Teaching Heart Auscultation to Health Professionals

Methods for Improving the Practice of an Ancient but Critical Skill

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Foreword

Treatises on auscultation, even those within textbooks, have failed to keep pace with advances in technology and contemporary teaching methods. This excellent and timely book sheds new light on how this valuable skill can be taught more effectively. The auscultation of cardiac sounds is deeply rooted in the practice of medicine, representing one of the first amplifications of observation. The critical linkage of observation and pathology was fundamental in elevating medicine from an art to a science. While being seminal in the development of medicine, the long history and many technological advances have left the acquisition and practice of skill in auscultation largely unchanged. This has resulted in a diminishing accuracy of current providers in performing auscultation and interpreting the findings, as expertly outlined in the introductory chapter of this book. The consequence of this lapse in expertise leads not only to missed disease, but to increased costs associated with further diagnostic evalutions for those misidentified as having disease.

How is it that such an ancient and simple practice has survived in the face of escalating technology? The answer is that it remains a relatively simple manoeuvre, which makes it a handy screening and diagnostic tool. Auscultation is often the entry point into more specific diagnostic testing, the results from which then provide the listener with ongoing feedback and skill development. It also allows us as healing practitioners to have direct physical contact with the patient and to peer within. The stethoscope has acquired some of the properties of a talisman, and is often seen as a token of legitimacy of our claim to be health care practitioners, certainly by eager students and novices.

Despite universal use, the utility of auscultation for screening and diagnosis has recently diminished primarily due to failure of educators and mentors to successfully bring the skills of providers to an expert level. There is a wealth of observation by which what we hear has been linked to specific pathology and pathophysiology. Yet diagnostic properties, such as sensitivity, specificity, positive and negative predictive values, likelihood ratios and pre- and post-test probabilities, have not been optimally assessed regarding aspects of auscultation. If auscultation were to be introduced de novo into clinical practice today, we might very well be interested in these properties, particularly regarding the expense in terms of time for skill development and practice versus its utility in the detection and specification of pathology. A few studies have been performed looking at diagnostic testing properties for the differentiation of innocent murmurs from those associated with cardiac pathology, with varying results depending on the type and experience of the specific health care provider group being studied. The results have been a bit discouraging. Some specific auscultatory signs are associated with specific pathologies (e.g. pansystolic murmurs associated with ventricular septal defects or atrioventricular valve regurgitation), and thus would be associated with a high sensitivity and specificity when noted. However, individual auscultatory components are rarely considered in isolation. One usually considers the heart sounds, murmurs and extra sounds together, and often in association with other aspects of clinical assessment, such as precordial palpation and medical history. This makes the assessment of diagnostic metrics complex, which lies in contrast to the simple utility of auscultation. Nonetheless, this type of information and a firm evidence base would be very important in informing teaching about auscultation.

The contemporary methods by which auscultation skills might be more effectively taught represent the primary focus of this book. The authors have made careful and expert consideration of novel technology and resources, and state of the art science of education principles specific to auditory learning. Auscultation involves hearing, perception and processing of cardiac sounds, each step of which needs to be specifically addressed and optimized. The conditions, equipment and technique of auscultation can have a great influence on what sounds reach our tympanic membranes. Newer methods have been developed to filter and amplify sounds, as well as to share sounds with multiple listeners and across novel media platforms. This has the potential to provide uniformity in the hearing of sounds. Specific sections of this book address this previously unexplored topic.

However, little has changed regarding how to teach listeners to selectively listen and to focus their perception on individual sounds and components, and then to synthesize that perception into a unified whole. This is the unique and important contribution of this book. The importance of perception is not unique to cardiac auscultation, but has parallels with other endeavours involving complex sound perception, such as speech and music. Evidence and methods from other fields certainly have relevance for auscultation of cardiac sounds, which are as yet an unexplored resource but expertly addressed within this book. The addition of imaging or visual cues may be an important method to augment and focus sound perception. Once perceived, cardiac sounds must be given meaning in terms of their relationship to pathology and pathophysiology. These processing and interpretation steps clearly lie within the realm of clinical teaching, both in didactic formats and in case-based settings. Well-designed and innovative curriculae and a compendium of available resources are needed and provided.

The improvement of teaching methods will lead to the improvement of auscultation skills, which will lead to better detection and differentiation of cardiovascular pathology by a broad range of health care providers, which will further lead to better outcomes for our patients. At each step, evaluation is necessary, and the development of a strong evidence base is critical for ensuring that auscultation continues to have enduring relevance and utility in clinical practice. A comprehensive and informed discourse on this topic is long overdue, and will facilitate innovation in this most fundamental of clinical skills. This book stands alone in the degree to which it comprehensively addresses new technology and new approaches to learning. However, it is not strictly an academic discourse, as much practical material is provided regarding curriculum and available resources. Teaching Heart Auscultation to Health Professionals will ensure that the teaching of auscultation is no longer a skill taken for granted, but an endeavour that is pursued with a high level of expertise and effectiveness.

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Preface

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2019 Edition

Since publication of the 2011 print edition and the open access 2015 online version (including heart sound recordings), reception of the book and associated material has been gratifying. International access to the website has been steady and a number of Canadian and international medical schools use the recordings for group and individual teaching. With the 200th anniversary of the invention of the stethoscope by Laennec in 2016 there has been a renewed focus on physical examination. A number of articles have appeared strongly urging better teaching and emphasizing the importance of careful examination before imaging. New teaching resources and apps for mobile devices continue to proliferate, although many are not field tested before marketing. Finally the availability and promotion of inexpensive cardiac ultrasound devices has led to their widespread use, often without evidence based recommendations.

In this revised online edition much has been added or updated. In Chapter 6 the conclusions of the Canadian-Australian study on heart murmur recognition have been added, with a late reinforcement module which is available through the website. Chapter 8 on technical aspects of teaching is completely revised to reflect web-based teaching using recordings accessed on this website. Similarly Chapter 10 on curricula and Chapter 12 on teaching devices have been updated. The potential of hand held ultrasound in teaching is reviewed in Chapter 2.

Preface to 2011 edition

Why a book on teaching heart auscultation in 2011? The concept of this book has been formulated gradually over my teaching career of over 30 years, prodded by the questions and provocative ideas of colleagues, in particular Dr Doug Roy. His chapter sets a challenging tone for the book, encouraging teachers to explore ways to resurrect the ancient but critically important skill of heart auscultation.

But surely the skill is now redundant with our plethora of truly remarkable imaging techniques for the heart? In reality, despite the undeniable advances in technology, heart auscultation remains one of the most important skills for health professionals for the detection of heart disease. The findings on auscultation may lead directly to a diagnosis in some cases or indicate the need for further diagnostic tests in others, but are often the first step towards diagnosis of suspected heart problems. Despite the importance of this skill, auscultation is remarkably poorly performed by medical students and practicing physicians, according to many recent studies. While most physicians carry a stethoscope, it is doubtful whether most of them could reliably distinguish pathological from normal heart sounds, especially in children. The poor performance with the stethoscope means that many patients are referred for expensive and time consuming investigations unnecessarily, while other patients who have true pathology may not be referred in timely fashion.

A major reason for poor auscultation skill is that teaching methods have changed little in the last 50 years. Medical schools generally do not employ modern protocols for teaching auditory skills, such as those validated by audiologists and neuropsychologists. There is a dearth of knowledge available to health professional schools about effective methods and technology for teaching heart sounds auscultation. Further, outcomes are rarely measured. In this book we aim to rectify the lack of information on teaching methods and promote better teaching of this skill, to equip health professionals with adequate skills to better serve their patients. The book has both an international and interdisciplinary range of contributions.

After a provocative introduction by Doug Roy and a review of the current state of auscultation by Andrew Mackie, Michael Barrett and Janice Pieretti offer their experience with a truly evidence- based approach to a new format of teaching. Repetition is emphasized, and the medium for their program is the internet. Rachel Caissie, a clinical audiologist, describes another new approach, adapting auditory training protocols which are in daily use for the hearing impaired. Auscultation teaching may have much to learn from music education. Rob Ellis provides background to how music is processed by the brain, with the implication that learning to recognize heart sounds may follow the same pathways. Thus heart sounds teaching might be informed by our understanding of the way in which music is learned.

Nancy ONeill, a neonatal nurse practitioner and educator, reminds us that it is not only physicians who require auscultation teaching. Nurses and other health professionals also require good teaching methods. A vital and unique technical chapter is provided by Brian Hoyt who brings many years of experience helping clinical teachers to record and reproduce heart sounds in an effective format, whether in class or online.

Assessment of auscultation skills is vital to learning and verifying competence. I have summarized current understanding of good assessment practice, offering advice based on my experience as well. A modern approach for auscultation teaching for health professionals is proposed to guide institutions in renovating their teaching. Finally, I have compiled a list of available teaching materials and equipment to help those searching for effective learning aids.

We are firm in our conviction that heart auscultation should not die and that the stethoscope is not just a totem or another piece of jewellery. We owe it to our patients to listen with skill to their hearts. We trust this book is a step in that direction.

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Much of the planning, writing and initial editing of the book took place at the Princess Margaret Hospital for Children, Perth, Western Australia, the location of the Editor's sabbatical. The Editor is most grateful for the hospitality shown by Dr. James Ramsay, Chief of Pediatric Cardiology, and the staff of his Division. Pam Nicol RN, Clinical Educator in Pediatrics and Child Health at the University of Western Australia, has been a wonderful and energetic collaborator on the trial of the new auditory training protocol for heart sounds that is outlined in this book. Dr. Ian Wallman and Rhonda Wallman were exemplary hosts in Perth, generously sharing their home with the Editor and his wife during the sabbatical. All the contributing authors have been most supportive of this book project and very patient with the Editor in helping transform rough ideas for topics into focused documents. Particular thanks are due to Dr. Doug Roy for his inspiration and mentoring over many years and unwavering energy to find better ways to teach auscultation.

Finally I deeply appreciate the encouragement and understanding my wife Carolyn provided during this project, which has demanded so much of my personal time and attention.

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Teaching Heart Sounds to Health Professionals

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My introduction to the stethoscope came at age fifteen years. I had contracted a febrile illness and my father, a family practitioner in a small town, was listening to my heart. Rheumatic fever was endemic at that time. I was consumed with interest as to what he could be hearing. As a medical student sometime later, using a stethoscope similar to that used by my father, I was dismayed by the lack of teaching in its use. The interest that was kindled was not to be satisfied until studying at a children's hospital four years later. My chief, a skilled auscultator, and I would daily examine some twenty patients with rheumatic fever. The findings of the softness of S1 and mitral and aortic regurgitation were commonplace, and even the Carey Coombs murmur could be occasionally elicited.

In 1951, at the time of my entrance into the practice of cardiology, in both adult and pediatric teaching hospitals, the teaching of cardiac auscultation was beginning to change. Samuel Levine's paper on the Apical Systolic Murmur and his method of grading systolic murmurs had been published.[1] Dr. Paul Wood's book, Diseases of the Heart and Circulation [2], published in 1950, became my bible. Changes also had occurred in the stethoscope. Rappaport and Sprague developed a combination bell and diaphragm, with a single tube leading to each earpiece, and marketed by Hewlett Packard, which became the Cadillac of stethoscopes in the late forties. Hewlett Packard lost control of this stethoscope and the new distributor ceased production of the stethoscope, which was displaced by the Littman model, perhaps acoustically inferior but lighter, easier to use and less expensive. Further improvements were introduced in the 3M Littman and this model we see today, in a variety of colours, cast around the neck of all health care professionals, purporting knowledge of its use.

Today when the topic of cardiac auscultation is discussed, one so often hears the expression, "It's not like it was in the old days". This is only in part true; cardiac auscultation indeed was extremely important, there being essentially few other diagnostic aids, but present knowledge of heart sounds and available teaching methods has greatly improved. Nonetheless medical students today graduate unable to differentiate the normal from the abnormal.

The lack of cardiac auscultation skill in graduating medical students has been repeatedly demonstrated[3,4,5], despite programs for its improvement[4,5]. Where health care professionals have no difficulty eliciting Korotkov sounds or the rumble of borborygmi, the reason for poor auscultation skill is generally considered to be the complexity of heart sounds and murmurs-too many different sounds for the brain to assimilate. Other reasons given include inadequate musical skill of the listener, variable intensity and frequency of heart sounds and murmurs within the same patient, and insensitivity of the human ear. Of interest is that there is no recommended format for the teaching of cardiac auscultation and the American Heart Association has no guidelines for this subject. Certain medical schools in North America have no teaching hours dedicated to this subject[6]. The availability of recordings of human heart sounds in computer programs[8,9] has resulted in a modest improvement in this skill deficit. This may be due to the incorporation of repeated listening, which has been shown to improve cardiac auscultatory skill[10].

This lack of skill brings with it important consequences for patient care. Many patients with normal auscultatory findings are being sent for expensive investigative procedures and where seventy percent of children have a heart murmur[11,12], this problem is great. More serious however is the fact that patients with an abnormal auscultatory finding such as the aortic ejection click, are not diagnosed until the patient becomes symptomatic years later. It is incongruous that the stethoscope is the icon for being a health care provider.

Given the apparent lack of emphasis on auscultation teaching in medical school curricula, we must also ask if the actual teaching of auscultation has been effective. Are the teaching methods appropriate? Simplification of teaching by teaching only the normal, and advising referral of anything else i.e. abnormal, to a specialist possibly should help. The inference is made by some education professionals that we are tilting at windmills[13]. A closer study of the teaching of cardiac auscultation is important, searching for the answer to the core of the problem, methods to teach the student "how to listen". The tendency is for the auscultator to listen for the tune or melody, when no tune exists, and fail to listen to the individual components of the cycle. For a sound to be musical, sound frequencies must be the same. As with a guitar string, vibration must occur. Blood does not vibrate, and therefore most heart murmurs which originate from blood turbulence are non-musical. It is the author's belief that methods to improve the teaching of cardiac auscultation should be directed at addressing the problem of how to listen selectively to all the components of the cardiac cycle.

Music teachers have been teaching students methods of improving their listening skills for years and a search for their experience is indicated. The general impression is that one's skill in frequency and rhythm appreciation i.e. musicality, is inborn and unchangeable. Computer programs to increase these skills i.e. solfege, are available[14], and definite skill improvement with their use is claimed. Communication between university music and cardiology departments is uncommon. However both disciplines must address a similar problem-musicality skill deficiency. Investigation of the methods which music departments use would seem indicated.

The word "musical" usually connotes a continuum of frequencies which occur very close together. As previously stated, blood does not vibrate, as vortices which are being shed are of different frequencies. The first and second heart sounds, caused by tissue movement, are too short in duration to be musical. Therefore heart sounds and murmurs are non-musical "noises". Yet they are a continuum of mixed frequencies and are a form of music, albeit non-musical music, and occur in rhythms that vary. Thus, in the appreciation of heart sounds and murmurs, methods that are proven to work in music teaching should apply to teaching cardiac auscultation.

A further argument for adapting methods of music teaching for cardiac auscultation is that there is general belief that good cardiac auscultators are musical. Five percent of people are tone-deaf[15] . The remainder have varying degrees of musicality, with the highest having perfect pitch and rhythm. Music teachers have strong evidence that one's musicality can be improved, with certain teachers even believing that everyone can achieve perfect pitch. Computer downloads are available which purport to increase musicality[14]. Suggestions of ways in which one's musicality may be increased include: repeatedly listening to recordings; daily listening; attempts to replicate; tune in on YouTube and snap fingers or clap hands to rhythms.

Novel ideas which might bring the methods of music teaching and sound recognition to bear on heart auscultation include session(s) by music teachers in first-year medical training; assessment of students' musicality, and follow-up after institution of programs to increase musicality; assessment of cardiac auscultation skill prior to beginning use of the stethoscope. It is recognized that the personality of the student is another factor, i.e.: the presence of a talent does not necessarily assure its use.

A health care professional is graduating and plans to solo practice in a remote area, miles from availability of cardiac ultrasound. The student does not possess the skill to differentiate normal heart sounds from abnormal. Recognizing that no health care plan is perfect, the area will suffer when this person places a stethoscope on a patient's chest. Where does the cause of this deficiency lie? In the student? In the university? In the local medical association? In the government?

Teachers must realize that improvement in this area of health care delivery is possible and take steps to correct this deficiency.

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Auscultation: A Review of Teaching Methods

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Highlights

- auscultation skills among medical students and residents are poor
- auscultation skills can be improved with effective teaching methods
- bedside examination remains an important method of auscultation teaching but should be supplemented by additional teaching tools
- the most effective auscultation teaching method has not been defined but repetition and focus on normal vs. abnormal are essential
- CDs can provide effective learning at less cost than simulators
- future studies should assess transferability to real human subjects

Abstract

Heart murmurs are a common reason for referral to cardiologists, particularly among children, and may be the first clue to the presence of heart disease. However, murmur evaluation is a challenging skill that requires substantial practice and clinical experience in order to

do well. Auscultation skills among medical students and residents are poor but can be improved with a variety of teaching methods. Auscultation learning can occur at the bedside, in classrooms, in small group seminars, or as an independent exercise using CDs, the Internet, or other sources of heart sounds. No single method has been shown to be superior to others. Challenges with the existing literature include small sample sizes, lack of standardization of learner assessment tools, short durations of follow-up, and evaluations using recorded or synthetic sounds rather than human subjects. Regardless of the teaching method(s) adopted, structured learner evaluation is recommended, as is an emphasis on distinguishing innocent from pathologic heart sounds rather than the subtle characteristics of one pathologic sound over another.

Heart murmurs are the most common cardiology problem confronting general pediatricians and family physicians[1], and can be heard in at least 50% of children at some point in childhood.[2] Murmur evaluation is important, as the presence of a murmur may be the first clue to the presence of congenital heart disease (CHD). However, many physicians are uncomfortable with the task of differentiating innocent from pathologic murmurs in children. As a consequence, the presence of a heart murmur is the most common reason for referral to pediatric cardiology clinics. Among adults, murmur evaluation is also an important clinical problem; even in the absence of symptoms, the presence of a murmur may be the first clue to the presence of valvular or congenital heart disease.

Cardiac auscultation is an invaluable skill that requires practice and repeated clinical exposure in order to master. Unlike many concepts taught to medical students and postgraduate trainees, auscultation cannot simply be learned through rote memorization or understanding of physiologic concepts. As a consequence, the task of teaching auscultation is also challenging. No single teaching method has been widely adopted in the medical education community, and there is a paucity of literature comparing different auscultation teaching methods. Further, there is substantial evidence that auscultation skills of medical students[3], residents[4-8], and practicing physicians[9] are poor, supporting the notion that increasing availability and reliance on medical technology is having a negative impact on clinical skills, despite the perception of physicians that auscultation remains an important skill.[9] As a consequence, auscultation teaching is becoming an increasingly relevant field and merits ongoing development and investigation.

The objectives of this chapter are to 1) discuss the evidence regarding the effectiveness of "traditional" auscultation teaching methods, 2) describe the evolving role of "novel" teaching tools, and 3) discuss the considerations required in developing an auscultation teaching program.

Part I: Auscultation Teaching: Traditional Methods

Bedside teaching. The opportunity to manage and care for patients remains the *raison d'être* of most medical trainees and practicing physicians. Experiences gained at the bedside remain an invaluable opportunity to both teach and learn. Advantages of bedside learning include the opportunity to hear "real" as opposed to recorded or computer-generated heart sounds, to immediately compare murmurs and other heart sounds as heard in different auscultatory areas, during different maneuvers (e.g., Valsalva) or in different positions (e.g., left lateral decubitus position), and to place heart sounds in context with other physical findings (e.g., jugular venous distention). Most importantly, bedside teaching most closely approximates the circumstances under which learners will be applying their auscultation skills when confronted with their own patients in the future. However, there are challenges to bedside auscultation learning. These include the difficulty of examining uncooperative patients (e.g., young children), high ambient noise levels, the impracticality of teacher and learner listening simultaneously (unlike recorded heart sounds), infrequent exposure to rare physical findings, and in many settings a high ratio of learners to patients. Ewy and colleagues described their experience with bedside teaching. They reported that less than 50% of time scheduled for bedside teaching was actually spent at the bedside, that faculty members often demonstrated cardiac examination skills without student participation, and that individual assistance with clinical skills was lacking in the experience of 80% of students. Patients who were either unavailable or too frail served as an additional challenge.[10] For a further discussion on the subject of faculty-observed clinical skills, the reader is referred to a thorough review.[11]

There is a paucity of literature on the effectiveness of bedside auscultation teaching, independent of the potential learning impact of simply seeing and examining multiple patients during a cardiology, general internal medicine, or general pediatric rotation. Despite this lack of literature, and the barriers to bedside teaching as noted above, this teaching method offers an invaluable opportunity to model communication skills and “bedside manner”. Furthermore, trainees retain information relatively well when it relates to real cases as compared to when they are provided information that is not in the context of actual patients.[12] As such, bedside teaching and learning should remain a practice that is valued and pursued when the opportunity presents itself.

Classroom teaching. Classrooms offer the opportunity to teach a large number of learners simultaneously, to provide multiple audio examples of auscultatory findings including rarely heard sounds, and for teacher and learner to hear and discuss sounds at the same time. Classrooms also offer the opportunity to discuss concepts such as the physiologic basis of murmurs, which may provide relevant background prior to patient encounters. However, inherent limitations of the classroom exist. These include the need for specialized equipment such as stethophones to reproduce sounds with satisfactory fidelity, and the lack of “real-life” context such as co-existing physical findings that bedside teaching provides.

Learners at all levels, including practicing physicians participating in continuing professional development (CPD), have been exposed to classroom teaching of auscultation. Ostfeld and colleagues demonstrated an improvement in auscultation skills of 3rd year medical students listening to pediatric heart sounds after a single cardiologist-led teaching session that used a commercially-available CD-ROM.[13] However it is not known if that intervention led to a sustained improvement in skill level, as students were assessed only two weeks following the teaching session. Classroom teaching using multiple stethophones attached to a single computer has been well received by students and showed similar effectiveness to CD-ROM-based teaching.[14] Classroom teaching allows for other innovations; Vukanovic-Criley and colleagues successfully incorporated interactive multimedia into the classroom, demonstrating both visual and audible cardiovascular findings with significant pre-post improvement in auscultation skills among medical students (See Multimedia teaching programs, below).[15]

Cardiology rotation. Medical students and residents in family medicine, pediatrics, and internal medicine may have the opportunity to participate in a cardiology rotation. This potentially provides concentrated exposure to multiple patients with cardiac physical findings over a short period of time, and the potential to receive bedside teaching from expert examiners. Cardiology rotations should incorporate bedside teaching, but it is worth noting that these learning opportunities are not synonymous; bedside teaching may occur within settings other than cardiology rotations, such as a clinical skills course for medical students; conversely, although cardiology rotations typically offer the learner plenty of auscultation opportunities as part of patient care, they may offer no actual teaching if in a setting where teaching is not a priority.

Cardiology rotations that include a substantial ambulatory (outpatient) component will provide exposure to a greater number of patients and potentially to a greater variety of physical findings than rotations that are inpatient-focused. Unfortunately there is a lack of literature regarding the impact of a pediatric cardiology rotation on auscultation skills, with some data in fact suggesting no substantial benefit.[6] Internal medicine rotations have also not been associated with a measurable improvement in cardiac examination skills.[15-17] However, Dhuper and colleagues compared pediatric residents who had completed a cardiology rotation with residents who had not. Using pediatric patients, they found a higher diagnostic accuracy for a pulmonary stenosis murmur and an innocent heart murmur among those in the former group.[7] Six of seven (86%) third-year residents, all of whom had completed a cardiology rotation, accurately diagnosed an innocent murmur compared to only 1/7 (14%) of 1st year residents, none of whom had completed a cardiology rotation. However, the authors were unable to separate the potential effect of number of years of training from the completion of a cardiology rotation. It may be that simply having greater experience with patient encounters outside of the cardiology rotation resulted in the improved skills among the 3rd year residents.

Mattioli and colleagues evaluated 26 second and third year pediatric residents attending a 4-week cardiology rotation.[18] Each resident attended cardiology clinic and performed auscultation on at least 50 patients, some with and others without heart disease. Evaluation at the beginning and end of the rotation was performed using recorded human heart sounds. Accurate recognition of the presence of a murmur improved from 66% ± 17% at the beginning of the rotation to only 76% ± 16% at the end of rotation, though this difference was statistically significant. Recognition of an innocent murmur was poor at the pretest (37% ± 33%) but improved modestly to 54% ± 27% at the post-test, also a statistically significant change. Recognition of a pathologic murmur was 75% ± 24% pre- and 84% ± 16% post-rotation (not statistically significant). Residents were considerably better at recognizing the presence of heart disease than the absence of heart disease at the post-test (86% ± 13% versus 59% ± 25%, respectively). This study supports the notion that auscultation skills can be taught in the clinical setting with improvements apparent over a relatively short period of time, but underscores the need to improve the confident recognition of innocent murmurs to ensure appropriate referrals. However, the emphasis on auscultation teaching and learning that existed in this centre at the time of the study may mean that the post-rotation results are better than would be expected of residents undergoing cardiology rotations in other programs. Unfortunately there is often a lack of emphasis on acquiring auscultation skills during cardiology rotations, and an absence of formal auscultation evaluation pre and post, and this reduces the motivation to teach and learn bedside skills.

Compact disks. A variety of compact disks (CDs) have been developed with high-quality recordings of a variety of heart sounds as outlined in Chapter 12 on auscultation resources. Like the classroom, these CDs provide the opportunity to listen to a wide variety of heart sounds. However, CDs also afford more flexibility, allowing the learner to listen with multiple repetitions and at a time that is convenient to him or her (for a discussion of the value of repetition, please see “Repetition” below, and Chapters 4 and 5). CDs also offer other potential advantages; they allow the learner to interact with text and graphic material in addition to audio material, and to progress at his/her own pace. CDs also reduce the teaching burden for medical school faculty and offer the opportunity for assessment using imbedded quizzes.

Roy and colleagues evaluated the role of Ears On™ in a group of family physicians.[9] Ears On™ includes approximately 250 heart sound recordings, almost all from patients. Following a baseline assessment of auscultation skills, 42 physicians agreed to participate in 9 months of self-study with at least 15 hours of time spent using the CD. Post-intervention evaluation of the 21 participants who returned for repeat testing revealed that 19 had a significant improvement in their ability to correctly identify heart sounds, with an average of 4.3 ± 1.9 correct answers for 12 heart sounds at baseline, compared to 8.0 ± 2.3 correct answers on the post-test. Eleven participants noted that they had used the CD to help resolve clinical problems seen in practice.

Of those who did not complete the post-intervention assessment, the most common cited reason was inability to find 15 hours to use the program, reflecting a reality of busy clinicians.

Finley and colleagues conducted a controlled trial of classroom versus Ears On™ CD-ROM teaching of 2nd year medical students.[14] Twenty-one students spent approximately 3 hours over 3 days using the CD, followed by a quiz on the 4th day. A similar number of students participated in a 2-hour lecture reviewing 20 cases chosen to reflect the same sounds heard on the CD. The classroom setting involved multiple stethophones attached to a single computer, and was followed immediately by the same evaluation as the CD group. While the classroom group scored higher on unstructured, open-answer questions, equivalent scores were obtained between groups on multiple-choice questions. Both teaching methods were rated highly by students, and while no student had exposure to both teaching interventions, most felt that exposure to a combination of teaching methods would be ideal.

Ears On™ has also been compared to a cardiology rotation. Mahnke and colleagues[6] evaluated residents using Ears On™ with residents who had no access to the CD but exposure to an outpatient clinic during a 1 month cardiology rotation. Both groups of residents were evaluated before and after these interventions using recorded heart sounds of 5 common clinical scenarios: atrial septal defect, restrictive ventricular septal defect, moderate valvar pulmonary stenosis, bicuspid aortic valve with aortic regurgitation, and an innocent (Still's) murmur. The authors demonstrated a modest improvement among the Ears On™ group (21% improvement in accuracy, primarily due to improved recognition of an innocent murmur). There was no pre-post improvement in skills in the resident group that was exposed to the outpatient cardiology clinic. In summary, CDs are a valuable tool for auscultation teaching with demonstrated effectiveness at least equal to that of other traditional teaching methods but with advantages including flexibility of use and imbedded text, graphics, and assessment tools.

Part II: Auscultation Teaching: Novel Methods

Patient simulator. The use of patient simulation devices for learning clinical skills has become commonplace in medical schools. The first mannequin made for teaching cardiac auscultation was introduced in 1968 and named "Harvey."[19] Another such device, HeartLab™, developed by Dr. Bryan P. Bergeron (Harvard Medical School) in the 1980s, generates synthetic heart sounds that can reproduce an assortment of heart murmurs and other sounds, either singly or in combination.[20] Like CDs, this technology allows the learner to be exposed to multiple different heart sounds and to hear the same sound repeatedly.

In a relatively large multicentre study of instruction with "Harvey", comparing fourth-year students completing a four-week cardiology elective with Harvey instruction (n = 116) to fourth-year students completing a four-week cardiology elective alone (n = 92), Ewy et al. demonstrated that instruction with the patient simulator translated into a slightly higher performance on skills testing with actual patients.[10] Although the device was viewed very favourably by students and faculty, identified weaknesses included the lack of respiratory sounds and thrills, and the inability to assess the effect of interventions such as the Valsalva maneuver.

Sverdrup and colleagues conducted a randomized controlled trial of patient simulator training using the CardioSim Auscultation System (Cardionics Inc., Webster, TX) versus bedside teaching.[21] Forty-nine 3rd year medical students, all of whom had already received core cardiology teaching, received either four hours of simulator training or four hours of additional bedside exposure. Students were then evaluated through examination of four patients, approximately 5-6 weeks following these interventions. No difference was found between students who had simulator training versus additional bedside exposure. Unfortunately the study was limited by the lack of a pre-intervention assessment, the small number of patients available for the post-intervention evaluation, and the absence of innocent murmurs in this group.

de Giovanni and colleagues evaluated the Harvey ("high-fidelity") simulator versus CD-ROM ("low-fidelity") simulator in a group of thirty-seven 3rd year medical students.[22] Students received one hour of introductory teaching and then were randomized to 3 hours of either Harvey or CD instruction, both groups receiving identical subject content. Approximately 6 weeks later students were evaluated in an OSCE format using human subjects, rather than recorded sounds. No difference was found in diagnostic accuracy between these two student groups. Assessment of performance with patients is an important strength of this work, as the authors assessed the transferability of auscultation teaching to real-life circumstances. OSCE evaluation also included an assessment of clinical skills by an observer blinded to the type of instruction the student received; again, no difference between clinical skills of Harvey and CD students was observed. These results support the use of lower-cost CDs over high-cost simulators, the former also offering easier access to students. These findings were also consistent with Kneebone, who has argued that "…lower levels of fidelity may reduce technological limitations and cost without compromising outcomes."[23]

Multimedia teaching programs. Vukanovic-Criley et al. reported their experience with multimedia teaching programs, which allowed for what they termed virtual patient examinations (VPEs).[15] These consisted of actual patients filmed at bedside with integration of recorded heart sounds and visual signals in order to develop eye/ear integration and to more closely reflect the actual process of examining a patient.[24,25] This teaching intervention was provided in a classroom in which students listened through their stethoscopes, attached to individual speaker pads, while watching a video of a patient being examined or dynamic graphics of cardiac or valvar action. Eight teaching sessions were held over a total of 12 hours. Twenty-four 3rd year medical students assigned to an 8-week internal medicine rotation and receiving this intervention were compared to 58 students experiencing the internal medicine rotation alone, without supplemental teaching. Videos used for testing differed from those used during the teaching intervention. The authors found that the intervention group improved significantly in mean scores pre- versus post-intervention (58.7 vs. 73.5% correct, respectively; $p = 0.0001$) whereas the control group did not improve (60.1 pre vs. 59.5 post, p = NS). When retested over a year later, a subset of 8 intervention group students had higher mean scores (83.6) compared to 9 control students (65.0). Sub-scores in inspection, auscultation, and cardiac exam knowledge also improved in the intervention group. This study demonstrated that an innovative curriculum that emphasized not only auscultation but also the visual and timing aspects of cardiac examination resulted in a sustained improvement in cardiac examination competency scores. Further, clinical rotation alone resulted in no measurable improvement in cardiac examination skills. A multimedia computer system by the name of UMedic has also been shown to improve auscultation skills in pre-post testing of senior medical students after two weeks of instruction.[17] In summary, multimedia programs are an innovative and effective teaching tool.

Electronic stethoscopes. Electronic stethoscopes offer the potential to generate phonocardiograms and spectrograms when used with appropriate software[26]; these in turn can be viewed simultaneously during auscultation by learners, potentially offering a learning advantage over auscultation alone. Germanakis and Kalmanti reported a small study of 12 final-year medical students who listened to 125 human recordings including phonocardiograms.[27] Pre-post evaluation demonstrated an improvement in accuracy from 43.6% to 73.7%. However, this study did not compare learning by auscultation alone to learning by auscultation and simultaneous phonocardiogram viewing. Michaels and colleagues demonstrated that detection of S3 and S4 in digitally recorded heart sounds was improved when listeners had the opportunity to both listen to and visually inspect the heart sounds using acoustic cardiographic tracings, compared to auscultation alone.[28] This was particularly true among more experienced observers. However, this study did not evaluate the potential role of cardiographic tracings as a teaching tool.

Sound analysis software using advanced signal processing technologies has been developed in recent years.[29] Used with electronic stethoscopes, this technology interprets heart sounds and determines whether or not the auscultation findings warrant further evaluation (i.e., are likely to be pathologic), with the potential to replace or at least serve as an adjunct to the clinician's ears. However, to date there is limited data to support this capability[30]. A study of primary-care physicians listening to 100 pre-recorded heart sounds with and without a computer-based decision support system revealed that referral decisions were improved with use of the computer-assisted auscultation.[31] However, higher heart rates among young children and difficulty sitting still to obtain high quality recordings will likely continue to pose challenges for this evolving technology, emphasizing the ongoing importance of strong clinical skills.

Repetition. The value of repetition is also covered in Chapters 4 and 5. Briefly, Barrett and colleagues have demonstrated remarkable improvement in the accuracy of heart murmur assessment among 2nd year medical students after listening to 500 repetitions of four heart murmurs (aortic regurgitation, aortic stenosis, mitral regurgitation, mitral stenosis).[31] This was true whether these heart sounds were listened to in a monitored setting (i.e., classroom) or in an unmonitored setting (i.e., on their own time) using a CD. Barrett and colleagues subsequently conducted a study of 3rd year medical students undergoing a 1-month ambulatory medicine rotation.[16] Sixty-five students in the intervention group listened to simulated heart sound recordings on a CD an average of 2.5 times by self-report, resulting in an average of 500 repetitions of each heart sound. Fifteen controls who had the same ambulatory medicine rotation but no CD scored significantly lower on the posttest. In both studies, Barrett demonstrated that accurate recognition of recorded human heart sounds also improved as a consequence of repeated exposure to simulated sounds. However, the transferability of CD repetition to accurate diagnosis when examining human subjects was not assessed.

Personal digital assistants. Investigators at the Medical College of Wisconsin have published their experience with the use of personal digital assistants (PDAs).[32,33] Torre used PDAs to capture students' clinical experience with clinical auscultation during a two-month medicine rotation.[32] The PDAs also provided educational content regarding the clinical characteristics of common systolic and diastolic murmurs as well as third and fourth heart sounds. Students reported a high frequency of use and satisfaction with the tool; 70% felt that the PDA-based software helped them improve their auscultation knowledge and skills but there was no actual assessment of students either pre or post use of the PDA.

Internet-based methods. A number of auscultation applications have become available to users of "smart phones" that are available via the Internet. At the time of writing, these include "iMurmur 2", "Stethoscope Expert", "iStethoscope Pro", "iAuscultate", and "Auscultation". Undoubtedly the number of available applications will increase rapidly in the next few years. In general these applications feature synthetic sounds that, like CDs, can be listened to repeatedly and at the convenience of the learner. To date the learning impact of these applications has not been published.

CD-type programs can also reside on the Internet, further improving availability and flexibility in learning and testing. Other Internet-based tools include podcasts with sounds and commentary[34], and an online curriculum that has been developed by Dr. Michael Barrett in conjunction with the American College of Cardiology. The latter is described in further detail in Chapter 4.

Part III: Considerations in establishing an auscultation teaching program

A thorough discussion on the subject of curriculum development is beyond the scope of this chapter. Multiple resources are available, including publications by Prideaux[35] and Kern.[36] However, a few considerations are noted below.

An important early step when establishing an educational program of auscultation is to decide what the objectives of the program will be. The objectives may differ depending on the level of the learner (e.g. 1st year medical student versus pediatric resident). Regardless of the trainee experience, a consistent learner objective should be the distinction between innocent and pathologic murmurs rather than the accurate identification of individual pathologic lesions (e.g. aortic stenosis versus hypertrophic cardiomyopathy). The reason for this is that children with suspected pathologic murmurs require referral to a pediatric cardiologist who will make the specific diagnosis. Studies have shown that referral directly to echocardiography with subsequent referral to a cardiologist when the echocardiogram is abnormal is both cost-ineffective[37,38] and creates the potential of false negative (or false positive) diagnoses when children are referred to adult echocardiography laboratories.[39,40] Adults with suspected pathologic murmurs also require further evaluation, either referral to a cardiologist or for echocardiography and to a cardiologist only when the echocardiogram is abnormal. Therefore, as emphasized in the preceding chapter by Dr. Roy, educational programs for non-cardiologists should focus on general aspects of murmur evaluation (present versus absent, innocent versus pathologic) rather than correct diagnosis of a variety of different pathologic murmurs, to avoid unnecessary referral to specialist care.[18] The subtle aspects of cardiac auscultation are probably relevant in clinical practice only to those undergoing cardiology training.

Once learner objectives have been determined, the issue of when to teach in the curriculum will need to be considered. However, the ideal time to address auscultation teaching has not been addressed to date; likely more than once is needed. An introduction to cardiac auscultation should occur in conjunction with other topics related to the cardiovascular system in the first or second medical year. This provides the student with the necessary background to begin cardiovascular examination and provides relevance to learning cardiac anatomy and physiology. Classroom settings lend themselves well to this initial step of auscultation teaching. Basic heart sounds including normal first and second heart sounds, and physiologic splitting of S2, can be readily covered in this manner. Features that help distinguish innocent from pathologic murmurs can also be covered at this stage. However, the results of classroom auscultation teaching as discussed above, in concert with the poor skills of postgraduate trainees, indicate clearly that classroom teaching alone is insufficient. A structured approach to auscultation teaching should ideally recur in the third or fourth clinical years, when the subject relevance will be reinforced by regular patient contact and examinations. This is probably done best in conjunction with rotations in internal medicine and/or pediatrics. Auscultation teaching at this stage should be accompanied by structured assessment; as discussed in Chapter 3.

The clinical background of teachers is an additional consideration in developing an auscultation teaching program. Although many publications report teaching interventions led by cardiologists rather than generalists[9,14,16,31], sound knowledge and experience with cardiac examination, coupled with a commitment to the subject material and to teaching in general, is more important than the title of "cardiologist" versus "internist" or "pediatrician". Self-teaching is also important, as the value of repetition demonstrated by Barrett[16,31] requires that commitment come from the student him- or herself. Senior residents should also be encouraged to contribute to bedside teaching of more junior learners.

The burden on human and material resources must also be addressed in planning a teaching program. Classroom teaching and internet or CD-based methods allow for a low ratio of teachers to learners and relatively little time commitment from faculty. Bedside teaching, on the other hand, places a significant time burden on clinicians. Simulators are expensive but may be justifiable when used to teach about multiple organ systems and when program coordination allows for use by multiple learners at various levels of training. CDs and other internet-based sounds may have initial costs but these are typically modest relative to sophisticated simulators, and have the advantage of relatively low maintenance costs.

Challenges

The existing literature on heart sound teaching, as summarized in this chapter, has a number of limitations. These include small sample sizes, lack of standardization of learner assessment tools, short follow-up, and in many studies the use of recorded heart sounds rather than real patients for the post-teaching intervention assessment. Few studies compare one teaching intervention to another, further limiting the ability to make conclusions about one technique versus another. It is therefore unclear whether many teaching methods that use technical devices result in post-intervention improvement because the methods are truly effective, or because the learner is inspired to spend more time mastering the subject (e.g. applying greater effort when listening to patients). CDs, simulators, internet-based devices, and other sources of recorded heart sounds may not include simultaneous lung sounds or allow for effect of change in position or Valsalva maneuver on murmur quality, thereby not reflecting real life. Simulators, though sophisticated and capable of providing some associated ‘physical findings’ often lack thrills and certainly do not provide for training in bedside manner. Finally, a variety of innocent murmurs often heard in children, such as the Still’s murmur and physiologic peripheral pulmonary stenosis, are underrepresented in simulators and other recorded heart sounds.

Summary

In summary, auscultation skills in trainees remain poor but can be improved. The most effective teaching method has not been defined; further investigations, ideally assessing transferability to human subjects, are required. The emphasis with any method, particularly with junior learners, should be on normal versus abnormal heart sounds rather than on the subtle characteristics of one pathologic sound versus other pathologic sounds. Repetition is valuable and should be incorporated into all teaching methods.

Role of hand held cardiac ultrasound in teaching auscultation

(Contributed by John P Finley MD CM)

At the time of writing a number of medical schools have incorporated hand held ultrasound in undergraduate teaching. In many cases the intent has been to illustrate normal and abnormal anatomy and physiology, while in other cases the aim has been to give a grounding in ultrasound for later refinement and application to clinical practice. While it is clear that in competent hands these devices can reveal abnormalities missed on physical examination[42], its role in improving physical examination and auscultation in particular, is rarely addressed. Most studies have emphasized making the diagnosis, not reinforcing accurate examination skills. However, a 2018 study by Leggett et al[43] reported their experience with 8 medical students examining 8 patients after a brief training period with ultrasound. The diagnostic accuracy of acoustic stethoscopy, digital stethoscopy and hand held ultrasound were compared in cases of mitral insufficiency, aortic stenosis and aortic insufficiency. There was significant improvement in auscultation scores after the training period with ultrasound. The authors comment: “This tool provides visual feedback at the patient bedside and immediately after auscultation. This can strengthen the student’s cognitive association between the valve lesion and the resulting heart murmur. The ability to mentally imprint the murmur with both auditory and visual feedback is likely to result in improved recognition of the sound subsequently.”

Galusko et al[44], in a review of 12 articles on hand held cardiac ultrasound, found that students had a better knowledge of anatomy and physiology and increased motivation to learn, presumably linked to the visual display of these features.

A larger Norwegian study[45] involving 21 medical students and 72 patients, many with valve pathology, showed higher diagnostic accuracy with ultrasound compared to physical examination for mild-moderate mitral regurgitation (69% versus 29%), but not for aortic stenosis or insufficiency. No assessment was made of the effect on auscultation performance.

In summary, hand held ultrasound has the potential to improve physical examination skills, which remain the foundation of clinical assessment. Combining ultrasound and physical examination provides an ideal setting for emphasizing that the results of hand held ultrasound should always be interpreted in light of the clinical assessment. However, limitations to widespread introduction of ultrasound to the teaching of physical examination include device cost, availability of trained teachers, and the training time required within a crowded curriculum.

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Assessment of Performance of Auscultation

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Highlights

- assessment stimulates learning
- assessment of auscultation requires careful design and adherence to the objectives of teaching this difficult skill
- auscultation teaching and assessment must be repeated at least once in curricula
- simple objectives are more likely to be useful, e.g. distinction of normal and abnormal murmurs rather than diagnosis

Abstract
Assessment is an important stimulus for learning. It must be valid, reliable, content appropriate, transparent to student and assessor, feasible and have suitable scope. Both formative and summative testing is useful for learning a skill such as auscultation, and increasingly the mastery approach to skill learning is emphasized in medical education. Auscultation teaching and assessment should be repeated at least once, preferably more, during medical education as competence decreases with lack of practice. Effective auscultation teaching and assessment have been described in a classroom setting with small and large groups, on clinical rotation, in OSCE format and more recently on websites. Recordings of synthesized heart sounds are used by some programs but live recorded sounds have the advantage of realism and inclusion of breath sounds. Whether

to integrate auscultation assessment with diagnostic formulation and other cognitive skill assessment will need to be decided for each program. The significant challenge faced by students in learning to recognize heart sounds argues for a focussed assessment of this skill. Objectives of the teaching program must be clear and matched in the assessment objectives.

General Aspects of Skill Assessment

It is widely accepted that assessment drives teaching[1]. Certainly, without assessment of the outcomes of teaching there is no assurance that it has been successful. Much has been written on the subject and the reader is referred to expert reviews for in depth discussion.[2-5] Some general principles are outlined below, as an introduction to specific details of heart auscultation assessment.

The functions of assessment, summarized by Jackson et al[2], include 1. supporting teaching and learning – are the teaching objectives met?, 2. accountability to the public, 3. certification. The design of assessment of a particular skill or knowledge set may vary depending on the main function of the assessment.

Good assessment has several attributes[2,3]: 1. Validity – are learning objectives represented, are the test instruments appropriate for the skill?; 2. Reliability – does the testing give consistent results regardless of examiner, the example tested, and over time?; 3. Content appropriate – does this match the desired competencies?; 4. Transparency – are the objectives and methods clear to both student and assessor?; 5. Feasibility – will it work in the local setting regarding time, staffing, cost?; 6. Scope – does the test represent the full range of the skill, knowledge and attitudes which are the teaching objectives?

Finally, the timing of assessment in relation to the learning may be formative ("Learning tests" for feedback), or summative (competence at the end of teaching). Test design may differ for these two assessment types. The minimum competence ("mastery") level will also need to be determined with provision for repeated testing if appropriate.

Specific Aspects of Heart Auscultation Assessment

Designing appropriate assessment of student performance of auscultation requires consideration of a number of features of the assessment process.

Aspects of Heart Auscultation Assessment

Timing in curriculum
Setting
Type of sounds
Technology
Context
Objectives and test contents
Format
Relation to level of training

For some of these features there is published experience to guide the design. For others individual preference based on experience or institutional constraints is the only guide, which in any case will inform whatever design is chosen. For each of the features published information is reviewed along with some personal observations. The comments relate to teaching of undergraduate medical students except where noted.

Timing in Curriculum

Heart auscultation teaching may occur early in the curriculum, with later sessions after a year or two and even in the final year. Earlier assessment will be more formative in nature and later, more indicative of the competence at graduation. Whatever scheduling is chosen should be informed by the main objective of the assessment which may be to assist the student in learning, or to assess competence/performance. Ideally testing would occur both early/middle and late in the curriculum to achieve both objectives.

Several reports[6-11] have assessed performance of medical students, usually mid-curricular. Reasons for choice of year of testing were either not stated or related to access to students. Vukanovic-Criley et al[11] assessed students in all 4 years of curriculum in a cross sectional study and reported improved scores with increasing year. Stern et al[8] in a report of 151 third year students retested a cohort 9-12 months later and found good skill retention while Kuzma et al[12] reported significant loss of skills in this time frame. In Barrett's institution, mastery testing is repeated in each of the first 3 years of their curriculum[9,10].

Finally, the interval between the teaching and assessment must be determined based on the objectives of assessment. Again, early testing will be more formative while later testing will be summative[8]. Web-based testing can allow individual flexibility in the timing of testing based on each student's grasp of the skill[10]. Our current protocol is to assess formatively in Year 2, 3-4 weeks after classroom teaching and self study with a CD-ROM although we would prefer to add a second assessment before graduation.

Setting

Various settings have been described for heart auscultation teaching as well as student assessment: in classrooms, on a clinical rotation, via dedicated websites, or in a scheduled OSCE session.

In a classroom setting, both small or large group assessments can be successful given appropriate technology[7,8,9].

The value of individual teaching on a cardiology rotation has been questioned by Mahnke[13] studying pediatric residents, but such rotations do occur for medical students and may allow for individual structured assessments.[14] Monitoring of auscultation findings of clerks on rotation has been described using personal digital devices[15]. The authors cite the importance to students of learning to record their findings properly in a standard manner, which are then reviewed by teachers. The outcome on learning has not been reported.

Web-based or digital recordings (CD-ROM, MP3 etc.) of heart sounds offer much flexibility for both teaching and assessment as reviewed in the chapters by Barrett and Pieretti and Mackie. Both formative and later summative (skill competence) assessment can be performed online from locations and at a time convenient for students. This is most valuable in the clerkship when many students are located remote from teaching hospitals. We have had successful experience with live audioconference-based teaching linking several sites. The heart sounds are accessed from a website but the students and teacher communicate via telephone conference for discussion.

Another consideration of assessment is who should perform it. Formative peer assessment has the advantage of providing a learning experience for the assessor as well as the student being tested. Properly executed, peer assessment can be less intimidating for the student[5]. Feedback may be better provided and received, coming from another student who appreciates the challenge from the student's level of experience. Self assessment, whether online or in a classroom setting, would likely be appropriate for practitioners, but also has a role in formative assessments for students.

OSCE-style assessment of auscultation is apparently included in very few Canadian medical curricula according to a recent personal survey. It is preferred in our pediatric curriculum at Dalhousie University, using live-recorded sounds, as it allows for integration of history and reasoning skills with the assessment of murmur recognition, in an easily scheduled, standardized format. Two murmurs are incorporated into one station of a total of 11 in the OSCE at the end of a clerkship pediatric rotation.

Type of Sounds

Sounds used in assessment may be from patients in person, live recorded, or synthetic. Historically, patients have been employed for teaching heart sound recognition and later assessment of the student's performance. Despite the current availability of recorded or simulated sounds, patients do offer the advantages of the realism of a clinical setting and sound fidelity. Other aspects of clinical examination besides auscultation can be part of the assessment, and the effect of postural changes and stethoscope position can be assessed, as in a real clinical setting[11,16,17]. Patient availability and cost are obvious limitations with the use of patients[18]. A variation on the use of patients might be a simulated patient for the history and some aspects of physical exam, along with a recording of abnormal human heart sounds, attributed to the patient for test purposes.

With the availability of high quality recordings of heart sounds and murmurs, teaching programs have been able to incorporate many more examples of abnormalities than could otherwise have been experienced in medical training, and to demonstrate them to many students simultaneously. Assessment of student performance of auscultation using human sound recordings has been reported by several groups[7,11,13,19,20]. None of these studies has compared performance on live patients with that of recorded sounds from patients. Collections of recorded heart sounds are available commercially, and electronic recording stethoscopes make possible the acquisition of archived sounds for teaching and assessment purposes. Inevitably the fidelity of the sounds on playback will depend on the quality of the recording and listening systems used. Stethophones will mimic the quality of sounds from an acoustic stethoscope, and transmit sound more effectively to the ear than stereo earphones, but there will always be differences from truly live auscultation (See Chapter 8). Interestingly, the type of stethoscope made no difference in auscultatory performance with patients in one study of 72 resident doctors[21].

Synthesized heart sounds, available for over 40 years, have been used in studies of student performance[6,8,9,10,22]. The authors cite the clarity of these sounds and absence of background noise. Barrett et al[10] compared the performance of 42 second year medical students in recognizing simulated heart sounds versus recorded human heart sounds and found they were comparable (approx. 89% vs. approx. 81%).

Some medical school programs combine recorded heart sounds (either synthetic or human sounds) with the use of a mannequin to lend realism to the auscultation[22]. Other physical signs can be programmed into some mannequins to allow assessment of skills in addition to, but related to, auscultation. The high cost of these mannequins has limited their use.

Our preference for assessment of students, residents and practitioners is for live recorded heart sounds heard through stethophones. The audio quality mimics a stethoscope, and breath sounds are clearly heard. Our archive of sounds can readily be augmented with new recordings from patients, providing an expanded base of examples for assessment.

Technology

Accurate assessment of auscultation performance depends on high quality recording and reproduction of heart sounds if patients are not involved. Whether the sounds are synthesized or actual human sounds, the recordings should be as free as possible of noise and artefact which could confuse the student. Background noises such as breath sounds and movement may or may not be admissible depending on the age of the patients and the realism of the setting desired.

As noted in Chapter 8 high quality recordings are routinely feasible at low cost with current equipment. Delivery of these high quality sounds to the student's ears is more problematic. Listening with individual earphones is essential as speakers and most stereo headphones reproduce heart sounds poorly. The choice between miniature earpieces or stethophones will depend on whether a stethoscope-like sound is desired. Cost and durability may be factors in this choice.

Context

Auscultation performance assessment may be limited to listening skills only (psychomotor skills) or integrated with assessment of the history and other physical findings (cognitive skills). Integration of cognitive or reasoning skills into testing may give a more operational, applied assessment than a restricted test of auscultation – i.e. "auscultation in practice". Vukanovic-Criley et al[11], in a study of 860 medical students, residents and practicing physicians, assessed cardiac knowledge, auscultation and pulse visualization and integration of physical findings, using a videotaped mannequin. They reasoned that such an assessment of competency was more indicative of performance than auscultation assessment alone, and is similar to that used in the American Board of Internal Medicine recertification examination. Published auscultation performance studies are at variance with this view. From a personal twenty year review, only two studies were identified which specifically integrated aspects beyond heart sounds and murmurs[11,18]. The review included assessments of medical students, residents and practicing physicians. Six studies employed patients, and may have included other physical signs in the process[16-18,20,22,23]. We contend that auscultation is the skill presenting the greatest challenge for learners, and thus merits focussed attention for both teaching and assessment of students. The history, other physical findings and clinical reasoning can be separately assessed in relation to auscultation findings.

Objectives and Test Contents

As with the assessment of any other skill, what the student is required to do in the testing should reflect what we expect them to be able to do after learning the skill. Further, the assessment will greatly influence what the students learn[1]. In designing a learning and assessment program for auscultation, educators must be very clear about their objectives which should be written explicitly for both students and teachers. Is the student expected to describe what is heard, to distinguish normal from abnormal sounds, or to make a diagnosis? The answer will depend on the stage of learning and differ for students, residents and practicing physicians. For example, in children with murmurs a major decision for general physicians and pediatricians is whether the murmur is innocent or pathological. This distinction is very difficult for many students, pediatric residents and practitioners and has led to large numbers of normal children being referred unnecessarily to pediatric cardiologists[25,26].

Our group of pediatric cardiologists feels the major objective of teaching auscultation to medical students must be to help them achieve competence in making the distinction between innocent and pathological murmurs and the identification of abnormal S2 splitting, and we are evaluating new teaching and assessment protocols to this end (See Chapters 5 and 6).

Testing could conceivably include aspects of S1, S2, other heart sounds and murmurs (timing, quality, loudness) and should only include what fits with the objectives for the learners. The assessment should include a check list of what is heard and if appropriate what action is indicated such as referral, review or reassurance.

As noted above, the minimum competence level must be decided in advance, and repeated testing may be allowed after additional teaching measures until mastery of the skill is demonstrated.

Format

Various formats of assessment questions have been reported, with most of the auscultation studies referred to above using open ended questions ("describe what you hear/ describe the abnormality/what is your diagnosis?"). Several reports describe the use of multiple choice questions[6,7,13,27], which allow for ease of marking or computer scoring. Finley et al[7] used a combination of both multiple choice and open ended questions and interestingly found different scores for the two formats. This study was a comparison between outcomes of teaching with sounds presented in a classroom for discussion versus self learning with sounds from a CD-ROM of cases involving murmurs. Both groups had similar scores with multiple choice questions but the group having classroom discussions fared better with open ended questions. We continue to use a combination of both types of questions and combined classroom and self learning. We feel that open ended choices mimic real life but the multiple choices allow for more breadth of questioning. Whatever the choice of format, the more questions asked, the more robust the assessment of the student, as is well described for OSCEs in general[3].

Relation to Level of Training

Assessment should be appropriate for the skill and experience of the learner. Medical and nursing students generally would have more limited objectives than specialty residents and their testing might be focussed on distinguishing normal from abnormal with limited emphasis on pathologic diagnosis. Physicians in practice might need limited or more advanced objectives depending on their experience.

Examples of assessment protocols:
- Formative – combines MCQs and open ended questions
- Summative – distinguish normal from abnormal murmurs

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The Power of Repetition in Mastering Cardiac Auscultation

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Highlights

- Cardiac auscultation is, in part, a technical skill
- Intensive repetition (500 beats of each murmur) is the key to mastery
- Web-based delivery of auditory material (MP3 files) is efficient
- Repeated posttesting on the web facilitates a mastery model of learning
- Auscultation is now tested on many board examinations

Abstract

Cardiac auscultation is, in part, a technical skill that improves dramatically with intensive repetition in a short timeframe. The auditory learning process intrinsic to mastering heart murmurs follows proven psychoacoustic principles in that an auditory template of each new sound must be created by the brain in order to store that sound in long-term memory. In going from classroom learning in a monitored setting to clinical rotations using compact discs, we have found that the required number of repetitions (500) for mastery of each cardiac murmur can be achieved in a clinical setting within 15 minutes. With available Internet downloading of mp3 files containing the requisite auditory repetition, medical students, general internists and even cardiologists can now access this auditory learning at a time and place of their own convenience. In addition, web-based testing facilitates the use of a mastery model for clinical skill acquisition. Students often need to take the posttest more than once to demonstrate proficiency. Web-based instruction and testing allows repeated listening and testing in a convenient and cost-effective manner.

I. The Power of Repetition

The current state-of-the-art of cardiac auscultation can only be described as disappointing. Numerous studies[1-5] over the last two decades have documented that medical students, residents, and even academic internists in many countries recognize less than 40% of abnormal heart sounds. In fact, cardiologists, who represent 5% of physicians in the US, are the only group that has been shown to recognize a majority of abnormal heart sounds and murmurs. The reasons for this lack of proficiency are complex and have been ascribed to a lack of opportunity to learn heart murmurs in the current medical curriculum as well as a lack of skilled role models in their instructors[3].

Whenever 95% of an audience is failing to master a skill, one questions whether that skill is being taught properly. When we contemplated the underlying cause for this lack of proficiency, it led us to a basic question: what do we know about how medical students learn to recognize heart murmurs? The medical literature is surprisingly silent on this question. We then asked a more basic question, namely how does any normal hearing adult learn to recognize a new sound?

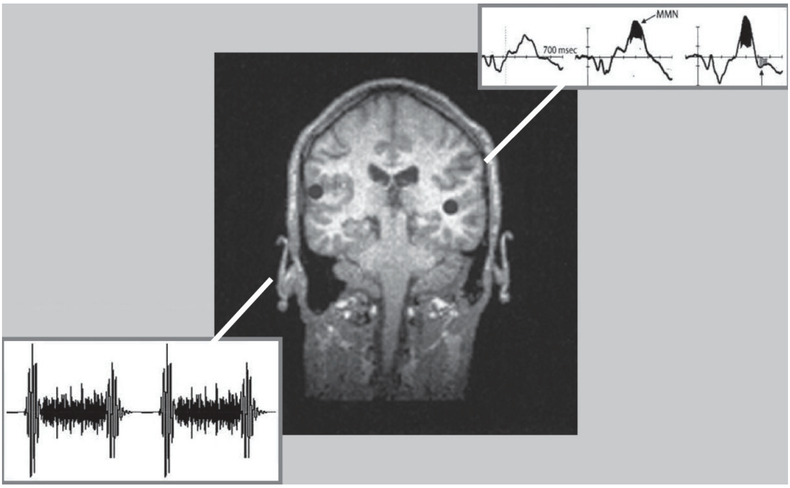
The answer to that question is psychoacoustics. This field is defined as the scientific study of the perception of sound. It is a basic science endeavor in which researchers record electroencephalograms on subjects while they listen to known and unknown sounds through a set of headphones. In an important paper in this field, Dr. Mercedes Atienza from the Harvard Medical School, exposed normal hearing subjects to a complex new sound and recorded their electroencephalograms during this learning process. Results demonstrated that when the brain begins to recognize a new sound, it forms a new wave on the electroencephalogram (EEG) called a mis-matched negativity wave. Once it appears on the EEG, this wave grows progressively larger over the next several days. Dr. Atienza and her group found that there was a fourfold range of repetition required for normal hearing subjects to master each new sound. In their study, anywhere from 1000 to 4000 repetitions of the new sound were heard over several hours resulting in an improvement in proficiency from 10% at the beginning of the study to 85% by the end of the study[6]. Similar results were found in a study of musicians, with jazz musicians having a more rapid learning curve than classically trained ones[7].

We were intrigued by this concept about how the brain learns a new sound and decided to conduct a proof of concept study with medical students to see if this psychoacoustic approach would apply to the learning of heart murmurs. We recruited 50 second year medical students of whom half sat in a classroom and listened to several hundred repetitions of the following four heart murmurs: aortic stenosis, aortic regurgitation, mitral stenosis, and mitral regurgitation. We tested the medical students on their ability to recognize these murmurs at a pretest, after they heard 250 repetitions of each of those four murmurs and again after they heard 500 repetitions of each murmur. The results demonstrated that the medical students recognized only 18% of these murmurs at the pretest but improved to 73% after 250 repetitions and improved further to 84% after 500 repetitions of each murmur[8]. An auscultation proficiency of 84% is comparable to that of most practicing cardiologists[9].

We divided our students equally into a monitored group who were directly observed during their auditory repetition exercises and an unmonitored group who received a compact disc with the same number of repetitions and listened to this material on their own time. There was no difference in the performance of these two groups. What really mattered was hearing 500 repetitions of each murmur which required approximately 15 minutes. All the students who completed this intervention were equally skilled in recognizing these 4 murmurs[8].

In the course of our study, we learned two important things about teaching auditory recognition of heart murmurs. First, we learned it was important to not vary the murmur being played. The rationale for this consistency is that the brain is creating an auditory template of that sound and if it hears a variation of the murmur, it disrupts the formation of that auditory template (See Figure 1). Accordingly, for our study, we used exactly the same example of mitral regurgitation for all 500 repetitions in our study. We followed the same procedure for the other three murmurs in our study.

Figure 1 **Psychoacoustic Basis of Auditory Learning**



Psychoacoustic Basis of Auditory Learning
This figure illustrates the mechanism of how intensive repetition of a murmur, in this case mitral regurgitation, facilitates the brain's creation of an auditory template of that murmur. As this auditory template is being created, a mismatched negativity wave (MMN) shown on the upper right, appears on the electroencephalogram and gradually enlarges over time.

We also realized that this degree of repetition was a missing element in the current medical school curriculum. Namely, students are never given sufficient repetition to form an auditory template of each heart murmur. Consequently, they never master these murmurs either in their medical school rotations or in subsequent medical training. It's not surprising then that they become residents and even attending physicians without this basic skill.

The fact that auscultation proficiency improves dramatically with intensive repetition may seem counterintuitive at first. However, this is because there is an entrenched bias in medical education towards teaching auscultation as if it was an intellectual skill. This approach has been based on the mistaken assumption that the auditory recognition of heart murmurs can be improved with greater understanding of pathophysiology of these sounds. That is, if we, as instructors could provide our students with a better understanding of the etiology of these sounds, then they would be able to recognize them when they heard them in their patients. In fact, studies[5,10] based on this assumption have been uniformly disappointing. On the other hand, once auscultation is seen as a technical skill, then the dramatic response to repetition makes sense.

II. Out of The Classroom and Into The Clerkship

Although our work in the classroom convinced us that repetition was the missing element in teaching cardiac murmurs, we wanted to demonstrate that similar results were possible in a clinical setting. Accordingly, we embarked on a study to reproduce these results during a general medical rotation. We performed a controlled intervention trial with 80 third year medical students on an internal medicine rotation. Students were divided into an intervention group (65) and a control group (15). The 65 medical students in the intervention group listened to a compact disk (CD) containing 200 repetitions of four murmurs: aortic stenosis(AS), aortic regurgitation(AR), mitral stenosis(MS), and mitral regurgitation(MR) and two extra heart sounds(S3, S4) over a 30 day period. All heart sounds on the CD were simulated heart sounds. The 15 control students had no auditory instruction with the CD. All students underwent both pre and posttesting of auscultatory proficiency using human heart sounds. By self report, the intervention students listened to the CD an average of 2.5 times which averaged 500 repetitions of each heart sound for the group as a whole.

Posttest results showed a significant improvement in identification of heart sounds from 39% to 89% in the intervention group. In comparison, the control group had no significant change in their pretest (37%) and posttest (34%) scores[11]. This study confirmed our earlier impression that intensive repetition was crucial for students to master a new cardiac murmur. The use of human heart sounds on the posttest demonstrated that students were able to generalize their auditory skill from a simulated heart sound on the CD to a human heart sound on the posttest.

We gained additional insight into students' learning needs from this study. Namely, the range of repetitions necessary for mastery of heart sounds was 200 to 800 beats with an average of 500 beats. The flexibility provided by independent listening to a CD was more efficient than classroom instruction in that some students needed less repetition while others needed more repetition for mastery. In addition, we found that many students uploaded the audio files to their MP3 players for convenience. This made the auditory exercises both portable and readily accessible.

III: From the Ward to the Web

We were impressed by the resourcefulness of medical students in using MP3 players to achieve the needed repetition. In addition, we also wanted to stop taking the CD player to the classroom each month for the pre and posttests. Our interest coupled with technical advances of the internet allowed us to move the entire auscultation course to the web. We designed the following study to see if similar results could be achieved using the internet as the exclusive medium for teaching and testing the auditory recognition required for cardiac auscultation.

In this study, 64 third year medical students were randomized to either an intervention group (50) or a control group (14). Pre and posttests were completed via a password protected university web site. At all tests, subjects listened to pre-recorded human hearts sounds in a randomized sequence and chose a diagnosis from a menu. The 50 students in the intervention group then downloaded an audio file in MP3 format from a university web page which contained 200 repetitions of four murmurs (AS,AR,MS,MR) and two extra heart sounds (S3,S4) and listened to it as many times as needed to achieve 70% mastery of these sounds. The control group downloaded a sham MP3 file with no auditory instruction. Similar to the prior study, there was a dramatic improvement in the intervention group from 29% to 82% and there was no significant difference in the controls (38% to 44%)[12]. This study demonstrated that an internet web site could be a powerful and cost-effective tool in teaching cardiac auscultation.

Important insights into our students' educational needs were also gained from this study. The students in the intervention group were permitted to take multiple posttests, each of which randomized the sequence of questions until a satisfactory passing score of 70% was attained. This approach permitted additional repetition of the material until mastery was achieved. As before, students reported that an average of 500 repetitions of each sound was needed for mastery.

Furthermore, we had an opportunity to perform a follow-up assessment of auscultatory proficiency over time. Our 50 intervention students participated in an objective structured clinical skills assessment (OSCE) at the end of their clinical year which included one station of heart sounds. We were somewhat surprised to find that their proficiency declined the further they were from their auditory training. Students gradually lost proficiency over a 9 month period[13]. Beyond this time, their skills were no different from the control students. This observation supports the theory that cardiac auscultation is indeed a technical skill that is maintained with practice and deteriorates with lack of use.

We also discovered that the success of this teaching model requires a clinical clerkship director to maintain the integrity of the course. To obtain these results, cardiac auscultation with auditory training had to be a required course with a minimum passing score. In our experience, medical students consistently express interest in auditory repetition methods, but many will not complete the task if left to their own devices. It is crucial for the effectiveness of this teaching strategy that the clinical clerkship director uphold academic standards similar to those in traditional courses.

IV: A Virtual Classroom in the Clouds

Based on our experience using the internet for teaching cardiac auscultation, we designed a completely web-based curriculum for the first 3 years of medical school. A total of 475 students were divided according to year. Each year took a pretest by logging on to a password protected university web site from which they would choose a diagnosis from a menu after listening to human heart sounds in a randomized sequence. All students then downloaded MP3 files which contain 200 repetitions of their respective heart sounds. One hundred seventy five first year medical students listened to five normal heart sounds, 175 second year students listened to five basic murmurs, and 125 third year students listened to five basic murmurs and two extra heart sounds. At the end of one month, all students returned to their respective web sites and took a posttest. All 3 classes showed significant improvement in auscultatory proficiency. The first year class score increased from 37% to 93%, the second year score increased from 43% to 95%, and third year score increased from 38% to 87%[14]. This study demonstrated that a web-based curriculum in cardiac auscultation could be highly effective across all levels of medical student training.

Several advantages were noted in this web-based teaching module using auditory repetition. Overall, the vast majority of students (95%) reported a high satisfaction with this approach to learning. In addition, the course was accessible to the students at any time of day. As each student independently listened to audio files, there was as much repetition available as needed for each individual. Furthermore, using the mastery model of testing, posttesting was repeated an average of 4 times until a passing score was obtained. More importantly, 90% of students reported they were able to recognize these murmurs in their patients, reflecting the ability to generalize from trained (simulated) to untrained (human) heart sounds after this exercise. Ultimately, this study demonstrated a vast improvement in cardiac auscultation skills as compared to those previously reported for medical trainees.

V: Auscultation Testing on the Boards

In the last few years several certifying examiners have begun to test auditory proficiency in recognizing heart murmurs on their computerized examinations. The National Board of Medical Examiners for medical students, the American Board of Internal Medicine examination for general internists as well as the Cardiovascular Boards for cardiologists, among others have used headphones to playback heart murmurs as part of their clinical cases. While that is true that accurate bedside auscultation requires more than just the ability to recognize a murmur on hearing it, it is arguably impossible to recognize these murmurs in a patient without being able to accurately recognize them on a quiz. We decided to explore the possibility that general internists and cardiologists already in practice could benefit from this innovative approach to teaching the auditory recognition of heart murmurs.

We recruited 1045 general internists who were attending an annual meeting for internal medicine between 2006 and 2010. All participants took a pretest to assess their ability to recognize either basic heart murmurs or a set of advanced murmurs including bicuspid aortic valve and mitral valve prolapse. Each participant then listened to 400 repetitions of each murmur over approximately 90 minutes while viewing phonocardiograms, two dimensional echocardiograms and images relevant to the murmurs. They then took a posttest utilizing a randomized sequence of human heart sounds. The average pretest score was 46 %. There was no difference whether testing was done on basic murmurs or advanced ones. The average posttest was 77% ($p<0.001$ by paired t-test)[15]. These general internists were, on average, nine years out of their residency and generally expressed a high degree of satisfaction with this type of training.

In 2013, the Cardiovascular Boards began testing the auditory recognition of heart murmurs for cardiologists. According to the medical literature, cardiologists as a group recognize approximately 80% of all heart murmurs. Most of these studies were done in the 1980s when a majority of practicing cardiologists had received training in phonocardiography during their fellowships. However, phonocardiography went out of practice with the arrival of two dimensional echocardiography in 1980. We wondered if cardiologists' auscultation skills had declined with the advent of 2 dimensional echocardiography.

Accordingly, to test this hypothesis we created the Heart Songs Learning Laboratory, an interactive workshop to test and teach heart murmurs to cardiologists attending the annual meeting of the

American College of Cardiology between 2011 and 2014. Overall, 1098 cardiologists attended this program and completed both a pretest, the training modules and a posttest. Once again all pre and posttest sounds were high quality recordings of human heart sounds while the teaching sounds were simulated heart sounds. Following the pretest, all participants listened to approximately 400 repetitions of each sound (averaging 12 minutes per murmur) while viewing phonocardiograms, two dimensional echocardiograms and cardiac catheterization images relevant to the murmurs being heard. Basic murmurs included aortic stenosis, aortic regurgitation, innocent systolic murmur, mitral regurgitation, and mitral stenosis. The advanced murmurs included bicuspid aortic valve, mitral valve prolapse, hypertrophic cardiomyopathy, atrial septal defect, patent ductus arteriosus, combined aortic stenosis and regurgitation and combined mitral stenosis and regurgitation. A posttest consisting of 5 questions for each module immediately followed the training and consisted of a randomized sequence of basic murmurs or advanced murmurs depending on the module chosen.

The pretest score on the basic heart murmurs was 47 % and rose to 88% on the posttest ($p<0.001$ by paired t-test). On the advanced murmurs, cardiologists scored an average of 64% correct at the pretest and this rose to 92% on the posttest ($p<0.001$ by paired t-test). We were surprised at the relatively low level of proficiency in the pretest phase of both of these modules, however we were gratified by the marked improvement in a relatively short period of time.

V: Summary and Conclusions

In summary, these data demonstrate that cardiac auscultation is, in part, a technical skill that improves dramatically with intensive repetition in a short timeframe. The auditory learning process that is intrinsic to mastering heart murmurs follows proven psychoacoustic principles in that an auditory template of each new sound must be created by the brain in order to store that sound in long-term memory and be able to recognize it in future encounters.

In going from classroom learning in a monitored setting to clinical rotations using compact discs, we have demonstrated that the required number of repetitions (500) for mastery of each cardiac murmur can be readily achieved in the clinical setting. With the advent of readily available Internet downloading of MP3 files containing the requisite auditory repetition, medical students can now access this auditory learning at a time and place of their own convenience. In addition, web-based testing facilitates the use of a mastery model for clinical skill acquisition. We found that students often needed to take the posttest more than once in order to demonstrate that they have mastered the skill. Web-based testing allows this repeated posttesting in a convenient and cost-effective manner.

Like other technical skills, auscultation declines with a lack of use over time. Specifically in nine months time, if this auditory skill was not refreshed, it declined to pretest levels. This indicates a need for ongoing training especially for those students or clinicians who do not regularly have exposure to a variety of cardiac murmurs. This would also imply that different clinicians will need to master different sets of sounds. For example, cardiologists need to be conversant with a wide range of murmurs including not only basic heart murmurs but more complex sounds such as combined mitral stenosis and regurgitation. Primary care physicians, on the other hand, will not hear these murmurs sufficiently often to remain skilled in recognizing them. However, primary care physicians need to be skilled in recognizing a number of common heart sounds that occur often enough in a primary care setting to warrant their mastery, such as innocent systolic murmurs, physiologic third heart sounds, splitting of the first and second heart sounds and the systolic ejection click of a bicuspid aortic valve.

We believe that the future of teaching cardiac auscultation lies in a combination of classroom instruction to explain the rationale behind this skill acquisition coupled with auditory repetition exercises delivered as MP3 files over the Internet. MP3 files of the 5 basic murmur used in our studies are currently available for free from the American College of Cardiology through their website at **www.cardiosource.org/Heart Songs**. In addition, there is a comprehensive curriculum of auditory repetition exercises of 20 different heart sounds and murmurs based on psychoacoustic principles currently available to 54 medical schools in the United States and Canada through the American College of Cardiology's institutional website.

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Auditory Training: From Speech Sounds to Heart Sounds

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Highlights

Repetitive listening exercises:

- significantly improve speech sound recognition by users of hearing aids and cochlear implants
- produce changes in cortical neural activity
- lead to rapid and long-lasting auditory learning

Auditory training techniques include:

- actively listening to multiple repetitions of target sounds
- undergoing exercises of progressive difficulty, e.g., from sounds that are acoustically dissimilar (gross discriminations) to sounds that share some acoustic properties (fine discriminations)
- receiving performance feedback after each listening trial

Abstract

Auditory training is an intervention method used in rehabilitative audiology that aims to help individuals with hearing loss use their residual hearing maximally. It emphasizes the development of listening skills to improve the recognition and interpretation of speech sounds despite limited hearing ability. This chapter explains how auditory training techniques may be adapted to help medical students and physicians improve their listening skills for heart auscultation. First, research supporting auditory training efficacy for enhancing sound perception in people with and without hearing loss

is reviewed, followed by a discussion of some of the auditory training strategies that are believed to promote auditory learning. The chapter then briefly describes how principles of auditory training have been applied to the design of a computer-assisted auditory training program that helps medical students and physicians develop a better mastery of the auditory skills necessary for differentiating between innocent and pathological heart murmurs.

In the field of audiology, auditory training refers to the process involved in improving the auditory skills of individuals with hearing loss through structured and repetitive listening exercises. In a nutshell, auditory training consists of exercises, also known as listening trials, where the person (1) listens to a large number of presentations of speech sounds or other kinds of sounds, (2) makes a judgement after listening to each presentation such as identifying the sound heard, and (3) receives feedback after each attempt about whether the judgment was correct or incorrect. A basic premise to this type of intervention is the notion that hearing is a sense but listening is a skill that can be improved with practice. Hearing loss is not only characterized by a reduction in the detection of auditory signals, but is often also accompanied by deficits in frequency and temporal resolution which can cause auditory signals to be perceived in a distorted fashion. Degraded auditory signals make speech recognition more difficult, particularly in the presence of background noise. While many people with hearing loss can be helped adequately with hearing aids or cochlear implants alone, others require more intensive hearing rehabilitation, including auditory training, for optimal speech perception with their hearing devices. Auditory training does not improve hearing levels; rather it helps individuals with hearing loss listen more effectively so that their ability to recognize speech sounds may be improved. Originally primarily used with children with hearing loss (and now integrated into auditory-verbal therapy), auditory training is also advocated for adults with auditory deficits acquired later in adulthood[1-4] and for normally hearing children with auditory processing disorders[5,6] or language learning difficulties.[7,8] Although most research on this topic has addressed primarily the benefits of auditory training for the identification of speech sounds, some attention has also been given to the impact of such training on the perception of other kinds of sounds. Therefore, auditory training may also be a valuable approach in teaching listening skills for auscultation of heart sounds.

Auditory Training Efficacy

Support for auditory training efficacy is well documented in speech perception research and in the neuroscience literature.[2,3,7,9-22] Hearing aid and cochlear implant users have been shown to make gains in the perception of speech sounds following intensive auditory training.[10,11,15] For example, in the study by Woods and Yund,[10] older adults fitted with hearing aids received an auditory training program consisting of numerous repetitions of listening exercises involving 54 nonsense syllables recorded by two talkers. Research participants underwent approximately one-hour long training sessions, five days per week for a period of eight weeks. Post-training, they showed significant improvement in their ability to identify the syllables compared to the test sessions prior to training. Improvement was noted within one week of training and performance continued to increase steadily over the course of the eight weeks. Moreover, the enhanced ability to identify the syllables generalized to untrained voices. That is, improvement was observed not only for the two voices used for the training program, but also for two novel talkers who were recorded speaking the same syllables and used only for the test sessions.

Other researchers have examined the impact of auditory training on the perception of more complex speech materials such as words and sentences.[2,3,12-14] After a 12-week training program that included repeated presentations of a set of 150 words, adults with hearing loss improved their performance on the trained words by about 40% and maintained their performance for at least three months post-training.[12] In a separate study[3] using a much larger set of different words (600 words) but a similar duration of training paradigm, thus resulting in less training time on each word, participants showed a smaller, albeit significant, improvement in scores. That is, scores improved only by 20% post-training. As pointed out by Humes et al,[3] these data suggest that listening to many repetitions of a smaller set of words may lead to greater gains in auditory perceptual skills than listening to fewer repetitions of a much larger number of words.

The ultimate goal of auditory training is to help individuals who use hearing aids or cochlear implants recognize messages spoken during everyday conversations. Adults with hearing loss have been shown to improve significantly on measures of self-reported hearing difficulties during everyday social interactions after completing the Listening and Communication Enhancement (LACE™) auditory training program.[2] Such transfer of skills to daily situations relies on two critical issues in auditory training: first, the generalization of auditory skills to situations involving listening to novel materials, i.e., words or sentences not used during training, and second, the generalization of skills when listening to novel speakers or untrained voices. A speech sound can be somewhat acoustically different when it is articulated by different talkers who vary in voice pitch, voice level, and articulation patterns; therefore people with hearing loss must be able to transfer their auditory skills when listening to novel and unfamiliar talkers. Several studies have used multiple talkers during training to facilitate the transfer of auditory perceptual skills to talkers not used during training;[2,3,10-12,14,20] and, in general, data show that the improved skills do generalize to novel talkers.

The effect of auditory training has also been investigated in normally hearing individuals, using non-speech stimuli. Research by Moore and Amitay[7] showed that normally hearing adults can significantly improve their ability to perform frequency discrimination tasks after listening to 1500 to 2000 trials in less than two hours of training. In this study, participants were asked to listen to two or more pure tones varying in frequency and requested to identify the higher or lower pitch pure tone through matching exercises or picking the odd tone out of a set. The difficulty of the listening task was adaptive, such that the trial immediately following a correct response included pure tones that were closer in frequency whereas an incorrect response was followed by a trial with pure tones more disparate in frequency, thus keeping the task sufficiently challenging. Following training, participants demonstrated a decrease in the frequency difference that they required to discriminate between the pure tones.

There is also strong neurophysiologic evidence that suggests that auditory listening exercises can affect neural activity in the auditory system.[17-22] Tremblay, Kraus, McGee, Ponton, and Otis[18] trained young normally hearing adults to identify subtle differences between two acoustically similar syllables ("mba" and "ba") and measured their brain activity using auditory cortical evoked potentials before and after training. Initially, the two syllables were both perceived as "ba" but with training, participants were able to distinguish between "mba" and "ba". As the participants' ability to distinguish between the two sounds progressed, there were accompanying changes in auditory cortical evoked potential waveform morphology. Neurophysiological changes post auditory training have been observed to occur rapidly, i.e., after 45 minutes of training,[19] to precede improvements in auditory perceptual skills in some people,[19] and to be maintained at least 36 hours after training.[22] Moreover, neurophysiological changes have been shown to generalize to novel sounds not used during training.[20]

Principles of Auditory Training

Many auditory training programs share a number of common training principles, such as allowing for multiple repetitions of the sounds used for training, providing listeners with immediate feedback on their performance following each listening trial, and progressively increasing the difficulty level of the listening tasks. The next sections of this chapter outline some of the auditory training parameters that are viewed as essential for promoting auditory learning.

Multiple Repetitions of Stimuli

It is well accepted that the optimal condition for auditory perceptual learning to occur incorporates intensive training that involves actively listening to many, many items during successive training sessions conducted over a relatively short period of time.[2-4,10,23,24] However, it is less clear which specific training protocols are most effective. Some researchers have used fairly long training regimes, such as approximately one hour of training several days per week for three to four consecutive weeks[14,15,24] or even up to eight to 12 weeks;[3,10,12] however, auditory perceptual changes were generally observed within the first week or two of training, with performance continuing to improve over the subsequent weeks of training.[2,10] In contrast, other researchers have documented auditory perceptual learning after much shorter training paradigms, such as a total of four to six training sessions all concentrated in one week.[16,18,21,25] Studies that have documented neurophysiological changes induced by auditory training typically observed such changes following a small number of auditory training sessions[18,21] or even following a single training session.[19,22] Individual variability in auditory learning following training has also been noted on perceptual tasks, with some individuals learning at a faster rate than others,[7,19,25] as well as in the maintenance of neurophysiological changes post-training.[22]

In appears that whether one conducts auditory training sessions daily versus weekly may have less influence on improvements in performance than the actual amount of training or total number of training sessions. Nogaki et al[25] compared perceptual skills of normally hearing listeners after completing five auditory training sessions that were delivered either within one week, three times per week, or once per week for five weeks. Results showed that training rate did not have an impact on performance. On the other hand, the specific auditory training task may be more likely to have an effect on the number of repetitions needed to yield an improvement in performance. Wright and Sabin[26] investigated the number of trials needed for normally hearing young adults to show an improvement on a pure tone frequency discrimination task and a temporal-interval auditory discrimination task. Participants listened to either 360 trials or 900 trials daily for six days. For the temporal-interval task, improvement was shown with 360 listening trials per day, and subjecting the listeners to additional practice trials did not lead to greater gains. In contrast, for the frequency discrimination task, 360 listening trials were insufficient to produce auditory learning but improvements occurred with 900 trials. Also using a frequency discrimination task with normally hearing adults, Moore and Amitay[7] noted auditory perceptual improvements after 500 trials, which continued to increase with additional trials until a plateau was reached after 1500 to 2000 trials.

Feedback and Task Difficulty Level

In the vast majority of the studies on auditory training, feedback on performance was provided immediately after each listening trial.[2,3,10,14,16,18,21] Indeed, the importance of providing the listener with immediate feedback regarding progress or lack of progress during training is strongly advocated as a way to promote optimal auditory learning.[4,5,9,13,27] When a group of young normally hearing listeners who received feedback during auditory training was compared to another group who did not, lower gains in word recognition ability were observed for the group who did not receive feedback.[13]

Computer-assisted auditory training programs are well suited for easy implementation of immediate feedback after each listening trial.[2,4,10,14,24,,28,29] Moreover, as listening exercises must be challenging enough to maintain motivation and interest but yet not so difficult that they create frustration,[2,4-6,23,24] computer-assisted auditory training programs enable difficulty levels to be automatically adapted based on the performance of each individual. For example, the LACE™ program[2] uses an adaptive difficulty level where a correctly identified sentence is followed immediately by a more difficult sentence and an incorrectly identified sentence is followed by an easier sentence. For listening trials using a multiple-choice format, the task is increased in difficulty following three consecutive correct responses.

Designing Auditory Training Steps of Progressive Difficulty

Listening exercises that progressively increase in difficulty are an integral part of auditory training programs. Erber[30,31] proposed a hierarchy of listening skills outlining four levels of auditory skills: (1) sound awareness, (2) sound discrimination, (3) sound identification, and (4) sound comprehension. This auditory skills hierarchy is often used as a framework for the organization of auditory training curricula.[2,6,23,24] The first level, *sound awareness,* is the most basic auditory skill and simply refers to being able to detect the absence or presence of a sound. The second auditory skill level is *sound discrimination* which refers to the ability to judge whether two or more sounds are the same or different from one another, regardless of whether one is able to associate meaning with the sounds or name them. Obviously, the more disparate two sounds are acoustically, the easier it is to judge whether they are the same or different. Therefore, when progressing from easy to more difficult listening exercises, acoustically dissimilar pairs of sounds that involve broad or gross discriminations are used before gradually moving to similar pairs of sounds that require fine discriminations.[23,24,31] For example, a listening trial involving gross sound discriminations may require a person to listen to short versus long sounds, such as judging whether the monosyllabic word “bat” sounds the same as, or different from, the multisyllabic word “banana”. This listening exercise merely requires the discrimination of speech duration cues and does not require the recognition of the words “bat” and “banana”. In comparison, asking a person to discriminate between two consonants that share some common acoustic properties, such as the consonants /g/ and /k/, targets finer discrimination skills and therefore represents a more challenging auditory task. Auditory exercises to improve discrimination of these consonants may involve listening to pairs of words such as “goat-coat”, “coat-goat”, “goat-goat”, or “coat-coat”, and judging whether the two words in each pair are the same or different. Other types of auditory discrimination exercises may involve picking the odd sound out of a set (e.g., “coat, coat, goat, coat”).

The third level in Erber’s[30] hierarchy of auditory skills is *sound identification* which involves the ability to correctly label or name a sound or word that is heard. Two categories of sound identification tasks may be used for planning the difficulty level of auditory training exercises: *closed-sets* and *open-sets*. In a closed-set format, a restricted choice of alternative responses is provided in a written or picture format. For example, individuals may be provided visually with the following closed-set of words: “bead, seed, mean, wreath”; they then hear the target word “seed” and are asked to pick the correct word among the set of four, similar to a multiple-choice test. In contrast, in an open-set the target word “seed” would be presented in isolation through audition only, and the person is simply asked to repeat the word that was heard.

Auditory training exercises typically gradually progress from closed-sets to open-sets as the open-set response format is a much more challenging task than the closed-set response format.[22,31,32] When constructing closed-sets, the acoustic characteristics of the items within the set are taken into account and related to hearing loss characteristics as a way to vary listening difficulty. For example, people with hearing loss generally hear low frequencies better than high frequencies; therefore vowels, having greater low frequency energy, are usually easier to perceive than consonants which tend to be weaker with many characterized by high frequency energy (for example, /s/, /f/, /th/, /h/, /sh/). Thus, an easier sound identification task may involve a closed-set of items that vary in both consonants and vowels, while a more advanced difficulty level may comprise items that differ only by high frequency consonants that are similar in their acoustic properties, such as “sigh, shy, hi, thigh”.

The final level in Erber’s[30] hierarchy of auditory skills is *sound comprehension*. This refers to the ability to interpret the sounds that have been identified and to understand the meaning of spoken messages. Facilitating the generalization of improved auditory skills to a variety of speech materials, talkers, and acoustic environments, is an important aspect of auditory training. To help achieve the transfer of skills to novel or unfamiliar talkers, it is advocated that multiple speakers be used during training,[23,24] and that, post-training, individuals’ auditory skills be assessed using untrained stimuli.[4] The use of multiple talkers can be easily implemented with computer-assisted listening exercises with recorded speech. The auditory training program developed by Stacey et al[14] for example, employs twenty different talkers representing male and female adults’ as well as children's voices.

An Auditory Training Program for the Recognition of Innocent and Pathological Heart Murmurs

Caissie and Finley adapted auditory training techniques employed in rehabilitative audiology to develop auditory training exercises to assist medical students in recognizing innocent and pathological heart murmurs (Chapter 6). The main intent was to develop a computer-assisted teaching tool enabling the distinction of those murmurs that are pathological and that require further medical investigation from the far more common innocent murmurs. Key elements of the program include listening to multiple repetitions of heart murmurs recorded from a variety of patients, provision of immediate feedback after each listening trial, and progressive adjustment of task difficulty levels tailored to individual learners' performance. Listening exercises were designed following principles of auditory training described earlier in this chapter. The program consists of several closed-set listening exercises that progress in difficulty level and that are based to some extent on Erber's[30] hierarchy of auditory skills. The program does not address the *detection* of murmurs (sound awareness level) in comparison to normal heart sounds with absent murmurs; rather it emphasizes first the *discrimination*, and later the *identification*, of innocent versus pathological murmurs.

The computer-assisted program consists of three levels of training. Level I of the training program employs a same-different sound discrimination task; Level II uses a sound identification task with a closed-set response format; and Level III involves the identification of heart murmurs presented in isolation. Multiple training steps are embedded within each of the three levels. As they progress through the auditory training program, students are required to listen to hundreds of repetitions of innocent and pathological heart murmurs. Similar to computer games, they must achieve a certain correct performance criterion to be able to advance to the next step. More details on the construction of the listening exercises are presented in Chapter 6.

As for any auditory training programs, an important aspect is the generalization of training to heart sounds from novel or unfamiliar patients, that is, when listening to heart murmurs that were not utilized during training. Consistent with auditory training protocols that use speech materials recorded by several talkers as a way to facilitate transfer of auditory skills to novel or untrained voices,[2,3,10-14] the heart sounds training program was designed using heart murmurs recorded from a large number of patients to help the generalization of skills to novel patients. Support for generalization of auditory skills has been documented when listening to speech sounds produced by novel voices[10-11] as well as when listening to non-speech stimuli.[7] Improved proficiency in cardiac auscultation has also been found to generalize to novel patients following auditory training that involved listening to numerous repetitions of six pathological heart sounds.[34]

The efficacy of repetitive and structured listening exercises for improving speech perception skills is well documented for individuals with normal hearing and with hearing loss. Similar auditory training procedures also appear to be highly promising for helping medical students and physicians gain a better mastery of the auditory skills necessary for the correct identification of innocent and pathological heart murmurs. The following chapter provides preliminary data to examine the efficacy of auditory training as an innovative teaching approach for heart auscultation.

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An Auditory Training Program for the Recognition of Innocent and Pathological Heart Murmurs

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Highlights

The auditory training program is comprised of interactive software allowing students to:

- listen to numerous repetitions of heart sounds and murmurs
- learn to distinguish between normal and abnormal murmurs through listening exercises arranged in 7 steps of progressive difficulty

Results of trial for both medical and non-medical students:

- over 90% accuracy is achieved for recognition of innocent and pathological murmurs after an average of one hour of training
- medical education is not necessary to successfully complete the program
- performance declined two months later; this may be related to limited opportunities for continued practice
- one year post test, a brief reinforcement program restored recognition skill to over 90%

Abstract
This chapter examines the effectiveness of a novel heart murmur recognition program that was designed using auditory training techniques borrowed from audiological rehabilitation principles and practices. During the initial trial of the training program, it was administered to both medical and non-medical students to help teach the auditory distinction between innocent and pathological heart murmurs. Preliminary data obtained pre- and post-auditory training showed a significant improvement in the non-medical students' ability to distinguish murmurs immediately post-training. Subsequent trials with Australian and Canadian medical students showed similar improvement. However, that improved performance declined two months after training. One year later a brief reinforcement program restored skills to the high levels achieved with initial training. Issues pertaining to the implementation of the program and the maintenance of skills over time are discussed.

A computer-assisted auditory training program to help teach auscultation of innocent and pathological heart murmurs was developed based on the principles of auditory training described in Chapter 5. The auditory training program teaches students how to distinguish between innocent and pathological heart murmurs as acoustic events; that is, cardiac diagnostic information is not provided with the training program, nor are students expected to diagnose the reason for the murmurs. Rather, the focus is on learning to distinguish between the acoustic characteristics of innocent versus pathological heart murmurs through hearing only. A second important feature of the program is repeated comparison of heart sounds, which are clearly normal, clearly abnormal, and those that share some features of both. The training program is based on the principle that the recognition of subtle differences between acoustic events can be improved with practice that involves listening to many occurrences of the target sounds.[1-6] Similar to learning to play a musical instrument, over time one learns to "train one's ears" to the musical notes after repeated exposure to the sounds. Auditory training improves the brain's ability to recognize or identify sounds that have been detected by the peripheral auditory system[7].

Description of the Auditory Training Program

The auditory training program developed for heart auscultation consists of several listening exercises (or listening trials) that automatically increase in difficulty based on the individual learners' performance. The auditory training program employs a pool of 26 innocent and 30 pathological heart murmurs recorded from 56 patients. The heart sounds were recorded on children between the ages of several months and 18 years who were either normal or exhibited a variety of heart conditions. In order to construct auditory training exercises that varied in their level of difficulty, it was first necessary to group the recorded sounds according to whether they provided an easier listening task (dissimilar sounds) or a harder listening task (similar sounds). To achieve this, the 56 heart sounds were first classified into three categories: (1) typical innocent murmurs, (2) distinctly pathological murmurs (i.e., dissimilar sounds to target gross auditory discrimination), and (3) "atypical" pathological murmurs with some auditory features of innocent murmurs (i.e., similar sounds to target fine auditory discrimination). The computer-assisted program has three levels of training with multiple steps embedded within each level. The listening exercises become progressively more difficult with each training step, and one must achieve a certain correct performance criterion before proceeding to the next step. The software randomly selects murmurs from appropriate sound categories for the various training steps. Each sound recording is approximately 6 to 8 seconds in duration, and students can listen to a recording as often as they want to prior to providing a response. Feedback on performance is provided following each listening trial.

Level I of the training program employs a same-different sound discrimination task where the listener is required to pick the odd sound out of a set of four sounds. Four heart murmurs (recorded from four patients) appear on the computer screen; they consist of either three innocent murmurs and one pathological murmur, or three pathological murmurs and one innocent murmur. The program is designed so that, at first, the odd sound is quite different from the other three while the other three sounds resemble each other. The student's task is to identify the one that does not belong (the odd sound). At this stage, the students are not required to identify the sound as either innocent or pathological murmur. Feedback is provided immediately after each answer, and the student continues trying as necessary until he or she is able to identify the odd sound in the set of four. Initially, Level I only utilizes sets involving pathological murmurs that sound very different from innocent murmurs in order to target gross sound discriminations (Step 1). Once the student is able to correctly identify the odd sound from six sets in a row, the auditory task increases in difficulty; that is atypical pathological murmurs that sound similar to innocent murmurs are used to target more challenging finer sound discriminations (Step 2). Once the students exhibit correct performance for six consecutive listening trials in Step 2, the software automatically brings them to Level II.

Level II of the training program uses a sound identification task with a closed-set response format (see Chapter 5 for more details on sound identification using closed versus open sets). As with Level I, four heart murmurs appear on the computer screen, with one of them being either innocent or pathological depending on the set. The students' task is to either find the innocent murmur or the pathological murmur in each set. As in Level I, they are provided with immediate feedback after each listening trial, and if unsuccessful, they continue to try until they determine the correct answer for that set. Level II is comprised of three progressively more difficult steps, and six correct responses in a row are needed to be able to proceed to the next step. At first, only distinctly pathological murmurs that sound quite different from innocent murmurs are used (Step 3), and only one sound within each set needs to be identified (Steps 3 and 4). As students progress through the steps of Level II, they are presented with a mix of innocent murmurs, distinctly pathological murmurs, and atypical pathological murmurs, in each listening trial (Steps 4 and 5) and are required to identify each of the four sounds in the set as either an innocent murmur or a pathological murmur (Step 5). When they are unsuccessful in correctly identifying all four sounds in a set, the feedback provided will indicate which of the four sounds were incorrectly identified. This allows them to re-listen to a sound after an incorrect response while knowing what type of murmur it should be. In Step 5, once they can correctly identify, on their first attempt, each of the four sounds in six consecutive sets, in other words when they can successfully identify 24 murmurs in a row, they may proceed to Level III.

Level III of the auditory training program involves the identification of heart murmurs presented in isolation. That is, only one heart murmur appears on the screen at a time, and the student is asked to label it as innocent or pathological. This listening task does not represent a true open-set task as there are only two possible answers; therefore it is closer to a two-alternative forced-choice procedure. Nevertheless, the increased difficulty level arises from the fact that when making a judgment about a particular sound, the student no longer has access to other sounds, for comparison to the target sound, to facilitate judgment. Similar to previous training steps, first, only those pathological murmurs that sound markedly different from innocent murmurs are used (Step 6) before progressing to the identification of pathological murmurs that sound similar to innocent murmurs (Step 7). In this final step of the training program, students are required to identify heart murmurs presented in isolation and randomly derived from the entire pool of recorded sounds.

Initial trials

The auditory training program was first piloted on a group of 21 Canadian non-medical student volunteers, and then tested on a group of medical students at the University of Western Australia. Further testing was conducted on medical students at Dalhousie University. This chapter reviews of the results for the non-medical students and the University of Western Australia medical students. Results for the full group of medical students, including those from Dalhousie University, are described in Finley, Caissie, Nicol, and Hoyt[13].

A cohort of 120 medical students from the University of Western Australia were invited to participate in the study and randomly assigned to either the intervention group or the control group. The non-medical students were between the ages of 18 to 34 years while the medical students' ages ranged from 20 to 50 years. Prior to beginning the auditory training program, all participants underwent a hearing screening at 25 dB HL at audiometric frequencies between 250 Hz and 4000 Hz to ensure that hearing was within normal limits in each ear.

Students were asked to listen to the recorded heart sounds in a quiet room, using stethophones that were connected to a computer. A research assistant was available during auditory training so that guidance about the software could be provided when necessary. First, a brief demonstration of typical sound murmurs was provided by having the students listened to the recordings of an innocent and a pathological murmur. Then, in order to measure their pre-training skills, students performed a two-alternative force-choice identification task, where they listened to 20 heart murmurs and identified each one as either an innocent or a pathological murmur. Next, non-medical students and the medical students assigned to the intervention group completed the training program. Immediately after training, they performed a post-test of 20 recordings similar to the pre-training test. Another similar assessment was performed by the students two months after completing the training program. The medical students who were assigned to the control group were re-tested following two months of clinical activity in pediatrics but without structured heart sound teaching.

All pre- and post-training tests included 20 heart murmurs randomly selected by the software from the entire pool of heart murmurs, thus specific test items differed from test to test and from participant to participant. Immediately after completion of these tests, students were provided with their correct percentage scores.

Results

In the non-medical group all 21 participants completed the full training program with the 2-month follow-up test. Of the 60 medical students randomized to the intervention group, 47 completed the training and the immediate post-training test, and 36 of these students completed the two-month follow-up test. Out of the remaining 13 students, 11 started the auditory training program but did not complete it, and 2 participants' data were lost at the beginning of the study due to a server problem. Of the sixty medical students who were invited to participate in the control group, 54 completed the pre-test and 41 completed the post-test two months later. Wilcoxon Signed Rank tests were performed to determine if the pre- and post-training mean scores were significantly different. A level of significance of 0.05 was retained for the comparisons.

The non-medical students had a mean pre-training test score of 73% (95% CI=67, 78%; range=55-95%) and their immediate post-training test score improved to 92% (95% CI=88, 95%; range=70-100%). There was a significant difference between pre-training testing and post-training testing ($p<0.001$, 95% CI =13, 24%). After two months, the follow-up test score for non-medical students was 80% (95% CI=75, 85%; range=55-100%). The difference between the 2-month post-training and pre-training test score, (95% CI -0.05, 13.9%) was of borderline significance ($p=0.052$). The medical students' scores were: pre-training test, 77% (95% CI=74, 81%; range=45-100%); and immediate post-training test, 92% (95% CI=90, 94%, range 70-100%). This also represented a significant improvement between pre- and post-training tests ($p<0.001$, 95% CI =10, 18%). For medical students, the two-month follow-up score was 82% (95% CI=78, 86%; range=50-100%), which was a significant decrease from the immediate post-training test score ($p<0.001$) but a non-significant increase over the pre-training test score ($p=0.109$, 95% CI=-1.04, 9.93%). The control group who received no structured heart sounds teaching had scores of 78% (95% CI=75, 81%; range=50-95%) on the pre-test, and 81% at the two-month follow-up test (95% CI=78, 84%) which was a statistically significant difference from the pre-test score ($p=0.04$, 95% CI=0.11, 7.2). This follow- up score however did not differ from the two-month follow- up mean score for the study group who had taken the training test. Student reaction to the program was largely positive, with students agreeing that the instructions were clear; the program was interesting and taught a core skill which appeared to be transferable to clinical settings. At the beginning of the study, the students were asked about any previous musical training; however no relationship was found between scores and musical training. As they progressed through the auditory training program, students were required to listen to numerous repetitions of innocent and pathological heart murmurs. Exposure to a large number of repetitions of the target sounds is essential to facilitate auditory perceptual learning[2,7]. It is difficult to determine exactly how many repetitions of heart beats students listened to because they could re-play a sound if they needed to hear it again. An estimate of the minimum number of repetitions can be made as follows: (1) Each recording was a minimum of 6 seconds in duration, with an average of 8 heart beats per recording. (2) Exercises in Levels I and II included four recordings per listening trial, and Level 3 had one recording per listening trial. (3) Using the average number of listening trials needed to complete all three levels of the program, it may be estimated that students listened to at least 1230 repetitions of both normal and abnormal murmurs (See Appendix for calculation).

The training program took 40 to 150 minutes (an average of one hour) to complete depending on the individual's auditory skills and previous experience with heart auscultation. Most students were able to complete the program in one or two training sessions. Medical education was not necessary to achieve success with the program, although non-medical students took longer to complete the program. They required an average of 108.4 trials compared to 88.8 trials for medical students, where a "trial" is an attempt at a screen with 4 murmurs (Levels I and II) or 1 murmur (Level III).

Results for the medical students from Dalhousie University showed trends similar to those observed with medical students from the University of Western Australia.[13] In addition, long-term effects of the auditory training program were evaluated one year later for a subgroup of medical students from Dalhousie University.[13] These results showed a further decline in performance compared to the two-month post training scores; however performance returned to a high level after a 15-minute refresher training program.

Discussion

The initial results from our trial of this new auditory training program indicate considerable success with teaching murmur recognition. Over 90% accuracy is achieved with an average of one hour of training. This is a considerable improvement over the typical performance of medical students and residents[8,9], and medical education is not necessary for success with the program. The high levels of murmur recognition are likely related to several factors: (1) the simple, practical question being asked: Is the murmur normal or abnormal?, (2) considerable repetition, and (3) repeated comparison of normal and abnormal sounds. These factors should be the foundation of learning programs related to heart sounds. All too frequently murmur recognition is made difficult for students by the presentation of too many types of sounds with little repetition and practice. Repetition has been shown to be crucial in auditory training[2,7] and in the work of Barrett et al.[10] in relation to heart sounds recognition. The practical skill required by the general physician is the ability to distinguish normal from abnormal, not necessarily to be able to identify large numbers of different murmurs.

It should be pointed out that chance performance level for our pre- and post-training tests is 50%, and pre-training test scores tended to be relatively high. For some students with high performance pre-training, there was limited room remaining to measure the full extent of any improvement. Moreover, a statistically significant improvement of less than 5%, such as that shown by the control group of medical students, is equivalent to 1 more correct response out of 20, which is not likely to be clinically relevant.

Both non-medical and medical students exhibited a decline in performance two months after completing the auditory training program. However, these post-training test scores should be interpreted with caution. Follow-up testing tended to occur two months into the school semester, often coinciding with heavier workloads such as during exam time. Indeed a number of students who had completed the pre-test and post-training test did not return for the follow-up test two months later due to a lack of time. Thus student fatigue or increased stress may have negatively affected follow-up test scores. Increased stress and heavy workload issues may also explain why 11 participants from the intervention group started the auditory training program but were not able to successfully complete it.

The decline in performance two months later may also have resulted from a lack of continued or regular exposure to heart sounds during everyday educational activities after training, especially in the case of non-medical students. Even for the medical students, there was very limited and unstructured exposure to heart sounds in the two-month interval before the follow-up post-training test. Especially since this auditory training program was their first encounter with these murmurs, it is perhaps not surprising that their recognition performance was not sustained. Continued exposure to the target sounds facilitates the maintenance of newly acquired auditory skills[11]. For example, in the rehabilitative audiology of adults with acquired hearing loss who are fitted with cochlear implants, the focus of auditory training may be on re-learning the recognition of speech sounds and meaningful environmental sounds (such as door bells, car horns, etc.) during structured listening exercises in the clinic, but learning to listen is also integrated with acoustic experiences that occur during everyday activities. Hence, the frequent exposure to speech and environmental sounds during any given day provides the cochlear implant user ample opportunity to continue practicing their auditory skills.

The reasons for the observed decline of performance two months post-training are currently under study. It appears that providing some form of reinforcement or continued exposure to heart sounds would be necessary to help with the maintenance of heart auscultation skills, especially for those students whose education program may not involve heart auscultation practice for extended periods of time. However, it is difficult to predict the optimal amount of exposure time that may be required for skills maintenance. For students who have limited opportunities to practice heart auscultation in the clinic, listening to recorded heart sounds for a few minutes a couple of times per week might be sufficient to facilitate skills maintenance. More research is needed to explore potential reasons for the decline post-training and the steps that may be taken to reduce it.

One might argue that any decline in performance post-training would rapidly reverse and the previously attained level be recaptured after a short refresher practice. This would be a scenario similar to the drop in performance that may be experienced by a musician who does not maintain regular practice, in that their previous performance level is rapidly regained after resuming practice. Preliminary results from a reinforcement program one year after initial auditory training suggest a return to the high post training levels after only fifteen minutes[12,13]. The auditory training program that was developed for medical students may also be used by physicians, nurses, and other health professionals who want to improve their auditory skills for heart auscultation, or want access to a practice tool for maintaining their current ability or regaining a previous performance level.

The data presented in this chapter provide support for further investigation of auditory training as an innovative teaching approach that could be integrated in the curricula of medical and other professional schools or used as an independent learning tool by both students and practitioners[13]. Early results from further study of the auditory training program in the Canadian context, at Dalhousie University, are similar to the Australian experience, despite differing curricula[12,13].

Addendum (2019)

The study outlined in this chapter was extended with a one year post-test and reinforcement[12]: 22 Canadian medical students who had performed the training were retested 1 year later on 20 random recordings including 10 additional novel items in a mastery-style reinforcement programme; any student scoring less than 90% took another 20-item test, and if that test score was less than 90%, the student took a final 20-item test. Each test provided feedback and implicit retraining.

The 1-year follow-up test median was 81% (55–100%) a significant decline from the 2-month post-test ($P < .005$). Only six out of 22 students achieved the 90% level at this test, but after first and second reinforcement tests, an additional six and two students, respectively, reached 90%. The median final score achieved after late reinforcement was 90% (70–100%), an improvement achieved after only 10-15 minutes.

Student reaction to the programme was largely positive, judging from a questionnaire, with most participants expressing satisfaction with skill improvement and even transferablility to patient assessment.

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Appendix

There were an average of 72.8 tries in Level I and II and 16 tries for Level III. Assume each student listens to a minimum of 6 sec of each recording, with an average heart rate of 8 beats in 6 sec (averaged over 10 recordings).

There are 4 examples per screen for Levels I and II for each of the 72.8 tries so 4 murmurs are heard for each try. Each murmur is heard for 8 beats.

Thus the number of repetitions is 72.8 x 4 x 8 =2330 for Levels I and II and 16 x 1 x 8 = 128 for Level III. The total is 2458. There are 2 types of murmur, so the estimated minimum number of repetitions of each murmur is about 1230.

Music at the Heart of the Matter

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Highlights

- anecdotally, the link between musical training and auscultation ability has been suggested since the nineteenth century
- more recently, experimental evidence has found that both long-term and short-term musical training leads to significant changes in neural activity and behavioral performance during auditory perception tasks
- current methods that encourage labeling of sounds with musical terms (pitch, intensity, timbre, duration) may facilitate perceptual encoding of sounds and improved performance during subsequent identification
- novel methods that engage auditory–motor networks by vocalizing and tapping heart sound patterns may further facilitate learning, encoding, and subsequent discrimination

Introduction

Discussions of the relationship between music and auscultation of the heart date back to the middle of the nineteenth century. The four cardinal dimensions of music—pitch, loudness, timbre, duration—have long been used to describe heart sounds (e.g., Ballard, 1854[1]; Fagge & Pye-Smith, 1888[2]; Allbutt, 1898[3]). Other physicians have commented anecdotally on the connection between musical expertise and auscultation skill (e.g., Flint, 1883[4]; Quimby, 1898[5]).

The present chapter evaluates both of these connections (musical properties and musical training) from the perspective of *music psychology:* the empirical study of the perception, cognition, and response (emotional and physical) of individuals or groups of individuals to music or music-like stimuli (for recent in-depth volumes on the topic, see e.g.[6-9]). Specifically, it will (1) review recent evidence that musical training changes brain structure, brain function, and performance on auditory tasks; (2) discuss the use of musical dimensions, musical accents, and musical rhythms as mnemonic devices to enhance the perceptual representation of heart sounds; and (3) propose the application of learning strategies that engage *auditory–motor networks* in the brain to further solidify students' ability to identify and differentiate heart sounds. Together, the latter two strategies (listening mnemonics and auditory–motor network engagement) may help reveal a richer acoustic picture and perceptual experience that may translate into increased sensitivity during auscultation.

Musical Training and Auditory Abilities

Long-Term Musical Training

One of the dominant research questions within music psychology is to understand how a lifetime of intensive musical training changes the brains of musicians compared to non-musicians[10-12]. Structural imaging studies have found that musicians have increased gray matter in auditory, motor, and visual-spatial regions[13,14] and increased connectivity between the two hemispheres via the corpus callosum[15]. Functional imaging studies have shown that adult musicians show more elaborate patterns of activation—in both perceptual and motor areas of the brain—than adult non-musicians when listening to music[16-19]. Electrophysiological studies have revealed that musicians show enhanced cortical representation of musical stimuli[20-22], speech stimuli[23], and emotional vocalizations[24]; and also show enhanced sensitivity to acoustic stimuli presented within a noisy background[25]. These results suggest that a lifetime of musical training does not just selectively enhance sensitivity to music itself, but has facilitatory *transfer effects* into broader cognitive processes such as attention, language processing, and memory[26].

Nature and Statistics

Long-term, explicit musical training is not the only route by which listeners acquire musical knowledge. Human listeners come into the world with highly developed auditory processing abilities[27,28]. Furthermore, from their earliest days[29], human listeners engage *statistical learning* mechanisms[30] to passively and tacitly glean rules and regularities about musical and linguistic structures. These statistical learning mechanisms are enhanced by early musical training, as illustrated by the case of *absolute pitch* (or "perfect pitch") abilities. By convention, musical pitches are "absolute"—for example, the A above middle C is tuned to a value of 440 Hz. A small proportion of individuals in the population have the ability to tap into this absolute mapping of pitch to pitch label, and can effortlessly hum or sing a requested pitch, or label a heard pitch[31].

The importance of statistical learning is evident when examining the relationship between absolute pitch ability and the age of onset of musical training[32]. A survey of 600 musicians found that over 40 percent who had begun training before the age of four reported having AP, whereas only three percent of musicians who had begun training after the age of nine reported having AP[33]. Furthermore, work by Schlaug et al[34,35] has subsequently shown that a well-known, left–right asymmetry in the size of a cortical region referred to as the *planum temporale*[36]—an asymmetry which itself predicts individual differences in dyslexia[37] and the hemispheric lateralization of language[38]—is further enhanced in musicians with AP. This example serves to illustrate the profound ways in which early, intensive exposure to music can change the brain.

Another musical dimension that human listeners show an early sensitivity to is *rhythm*. Human infants show preferential responses to different musical rhythms[27], and synchronizing movements to musical rhythms has been regarded as a cultural universal[39]. Interestingly, a few other animal species show synchronization abilities. Most famous among them, perhaps, is the case of "Snowball." Snowball is a male sulphur-crested cockatoo with a penchant for "dancing" to the Backstreet Boys (a feat which has garnered him over 4.5 million hits on YouTube[40]). He also attracted the attention of researchers at the Neurosciences Institute in San Diego, who found that Snowball did indeed synchronize to the beat of the music, at a variety of tempos[41]. More striking still was that Snowball was not alone: Schachner et al.[42] found over a dozen other species—primarily birds—which exhibited evidence of beat synchronization. Notably absent from the list were nonhuman primates and domesticated species. These findings are consistent with Patel's[43] hypothesized relationship between species that exhibit *vocal learning* (i.e., vocal mimicry as a key feature in the acquisition of auditory communication skills) and species that exhibit beat synchronization.

Short-Term Musical Training

Long-term musical training is not the only method by which listeners develop enhanced perceptual capabilities. A number of studies have revealed that short-term pitch discrimination[44,45], phoneme discrimination[46,47], or motor[48-50] training in adults (as well as children[51,52]) mirrors—at the neurophysiological level—the effects of long-term musical training on neural responses to auditory stimuli. In the studies cited here, training ranged from five to 20 days. Furthermore, all these studies reported improved performance after training. This suggests that, while not all individuals become expert *musicians,* a lifetime of musical exposure (e.g., statistical learning) and brief but intensive training can contribute to make them—at least for a time—expert *listeners*.

Musical Dimensions and Auditory Patterns

The dimensions of pitch, loudness, timbre, and duration share a common ability to create accents. An accent refers to an element (e.g., a tone) in a sequence of elements that stands out along some auditory dimension. More concretely, an accent is a "deviation from a norm that is contextually established by serial constraints"[53]; thus, an accent acquires its status from surrounding elements[54]. In musical contexts, accented *(A)* versus unaccented *(u)* tones help create the percept of rhythm and meter[53,55,56]. In linguistic contexts, accents create poetic feet: for example, the iamb *(u A)*, trochee *(A u)*, spondee *(A A)*, dactyl *(A u u)*, and anapest *(u u A)*.

Patterns of accents create patterns *of time* and patterns *in time*[57]. Patterns of time refer to patterns of event durations: for example, differences in note lengths that distinguish between, say, "Frère Jacques" and the "Toreador" song from Bizet's *Carmen*. Patterns in time refer to patterns based upon distinctions in pitch, loudness, and/or timbre[55,58].

Strategy 1: Listening to the Heart with a Musical Ear

Pitch, loudness, timbre, and duration have long been used to characterize heart sounds and murmurs[1-3]. In the context of the preceding discussion on short-term auditory training, however, it can be hypothesized that practiced use of (1) the mnemonic application these labels to heart sounds and murmurs, (2) listening for patterns of time and patterns in time, created by accents within these musical dimensions, will lead to a richer, more explicit perceptual representation of the sound itself. As a result, it could further be predicted that this enriched perceptual experience will result in improved behavioral performance during identification, discrimination, and classification of heart sounds.

Engaging Auditory–Motor Networks

Another area of research with relevance to auscultation training is the role of multi-sensory learning and auditory–motor networks in the brain. An ever-growing body of research consistently points to a powerful effect of music making on brain plasticity[10,11,59,60]. Auditory–motor network engagement is a key component of clinical interventions for language recovery[61] and gait rehabilitation[62] in stroke patients, exercise efficacy in patients with dementia[63], and language acquisition in nonverbal children with autism[64]. Schlaug et al.[65] have undertaken an extensive evaluation of Melodic Intonation Therapy (MIT)[66]. MIT was developed out of observations that patients who have suffered a left-hemisphere stroke resulting in Broca's aphasia (i.e., severe or complete loss of language production abilities) are often still able to produce well-articulated, linguistically accurate words while singing. The intervention is designed to engage right-hemisphere homologues of left-hemisphere language regions that had been compromised as a result of the stroke.

MIT translates a prosodic spoken phrase into a melodically intoned pattern on two pitches a minor third apart (e.g., an A to a C on a piano keyboard). The upper pitch is sung on accented syllables, and the lower pitch on unaccented syllables. At first, the therapist sings in chorus with the patient as they learn the intonation patterns, gradually decreasing involvement as therapy sessions progress (usually 75–80 1.5-hour sessions in total). Another component of MIT deemed critical to its efficacy is the rhythmic tapping of each syllable (using the patient's left hand) while phrases are intoned and repeated. As hypothesized by Schlaug et al.[67], this behavior activates a right-hemispheric sensorimotor network that jointly coordinates hand movements and orofacial and articulatory movements. Evidence that motor and linguistic cortical representations of objects are closely tied is supported by behavioral[68], neurophysiological[69], and functional magnetic resonance imaging[70] data. That the therapist mirrors the target actions along with the patient may also tap into the putative "mirror neuron" system jointly involved in action perception and performance[71]. More recently, a related therapeutic approach has been applied to nonverbal children with autism[64], again designed to tap into the rich cortical representations shared by the orofacial and articulatory control systems.

Strategy 2: Vocalizing and Tapping

The above discussion leads to a second strategy that could be applied during auscultation training: recruitment of auditory–motor networks during the learning phase. Strategy 1 suggests the explicit labeling of heart sounds using terms derived from the musical dimensions of pitch, intensity, timbre, and duration. Next, Strategy 2 could be applied: students could reproduce the heart sound patterns with their voice (mimicking perceived pitch, intensity, timbre, or duration patterns) while simultaneously tapping the patterns. Use of these multiple afferent channels during learning should lead to a richer perceptual experience. Furthermore, consistent with previous studies investigating short-term musical training effects[44-52], it could be hypothesized that the combined use of these two strategies during learning will translate into improved performance in identifying and discriminating heart sounds.

Conclusion

The present chapter has reviewed experimental evidence supporting the effects of long-term musical or auditory training on neural responses and behavioral performance during auditory perception and production tasks. It is perhaps unsurprising that a lifetime of musical training leads to significant changes in both neural activity and behavioral performance during auditory perception and memory tasks. In the same vein, the connection between musical training and auscultation ability has been made anecdotally since at least the turn of the last century[4,5]. More recently, this association has been confirmed in a sample of over 400 physicians in training[72].

As reviewed here, however, performance on auditory tasks also improves after short-term auditory training[44-52], suggesting that the benefits acquired over years of training can, at least in part, be conferred relatively rapidly. Thus, with respect to auscultation, it could be predicted that focused, intensive training using the two strategies described above may lead to a richer perceptual experience during the learning phase, translating into improved accuracy during subsequent identification and discrimination. Additionally, a hearing test might be administered to medical students prior to auscultation training, to make both students and their teachers aware of challenges that individual students might face during training (cf. [73,74]).

Music fills our lives (by choice or not) from the moment we awake until the moment we fall asleep. Every culture on the planet has vocal music, and nearly all have instruments[39]. Americans spend more money on music than on sex and prescription drugs, with album sales alone topping $30 billion annually[75]. As of the first quarter of 2011, nearly 300 million iPods have been sold since the product's debut in 2002.[76] "The dissemination of music in places where the audience is not in voluntary attendance, but is captive, has increased tremendously in recent years," wrote Hunter[77]—some 35 years ago. Thus, making use of our "musical sense" taps into a systematic and systemic response to auditory stimuli. This sense helps us comprehend and interact with a complex auditory world, from the pulse of the dance floor to the pulse of the heart.

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Technical Aspects of Effective Teaching of Auscultation

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Highlights

- individual earphones or stethophones provide adequate fidelity for most heart sounds
- audio speakers do not give suitable reproduction for teaching or listening

Contents

- acoustics of heart sounds, perception of sounds
- recording of heart sounds and murmurs
- reproduction
- classroom teaching in one site
- distributed teaching sites

Acoustics of Heart Sounds

Origin of heart sounds and murmurs

A full discussion of this subject[1], is beyond the scope of this book but it is important that educators understand a few basic facts about the origin of heart sounds and murmurs. The first and second heart sounds originate with the closing of the atrioventricular (mitral, tricuspid) and semilunar (aortic, pulmonary) valves respectively. They can be high amplitude, short duration sounds, similar to spikes or impulse-like signals. Stenosed or malformed valves may also produce clicks and creaks, which are similar to spikes. These sounds are related in complex ways to the deceleration of blood impacting on the valves. In the case of the semilunar valves, the arterial roots also receive the impact of rebounding blood from the pulmonary and systemic arteries, and are involved in sound production. The sounds transmit to the chest surface, often circuitously, and may be expected to be loudest, or most distinct, in specific areas. Exactly where sounds are loudest in any individual may depend on chest wall anatomy, fat deposits, lung properties and internal anatomic variations. However the standard anterior listening locations are: “aortic”-right sternal border second interspace, “pulmonic”- left sternal border second interspace, “tricuspid”-left lower sternal border fourth interspace, and “mitral”-apical. In practice, one may have to move slightly from these positions to hear sounds most clearly.

Murmurs, which are sounds having significant duration compared to the more discrete first, second, third and fourth sounds, are generally produced by one of two mechanisms: turbulence (or vortex shedding) related to nonlaminar flows, or tissue vibration, as in the innocent murmur of childhood. Murmurs transmit to the chest surface in locations related to the flow of blood, in the case of turbulent murmurs, but are also influenced by anatomic features noted above. The appreciation of the different sounds created by tissue vibration and by turbulent flow is of great diagnostic importance, particularly in children, and thus deserves considerable emphasis in teaching programs.

Frequency range of heart sounds and murmurs

The audible frequency range of sound emanating from the heart and vessels is roughly 20-1000 Hz. The lower the frequency, especially below 50 Hz, the more difficult sounds are to hear. Playback systems for recordings of heart sounds and murmurs must be able to reproduce sounds accurately, especially in the lower frequency range. The third and fourth heart sounds and diastolic murmurs are notorious for being inaudible by students, and it is often necessary to increase the playback volume of recording above normal to enable these sounds to be heard. Even so, some individuals with apparently normal hearing will have great trouble hearing these low frequency sounds. Devices for reproducing heart sounds for teaching should have high and low pass filters to mimic the bell and diaphragm of the acoustic stethoscope and accentuate the low and high frequency sounds respectively.

Recordings of heart sounds and murmurs

Recording heart sounds and murmurs with fidelity requires experience, specialized equipment and much attention to detail which is not usually relevant to educators. However, since some teachers may be using electronic stethoscopes and group teaching microphones on live subjects, a few comments may be helpful. Practice with the equipment is essential before attempting to teach students. A quiet environment is essential, but seldom found in a busy clinic or inpatient unit. A steady hand is also necessary as much noise can be introduced from the skin-microphone interface, especially on hairy chests or with active children. Teachers employing electronic stethoscopes should be aware of and point out the difference in the sounds provided by acoustic and electronic stethoscopes since students will not likely be using the latter in practice. Some, but not all, electronic stethoscopes have electronic filters which model the filtering characteristics of the binaural earpiece of the acoustic stethoscope, as well as characteristics of the bell and diaphragm stethoscope head. Other electronic stethoscopes offer high volume gains providing an unrealistic listening experience compared to the acoustic models. Electronic stethoscopes can reproduce sounds from the chest that are not heard in acoustic scopes, thus using them for diagnostic purposes may be challenging.

Reproduction

For students to achieve competence and confidence with auscultation in the clinical setting, high quality reproduction of heart sounds and murmurs is essential. If the sounds they are hearing through their acoustic stethoscopes are very different from what they hear in a teaching session, insecurity will be inevitable, and they will be reluctant to rely on what they hear, apart from perhaps identifying rhythm. There is debate on the usefulness of synthetic heart sounds in teaching, with some studies indicating good transfer of skills learned from recordings of synthetic sounds, to patients. However the availability of good quality live recordings and equipment for simultaneous auscultation by several listeners to subjects enables teaching programs to easily incorporate actual heart sounds for all or part of the instruction. The equipment used for sound reproduction must be appropriate for the frequency range and loudness of the sounds, and for the teaching environment.

Current sound recordings are digital, requiring either a CD or MP3 player or computer They may also be accessed from websites using mobile devices. Minimum acceptable recording characteristics are mono (single channel) with 16 bit samples recorded at least 8 KHz. Most current laptop computers can reproduce heart sounds adequately.

Delivery of sounds to the listener requires a speaker, usually in a head set or earphones. Stethophones have the advantage of mimicking to some extent an acoustic stethoscope, having air columns in the hollow metal tubes linking the tiny speaker to the ear pieces. Both hard-shell vertical in-the-ear headsets and soft moldable ear "buds" may also give reasonable sound reproduction, although they must extend well into the ear canal and exclude external noise to some extent. We are unaware of any studies comparing the physical sound characteristics, the teaching effectiveness or clinical quality of these devices. Stereo over-the-ear headphones, both open shell and acoustic-sealed-to-the- head models, in our experience, do not faithfully reproduce some sounds, notably the innocent murmur, the most common murmur in children and arguably the most important for learners to recognize. It is important that the headsets are not used at high volume. Apart from presenting an unrealistic representation of the heart sound, the sound transducers may be driven to their mechanical extremes, producing artifacts in impulse-like sounds (S1, S2, clicks). The low frequency response for headsets is important, with a low end range extending to 20Hz desirable.

Computer and stereo room speakers are not adequate for teaching or even individual listening . Stereo room speakers, even of high quality, are extremely difficult to use for heart sound reproduction. The sound perceived is very dependent on room acoustics, size, position of speaker within the room, etc, and the low frequency sounds are often lost. Again the innocent murmur is not well reproduced by these speakers in a room setting.

Video and audio conferencing equipment often involves compression and reconstruction of the signals, which can lead to problems, especially involving the reproduction of impulse-like sounds (S1, S2, clicks). Often artifacts are produced in the vicinity of the impulse, which can be misinterpreted as splits, or multiple clicks, confusing the novice learner at remote sites.

Classroom teaching in one site

Distribution of sounds to multiple listeners in one site can be achieved in several ways. For individual students, the audio amplifier in most laptop computers is adequate to drive two headsets using an adapter to connect both headsets to the “audio out” connector. Devices using Bluetooth® wireless transmission are more practical if synchronous listening is desired. Alternatively, mobile devices sourcing sounds from websites by groups of listeners, while not truly synchronous, do allow listening to a common source which can be the focus of discussion of the sounds[2].

Distributed teaching sites

Increasingly, medical students spend rotations in a variety of sites, requiring facilities for distance education. Simultaneous live and / or online teaching at several sites can be performed in several ways. For clinical clerk sessions we use a web- based archive of "unknown" heart sound recordings (usually **teachingheartauscultation.com>learning programs**) which students at several sites can access simultaneously. They listen with individual earbuds attached to their mobile device.

Two- way voice communication to direct the session and allow discussion takes place with a telephone audio conference using speakerphones. Thus the heart sounds are heard through a separate audio device from the discussion. In practice the teacher instructs each student to access a recording, labelled by letter only, and after all students have listened, one student is invited to describe what is heard, beginning a discussion with all students present and mentored by the teacher. This has been very well received by students over several years, and is very economical. Videoconferencing is also possible to allow visual teaching during such sessions, but the heart sounds must be delivered via a separate audio channel (from a website) to provide adequate sound quality.

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Heart Sounds Auscultation: Learning from the Nursing Perspective

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Highlights

- mentoring is helpful to develop this skill
- further evaluation of teaching methods is needed
- new teaching methods should be explored

Objectives:

- Current techniques for teaching heart sounds auscultation to nurses
- Development of the skill in the clinical setting
- Assessment of skills

Teaching Techniques

There are many techniques currently utilized for teaching auscultation of heart sounds in nursing education. The skill of identifying heart sounds and distinguishing normal from abnormal is not easily mastered. Clear objectives are needed. Effective learning requires experience, sufficient time for practice, and mentoring from an experienced practitioner[1]. Typically, the use of a stethoscope is introduced in formal nursing education but the development of the skill evolves during a nurse's continuing education and experiences[2]. There is no substitute for direct patient contact for learning to assess heart sounds but this situation does require an experienced teacher to validate the learner's findings.

To assist in the development of auscultation skills different techniques have been utilized in the learning environment such as classroom and textbook learning, simulator learning and computer mediated learning. One study has shown that nurses had the same success as physicians and other health care professionals in recognizing murmurs using directly recorded cardiac auscultatory events from actual patients transmitted via wireless infrared stethoscopes[1]. Simulators have been used with some success but their size and portability do not always allow easy access for learning[3].

Skill Development in the Clinical Setting

First, objectives should be set appropriate for the level of education and expected practice. The approach to teaching evaluation of heart sounds is different depending on the level of education, experience and the role of the nurse learning the skill. Nurses should be able to recognize normal heart sounds and the split of the second sound. Murmurs should be recognized as normal or abnormal. Nurses working in intensive care units and emergency departments require advanced skills in auscultation of heart sounds. Pediatric Nurse

Practitioners should aim to recognize abnormally wide splitting of the second heart sound and differentiate common murmurs such as innocent murmurs, aortic and pulmonary valve stenosis, ventricular and atrial septal defects, and patent arterial ducts. Examples of abnormal sounds will likely need to be derived from recordings, preferably in an educational and case format, e.g. –EarsOn[4]

Second, a systematic approach is essential as it helps to develop a routine and the skills of assessment. Third, an experienced mentor will help the learner develop the skills to distinguish and identify heart sounds[5].

Nurse Practitioners (NP) are growing in numbers as are the variety of clinical settings in which they practice. Currently, auscultation of heart sounds is taught in the clinical setting of the NP's education and developed during practice experience. Continuing Education programs, such as conferences and teaching sessions, provide opportunity for further development of skills. A recent example is the workshop on auscultation of heart sounds by a Cardiologist at a conference of a Provincial association of NPs (Nurse Practitioner Association Conference, Wolfville NS, April 2010).

Primary Care Nurse Practitioners are required to assess and treat many patients of all ages who may require evaluation for cardiac findings. Specialty Nurse Practitioners (SNP) who work in tertiary care areas routinely utilize cardiac assessment skills and through their work further develop this skill. The practice of the SNP often includes teaching the assessment of heart sounds; thus SNPs become the resource for many health care providers such as nurses, medical students, respiratory therapists and other nurse practitioners. There is potential to build on this teaching opportunity and utilize teaching methods such as computer mediated learning tools to further evaluate the learning experience.

Assessment

Currently, the assessment of nurses' skill with auscultation of heart sounds takes place in the clinical setting by a preceptor or instructor. This assessment is observational and on an individual level. The success of nurses participating in a research study evaluating heart sound teaching with recordings suggests that this modality deserves further study and possible application in nursing education[1]. Further utilization of computerized sound assessment techniques would be worthwhile for nurses and nurse practitioners learning heart sound evaluation. At our institution, the evaluation of Nurse Practitioners involves the use of OSCE testing and increased emphasis on the assessment of heart sounds could be incorporated into this testing process.

There are thus many opportunities to improve the assessment of nurses' abilities to evaluate heart sounds through mentoring and utilizing the available and developing electronic technologies.

Improving Teaching Programs

Incorporating more teaching on evaluation of heart sounds in nursing education and continuing education opportunities would contribute to improved development of this skill. As noted, bedside experience with real patients is considered a valuable form of learning and acquiring skill in cardiac assessment, but little data exists to validate this theory[1]. A skilled preceptor is thought to be the most valuable educational tool for developing cardiac assessment skills but is often not available to the bedside nurse[5,6]. It is this lack of availability of skilled preceptors to the bedside nurse that can cause learners to have a lack of confidence in their assessment skills[7]. I believe there would be benefit from formalizing the assessment of this skill and the ongoing education for nurses and NPs. Other modalities of learning have been shown to improve cardiac assessment skills, such as heart sound simulators and audio recordings[1,7]. Application to nursing education appears warranted.

The principles of adult learning indicate that as learners mature they become more self-directed, past experiences contribute to the quality of new learning and learners are motivated to learn solutions to problems[7]. These principles offer a base on which to build more effective learning experiences for nurses, incorporating mentoring during bedside assessments and simulated learning experiences.

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Recommended Curricula for Teaching Heart Sounds Auscultation

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At the time of writing, undergraduate medical education curricula are undergoing rapid and significant changes in both format and content. The new curricula typically feature distance learning, simulation and integration of clinical and basic science learning. Skills teaching in some curricula is being revised, and may utilize video presentation and simulation but unfortunately may lack patient contact or personal interaction with a teacher. Newer concepts of teaching auscultation may or may not be informing the revised curricula.

With this evolving background there is no auscultation curriculum which fits all medical education programs. The best teaching and learning program for a particular institution will take advantage of the strengths of the resources available, especially the teaching staff. As noted in the chapters by Drs Mackie and Finley, much of auscultation teaching and assessment is not evidence- based and there is much scope for research in this context.

Nonetheless there are effective teaching principles outlined in this book which should be the foundation of any auscultation teaching curriculum. We offer below a template for curricula for physicians and nurses. The actual timing of the teaching will depend on the institution; we assume a 4 year program of medical education with clerkship in years 3 and 4. The important elements are the sequence of teaching sessions, opportunity for small group teaching with a mentor, self- learning, much repetition, obligatory assessment using a mastery model with a minimum passing score, online recordings and materials, and reinforcement several times in subsequent years after the principal teaching segment. In addition to this outline it is assumed there will be some auscultation experience in small group bedside teaching and clinical rotations.

Undergraduate Medical Education

Year 1 – introduction to physiology of heart sounds, large group listening for illustration. Online access to normal heart sounds.

Year 2 – small/medium group teaching and listening

- self directed learning for minimum of 500 repetitions of heart sounds and murmurs using online/ downloaded recordings. Emphasis on normal vs abnormal, and only common abnormalities.
- obligatory assessment, possibly online, requiring mastery to a minimum score
- reinforcement/review session, possibly online, once in Year 2

Years 3-4 – at least 2 reinforcement/review sessions

- OSCE assessment should be considered for Pediatrics and Internal medicine rotations

Postgraduate Medical Education

Emphasis on heart auscultation will depend on specialty. Family medicine, Internal medicine and Pediatrics should have an obligatory curriculum. Pediatric cardiology and adult cardiology would have an advanced level curriculum. Online resources will be essential. Specific objectives and teaching sessions will be important, and assessment will be the key to successful learning.

Continuing Medical Education

Credit should be available for auscultation learning programs which could be online, at conferences and through refresher courses. These should be available in several levels of difficulty, appropriate to the type of practice of the individual practitioner.

Nursing and Other Health Professions

Because of the wide scope of practice, for nursing, paramedical personnel and other health professions, recommendation of specific curricula is not feasible. However, it is likely that insufficient emphasis is placed on heart auscultation in many training courses. Recognition of normal vs abnormal should be the most important objective of any program. Recordings, online or downloaded, should be available containing uncomplicated examples with provision for much repetition and later assessment of skill. Learning with a mentor remains a highly valuable experience.

Vocalization and Imitation in Learning Sound Recognition

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Hypothesis: vocalizing to imitate heart sounds and murmurs can improve their recognition

It is generally recognized that human learning is facilitated by imitation. At any age, imitation of actions, sounds and visual objects is important in learning the recognition and reproduction of what is perceived[1]. Among vertebrates, some like dogs are auditory learners and can recognize sounds, as judged from their behaviour. Others such as songbirds, seals, bats, whales and humans can imitate perceived sounds and are vocal learners. Studies of songbirds have revealed the importance of imitation of sounds created by a bird tutor, in the learning of songs by young birds[2]. It is evident that young birds must mimic the sounds they hear from a parent in order to develop appropriate songs themselves. In order to accurately mimic sounds they must also hear their own attempts and compare these with what they have heard from the parent. This comparison is possible due to neural connections between the aural input from the ear and motor control centre for the larynx, and possibly to “mirror neurons” which activate when actions are both performed and heard[1]. Experimental corruption of auditory neural signals leads to corruption of the sounds created by the birds.

In humans, normal hearing is important for accurate speech acquisition. Further, imitation facilitates learning of both speech and song. Functional Magnetic Resonance Imaging studies show activation of auditory and motor areas of the brain during vocalization, consistent with activation of auditory feedback influencing the sounds produced[1]. Musical training in many cultures involves extensive imitation which has been shown to enhance voice and instrumental learning[3].

Thus, evidence in several species supports the crucial role of imitation in accurate speech and song production. Since this is apparently dependent on the comparison of vocalized sound and external sounds, it is reasonable to suggest that part of this process is enhanced recognition of the perceived sounds. This suggests that vocalization may enhance not just the mimicry but also the recognition of certain sounds.

Relation to Heart Auscultation

The teaching of heart sound and murmur recognition typically involves listening to live, recorded or synthesized sounds in order to provide examples of sounds for later recognition by students. Many teachers are adept in vocally mimicking heart sounds and murmurs which can give emphasis to their teaching. I suggest that a further step in the use of this mimicry is to encourage students to mimic heart sounds themselves. There are several reasons for this suggestion.

First, as noted above, vocalization may enhance more accurate recognition of what students are hearing. Second, the act of producing sounds engages muscle groups and motor areas in the brain as well as the auditory areas. There is some evidence from investigation of music recognition that with more areas of the brain activated, memory is enhanced[4,5].

Third, with vocalization I argue that learning becomes a more active process than the passive learning of simply listening, and active learning tends to be more effective than passive. Some instrumental music educators use vocalization of instrument sounds to enhance the learning of tone production[5].

Assessing the effect of vocalization on heart sound and murmur recognition is problematic since it is such a simple intervention that a controlled investigation would be difficult. However, given the minimal time required, the ease of introducing it into presentations and the apparent lack of adverse consequences, I am using the technique in all medical student auscultation teaching. It is well received and often adds some humour to the teaching.

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2. Koelsch S, Siebel WA. Towards a neural basis of music perception. *Trends in cognitive sciences* 2005; 9:578-584
3. Campbell PS. Lessons from the world. A cross-cultural guide to music teaching and learning. New York, Schirmer Books 1991, P. 101-106
4. Levitin DJ. This is your brain on music. New York, Plume 2006, P. 164-166
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6. Hastings D. Personal communication.

Auscultation Teaching Devices and Materials

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This is a collection of aids for auscultation teaching as of June 2019.

I have not critically reviewed all those listed and their inclusion does not necessarily represent endorsement. Unfortunately it is not possible to confirm that all are available. Sources can be found with a search engine. I can not guarantee the accuracy of the web addresses.

Websites

teachingheartauscultation.com – includes adult and pediatric cases with live patient recordings and murmur recognition program (see Chapter 6) All downloadable. For individual and group teaching. Open access.

Biosignetics – www.bsignetics.com

Blaufuss Heart sounds and arrhythmias – www.blaufuss.org

Easy auscultation – www.easyauscultation.com

emurmur – https://emurmur.com/academic/

HeartSongs5 Barrett M. – www.acc.org>heart-songs-5 – recordings of a variety of synthetic heart sounds and commentary emphasizing repetition. Quizzes included. Excellent echo images.

imurmur 2 – the Apple murmur tutor app from itunes

ihuman – http://www.i-human.com/

Johns Hopkins – Thompson WR, Tuchinda – http://murmurlab.org

C Littmann – https://www.littmann.com/3M/en_US/littmann-stethoscopes/education-center/lli-app/

The auscultation assistant – https://www.wilkes.med.ucla.edu

Thinklabs – www.thinklabsmedical.com

U Washington Dept of Medicine – https://depts.washington.edu/physdx/heart/demo.html

Recordings

Beyond heart sounds. The interactive cardiac exam. Criley JM. Armus Corp. 1999. Burlingame CA. 10 cases with investigations and videos. Question format. Heart Sounds Builder allows creation of sounds and murmurs.

Clinical auscultation of the cardiovascular system. Harvey WP, Canfield DC Laennec Publishing Fairfield NJ 1997. 10 audio tapes including quiz of 61 cases. A classic if you can find it.

Clinical Cardiology. Houghton AR, Sensky PR. OCB Media 2004. Adult murmurs, general cardiac assessment , review of adult clinical cardiology with diagnostic procedures.

Paediatric cardiac auscultation. Altman CA, Nihill MR, Bricker JT. Lippincott,Williams and Wilkins 2000. Live recordings and videos.

Paediatric cardiovascular examination. Mckean M, O'Callaghan C, Runciman M. OCB Media 2006. Pediatric murmurs and general cardiac assessment and review of clinical cardiology, including diagnostic procedures.

Physiological Origins of Heart Sounds and Murmurs. Revised. Criley & Criley. Lippincott Williams and Wilkins. Date not specified. Recordings, videos, animations with hemodynamics, investigations, etc.

The virtual cardiac patient. A multimedia guide to heartsounds and murmurs. Keroes J, Lieberman D. Lippincott Williams and Wilkins 2005. 28 simulated heart sound recordings. Quiz format.

Books with recording

Heart sounds made easy. 2nd Ed. Brown EM, Leung TS, Collis WB, Salmon AP. Churchill Livingstone Elsevier 2008

Pediatric Heart Sounds. McConnell ME. Springer 2008

Understanding Pediatric heart sounds and murmurs. Lehrer S. Elsevier 2002

Hardware

Ventriloscopes
http://www.ventriloscope.com/

SimScope
https://www.cardionics.com/product/learning-systems/simscope-wifi-the-hybrid-simulator

Heartman
https://www.cardionics.com/product/learning-systems/simscope-wifi-the-hybrid-simulator

3M Litmann Listen In
https://www.cardionics.com/product/learning-systems/3m-littmann-listen-in-mobile-kit

Self Teaching System
https://www.cardionics.com/product/learning-systems/self-teaching-system-sts-for-cardiac-auscultation

Stethio
Stethio.com

Afterword: Future Prospects

The contents of this brief monograph indicate that action is urgently needed to reform the teaching of heart auscultation to prevent it from becoming a lost skill. And while more research into teaching methods and outcomes is inevitably needed, certain principles of effective teaching are clearly established, as noted by Drs. Barrett and Pieretti. What is lacking is widespread adoption of these principles in curricula. Primary responsibility should rest with the associations of medical and health professional schools whose objective is to produce competent graduates. Reform may be encouraged by accrediting and licensing organizations. Agencies that accredit health professional schools could play an important role in insisting on better standards for skills teaching, as could professional organizations by providing more effective continuing educational programs for graduates. Licensing bodies could consider assessment of auscultation skill as part of recertification or maintenance of competence.

Research into educational methods, devices for teaching, and the neuropsychology of sound recognition is clearly needed. Methods of teaching could usefully be informed by the techniques already being employed in diverse disciplines such as audiology, music education, psychology and others.

Failure to address the deficiencies of current auscultation teaching will rapidly lead to further erosion of the skill and the disappearance of a useful clinical tool. The increasing use of portable imaging technology, often driven by financial interests, may prove an irresistible alternative to intelligent use of the inexpensive acoustic stethoscope.

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