performed systematically over five locations on the anterior chest wall areas, as indicated in Figure 3: Aortic area, which is located in the left sternal border of the second intercostal space (ICS); the pulmonic area, which is located in the right sternal border of the second; Third ICS is called Erb Point and the fourth and fifth left ICS in the mid-clavicular line, also referred to as tricuspid area and as the mitral area, respectively.

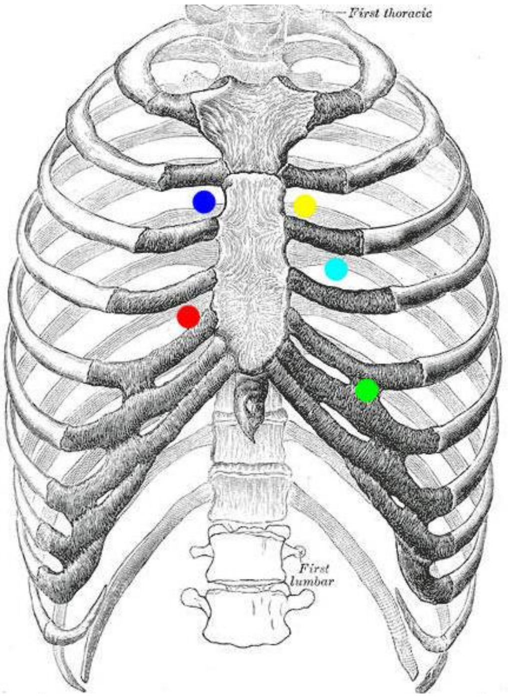


Figure 4: Main four auscultation areas: blue - aortic; yellow- pulmonic; red - tricuspid; light blue – erb point; green – mitral (EstudMed, 2015)

Heart auscultation is initiated with the patient seated or in the supine position, in a quiet room. During auscultation, the chest piece is repositioned several times as the auscultator moves it slowly between the different areas.

2.2.3. Heart diseases

Heart sound characteristics are linked to blood pressure, and its interpretation is important for the detection of some heart diseases. According to WHO, in 2008 about 17.3 million died people from cardiovascular diseases, particularly heart attacks and strokes (WHO, 2013).

There are many different conditions that affect the normal function of the heart. The most common are:

- Coronary artery disease, results from a buildup of plaque on the inside of the arteries, which reduces blood flow to the heart;
- Congenital heart diseases, which are structural heart or intrathoracic great vessels defects present at birth, that are potentially of functional significance;
- Abnormal heart rhythms called arrhythmias mean heart beating too fast or too slow;
- Cardiomyopathy which refers to heart muscle disease;

- Heart infections are caused by virus which attacks the heart muscles and causes the disruption of the electrical pathways that signal the heart to beat properly;
- Cardiovascular disease related with blood vessels;
- Heart valve disease occurs when the heart valves do not work the way they should because they are damaged.

Almost all of these can be detected by heart auscultation, which allows a quicker diagnosis avoiding bigger problems. Although coronary disease, heart failure and hypertension are more frequent when compared with heart valve disease, this last contributes to the wide spectrum of arterial diseases such as aortic aneurysms, intramural hematoma, atherosclerotic, among others, and therefore requires attention (Erbel et al., 2014).

Heart valve disease occurs when the heart valves do not work the way they should. The valves are situated at the exit of each of the four heart chambers and their function is to keep blood flowing through the heart in the right direction and that there is no backward leakage. However, a variety of conditions can lead to valve damage. The two main problems that we can found in heart's valves called stenosis or regurgitation (also called insufficiency).

The stenosis can occur in all four valves (if aortic valve developed a stenosis, the condition is called aortic stenosis; and so on) and it's related with the obstruction of blood flow across the aortic valve. The narrowed opening may make the heart work very hard to pump blood through it and can lead, for example, to heart failure. Aortic stenosis typically results in a heart murmur and, nowadays, is the most common valve heart disease in the developed world (Czarny & Resar, 2014).

The regurgitation is the name for non-sealed valves. The valve does not close tightly and some blood will leak backwards across the valve into the upper heart chamber from the lower chamber or leaks through the leaflets when they should be completely closed. This leads to less blood flowing to the rest of the body. The heart tries to compensate and pumps harder, which can lead to congestive heart failure. Similarly to stenosis, it can occur in all four valves and the condition's name depends in which valves it occurs and results in a heart murmur. (Encyclopedia, 2014)

Heart valve diseases can be developed before birth, by complications of an infection, autoimmune diseases, exposure to certain drugs, coronary heart disease and high blood pressure. The cause can be also unknown (Go et al., 2014).Today, treatment may involve medication but often valve replacement is necessary, with an insertion of an artificial heart valve.

3. State of the art

3.1. Research methodology

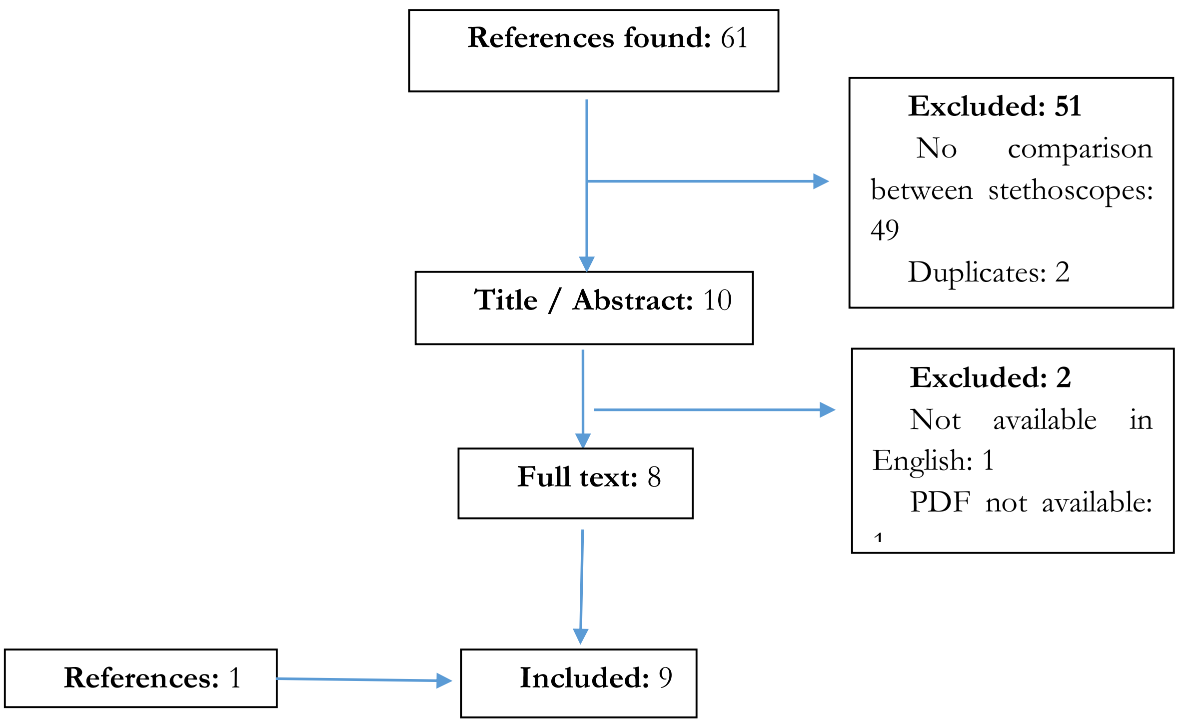
In order to understand how previous studies have compared the performance of acoustic and electronic stethoscopes, the following research methodology was used. Articles were initially identified by searching PubMed and Google Scholar. The final search included the terms: stethoscopes, comparison, evaluation and randomized trial.

The query used was: "stethoscopes"[All Fields] AND ("comparison"[All Fields] OR "evaluation"[All Fields] OR "randomized trial"). Efforts were made to gather all full-text papers, including contact with authors.

Afterwards, these were further selected during two phases. The first phase was based on the analysis of the title and abstract of the articles found in the initial search. Articles were classified as included or not, according to its relevance for the research question. The second phase was the analysis of the full-text paper of study. Again, articles were classified as included or not.

3.2. Results of the article selection process

We did not found any published articles about comparisons between different electronic stethoscopes. However, there are many between electronic and conventional stethoscopes. This initial search using the previously described query was made on the 2nd of October of 2014.



Nine studies were included in this analysis. The work carried out by (Philip & Raemer, 1986) was not found during our search, but it was present in the references of the study proposed by (Grenier, Gagnon, Genest, Durand, & Durand, 1998). Given its relevance, we decided to include it in our final list of articles.

3.3. Analysis of comparative studies

The variables extracted from the selected published studies were the year of publication, the country of origin, the number of citations and number of evaluators, study population, the objectives of comparison, methodology and statistical analysis. The results are shown in Table 2:

Table 1: Analysis of comparative studies

Paper, Year, **Number of citations**	**Number of evaluators**	**Participants**	**Variables of comparison**	**Methodology**	**Statistical analysis**
Effect of teaching and type of stethoscope on cardiac auscultatory performance, 2006, 11	72 house officers, with 0-18 months of postgraduate clinical experience	20 patients, 16 with disease and 4 without disease	Teaching; type of stethoscope	Division in 4 groups associated with the possible 2 variables combination; Multiple-choice questionnaire	Accuracy, agreement (*k* values); t tests, unpaired t tests, general linear models
A randomized trial comparing electronic and conventional Stethoscopes, 2005, 12	24 physicians: 4 specialists in cardiology, 4 specialists in general internal medicine, 4 specialist registrars, 4 senior house officers, 4 house officers and 4 medical students.	42 patients, one third of the patients without disease	Agreement between clinicians; type of stethoscope	Each group with 4, was divided in 2 groups associated with the type of stethoscope; Multiple-choice questionnaire	*K* values for all 12 pairs of observers
An electronic stethoscope is judged better than conventional stethoscopes for anesthesia monitoring, 1986, 13	21 members: 11 residents, 4 certified registered nurse anesthetists and 6 staff anesthesiologists	____	Clarity of sounds; efficacy of monitoring; other qualities; type of stethoscope	Questionnaire; Rating system: +3 - much better to -3 - much worse	Wilcoxon signed rank test for differences

Paper, Year, **Number of citations**	**Number of evaluators**	**Participants**	**Variables of comparison**	**Methodology**	**Statistical analysis**
Auscultation in Flight: Comparison of Conventional and Electronic Stethoscopes, 2010, 8	9 physicians: 7 anesthetist, 2 intensivist	36 evaluations[a]	Assess heart and lung sounds; type of stethoscope	Questionnaire; Visual rating scale: 0 - hear nothing, to 100 - hear perfectly	Paired t-tests
Cardiac auscultation training of medical students: a comparison of electronic sensor-based and acoustic stethoscopes, 2005, 12	48 third year medical students; (2 cardiologists defined the correct answers)	10 patients, one twice	Auscultation skills, type of stethoscope	Division in 2 groups associated with the type of stethoscope; Train the students with the type of stethoscope respective; Teaching of auscultation; Multiple-choice questionnaire; Rating system: number of points from 1 to 6 for each question and total score for the questionnaire.	Student's t-test, chi-square

Paper, Year, Number of citations	Number of evaluators	Participants	Variables of comparison	Methodology	Statistical analysis
Clinical Comparison of Acoustic and Electronic Stethoscopes and Design of a New Electronic Stethoscope, 1997, 42	9 cardiologists, 10 general practitioners, 11 nurses	378 auscultations[a]	Clinical performance; Type of stethoscope	6 stethoscopes, 3 of each type; Each patient was auscultated 3 successive times by using 3 randomized different stethoscopes; Evaluation grid: 1 – excellent to 5 – not acceptable; The questions depended of clinical position;	Frequency of appreciation
Comparison of conventional and sensor-based electronic stethoscopes in detecting cardiac murmurs of dogs, 2012, 3	2 investigators: 1 final year veterinary student, 1 an expert in physical examination of the canine cardiorespiratory system	21 dogs, with disease	Diagnostic capabilities; type of stethoscope	Questionnaire; Arbitrary classification system: 0 - no difference between stethoscopes to 3 - advantage for the electronic stethoscope	Sensitivity , *k* -values, Fisher's exact test

Paper, Year, Number of citations	Number of evaluators	Participants	Variables of comparison	Methodology	Statistical analysis
Clinical evaluation of the 3M Littmann Electronic Stethoscope Model 3200 in 150 cats, 2013, 0	Acoustic stethoscope 2 observers: 1 board certified cardiologist with more than 20 years of experience with cardiac auscultation, 1 cardiology resident with 3 years of clinical experience Electronic stethoscope 8 observers: 3 cardiology diplomats, 3 cardiology residents, 3 small animal rotating interns	150 cats	Clinical performance; Type of stethoscope	Auscultation with traditional stethoscope by 2 observers; 30 seconds of heart sounds were recorded using an electronic stethoscope; The sounds were compared, off line, with each other by the 8 observers;	*k* - Cohen's , *k* – Fleiss's, McNemar's test
Pulmonary Auscultation in the Operating Room: A Prospective Randomized Blinded Trial Comparing Electronic and Conventional Stethoscopes, 2013, 1	Anesthesiologists	100 patients, who had general anesthesia for various surgeries	Quality of pulmonary auscultation; type of stethoscope	3 stethoscopes (2 acoustic, 1 electronic); Questionnaire; Numeric scale: 0 - hear nothing to 10 - hear perfectly	Mixed-effects linear regression

[a]Unknown number of patient

As shown in the Table 1, all the studies compare the type of stethoscope with other variables such as the clinical performance, by using questionnaires. About the methodology used in the comparisons, there are two types of studies: some compare the answers given by observers about the patient's disease with the echocardiography or opinions of experts, which establish the correct diagnoses; others compare only the quality of sound between the stethoscopes evaluated.

K values are the statistical method more used in the studies because it allows us to calculate the agreement between observers, which is a crucial factor in this type of comparisons. Another important point, is the fact that the majority of analyzed studies ensure the homogeneity of analysis, making groups with observers which have identical level of experience. This detail, allows us to make comparisons between levels of experience, regarding the performance with a particular type of stethoscope. For example, it's not expected that students have greater auscultatory proficiency than the most experienced physicians. (Høyte, Jensen, & Gjesdal, 2005)

The number of evaluators used varies and decided by the authors. While in studies carried out by Høyte et al., Iversen et al., and Philip & Raemer (Høyte et al., 2005; Iversen et al., 2005, 2006; Philip & Raemer, 1986) have a relatively high number, the others studies have a small number of evaluators. This can compromise the results, because the studies with a higher number of observers, theoretically, would be able to find a significant difference regarding the analyzed variable between groups of observers. According to Iversen et al., (Iversen et al., 2006) a high number of observers gives their study the largest discriminative power. Furthermore, when the number of observers included in each group is small and the comparisons among levels of experience depend on groups with only few observers, the observational skills of a single observer could have a marked impact on the average agreement. Also the low number of patients participating could of course be a problem regarding the representation of diseases, as mentioned in the study carried out by Iversen et al.

An important comment drawn by some authors (Iversen et al., 2006) is the need for studies on how the type of stethoscope affects a student's ability to his auscultatory skills. These should measure the effect of teaching among the most inexperienced doctors for whom it seems reasonable to assume that the reliability of their cardiac auscultation would give room for most improvement and not among experienced doctors because already have a lots of experience.

All these findings were deemed relevant, and shaped the decisions made for our comparison methodology, as explained in the following chapters of this thesis.

3.4. Analysis of types of stethoscopes compared

The stethoscopes evaluated in these articles are presented in Table 2.

Table 2: The stethoscopes evaluated in analyzed studies

	(Iversen et al., 2005)	**(Vörös, Bonnevie, & Reiczigel, 2012)**	**(Iversen et al., 2006)**	**(Hoffmann et al., 2013)**	**(Blass et al., 2013)**	**(Philip & Raemer, 1986)**	(Tourtier et al., 2010)	**(Høyte et al., 2005)**	(Grenier et al., 1998)	**Total**
Acoustic										
Rappaport- Sprague		X							X	2
Holtex Ideal				X						1
Littmann Cardiology III				X			X			2
Welch Allyn - Elite					X				X	2
3M Littmann Master Cardiology			X							1
3M Littmann Classic II SE Stethoscope	X	X	X						X	4
Electronic										
3M Health Care - Littmann 4000	X									1
3M Health Care - Littmann 3200				X	X					2
Labtron- Graham Field									X	1
EST40 Bosch									X	1
3M Health Care - Littmann 3000							X			1
ST3 Starkey Laboratories									X	1

Table 3: The stethoscopes evaluated in analyzed studies (cont.)

	(Iversen et al., 2005)	**(Vörös, Bonnevie, & Reiczigel, 2012)**	**(Iversen et al., 2006)**	**(Hoffmann et al., 2013)**	**(Blass et al., 2013)**	**(Philip & Raemer, 1986)**	(Tourtier et al., 2010)	**(Høyte et al., 2005)**	(Grenier et al., 1998)	**Total**
Welch Allyn - Elite Electronic Stethoscope		X								1
The stethoscope-Meditron								X		1

It is clear from Table 2 that not only there are a lot of electronic stethoscopes present in these studies, but more importantly they are spread among such studies, limiting our ability to understand the role and true potential of electronic stethoscopes. If we look at the market, this is even clearer. After a search in sites of commercialization and reviews of stethoscopes, the electronic stethoscopes that to the best of our knowledge are available on the market are the following:

- 3M Health Care - Littmann 3200;
- Cardionics - E-Scope II Electronic Stethoscope;
- Welch, Allyn - Elite Electronic Stethoscope;
- GS Technology - JABES Electronic Stethoscope;
- Thinklabs - ds32a Digital Electronic Stethoscope;
- Contec Medical Systems – CMS VE;
- Sun Meditec – WISE (Wireless Digital Stethoscope);
- Dong Jin Medical – i-scope 200;
- HB Meditech - SP-S2 Electronic Stethoscope;
- Mabis healthcare – Signature Series Electronic Stethoscope;
- Koratek – AUSCO ES-3100;
- ADC - ADSCOPE 657;
- ThinkLabs One.

Table 3 summarizes the most relevant technical characteristics of each one of them.

Table 4: Technical characteristics of the most relevant electronic stethoscopes available on the market

	3M Health Care - Littmann 3200	**Cardionics - E-Scope II Electronic Stethoscope**	**Welch Allyn - Elite Electronic Stethoscope**	**GS Technology - JABES Electronic Stethoscope**	**Thinklabs - ds32a Digital Electronic Stethoscope**
Price	311,25 €	335 €	315 €	199 €	325 €
Sound Quality					
Digital or Amplifying or Both	Both	Amplifying	Amplifying	Both	Amplifying
Sound Amplification Range	24X	30X	Up to 93 dB	20X	100X
Ambient Noise Reduction					
Included	Yes	No	No	Yes	Yes
Noise reduction On/Off button	No	N/A	N/A	No	Yes
Acoustic mode	No	No	No	?	Yes
Filter					
Frequency Options	Bell/Diaphragm/Extended Range	Diaphragm/Bell	Diaphragm/Bell	Bell/Diaphragm/Extended Range	Diaphragm/Bell
Diaphragm	Electronic	Electronic and Hardware	Electronic	Electronic	Electronic
Frequency response					
Frequency	?	?	20-20000 Hz	?	15-20000 Hz
Frequency bell	Amplifies 20-1000 Hz, but mostly lower freq sounds between 20-200 Hz	45-900 Hz	20-240 Hz	20-200 Hz	?
Frequency diaphragm	Amplifies 20-2000 Hz, but emphasizes the sounds between 100-500 Hz.	50-2000 Hz	350-1900 Hz	200-500 Hz	?
Frequency extended	Amplifies sounds from 20-2000 Hz, but provides more low freq response between 50-500 Hz.	N/A	N/A	20-800 Hz	N/A

User Interface					
Dedicated On/Off Button	Yes	Only Off Button	Only Off Button	Yes	Yes
Power Stay-On Time	10-30 seconds before entering standby. 30 minutes to 5 hours before power off	2 minutes (possibility to 8 and 60 minutes shut off)	3 minutes	3 minutes	2-5 minutes
Sleep mode indicador	Yes	No	No	No	No
Display	LCD	No	LED	LED	LED
Frequency Mode Indicator	LCD	No	No	LED	No
Volume Level Indicator	Yes	No	Yes	No	Yes
Patient Heart Rate Display	Yes	No	No	No	No
Volume Control	Yes (9 levels)	Yes (64 levels)	Yes	Yes (7 levels)	Yes (10 levels)
Mute function	No	No	No	No	Yes
Advanced Features					
On-Board Recording	Yes (29 seconds)	No	No	No	No
Bluetooth Capability	Yes	No	No	No	No
Communication mode	Infrared	Wired (jack)	Wired connection	Wired connection	No
Wireless Capacity	No	No	No	No	No
Connector	No	Square 4 pin connector	Audio 2.5 mm (stereo)	Audio	Audio 2.5 mm
Retained settings/Programming Preset Modes	Retains settings in standby mode. Restores factory setting when fully powered off (these settings can be modified).	Retains audio.	No	Retains volume and mode.	Retains bell, diaphragm and amplification setting. Power-on mode can be preset.
Adjustments					
Eartips angle	No	No	Yes	?	Yes
Headphone tension	Yes	?	No	Yes	Yes
Cleaning					
Alcohol cleaning	Yes	Yes	Yes	No. Use mild detergent.	Yes
Maintenance					
Diaphragm replacement	Yes	Yes	No	Yes	Yes

Eartips replacement	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Battery					
Type	1 X AA	1 X AAA	1 X CR123A	2 X AAA	2 X AAA
Low battery indicator	LCD level	No	No	LED	LED
Specifications					
Weight	186 grams	176 grams	170 grams	170 grams	180 grams
Length	69 cm	96.5 cm	82.5 cm	73.6 cm	73.7 cm

	Contec Medical Systems – CMS VE	**Sun Meditec – WISE (Wireless Digital Stethoscope)**	**Dong Jin Medical – i-scope 200**	**HB Meditech - SP-S2 Electronic Stethoscope**	**Mabis healthcare – Signature Series Electronic Stethoscope**
Price	133,01 €	226 €	180,86 €	N/A	N/A
Sound Quality					
Digital or Amplifying or Both	Amplifying	Amplifying	Amplifying	?	Amplifying
Sound Amplification Range	32X	Up to 100 dB	20X	?	Up to 24 dB
Ambient Noise Reduction					
Included	?	Yes	No	?	Yes
Noise reduction On/Off button	?	No	N/A	?	No
Acoustic mode	?	?	?	?	?
Filter					
Frequency Options	Bell/Diaphragm/Extended Range	Bell/Diaphragm/Extended Range	Bell/Diaphragm/Extended Range	Bell/Diaphragm/Extended Range	?
Diaphragm	Electronic	Electronic	Electronic	?	Electronic

	Contec Medical Systems – CMS VE	Sun Meditec – WISE (Wireless Digital Stethoscope)	Dong Jin Medical – i-scope 200	HB Meditech - SP-S2 Electronic Stethoscope	Mabis healthcare – Signature Series Electronic Stethoscope
Frequency response					
Frequency	20-20000 Hz	?	?	5-5000 Hz	?
Frequency bell	20-230 Hz	20-350 Hz	20-500 Hz	20-200 Hz	?
Frequency diaphragm	100-800 Hz	350-1200 Hz	100-1500 Hz	200-500 Hz	?
Frequency extended	20-800 Hz	20-2000 Hz	20-1500 Hz	20-2000 Hz	?
User Interface					
Dedicated On/Off Button	Yes	No	Yes	?	No
Power Stay-On Time	3 minutes	3 minutes	20 seconds – 3 minutes	3 minutes	2 minutes
Sleep mode indicador	No	No	No	?	No
Display	LCD	LED	LED	?	LED
Frequency Mode Indicator	LCD	LED	LED	?	LED
Volume Level Indicator	Yes	No	Yes	?	No
Patient Heart Rate Display	Yes	No	No	No	No
Volume Control	Yes (16 levels)	Yes (10 levels)	Yes (5 levels)	Yes (16 levels)	Yes (8 levels)
Mute function	No	No	No	No	No
Advanced Features					
On-Board Recording	No	No	No	No	No
Bluetooth Capacity	No	No	No	No	No
Wireless Capacity	No	Yes	No	No	No
Connector	Audio 3.5 mm	Audio 3.5 mm	Audio 3.5 mm	Analog output port	No
Retained settings/Programming Preset Modes	Retains volume and mode.	No	Retains volume and mode.	Retains volume and mode.	Retains volume and mode.

	Contec Medical Systems – CMS VE	Sun Meditec – WISE (Wireless Digital Stethoscope)	Dong Jin Medical – i-scope 200	HB Meditech - SP-S2 Electronic Stethoscope	Mabis healthcare – Signature Series Electronic Stethoscope
Adjustments					
Eartip angle	N/A	N/A	N/A	?	?
Headphone tension	N/A	N/A	N/A	?	?
Cleaning					
Alcohol cleaning	Yes	?	?	?	Yes
Maintenance					
Diaphragm remplacement	Yes	?	?	?	Yes
Eartips remplacement	N/A	N/A	N/A	?	Yes
Battery					
Type	Mini USB, 4.2V rechargeable battery	Battery (Transmitter-DC 3V, Receiver-DC 5V)	2 X AAA	1 X CR123A	3 X LR44
Low battery indicador	LCD level	No	LED	?	LED
Specifications					
Weight	50 grams	270 grams	79 grams	175 grams	?
Length	5.7 x 3.2 x 3 cm	14.4 x 6.3 x 7.3 cm	4.7 x 8.9 x 3 cm	74 cm	?

	Koratek – AUSCO ES-3100	ADC - ADSCOPE 657	ThinkLabs One
Price	N/A	180.86 €	704.54 €
Sound Quality			
Digital or Amplifying or Both	Amplifying	Amplifying	Amplifying
Sound Amplification Range	15X	16X	100x
Ambient Noise Reduction			
Included	Yes	?	Yes
Noise reduction On/Off button	?	?	No
Acoustic mode	?	?	?
Filter			
Frequency Options	Bell/Diaphragm	Bell/Diaphragm/Extended Range	Bell/Diaphragm
Diaphragm Frequency response	?	?	?
Frequency	?	?	20-2000 Hz (five filters mode)
Frequency bell	?	15-200 Hz	30-500 Hz
Frequency diaphragm	?	100-500 Hz	80-500 Hz
Frequency extended	?	15-1000 Hz	?
User Interface			
Dedicated On/Off Button	Yes	Yes	Yes
Power Stay-On Time	2 minutes	3 minutes	1-10 minutes
Sleep mode indicador	No	?	?
Display	LED	LED	LED
Frequency Mode Indicator	LED	LED	LED
Volume Level Indicator	?	?	Yes
Patient Heart Rate Display	No	No	No
Volume Control	Yes (8 levels)	Yes (8 levels)	Yes (10 levels)
Mute function		?	?
Advanced Features			
On-Board Recording	No	No	?
Bluetooth Capability	?	No	?
Wireless Capacity	?	No	?
Stereo Jack	?		Audio 3.5 mm
Retained settings/Programming Preset Modes	Retains volume	Retains volume and mode	?
Adjustments			
Eartip angle	?	Yes	Yes
Headphone tension	?	?	?
Cleaning			
Alcohol cleaning	?	?	Yes
Maintenance			
Diaphragm remplacement	?	?	Yes
Eartips remplacement	?	?	Yes
Battery			
Type	2 X AAA	2 X AAA	Battery
Low battery indicador	LED	LED	LED
Specifications			
Weight	?	175 grams	?
Length	?	74 cm	?

N/A – Not Available; ? - Information not available

Given all this, it is safe to assume that the quality of all of these can vary significantly, reinforcing the need for our comparative study of electronic stethoscopes. Given that it is unrealistic to compare all of them, a selection of the 6 most relevant stethoscopes was made, based on their popularity, presence in scientific studies, and market penetration. Figure 5 depicts these, which are now listed:

- GS Technology - JABES– Figure 5 (A);
- 3M™ Health Care - Littmann 3200 – Figure 5 (B);
- Cardionics - E-Scope II – Figure 5 (C);
- Welch, Allyn - Elite™– Figure 5 (D) ;
- Thinklabs - ds32a – Figure 5 (E);
- Sunmeditec - WISE – Figure 5 (F);

A - GS Technology - JABES

B - 3M Health Care - Littmann 3200

C - Cardionics - E-Scope II

D - Welch, Allyn - Elite

E - Thinklabs - ds32a

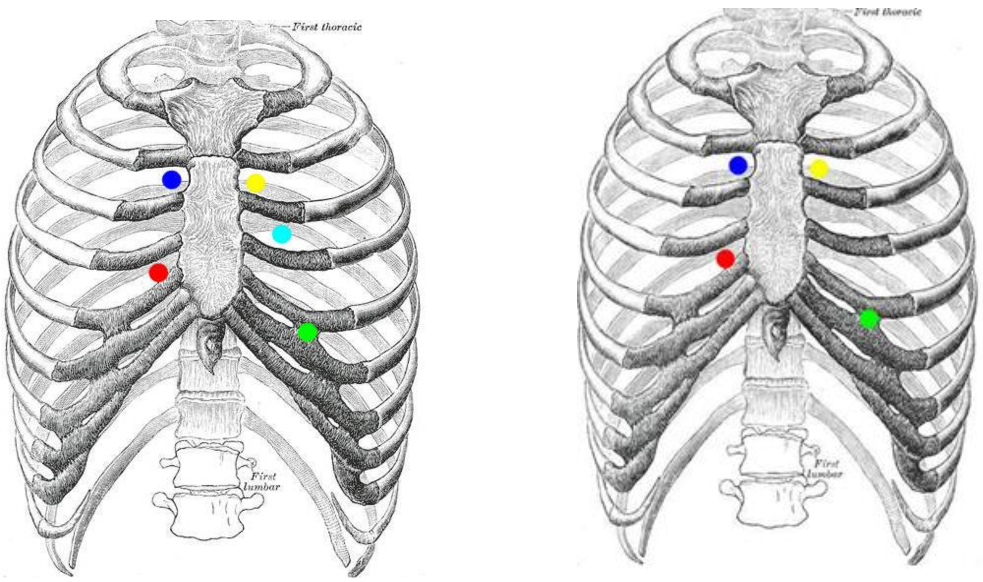
F – Sun Meditec - WISE

Figure 5: Six of the most relevant electronic stethoscopes available on the market.

4. Study Design

4.1. Dataset

The dataset used for this comparative study of electronic stethoscopes is composed by sounds recorded from 89 patients. Each patient's cardiac sound was recorded with the six different types of stethoscopes (more details on these in section 3.4 of this thesis), in five cardiac spots if the patient's disease is mitral regurgitation and six if the patient's disease is aortic stenosis – See Figure 6. The area excluded is the Erb Point represented on light blue because it is an accessory spot.



Mitral regurgitation: blue - aortic; yellow-pulmonic; red - tricuspid; light blue – erb point; green – mitral

Aortic stenosis: blue - aortic; yellow-pulmonic; red - tricuspid; green – mitral

Figure 6: The auscultation areas by pathology

The recording of 4 of the 6 stethoscopes – Cardionics, Jabes, Welch Allyn, Thinklabs – was conducted using a cable, 1 by WiFi transmission – WISE - and 1 by Bluetooth transmission – Littmann. The sounds with this last stethoscope were recorded with a specific system that is capable of collecting heart sounds by spot, using a tablet, called Digiscope Collector, and presented in Figure 7. The others were recorded with the Audacity software[1] , on a laptop computer. All of these sounds were recorded with a 8kHz sampling frequency, excepted Littmann which was recorded at 4kHz and after, converted to 8kHz with Audacity software.

[1] http://audacityteam.org

The volume of 5 stethoscopes was adjusted: Jabes and Thinklabs to 0,3; Welch Allyn and Wise to 1,0 and Cardionics to 0,7. All of these were empirically obtained with previous tests, in order to maximize signal strength and, at the same time, avoid distortion and sound clipping. All the stethoscopes were configured with diaphragm option active.

Whenever the physician changed the stethoscope position to a different spot, he knocked his fingers on diaphragm, to mark the passage with an easy to distinguish strong sound. This simplified the process of splitting the full audio recording into individual sound files for each spot. The exception was the Littmann, since we could use the DigiScope Collector application that conveniently simplifies all this process.

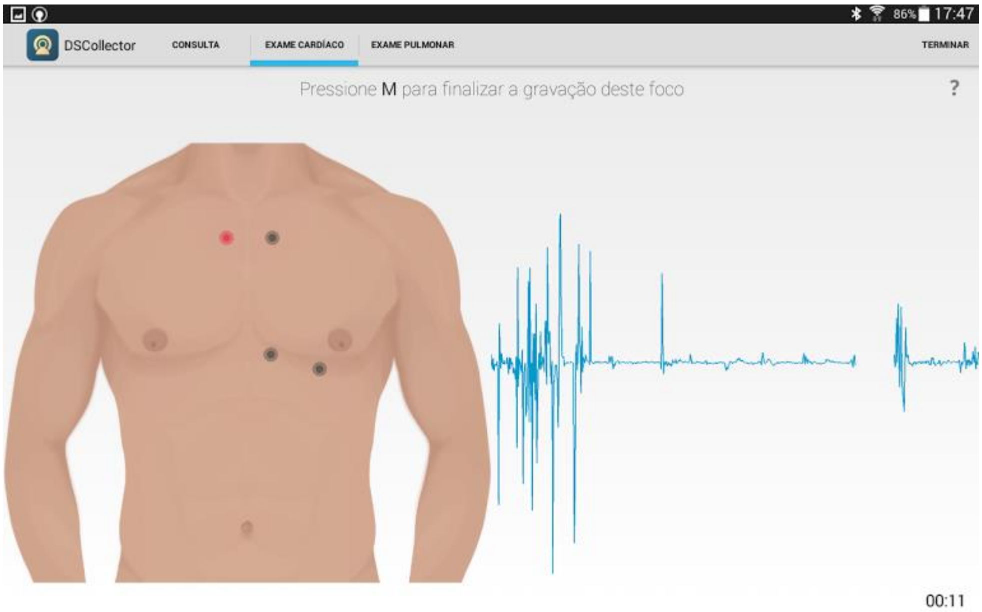


Figure 7: Digiscope - Software used to record sounds with the Littmann stethoscope.

Heart sounds were collected at Centro Hospitalar do Alto Ave (Guimarães, Portugal) between September and December of 2013, by the same cardiologist. The patients of interest were called for a consultation, based on echocardiographic findings, and during the consultation was explained to the patients, the objectives to the study, and in followed, the recording of sounds was conducted. All data were collected with a formal patient consent, assigned by them. Furthermore, was asked the Ethics Committee in order to obtain Authorization to proceed the study. The number of authorization is 274-12.

Recordings were conducted in a real hospital environment, always in the same room of the cardiology department, which during this period was used exclusively for this purpose. The ambient noise level was measured using the Smart Tools application (version 1.5.8) installed in a Samsung S4 smartphone and its typical value was about 65 decibels.

Due to technical problems and usability issues some of this data was either lost or did not have enough quality to integrate this study. In order to make this study viable, an extra 4 normal patients were recruited with a mean age of 71 years, and their heart sounds were recorded in a home environment by an experienced physician. Also, an extra 16 patients with aortic stenosis and mitral regurgitation were recruited and auscultated with the Littmann and the Cardionics stethoscopes at Hospital São João by a cardiology house officer, at the Internal Medicine and Cardiothoracic Department. All data was again collected with formal patient consent and all efforts were made to replicate as well as possible the environmental conditions of the main dataset. As explained later in section 4.4, this was enough to successfully complete the proposed study.

4.2. Dataset Analysis

The created dataset also includes data relative to the patients, like gender, age, weight, height, type of person, hairiness, measure sight, systolic and diastolic pressure, pathology, cardiac frequency and date relative to the situation like date, hour, local, position and noise level. A basic analysis using the SPSS[2] software was conducted to characterize the dataset: 53 of patients are female and 36 are male; the mean age is 71 years and 6 months; 30 patients without disease, 29 with mitral regurgitation and 30 with aortic stenosis; all the auscultations were collected with the patient sitting down.

As Attachment I shows, 89 patients recorded with Jabes, Thinklabs and Welch Allyn; 88 with Wise; 84 with Cardionics and 43 with Littmann (see Table 5). As explained in section 4.2, the data of Littmann and Cardionics were collected in two distinct moments and situations. Firstly, at Centro Hospitalar do Alto Ave, were recorded 18 cases with Littmann and 73 with Cardionics and later were recorded more 23 with Littmann and 16 with Cardionics at Hospital São João and patient's home. This is explained by technical difficulties that happened during the data collection process, which led to both the loss and the creation of data that was unusable for comparison purposes. Although this is far from ideal, we consider it to also be a relevant result, hinting that this technology is interesting but sometimes not robust enough for unobtrusive use, especially when wireless transmission is involved. Fortunately, it was still possible to obtain a dataset that was good enough for the comparison experiments presented in this thesis.

Table 5: Resume of sounds division by stethoscope

	Without disease	Mitral regurgitation	Aortic stenosis	Total
Littmann	8	15	20	43
Cardionics	30	21	33	84
Wise	30	29	29	88
Welch Allyn	30	29	30	89
Thinklabs	30	29	30	89
Jabes	30	29	30	89

[2] http://www-01.ibm.com/software/analytics/spss/

4.3. Evaluation Methodology

Inspired by previous literature in which evaluators were divided into groups of different levels of experience, we decided to select two different groups of evaluators for our studies:

- G1 - Expert group - Elements of this group perform heart auscultations many times on their daily routines and have experience in identifying pathologies
- G2 - Normal group - Elements of this group have received some form of training in the art of auscultation, but have a more limited field experience making it difficult to identify pathologies.

The first group (G1) included cardiologists and cardiology house officers. The second group (G2) included medical students and general practitioners.

The chosen evaluation tool was the questionnaire, as with previous studies described in literature. For the Expert Group (G1), a sound was presented and a question asked about which pathology was present, while for Normal Group G2 two sounds were given and a question asked to choose which one is better. The evaluation was a blind test with no other information about each patient's condition given, besides the heart sounds.

For our study purposes we only use one question related with sound quality, and eliminated other possible questions such as: compare the given sound with the sound of stethoscope in use in daily routines; evaluate background noise and evaluate if the given sound has enough quality to issue a diagnostic. This elimination is a pragmatic decision in order to obtain statistical relevance of the chosen question. Asking more required an unrealistic number of evaluators, which was not possible to obtain during the timeframe of this thesis.

4.4. Sample size

In order to obtain statistical significance of comparison results, the number of evaluators and observations necessary was calculated for each group. The term "observation" is often used in this thesis and represents the listening of a case with one or more sounds.

- **Group 1**

Statistically, the best stethoscope will be considered the one which allows the evaluator to identify a pathology better. In other words, we will measure the proportion of successful classifications using each stethoscope and find a difference between the six. The proportion of success is given by following equation:

$$\frac{\text{Number of times that the observer choose the true pathology with a specific stethoscope}}{\text{Total number of answers that the observer gave with a specific stethoscope}}$$

Thus the question which we need to answer in this sample size calculation is: How many observations are necessary for the study to have 80% power to detect a difference in the proportion of success of 0.2 between stethoscopes, with a significance level of 5%?

Using an online calculator Russ Lenth's power and sample-size[3], we defined the worst case (p1=0.5) in order to detect differences in proportions of successes of 20%. Other parameters were also defined: power= 80% and α=0, 05. Given this, the various possible evaluation scenarios are described in Table 6.

Table 6: Various hypothesis obtained through calculator

Differences in proportion of success	**Number of necessary evaluations by stethoscope**	**Number of cases assigned to each stethoscope**	**Number of evaluators for each stethoscope**
0.2	82	9	10
0.2	82	11	8
0.2	82	21	4
0.2	82	41	2

The number of cases assigned to each stethoscope and the number of evaluators needed for each stethoscope were obtained starting from the number of observations required by stethoscope, given by the calculator. Knowing that 82 observations are required per stethoscope to detect differences in proportion of success between stethoscopes of 0.2, the outlined multiplications with the number of cases and the number of evaluators to obtain a number equal to or greater than the number of observations is required. The option chosen is represented on the first line: 9 cases assigned to each stethoscope and 10 evaluators.

Thus, for each stethoscope we have the design presented on following table:

Table 7: The layout of study design of G1. The shaded column represents an outline of possible observer 1 answers

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	A									
2	B									
3	C									
4	C									
5	A									
6	B									
7	B									
8	A									
9	C									

[3] http://homepage.stat.uiowa.edu/~rlenth/Power/

10	A

In total, 100 observations were conducted with each stethoscope. Each evaluator conducted 60 observations, 10 cases by 6 stethoscopes. To ensure the difference detected between stethoscopes is not a factor of a physician's skill, the same observer will evaluate all of 60 cases. For each stethoscope we selected 4 patients with no disease, 3 with aortic stenosis and 3 with mitral regurgitation.

Each answer was analyzed, according to echocardiography, in order to obtain the number of true answers that determined stethoscope allows give, and therefore the percentage of success of each stethoscope. Were calculated also intervals at 95 % using a software[4], in which the method used was with a correction for continuity, because the sample size is small.

- **Group 2**

In this group, where were included medical students and general practitioners, were calculated, according to sounds distributions (see Table 4), all the possible comparisons between two sounds of the same patient but from different stethoscopes. For this purpose, the possible combinations between two stethoscopes, represented by ${}^{6}C_{2}$ and is equal to 15 pairs of stethoscopes, will be explore.

The number of observations needed for evaluate each stethoscope is given by multiplication of 15 by 16 (the number of cases recorded with the six stethoscopes) and is equal to 240. The number of evaluators needed, represented in following equation, was found regarding the acceptable number of observations that each physician can realized: 16. This number was obtained through opinion of the search and development community, since no have information on literature about that.

$$Number\ of\ evaluators = \frac{240}{16}$$

Thus, the number of evaluators necessary will be 15. Each Group 2 evaluator needs to compare the audio quality of 16 pairs of stethoscopes, given that it is not feasible to have them compare all possible combinations of stethoscope pairs for each patient. These random combinations for all these comparisons were first obtained, with the restriction that each evaluator has a maximum of two comparisons with the same pair of stethoscopes, and that each patient is only evaluated twice with the same pair of stethoscopes. Other sampling criteria were possible but this was chosen since it leads to a reasonably homogenous distribution of the samples among the full set of possible comparisons.

The number of times that determined stethoscope can be chosen is given by multiplication of 16 by 5 and is equal to 80. In order to obtain the stethoscope more chosen as the better, was count the number of times, that in 80, it was choose. Also, confidence intervals at 95 % were calculated.

5. Methodology

5.1. Sounds Treatment

Firstly, the best sounds were selected based on the visual inspection of the phonocardiogram (regularity, absence of noise), obtaining a total of 50 sounds by stethoscope. After this, all these sounds were listened to and the 16 best ones selected for each stethoscope (low ambient noise such as speech or heavy breathing sounds).

In all stethoscopes, with the exception of the Littmann, the sound were recorded in a single file (Figure 8), therefore it was necessary to split them by spot and save individual files corresponding the various spot (Figure 9). For this purpose were used the tools of Audacity software.

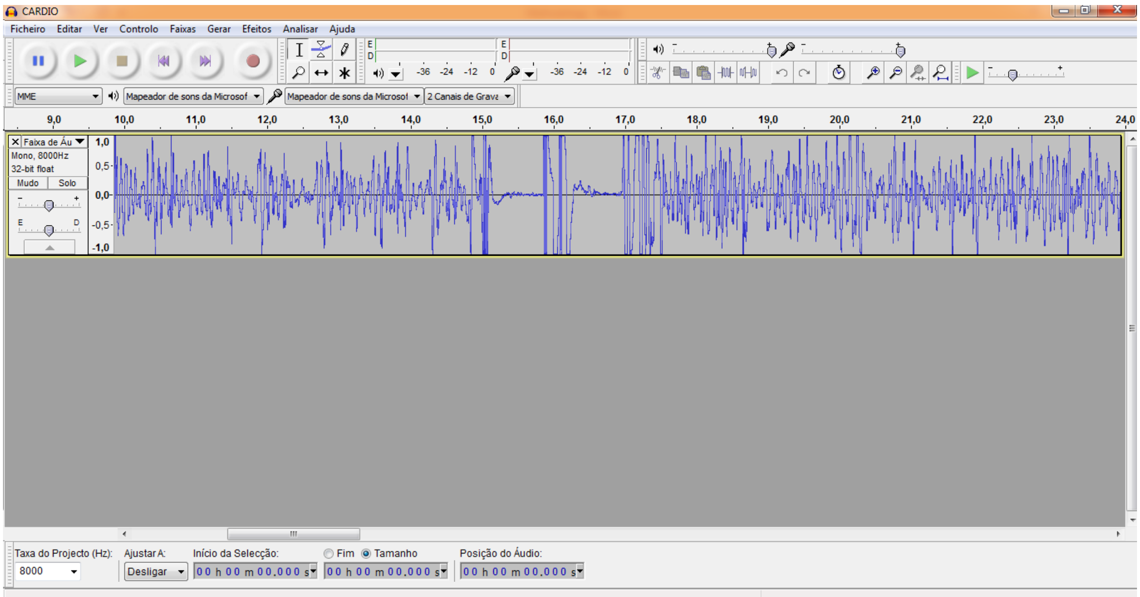


Figure 8: An example of sound before split: The break in the middle represents the moment of noise caused by a change of the auscultation spot

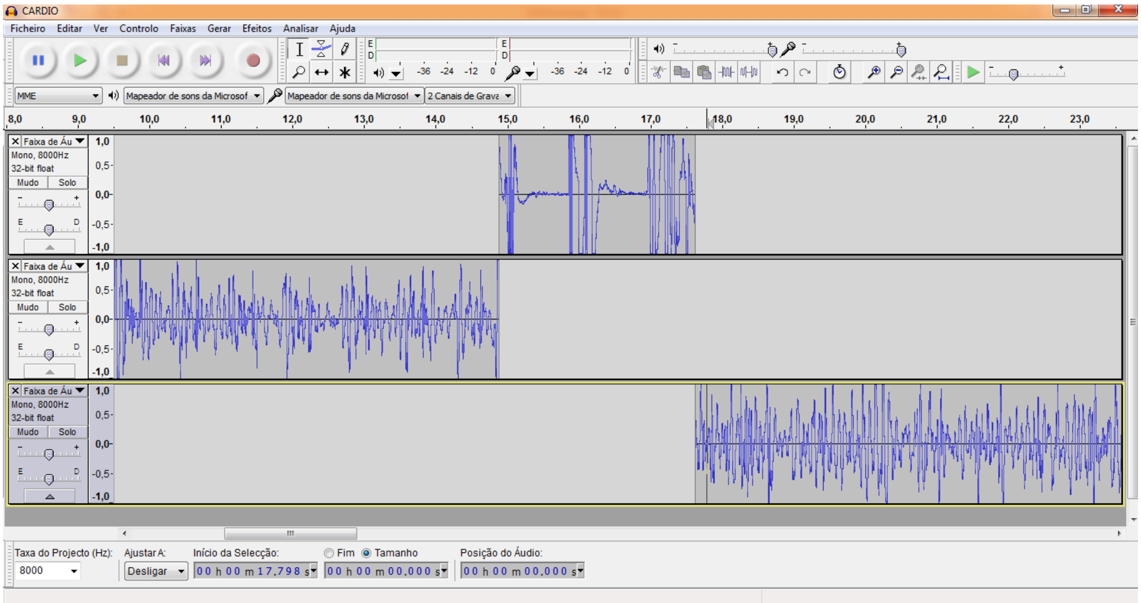


Figure 9: An example of sound after being split by spot: The break was eliminated (remained in first track, which won't be saved) and individual files created for the first and second spot (the first and second track, respectively)

Immediately after splitting into individual files, the sounds were normalized, by focus, to a maximum amplitude of -1,0 dB, on Audacity, as showed in Figure 10.

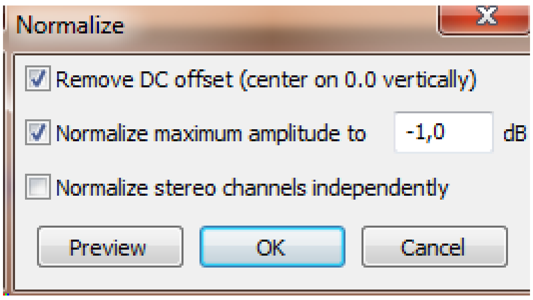


Figure 10: Normalizing the sounds

5.2. Listening Platform: Moodle

In order to listen to the stethoscopes' sounds and answer the evaluation questions the Moodle platform was used.

Upon the creation of two disciplines on Moodle that we called "Comparativo de Estetoscópios – G1" (Figure 11) and "Comparativo de Estetoscópios – G2" (Figure 12) and of configuring its structure, we provided, to each evaluator, a username and a password for enrollment in the course. After the individual login, we helped the evaluators, in order to obtain the quiz window.

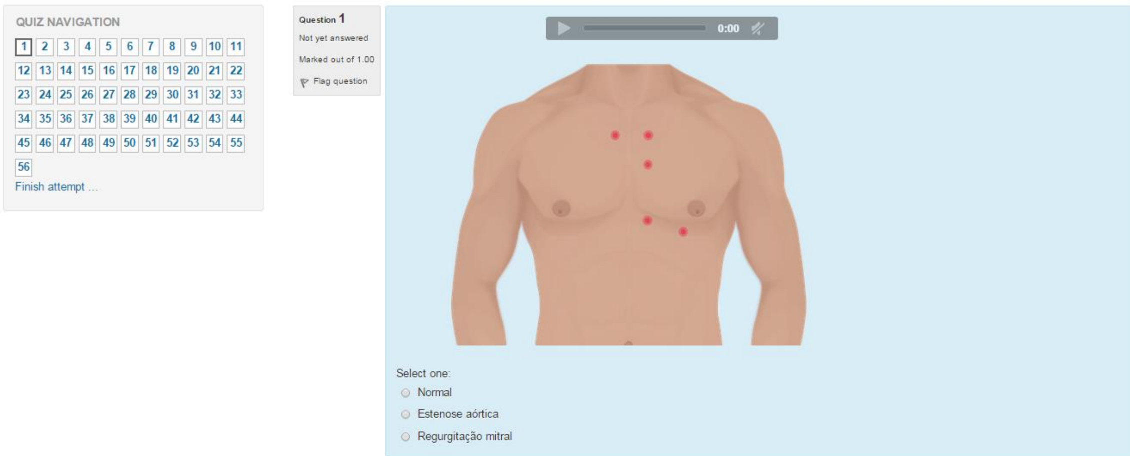


Figure 11: Questionnaire on Moodle for G1: red points represents the various auscultation spots, which were previously split.

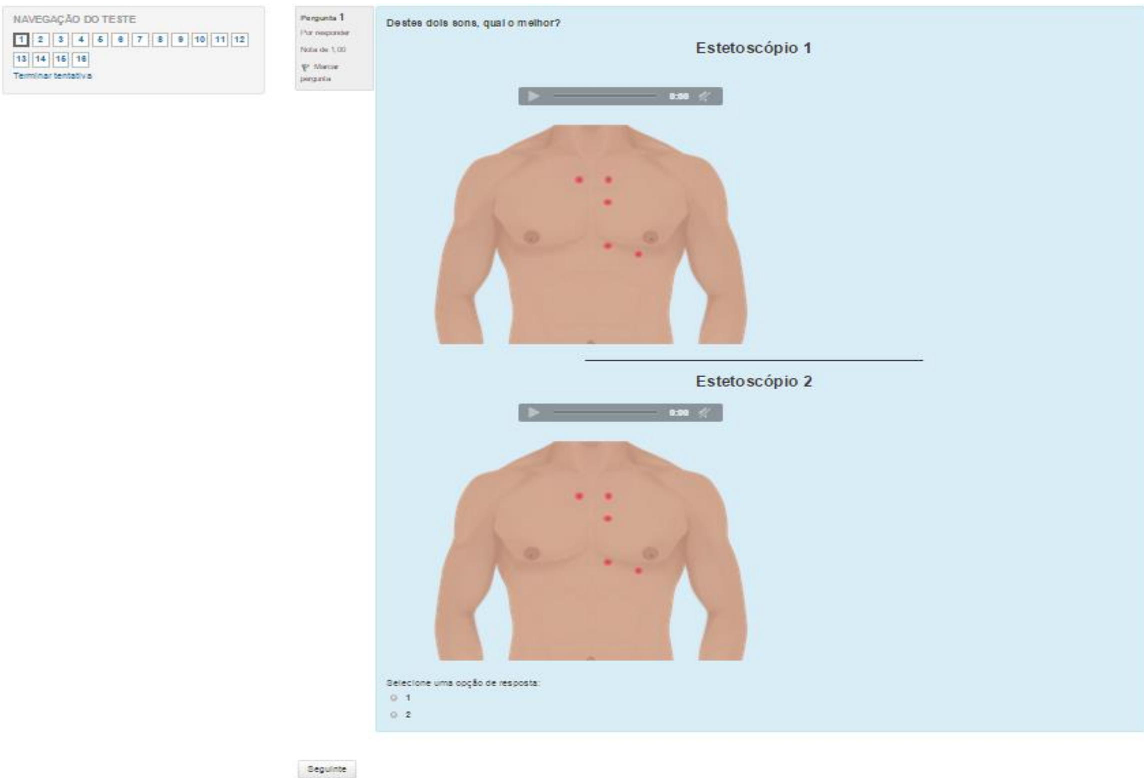


Figure 12: Questionnaire on Moodle for G2: red points represents the various auscultation spots, which were previously split.

For each case, a virtual torso will provide the possibility for the evaluator to listen to each auscultation spot's sound.

After answering the question, the observer can press the button "Next" and proceed with questionnaire. If necessary, they can repeat the question. At the end, they had no access to the test score neither its correction. The answers given were saved and can be consulted in various formats.

5.3. Headphones

To choose the best headphones to hear the heart sounds, the most important is the frequency response. As seen previously, a heart sounds spectral energy is concentrated in the frequency region between 20 Hz and 500 Hz. Thus, the headphones have to exhibit good frequency response in this range, which is not typical for common headphones such as the ones popular now for smartphones. Other additional criteria were defined: over-ear configuration instead of in-ear and on-ear, and not be wireless transmission.

After market research, the most promising headphones found are presented in the Table 7.

Table 8: Headphones selection

Brand	Model	Frequency response (Hz)	Price (€)
Grado	SR80e	20-20 000	79
Audio-Technica	ATH-M50x	15-28 000	136
Sennheiser	HD 650	10-39 500	410
AKG	K450	11-29 500	80
AKG	K545	10-25 000	199
Sennheiser	HD 700	10-42 000	604
Pioneer	M521	7-40 000	23.50

The chosen set of headphones was the Pioneer M521 because it offers the best frequency range and a nice quality-price relation. These headphones were used by researchers to split the sounds, and also by observers to answer the questionnaire.

5.4. Study Procedures

Efforts were made to assure the same environment between the two groups.

The headphones for each evaluator were provided (more details in subchapter 5.3). I was present in all of sessions to prepare the questionnaire on the computer and answer the doubts of physicians.

- **Group 1 – Expert Group**

The study of G1 was conducted in Hospital Santo António, Porto, in a room used routinely by physicians (see Appendix II), during September 2015. In order to access the questionnaire, an Asus computer was provided.

The ambient noise was measured using the Smart Tools application (version 1.5.8) installed in a Samsung Smartphone and its typical value was about X decibels.

4 physicians answered the questionnaire in 2 sessions of 30 minutes of each one. 4 physicians answered all of questions in one session of 30 minutes.

- **Group 2 – Normal Group**

The study of G2 was conducted in Hospital São João, Porto, in a classroom (see Appendix III), during September 2015. The ambient noise was also measured using the Smart Tools application (version 1.5.8) installed in a Samsung Smartphone and its typical value was between 33 and 41 decibels.

The students answered all of questions in four consecutive sessions of 15 minutes.

6. Results

6.1. Group 1

The answers of Group 1, relatively to the pathology, were saved in a table by stethoscope. (see Appendix IV).

Table 8 presents final results of the ranking of stethoscopes, based on % of success and confidence intervals.

Table 9: Final results of Group 1

Stethoscope	% of success	CI at 95%	Rank
Littmann	0.1	[0.04; 0.2]	4/5
Welch Allyn	0 .12	[0.05; 0.23]	2/3
Wise	0.17	[0.087; 0.29]	1
Jabes	0.1	[0.043; 0.21]	4/5
Cardionics	0.067	[0.02; 0.17]	6
Thinklabs	0.12	[0.05; 0.23]	2/3

6.2. Group 2

For each comparison was saved the stethoscope chose. The answers are presented on a table (see Appendix V).

The results of this group are present on Table 9.

Table 10: Final results of Group 2

Stethoscope	% of times	CI at 95%	Rank
Thinklabs	66	[55;76]	1
Jabes	65	[53;75]	2
Wise	48	[36;59]	3
Cardionics	44	[33;55]	4
Littmann	41	[31;53]	5
Welch Allyn	35	[25;47]	6

7. Discussion

The results of the Group 1, the Expert Group, indicate that no statistically significant difference between the stethoscopes. However, the Wise was the stethoscope that obtained the higher proportion of success, while Cardionics obtained the low proportion of success between the evaluated stethoscopes.

The results of Group 2, the normal group, indicate that Thinklabs was the stethoscope more chosen (66%), following by Jabes (65%), Wise (48%), Cardionics (44%), Littmann (41%) and, at least, Welch Allyn (35%).

The results also show a statistically significant difference between Thinklabs [55; 76] and Cardionics [33; 55]; Thinklabs [55; 76] and Littmann [31; 53]; Thinklabs [55; 76] and Welch Allyn [25; 47]. Also show a statistically significant difference between Jabes [53; 75] and Littmann [31; 53] and Jabes [53; 75] and Welch Allyn [25; 47].

During this work we have encountered some situations that may be considered as limitations or biases to obtain the described results. Main limitations are: the fact of recorded new sounds, because, despite the efforts made to replicate the environmental conditions of the main dataset, there are variables than we couldn't control; the observers being experiential different, because a physician which work on a central hospital, can have more experience than other who works in a periphery hospital and the study design considers evaluation by case and not by focus.

Furthermore, other limitations include the limited time with only 1 months collecting results; the sample size, that is interesting but limited and the stethoscope conditions may not be the same in the various recordings, over the time. Despite these limitations, our global results show statistically the Thinklabs is the better stethoscopes, according to Group 2 to record cardiac auscultation.

8. Conclusion

Advancements in medical technology have allowed physicians to better diagnose and treat their patients since the beginning of the professional practice of medicine. The electronic stethoscope is a good example of this, which in today's world, could plays an important role in every hospitals. However, there are a huge diversity available on the market and it is increasingly necessary, such happens in other health technologies, evaluate the performance of them.

In this thesis, we contributed to this field because is the first study of comparison of electronic stethoscopes, evaluating the effectiveness of them, as a recorder of heart sounds that may be used for education or telemedicine.

For this purpose were asked the physicians to evaluate the different six stethoscopes and evaluated results using the best practices described in literature. Despite a few limitations identified in Chapter 7, we consider that by interplaying directly with a real environment where observers have their own agenda and priorities, we obtained a set of quite interesting results.

8.1. Main Findings

Possibly, the most relevant main finding of this work is the confirmation that electronic stethoscope is a viable technology for record cardiac sounds to use in medical education and telemedicine. We have obtained statistically relevant results, according to Group 2, that quantify the Thinklabs as the better electronic stethoscope to record cardiac auscultation.

8.2. Main Recommendations

We believe that this study can put back the stethoscope as the most vital instrument for the diagnostic of heart diseases. Electronic stethoscopes investment could mean skills improvement and the consequent enhancement of health care services provided.

This study can further be improved increasing the number of observers and sounds evaluated, especially in student's analysis, with normal cases in order to obtain the best stethoscope to listen determined pathology. The main recommendation is that a study, including pulmonary auscultation, the new stethoscopes that arise such as Thinklabs One, where correlates this subjective comparison with an objective study, which evaluates the sound technical features of each stethoscope, could be interesting.

The main feature assignment is publish the results on a Journal.

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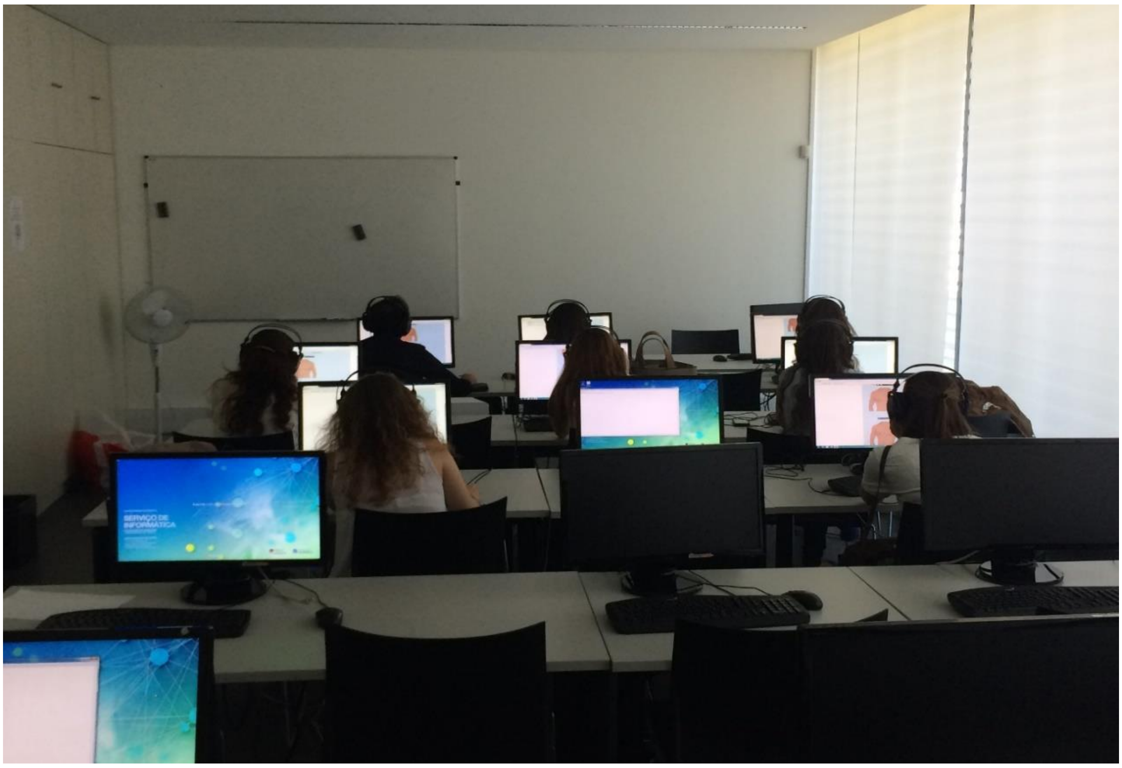
10. Appendix

Appendix I: Sounds distribution by stethoscope

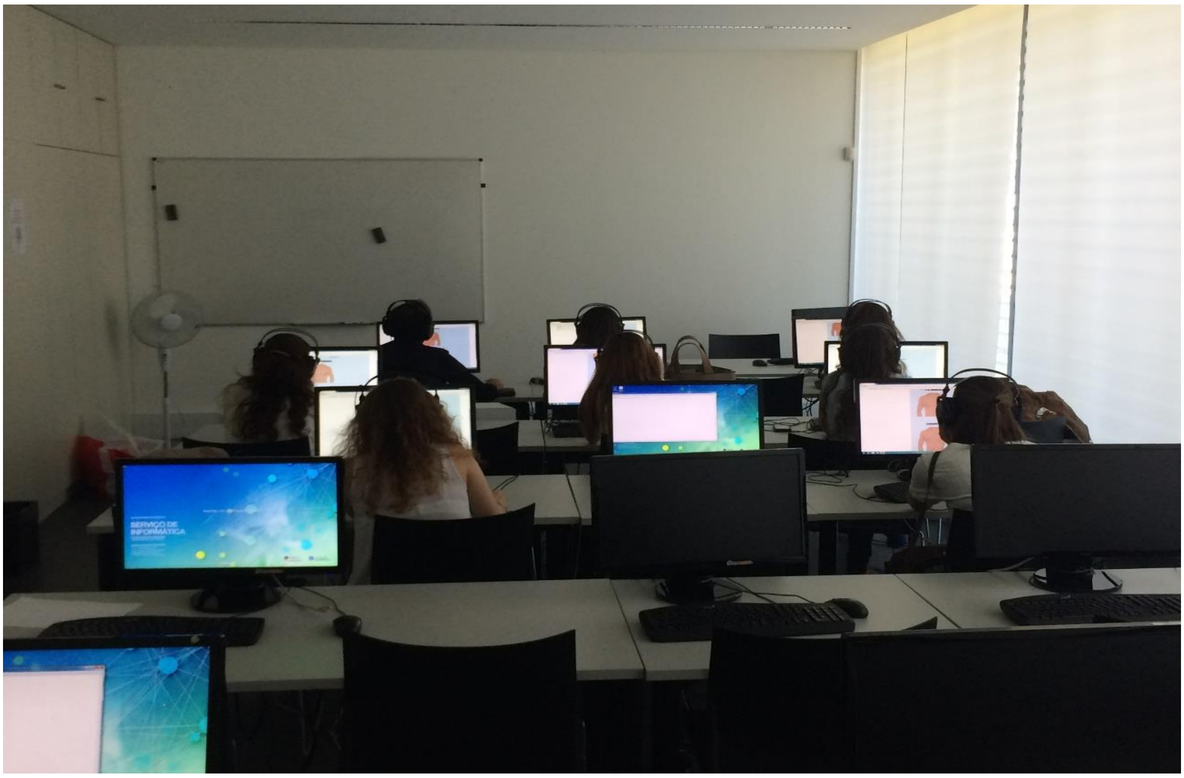
Patients	Cardionics	Littmann	Jabes	Wise	Welch Allyn	Thinklabs
1		X	X	X	X	X
2		X	X	X	X	X
3		X	X	X	X	X
4		X	X	X	X	X
5		X	X	X	X	X
6		X	X	X	X	X
7		X	X	X	X	X
8		X	X	X	X	X
9		X	X	X	X	X
10		X	X	X	X	X
11		X	X	X	X	X
12		X	X	X	X	X
13		X	X	X	X	X
14		X	X	X	X	X
15		X	X	X	X	X
16	X	X	X	X		X
17	X	X	X	X	X	X
18	X		X	X	X	X
19	X		X	X	X	X
20	X		X	X	X	X
21	X		X	X	X	X
22	X		X	X	X	X
23	X		X	X	X	X
24	X		X	X	X	X
25	X		X	X	X	X
26	X		X	X	X	X
27	X		X	X	X	X
28			X	X	X	X
29	X		X	X	X	X
30	X		X	X	X	X
31	X		X	X	X	X
32	X		X	X	X	X
33	X		X	X	X	X
34	X		X	X	X	X
35	X		X	X	X	X
36	X		X	X	X	X
37	X		X	X	X	X
38	X		X	X	X	X
39	X		X	X	X	X
40	X		X	X	X	X
41	X		X	X	X	X
42	X		X	X	X	X
43	X		X	X	X	X
44	X		X	X	X	X
45	X		X	X	X	X
46	X		X	X	X	X
47	X		X	X	X	X

48	X		X	X	X	X
49	X		X	X	X	X
50	X		X	X	X	X
51	X		X	X	X	X
52	X		X	X	X	X
53	X		X	X	X	X
54	X		X	X	X	X
55	X		X	X	X	X
56	X		X	X	X	X
57	X		X	X	X	X
58	X		X	X	X	X
59	X		X	X	X	X
60	X		X	X	X	X
61	X		X	X	X	X
62	X		X	X	X	X
63	X		X	X	X	X
64	X		X	X	X	X
65	X		X	X	X	X
66	X		X	X	X	X
67	X		X	X	X	X
68	X		X	X	X	X
69	X		X	X	X	X
70	X		X	X	X	X
71	X		X	X	X	X
72	X		X	X	X	X
73	X		X	X	X	X
74	X		X	X	X	X
75	X		X	X	X	X
76	X		X	X	X	X
77	X		X	X	X	X
78	X		X	X	X	X
79	X		X	X	X	X
80	X		X	X	X	X
81	X		X	X	X	X
82	X		X	X	X	X
83	X		X	X	X	X
84	X		X	X	X	X
85	X		X	X	X	X
86	X		X	X	X	X
87	X		X	X	X	X
88	X		X	X	X	X
89	X	X	X	X	X	X

Appendix II: Environment classroom conditions of Group 1 (Expert Group)



Appendix III: Environment classroom conditions of Group 2 (Normal Group)



Appendix IV: Answers of observers of Group 1 (Expert Group)

- **Littmann**

	Observers										Eco Findings
Questions	1	2	3	4	5	6	7	8	9	10	
1	Normal	Normal									Mitral
2	Stenosis	Normal									Mitral
3	Normal	Normal									Stenosis
4	Stenosis	Stenosis									Mitral
5	Stenosis	Stenosis									Stenosis
6	Stenosis	Stenosis									Stenosis
7	Mitral	Normal									Normal
8	Mitral	Mitral									Normal
9	Mitral	Stenosis									Normal
10	Stenosis	Normal									Normal

- **Cardionics**

	Observers										Eco Findings
Questions	1	2	3	4	5	6	7	8	9	10	
1	Mitral	Normal									Stenosis
2	Stenosis	Mitral									Stenosis
3	Normal	Normal									Stenosis
4	Stenosis	Normal									Mitral
5	Stenosis	Normal									Mitral
6	Stenosis	Stenosis									Mitral
7	Stenosis	Stenosis									Normal
8	Stenosis	Normal									Normal
9	Stenosis	Normal									Normal
10	Mitral	Normal									Normal

- **Jabes**

	Observers										Eco Findings
Questions	1	2	3	4	5	6	7	8	9	10	
1	Normal	Stenosis									Mitral
2	Normal	Normal									Mitral
3	Stenosis	Mitral									Stenosis
4	Stenosis	Mitral									Mitral
5	Mitral	Normal									Stenosis
6	Mitral	Mitral									Stenosis
7	Mitral	Normal									Normal
8	Stenosis	Normal									Normal
9	Stenosis	Normal									Normal
10	Mitral	Normal									Normal

- **Wise**

	Observers										Eco Findings
Questions	1	2	3	4	5	6	7	8	9	10	
1	Stenosis	Stenosis									Mitral
2	Normal	Normal									Stenosis
3	Mitral	Stenosis									Mitral
4	Stenosis	Stenosis									Stenosis
5	Stenosis	Normal									Stenosis
6	Mitral	Mitral									Mitral
7	Stenosis	Normal									Normal
8	Stenosis	Normal									Normal
9	Stenosis	Normal									Normal
10	Stenosis	Normal									Normal

- **Thinklabs**

	Observers										Eco Findings
Questions	1	2	3	4	5	6	7	8	9	10	
1	Stenosis	Stenosis									Mitral
2	Mitral	Normal									Mitral
3	Stenosis	Stenosis									Stenosis

4	Mitral	Normal									Mitral
5	Stenosis	Normal									Stenosis
6	Normal	Normal									Stenosis
7	Stenosis	Normal									Normal
8	Mitral	Stenosis									Normal
9	Stenosis	Stenosis									Normal
10	Mitral	Mormal									Normal

- **Welch Allyn**

	Observers										**Eco Findings**
Questions	1	2	3	4	5	6	7	8	9	10	
1	Normal	Stenosis									Mitral
2	Normal	Stenosis									Stenosis
3	Mitral	Stenosis									Stenosis
4	Mitral	Stenosis									Stenosis
5	Normal	Normal									Mitral
6	Mitral	Mitral									Mitral
7	Stenosis	Normal									Normal
8	Stenosis	Mitral									Normal
9	Stenosis	Normal									Normal
10	Stenosis	Stenosis									Normal

Appendix V: Answers of observers of Group 2 (Normal Group)

	Pairs of stethoscopes														
Cases	**WIxWA**	**WIxJ**	**WIxT**	**WIxC**	**WIxL**	**WAxJ**	**WAxT**	**WAxC**	**WAxL**	**JxT**	**JxC**	**JxL**	**TxC**	**TxL**	**CxL**
1	WI	J	WI	C	L	J	WA	WA	WA	T	C	J	T	T	L
2	WA	J	T	WI	L	J	WA	C	L	T	C	J	T	T	L
3	WA	J	T	WI	WI	J	T	C	WA	J	J	J	C	L	C
4	WI	J	T	C	WI	J	WA	WA	L	T	C	L	T	L	C
5	WI	WI	T	C	L	WA	T	WA	L	T	J	L	T	L	C
6	WI	WI	WI	C	WI	J	T	WA	L	J	J	J	C	L	C
7	WI	J	WI	WI	L	J	WA	WA	L	J	C	J	T	L	C
8	WI	WI	WI	WI	WI	J	T	C	WA	T	J	L	T	T	L
9	WI	WI	T	WI	L	J	T	C	WA	T	C	L	T	L	L
10	WA	J	WI	WI	WI	J	T	C	WA	T	C	L	T	T	C
11	WA	J	T	WI	L	WA	WA	WA	WA	T	J	L	T	T	L
12	WA	J	T	C	L	WA	T	C	WA	T	C	J	C	T	C
13	WI	J	T	WI	WI	J	T	C	WA	J	J	J	C	T	L
14	WI	J	T	WI	L	J	WA	WA	L	T	C	J	T	L	L
15	WI	J	T	C	L	J	T	WA	WA	J	J	J	T	L	L
16	WA	WI	T	C	WI	J	T	WA	WA	T	J	L	C	T	C