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Canadian Hearing Report

Revue canadienne d'audition

Vol. 5 No. 6

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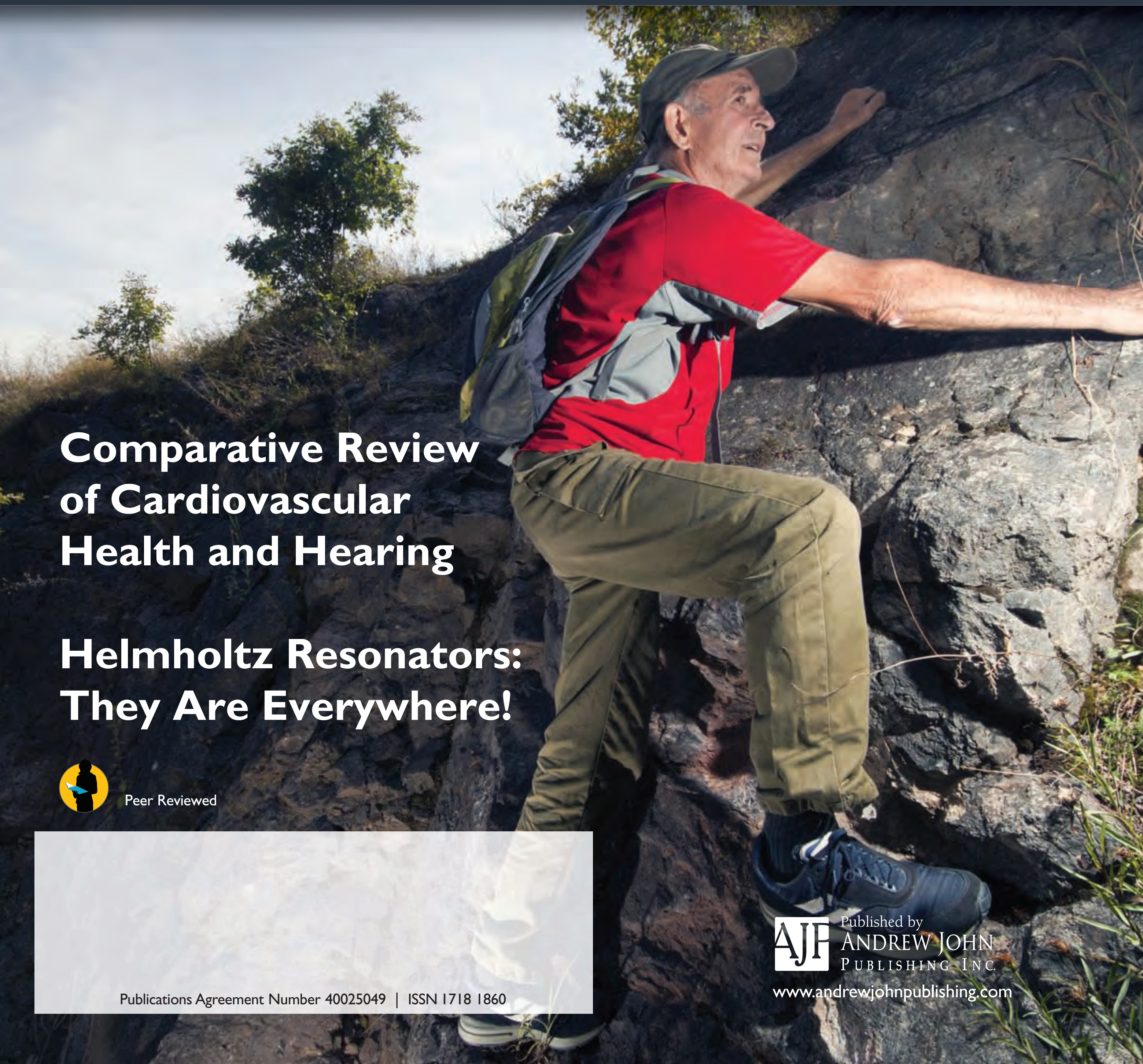

Comparative Review of Cardiovascular Health and Hearing

Helmholtz Resonators: They Are Everywhere!

Peer Reviewed

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Almost 30 years ago, my first job was as a staff audiologist at the Canadian Hearing Society. The sound booths were located in a converted garage in a three story house that once was the Finnish embassy. I had three colleagues (Tani Nixon was my boss and mentor, Glen Sutherland who knew everything about aural rehabilitation and knew the best restaurants in Toronto, and the third was another Marshall – Marshall Rosner). If Tani came into our shared offices and said "Marshall!" we became very adept at figuring out who was in trouble. Our first jobs in audiology are always important. They teach you the "ropes" that you didn't learn about in school. And to this day, I have close friendships with all these colleagues. The Canadian Hearing Society is now celebrating their 70th anniversary and Rex Banks (the current Tani) gives us a nice overview of where they were and where they are today.

Speaking of anniversaries, the School of Communication Sciences and Disorders at the University of Western Ontario is celebrating their 40th anniversary. Dr. JB Orange gives an excellent overview of their program and the celebrations. And does anyone know what the "JB" stands for?

On a different topic, I always knew that doing my push ups (and sit ups and crunches, and…) was supposed to be good for me, but now we have data showing that being in good cardiovascular shape actually minimizes the chances of sensori-neural hearing loss down the line. A peer-reviewed article (*Canadian Hearing Report* does offer the opportunity of having a submission peer reviewed) has been submitted by Doctors Hutchinson and Alessio showing that elderly couch potatoes actually have a greater sensori-neural hearing loss than their age-matched physically fit colleagues. It seems that presbycusis is not inevitable, or at least not to the same degree.

I recently ran into Scott Lake who is an engineer with Westone Laboratories at an American Academy of Audiology meeting and I managed to "persuade" him to write an article for us on one of my favourite topics – the acoustics of Helmholtz resonators. We have them everywhere in audiology, from the vent-associated resonance to a study of room acoustics, and this article extends our knowledge of what we already thought we knew about Helmholtz resonators. Scott's previous incarnation was in the automotive industry and some of the examples derive from his tenure there. The science and even some of the technology is easily transferable to the field of audiology.

Phillipe Fournier has written on the perceived benefits of using FM systems with cochlear implants. Like hearing aids, cochlear implants are limited in many situations and the use of assistive listening devices to improve the signal to noise ratio is always useful. I am actually quite surprised by how infrequently assistive listening devices such as FM systems are being recommended by our colleagues. Phillipe is a student at the University of Ottawa and an abstract of his work appears under the banner of "From the Classrooms." Isabelle-Anne Pleau, also a student at the University of Ottawa, has sent in an abstract as well and has tried to tease apart threshold information (with and without masking) in an attempt to delineate the relative contributions of sensory and non-sensory contributions as a function of age.

To round out this issue of the *Canadian Hearing Report*, we have a short piece that is written "For the Consumer" on noise cancelling headphones. **Please note that this article can be freely copied and given out to clients as desired.** Noise cancellation has been around since the 1930s but only recently has it found its way into consumer products and hearing aids. It is hoped that this is the first of many free-use "For the Consumer" information sheets that will appear in upcoming issues of *Canadian Hearing Report*.

I would like to take this opportunity to wish everyone and their families a pleasant and peaceful holiday season.

Marshall Chasin, AuD
Editor-in-Chief

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Mon premier emploi, près de 30 ans maintenant, a été à la Société canadienne de l'ouïe en tant qu'audilogiste. Les cabines de sons étaient situées dans un garage converti en maison de trois étages qui abritait jadis l'ambassade de la Finlande. J'avais trois collègues (Tani Nixon était ma patronne et ma conseillère, Glen Sutherland savait tout sur la réhabilitation auditive et les meilleurs restaurants de Toronto, et le troisième était un autre Marshall –Marshall Rosner). Si Tani venait dans le bureau qu'on partageait et appelait "Marshall!", nous savions pertinemment qui, de nous , était en difficulté. Nos premiers emplois en audiologie sont toujours importants. Ils vous enseignent les "rouages" que vous n'avez pas appris à l'école. Et à jour, j'ai des relations d'amitiés étroites avec tous ces collègues. La Société canadienne de l'ouïe célèbre maintenant son 70ième anniversaire et Rex Banks (le Tani d'aujourd'hui) nous donne une belle vue d'ensemble du passé et du présent.

En parlant d'anniversaires, the School of Communication Sciences and Disorders de l'université de Western Ontario célèbre son 40ième anniversaire. Dr. JB Orange nous offre une excellente vue d'ensemble de leur programme et des célébrations. Et est ce quelqu'un connait la signification du "JB"?

Passant à autres chose, j'ai toujours su que faire mes tractions sur les mains (et redressements assis et enroulements abdominaux, et...) était sensé m'être salutaire, mais nous avons maintenant des données qui montrent qu'être en bonne forme cardiovasculaire minimise les chances de surdité neurosensorielle en fin de compte. Un article évalué par les pairs (*la Revue canadienne d'audition* offre l'opportunité de recevoir des soumissions évaluées par les pairs) a été soumis par Dr Hutchinson et Dr Alessio montrant que les personnes âgées sédentaires ont une plus grande surdité neurosensorielle que les personnes âgées du même âge mais physiquement actives. Apparemment, la presbyacousie n'est pas inévitable, ou tout au moins pas au même degré.

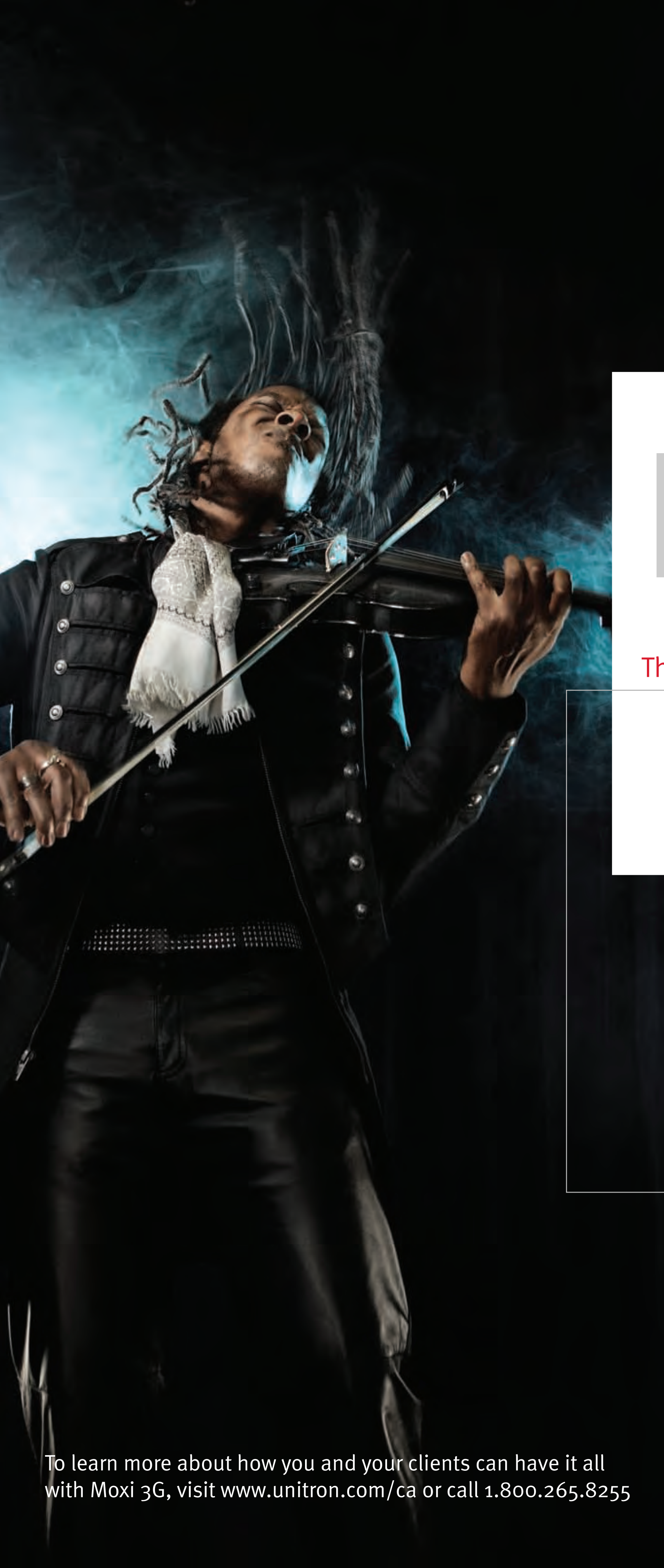
Je suis tombé dernièrement sur Scott Lake qui est un ingénieur avec Westone Laoratories au cours d'une réunion de l'American Academy of Audiology, et j'ai réussi à le "persuader" de nous écrire un article sur un de mes sujets de prédilection– l'acoustique des résonateurs de Helmholtz. Nous les avons partout en audiologie, de la résonance associée à l'évent à l'étude de l'acoustique de chambre, et cet article élargit notre savoir au sujet des résonateurs d'Helmholtz. Scott, dans une autre vie, est passé par l'industrie automobile et certains des exemples découlent de son passage. La science et même certaines technologies sont facilement transférables au domaine de l'audiologie.

Phillipe Fournier a déjà écrit au sujet des avantages présumés de l'utilisation des systèmes MF avec les implants cochléaires. Comme les appareils auditifs, les implants cochléaires sont limités dans plusieurs situations et l'utilisation des appareils fonctionnels pour malentendants pour améliorer le rapport signal/bruit est toujours utile. En fait, je suis assez surpris que nos collègues ne recommandent pas plus souvent les appareils fonctionnels pour malentendants comme les systèmes MF. Phillipe est étudiant à l'université d'Ottawa et un résumé de son travail apparaît sous la bannière "From the Classrooms.". Isabelle-Anne Pleau, aussi étudiante à l'université d'Ottawa, a envoyé aussi un résumé et a essayé de dissocier le seuil de l'information (avec ou sans masquage) dans une tentative de délimiter les contributions relatives des contributions sensorielles et non sensorielles comme une fonction de l'âge.

Pour terminer en beauté ce numéro de la *Revue canadienne d'audition*, nous avons un papier court qui est écrit "Pour le consommateur" traitant des écouteurs suppresseurs de bruit. **Veuillez noter que cet article peut être librement copié et donné au clients selon son bon vouloir.** La suppression de bruit est présente depuis les années 30, mais seulement dernièrement, elle a trouvé son chemin dans les produits pour consommateurs et appareils auditifs. Nous espérons que ce sera le premier de plusieurs papiers "Pour le consommateur" libres d'utilisation qui vont apparaître dans les prochains numéros de la *Revue canadienne d'audition*.

Je voudrai saisir cette opportunité pour souhaiter à toutes et à tous ainsi que vos familles des temps de fêtes paisibles .

Marshall Chasin, AuD
Éditeur en chef



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contents

DEPARTMENTS

3 Message from the Editor-in-Chief
Message du L'editeur en chef

ACADEMY NEWS

8 "Quick Notes" From The Executive Director
"Dépêches rapides " Du directeur exécutif

AUDIOLOGY NEWS

11 Audiology History at The Canadian Hearing Society: 70 Years of Excellence
BY REX BANKS

13 Celebrating 40 Years of Academic Excellence in Audiology and Speech-Language Pathology at the University of Western Ontario
BY JB ORANGE

38 Hearing News Network

38 Noise and Chemicals: Workers Are Losing Their Hearing

38 Reinventing the Road

COLUMNS

15 **FOR THE CONSUMER**
Noise Cancelling Headphones
BY MARSHALL CHASIN

16 **SPOTLIGHT ON SCIENCE**
Do ABRs Affect DPOAEs?
BY LENDRA FRIESEN

18 **FROM THE CLASSROOM: University of Ottawa**
Unmasked Thresholds and Minimum Masking in Infants and Adults: A Timeline for Separating Sensory from Nonsensory Contributions to Infant-Adult Differences in Behavioural Thresholds
BY ISABELLE-ANNE PLEAU

19 Users' Perspectives on the Benefits of FM Systems with Cochlear Implants
BY PHILIPPE FOURNIER

FEATURES

RESEARCH AND DEVELOPMENT FOCUS
20 Examination of the Associations between Cardiovascular Health and Hearing: Comparative and Historical Perspectives
BY KATHLEEN M. HUTCHINSON AND HELAINE M. ALESSIO

31 Helmholtz Resonators: They Are Everywhere!
BY SCOTT LAKE

Indicates peer reviewed article.

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"QUICK NOTES" FROM THE EXECUTIVE DIRECTOR

A very busy fall season for CAA began in earnest with our **2010 Conference and Exhibition** held October 5–8 at Le Centre Sheraton in Montreal. Delegates heard from an outstanding line-up of international speakers, highlighted by Dr. Richard Gans who gave the keynote address. Social highlights included a **"CAA's Got Talent Show"** during the Opening Reception, and a **Soiree Evening** with live entertainment by impressionist/ comedian Mat Gauthier. The **CAA Trade Show** once again provided a wealth of information about latest trends in audiology services and hearing equipment and supplies. I wish to thank our sponsors, manufacturers, and suppliers as well as all those who attended the conference for their continuing support.

This year's **President's Award** recipient was Anne Griffin, a renowned audiologist with the Central Health Care Board in Grand Falls, Newfoundland.

The **Jean Kienapple Award for Clinical Excellence** went to Sonia Marazzi, a respected audiologist with the North Shore Children's Hearing Clinic in North Vancouver, British Columbia.

The recipient of the **Student Poster Award for Outstanding Research** was Christine Turgeon from the University of Montreal. Other **Student Award** winners as nominated by their respective schools were:

- Emilie Gosselin, University of Montreal
- Bonnie Lampe, University of Western Ontario
- Maxime Maheu, University of Ottawa
- Mary MacDonald, University of British Columbia
- Robert Murphy, Dalhousie University

The Canadian Inter-organizational Steering Group for Audiology and Speech-Language Pathology recently released proposed **Competency Profiles** for the profession, and asked its member organizations, including CAA, to provide feedback by November 30, 2010. In addition, CAA is taking the lead role in a project to develop **Guidelines for the Assessment, Diagnosis and Intervention/Mediation of Auditory Processing Disorders (APD)**. The guidelines should be available early in 2011.

The **Federal Healthcare Partners (FHP) / Third Party Payers Group** met again with representatives of CAA and CASLPA in Montreal during the CAA Conference to discuss items of concern to Canadian audiologists. The FHP Group includes Veterans Affairs Canada (VAC), Non-Insured Health Benefits (NIHB), Department of National Defense (DND), the RCMP, and Blue Cross. A full report on decisions and recommendations coming out of our meeting will be posted soon on the Third Party Payer page of our website.

A further meeting was held with the **NIHB** group on September 30th to discuss the many questions from CAA members specific to NIHB.

We recently celebrated **National Audiology Week (October 18–24, 2010).** The CAA marketing team produced an online **Media Tool Kit** to assist CAA members in promoting the profession. Go to www.canadianaudiology.ca/myNAW to tell us about your National Audiology Week activities.

Now that our bid to co-host with CASLPA the **International Society of Audiology Congress** in Vancouver, British Columbia, in October 2016 has been accepted, we will be searching for a hotel venue, recruiting conference co-chairs and members to participate on the Planning Committee, and a professional congress organizer to manage the event. If you are interested or know of someone who is within CAA, contact me at director@canadianaudiology.ca

Finally, the 2nd Annual CAA Spring Audiology Seminar will be held at the beautiful Delta Beausejour Hotel in Moncton, New Brunswick. After last year's very successful inaugural event in Richmond, British Columbia, we will once again be featuring Dr. Michael Valente, director, Division of Adult Audiology, Washington University School of Medicine in St. Louis, Missouri. Online registration at www.canadianaudiology.ca opens on December 1 and space will be limited

Tom McFadden
Executive Director
Canadian Academy of Audiology

"DEPECHES RAPIDES" DU DIRECTEUR EXECUTIF

Une saison d'automne bien chargée a commencé avec notre **Conférence et exposition 2010** qui s'est tenue du 5 au 8 Octobre au Centre Sheraton à Montréal. Nos délégués(es) ont eu droit à des conférenciers exceptionnels de renommée internationale, le tout couronné par Dr. Richard Gans qui a été le conférencier d'honneur. Parmi les moments sociaux phares, le spectacle **"CAA's Got Talent "** à la réception d'ouverture, et une **Soirée Evening** avec le spectacle sur scène de l'impressionniste/ humoriste Mat Gauthier. Le **Salon professionnel de l'ACA** a encore une fois fournit une richesse en informations sur les dernières tendances en services audiologiques, équipements et fournitures auditifs. Je voudrais remercier nos commanditaires, fabricants, et fournisseurs ainsi que tous ceux et toutes celles qui ont participé à la conférence pour leur soutien continu.

La récipiendaire du **Prix du président** de cette année est Anne Griffin, une audiologiste de renom du Central Health Care Board à Grand Falls, à Terre Neuve.

Le **Prix Jean Kienapple pour l'excellence en clinique** est allé à Sonia Marazzi, une audiologiste respectée du the North Shore Children's Hearing Clinic à Vancouver Nord, en Colombie Britannique.

La récipiendaire du **Prix du mérite pour la présentation d'un poster en recherche exceptionnelle par un(e)étudiant(e)** est Christine Turgeon de l'université de Montréal. Les autres gagnant(es), dont les candidatures ont été avancées par leurs écoles respectives, du **Prix pour étudiant** sont:

- Emilie Gosselin, Université de Montréal
- Bonnie Lampe, University of Western Ontario
- Maxime Maheu, Université d'Ottawa
- Mary MacDonald, University of British Columbia
- Robert Murphy, Dalhousie University

Le **groupe directeur interorganisations pour l'audiologie et l'orthophonie** a dernièrement publié **les profiles de compétences** proposés pour la profession, et a demandé aux organisations membres, y compris l'ACA, de fournir une rétroaction au plus tard le 30 Novembre 2010. De plus, l'ACA joue un rôle de chef de file dans un projet qui vise à développer **Des lignes directrices pour l'évaluation, le diagnostic et l'intervention/ médiation des troubles des traitements des informations auditives.** Les lignes directrices devraient être disponibles tôt en 2011.

Le **groupe Partenaires au niveau fédéral en matière de soins de santé/Tiers payants** s'est encore réunit avec des représentants(es) de l'ACA et l'ACOA à Montréal pendant la conférence de l'ACA, pour discuter des sujets de préoccupations des audiologistes canadiens. Parmi le groupe des partenaires au niveau fédéral en matière de soins de santé, les Anciens Combattants Canada (ACC), Services de santé non assurés (SSNA), le Ministère de la défense nationale (MDN), la GRC et la Croix Bleue. Un rapport complet des décisions et recommandations résultant de notre réunion sera publié sur la page Tiers payants de notre site web.

Une réunion supplémentaire s'est tenue avec le groupe SSNA le 30 septembre pour discuter des plusieurs questions spécifiques au **SSNA** émanant des membres de l'ACA.

Nous avons célébré dernièrement **La semaine nationale de l'Audiologie (du 18 au 24 Octobre, 2010)**. L'équipe marketing de l'ACA a produit une **Trousse d'outils Media** en ligne pour assister les membres de l'ACA dans leurs efforts pour promouvoir la profession. Veillez visiter le www.canadianaudiology.ca/myNAW pour nous faire part de vos activités durant la semaine nationale de l'audiologie.

Maintenant que notre soumission pour être le co-hôte avec l'ACOA, du **Congrès de la Société internationale d'audiologie** à Vancouver, en Colombie Britannique en Octobre 2016, a été acceptée, nous allons faire la recherche de l'hôtel, le recrutement du président ou de la présidente et des membres pour participer au comité de planification, et le recrutement d'un groupe professionnel de planification de congrès pour gérer l'événement. Si vous êtes ou connaissez quelqu'un de L'ACA qui serait intéressé(e), veuillez me contacter au director@canadianaudiology.ca.

Finalement, le 2eme séminaire annuel du printemps de l'audiologie se tiendra au beau hôtel Delta Beausejour à Moncton, dans le Nouveau Brunswick. Suite à l'événement inaugural très réussi de l'année dernière à Richmond, en Colombie Britannique, nous recevrons encore Dr. Michael Valente, directeur, division de l'audiologie chez les adultes, de la faculté de médecine de l'université de Washington à St. Louis, dans le Missouri. L'inscription en ligne au www.canadianaudiology.ca sera lancée le 1er décembre et l'espace sera limité.

Tom McFadden
Directeur Exécutif
L'Académie Canadienne d'Audiologie

Audiology History at The Canadian Hearing Society: 70 Years of Excellence

By Rex Banks, M.A.CCC-A, Reg. CASLPO; Director, Hearing Health Care; Chief Audiologist; The Canadian Hearing Society

The Canadian Hearing Society is the largest organization of its kind in North America serving the needs of culturally Deaf, oral deaf, deafened, and hard of hearing people across Ontario and Canada.

Often associated with advocacy issues pertaining to the Deaf community, what many audiologists don't know is that since its inception in 1940, The Canadian Hearing Society has not only embraced the field of audiology, but has proven itself to be both a leader and innovator in the early days of the audiology profession in Canada. Along with establishing a national agency concerning itself with jobs for Deaf and hard of hearing individuals, the standardization and costs of hearing aids, rehabilitation of ex-servicemen and the distribution of expertise and information were key core components of the original mandate of CHS – which was initially known as The National Association for the Deaf and Hard of Hearing

To further these causes, in June of 1940, noted otologist of the time, Dr. G. Alexander Fee, was retained as a medical consultant to CHS. Dr. Fee examined approximately 25% of all new clients, administered functional tests with and without hearing aids, and advised clients as to possible benefit from treatment, hearing aids, and lip-reading. Additionally, Dr. Fee also answered inquires from distant points on behalf of the society.

The Second World War had just ended and much of the work of the society was focused on helping veterans who had returned from war service with severe hearing loss. CHS obtained a grant from the Department of Veteran Affairs to assist in providing amplification to 5,000 deafened servicemen. At the very same time and for the same reasons, the profession of audiology was in its infancy in the United States. Already, CHS' sense of the necessity of audiology was proving to be cutting edge and revolutionary.

Hearing aids were a focus of the1947–48 Annual Report. Dr. Fee described among his findings his patients' resistance to hearing aids, particularly in the younger age groups with moderate hearing losses. Fast forward to 2010, CHS audiologists are still concerned about this issue and are working with researchers at The University of Toronto to study the relationship between the stigma associated with hearing loss and/or aging and how these social perceptions affect the adjustment of hearing loss and the use of hearing aids

In the 1950s, the first of many grants to subsidize hearing aids for children was received and in 1952 CHS purchased its first audiometer at a cost of $845. This was a significant expenditure at the time but was deemed important and necessary as CHS began exploring this component of service. In 1962, a "sound-proof room" and audiometer were installed at the "Head Office." Two staff people were trained to administer hearing tests while the search for an audiologist commenced; an ambitious undertaking as there were no Canadian audiology training programs in existence at the time.

In 1967 audiologist Errol Davis was hired. He was the first audiologist in Toronto and soon reorganized the department into the most up-to-date audiological facility in Canada. The CHS Audiology Department set the standard for audiology clinics in teaching hospitals in Toronto and throughout the province.

From 1940 through the 1970s CHS conducted thousands of hearing aid evaluations and continued to expand its Audiology and Hearing Aid Programs along with the institution of a hearing screening van, which was donated by IBM and equipped by The Lions Club

In the early 1980s CHS supported the regulation of audiologists in conjunction with OSLA and worked closely with what was then called The Association of Hearing Aid Dispensers, responding to issues which arose from the Health Professions Legislation Review. CHS audiologists were also involved in helping establish the criteria for a governmental definition of deafness. After the Minister of Health announced the details of the newly established Assistive Device Program, CHS was contracted to provide expertise and administration to the Hearing Aid Services Monitoring Board (later known as the Advisory Committee on Hearing Aid Services).

In addition to audiological testing, hearing aid evaluations, electrophysiological assessment, aural rehabilitation, and hearing aid dispensing, in the 1980s the program grew to provide a significant role in the education of the professions of audiology and speech-language pathology. CHS became a recognized training site for all university audiology programs in Canada, the Speech-Language Pathology Program at the University of Toronto and the Communicative Disorders Assistant (CDA) program at Georgian College. CHS' audiology alumni list of volunteers, students and clinicians boasts some of the most well-known audiologists in Canada.

Today, The Canadian Hearing Society employs a provincial network of audiologists approaching hearing health care from a holistically minded point of view. CHS provides services, products and information relating to hearing loss as well as offering a wide-range of complementary education and support programs for both children and adults in an accessible environment. The Audiology Department remains integral to the fabric of CHS, touching virtually every department and affecting thousands consumers every year.

Celebrating 40 Years of Academic Excellence in Audiology and Speech-Language Pathology at the University of Western Ontario

By JB Orange, PhD, Associate Professor and Director

The School of Communication Sciences and Disorders at the University of Western Ontario (UWO), first established in 1970–1971 with its Founding Director Dr. James Stouffer, is celebrating its 40th anniversary during the 2010–2011 academic year. Current students, staff, and faculty, including alumnae/alumni and former staff and faculty, will be attending many of the several scholarly and social events planned over the course of the year to celebrate the school's important milestone.

The first and largest event was a combination scientific symposium and gala luncheon and dinner held at the UWO on Friday the October 1, 2010. Support for the day's events came from the Daniel Ling Speaker Series Fund, the Faculty of Health Sciences at the UWO, The Harmonize for Speech Foundation, The School of Communication Sciences and Disorders, and the National Centre for Audiology. Over 125 alumnae/alumni, current students, local and regional clinicians and faculty attended half-day symposium sessions in audiology and speech-language pathology. Registrants heard Dr. Robert Harrison, from the University of Toronto and SickKids Hospital, speak at the Hearing Science Seminar on the topic of "Auditory System Development and Plasticity." Others attended the Siemens Symposium led by Dr. Bill Hodgetts from the University of Alberta's Department of Speech Pathology and Audiology on the subject of "Bone Conduction Amplification: Present and Future Considerations." Other registrants attended the session titled "Recent Developments in Acquired Apraxia of Speech" given by Dr. Julie Wambaugh from the Department of Communication Sciences and Disorders at the University of Utah. Other delegates heard Drs. Lisa Archibald and Daniel Ansari, from our school and the Department of Psychology at the UWO, respectively, discuss the topics of "Numeracy and Arithmetic: The Roles of Development and Individuals Differences" and "The Psycho-educational Assessment from

Drs. Bob Harrison (left) and Richard Seewald at the gala dinner.

Dr. Ewan Macpherson on the bag-pipes.

Mr. George Shields (left) and Mr. Cam Miller.

London Men of A Chord.

(left to right) Drs. Margaret Cheesman, Vijay Parsa, Scott Adams, Ruth Martin.

a Speech and Language Perspective." The academic portion of the day ended with tours of faculty members' laboratories and individualized demonstrations of research activities.

The evening gala dinner, opened ceremoniously by the splendid bag-piping of one of our faculty members Dr. Ewan Macpherson, was marked by the official renaming of four student academic entrance and academic continuing awards in honour of Mr. Cam Miller, a longstanding barbershop singer and trustee of the Harmonize for Speech Fund. These awards will henceforth bear Cam's name. Cam worked tirelessly for many decades as a champion of our students, their research, and the academic mission of our school. Special guests included Cam and his wife Mary, Mr. George Shields and Mrs. Gail Shields, where George is the chairman of the Harmonize for Speech Fund. George delivered a moving and eloquent tribute to Cam, describing Cam's boundless energy, enduring support, and determined philanthropic focus on those with speech, language, hearing, and voice problems. During dinner, guests were serenaded by the London Men of A Chord, a close to 20 person barbershop singing chorus who honoured Cam and the school with exquisite in-tune melodies sprinkled with comical interludes. Former department/school co-directors Drs. Richard Seewald and Joseph Corcoran reminisced publically about their splendid time as co-directors. A PowerPoint slide show presentation, assembled by a group of current student volunteers, contained photos of former and current faculty with decades-marking clothing, hair-dos, and eyeglasses and which ran throughout the evening, yielding many laughs and comments such as, "Oh my goodness, is that ....!"

Other planned events to mark the School's 40th Anniversary include Dr. Ewan Macpherson presenting at the Annual Conference of the Canadian Academy of Audiology held in October 2010 in Montreal. Dr. Macpherson's talk addressed the importance of multidimensional spatial sound cues for sound localization among individuals with normal and impaired hearing. In addition, Dr. Ruth Martin, an award-winning neuroscientist and speech-language pathology faculty in our school, will be our sponsored speaker at the next Annual Conference of the Canadian Association of Speech-Language Pathologists and Audiologists being held in Montreal in late April 2011. Dr. Martin will address in her session the latest empirical evidence surrounding the concepts of swallowing neuroplasticity and efficacious approaches to rehabilitation of dysphagia.

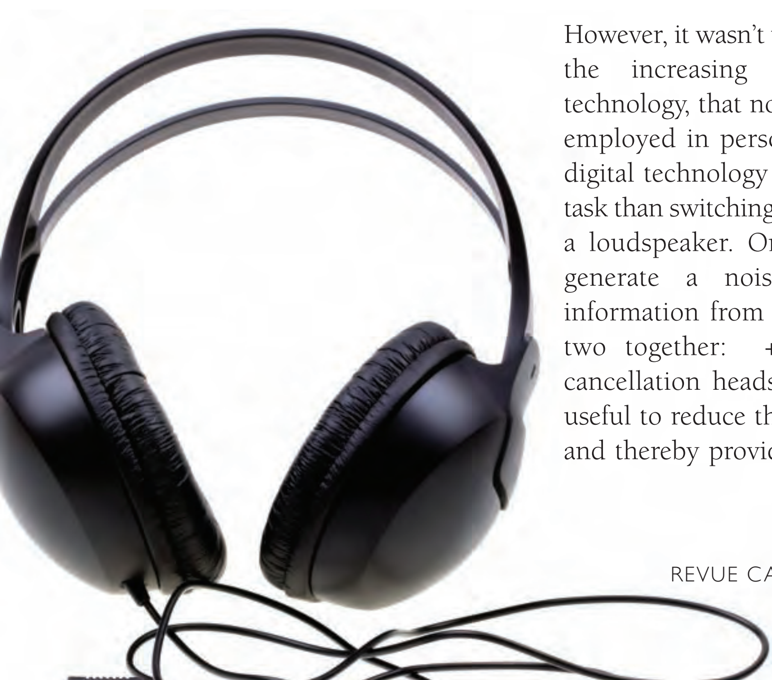
Careful reflection on the numerous and cutting-edge academic, clinical and professional accomplishments of students, alumnae/alumni, and faculty from the school over the past 40 years shows that there is much to celebrate and to acknowledge. Our graduates and faculty have helped advance multiple scientific bases of foundational knowledge related to hearing, speech, language, voice, cognitive-communication and swallowing disorders, and of innovative evidence-based rehabilitation approaches. The coming decades at the school will undoubtedly lead to additional exemplary leadership contributions that will advance scholarly thinking and clinician-scientist based practice patterns in audiology and speech-language pathology.

Noise Cancelling Headphones

By Marshall Chasin, AuD, MSc, Aud(C), Reg. CASLPO

In 1933 the *Journal of the Acoustical Society of America* published an article about using sound waves that were 180 degrees out of phase to "cancel" similar sounds in the environment. That is, a sound would be generated that would be identical to the noise it wanted to suppress, but be the opposite phase – as if an ocean wave peak met up with a wave trough going in the other direction, the net effect would be momentary calmness. This is the basis of noise cancellation.

Most unwanted background noise is lower frequency – it has energy on the left hand side of the piano keyboard and a feature of all lower frequency sounds is that it has a long wavelength (typically over a meter long). Given the technology of the middle part of the last century, it was a fairly simple task to generate low frequency sounds that would cancel similar frequency sounds but where a trough met up with a wave crest. One could simply reverse the wires connecting the back of one of two loudspeakers and if there were oriented correctly, the result would be a quieter sound. Keele University in England was one of the first to have an installation like this. A large loudspeaker was placed on the roof of the mechanical engineering building and it generated an identical sound to that which was constantly being emitted from the air exhaust system, but in opposite phase. The net result was a much quieter campus in the vicinity of the mechanical engineering building. Jaguar cars, since the 1980s have had noise cancellation loudspeakers (sometimes called "anti-noise") built into the exhaust system of their vehicles and this makes for a quieter ride all round.



However, it wasn't until the 1990s, with the increasing usage of digital technology, that noise cancellation was employed in personal headsets. With digital technology it's an even simpler task than switching the wires around on a loudspeaker. One simply needs to generate a noise but covert all information from + to – and add the two together: +2–2 = 0. Noise cancellation headsets have been very useful to reduce the background noise and thereby provide more comfort for the listener. There is a practical limit when listening through headphones since the human ear is so small – typically one can obtain a 12 decibel reduction but only below 1,000 Hz. This means that the loudness of the background noise can be reduced in half and only in the lower to middle portions of the piano. Since most background noise is in the lower to middle portions of the piano, this works quite nicely. And since this is more of a law of physics rather than engineering ingenuity, all noise cancellation earphones are pretty much the same. One would be hard pressed to say that a $200 set of noise cancellation earphones would be any better than a $20 pair.

Recently noise cancellation has even been used in hearing aids where the annoying squeal that is sometimes heard (called feedback) is "cancelled" by the generation of the same feedback squeal, but 180 degrees out of phase. The hard of hearing person can now turn up the volume of their hearing aids further without being as limited by the whistling.

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Do ABRs Affect DPOAEs?

By Lendra Friesen, PhD, Sunnybrook Health Sciences Centre

Evoked otoacoustic emissions (OAEs) are responses generated in the inner ear to various types of stimuli and are considered to be a byproduct of the cochlear amplification that enhances sensitivity and frequency selectivity. Clinically, the presence of distortion product otoacoustic emissions (DPOAEs) is used to indicate healthy middle ear and cochlear function, but does not determine absolute threshold with accuracy. DPOAEs are evoked using a pair of primary tones, f1 and f2 (where f1 is greater than f2). The evoked responses from these tones occur at predictable frequencies, depending on f1 and f2, and are known as distortion products. A recent finding in mice has revealed that the combined use of the auditory brainstem response (ABR) and DPOAEs, carried out in succession, with the ABR preceding the DPOAEs, yields a temporarily reduced DPOAE response.[1] Although the underlying mechanism of the reduced DPOAE immediately following ABR measurement remains to be determined, these results have important clinical implications in situations where both the ABR and DPOAEs are assessed.

DPOAEs provide a sensitive measure of outer hair cell function. They have been shown to be more sensitive than ABRs in detecting subtle auditory dysfunction. For example, several different studies have noted a decrease in DPOAE amplitude without a corresponding permanent increase in ABR thresholds.[2–4] In addition to permanent changes, transient decreases in DPOAE levels have also been described in response to toxic sound stimuli. Studies in both humans and animals have shown detectable reduction in DPOAEs in response to a sustained and intense noise exposure.[5–7] However, routine ABR testing has not been reported to impact DPOAEs.

In the Mhatre et al. study,[1] ABR thresholds were recorded from the vertex (non-inverted) to the ipsilateral mastoid (inverted), with the contralateral mastoid as the ground in several different strains of mice. The hearing range of mice is from about 1 khz to 70 kHz. Therefore the tonebursts and clicks used in this study were different from those used clinically. Broadband clicks and tonebursts of 8, 16, 24, and 32 kHz were presented at a rate of 33 per second and responses were averaged over 500 trials. Testing began at 85 dB SPL and was sequentially attenuated in 5 dB steps until threshold level was reached. In DPOAE testing, low level primary signals (L1 = 65 dB SPL, L2 = 50 dB SPL) primary signals (f1 and f2), with f2/f1 = 1.3, were generated with test frequencies ranging from 5 to 25 kHz. A peak at 2f1-f2 in the spectrum was accepted as a DPOAE if it was 3 dB above the noise floor. DPOAEs were collected before, immediately following, and one hour after ABR analysis in all mice.

In all strains of mice, results revealed that the levels of the DPOAEs collected immediately following ABRs were significantly reduced compared to the pre-ABR DPOAEs. Also, the DPOAEs obtained one hour following ABR testing showed recovery of the responses in all varieties of mice and there was no significant difference between DPOAEs collected pre-ABR and those obtained one hour following ABR measurements.

Superoxide radicals or reactive oxygen species (ROS) are elevated in noise trauma and anti-oxidant treatment has been shown to prevent hair cell damage and hearing loss.[8] Thus, Mhatre et al. investigated if excess production of ROS was responsible for the post-ABR DPOAE reduction. Specifically, the study tested if excess SOD1 expression can prevent DPOAE reduction immediately following ABR measurement in SOD1 transgenic mice. SOD1 is a cytoplasmic enzyme critical in neutralizing oxygen radicals and a major regulator of ROS levels within cells. The transgenic mice overexpress SOD1 nearly three-fold greater than their wild type (typically occurring in nature) littermates.[9] Similar to their wild type littermates, the SOD1 transgenic mice also demonstrated post-ABR DPOAE reduction, and thus did not support a role for superoxide radicals in transient reduction of DPOAE

The authors speculate that the amplitude reduction induced by the preceding ABR analysis may reflect a direct effect on the mechanosensory hair cells in response to continuous auditory stimulation. Alternatively, several studies have shown that activation of the medial olivocochlear neurons leads to reduction of DPOAEs.[10,11] Therefore, the ABR stimuli might activate the medial olivocochlear neurons that suppress the outer hair cells and their OAEs. Another cause of the reduction might be the activation of the middle ear muscle reflex. This activation results in stapedius muscle contraction, which alters the sound pressure in the ear canal, yielding a reduced response by the outer hair cell.

In conclusion, a practical outcome of this study is the authors' recomm-endation for the reversal of the auditory test order when assaying both ABR and OAEs, with the OAE measurements preceding ABR assess-ment, and thereby ensuring the DPOAE response is unaffected. If ABR measurements are to precede OAE evaluations, then a minimum interval of two hours is recommended between these tests.

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Unmasked Thresholds and Minimum Masking in Infants and Adults: A Timeline for Separating Sensory from Nonsensory Contributions to Infant-Adult Differences in Behavioural Thresholds

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ABSTRACT

The objective of the present research project is to extend results from a previous study by Nozza and Henson (1999) to a slightly older infant population. In the aforementioned study, it was demonstrated that infant unmasked thresholds differed from those of adults, and that a difference in minimum effective masking as a function of age and frequency was present. The conclusions from this study were that while infants' hearing thresholds were not significantly higher than adults, infants' threshold were increased by non-sensory factors such as fatigue and lack of concentration. Their sample of participants consisted of a group of 23 infants (M = 7.9 months, R = 6.7 - 9.4 months) and a group of 24 adults. A major flaw from the Nozza and Henson study was that the influence on test signals by the outer ear were not considered and hence values collected were biased by the fact that measurement equipments were calibrated for adult outer ears only. We are proposing an extension to the Nozza and Henson (1999) experiment to control for outer ear characteristics and determine whether there is indeed a difference in sensory status between infants and adults. The Minimal Masking Level technique used in Nozza and Henson will again be used to negate the influence of non-sensory factors commonly observed in infants. Also, the current study will look more precisely for a time course of the maturation of sensory abilities. Results from this study will help determine whether correction factors which highlight sensory immaturity must be applied to hearing threshold values obtained in infants when compared to audiometric reference values (i.e. normalized for the adult population). This will increase the accuracy of diagnoses for infants. Hearing-impaired infants are the most likely to benefit from this accuracy as treatment plans are defined based on hearing threshold data.

Users' Perspectives on the Benefits of FM Systems with Cochlear Implants

Student:
Philippe Fournier
Supervisor:
Elizabeth Fitzpatrick, PhD

ABSTRACT

This study explored: (1) the benefits of an FM system in real-world environments from the perspective of adults with cochlear implants, and (2) the factors and barriers to using an FM system with a cochlear implant. Using a qualitative research design, 14 adults with unilateral cochlear implants recorded their experiences during a two-month trial period with a personal FM system and responded to a questionnaire at the end of the trial. A detailed analysis of 169 journal entries (230 hours of FM use) permitted a description of the benefits and negative aspects associated with FM use in everyday listening environments. The primary benefits were related to improved access to and quality of sound, improved distance listening, ease of listening, and better social integration. Negative perceptions were associated with the equipment both with regard to physical aspects and adjustments. In addition, technical, individual, social, and environmental factors were identified that can influence the user's decision to use the FM device. Questionnaire responses indicated that the majority of individuals rated the FM system as somewhat or very helpful. The findings suggest that FM systems can improve communication in everyday listening environments for some adults with cochlear implants.

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Examination of the Associations between Cardiovascular Health and Hearing: Comparative and Historical Perspectives

By Kathleen M. Hutchinson, PhD and Helaine M. Alessio, PhD

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ABSTRACT

Purpose: Recent evidence has revised popular views about age-associated hearing loss, and has uncovered variables other than age that play a significant role in the decline in sensory function over time. The purpose of this review is to describe a quarter century of progress in understanding factors, other than age, that are associated with presbycusis, focusing on the influence of cardiovascular health.

Methods: Scientific evidence investigating noise exposure, cardiovascular health, personality, and other health variables was critically examined in this literature review.

Results: Over 25 years of research investigating hearing loss over time indicates that although aging plays a part, multiple factors, and in particular, cardiovascular health, impacts the rate and age at which hearing sensitivity is compromised and presbycusis occurs.

Conclusions: Factors other than age contribute to hearing sensitivity, opposing the long-standing expectation that hearing loss declines with age. Cardiovascular health is a powerful mediator of hearing sensitivity and individuals with high cardiovascular fitness can maintain better hearing acuity well into adulthood.

According to the Canadian Community Health Survey and the National Population Health Survey, hearing impairment is a common chronic condition in later life. In both Canadian studies, the prevalence of hearing loss increased with age and sociodemographic factors such as marital status, education, and income did not matter, except that hearing loss was more common among men.[1] Hearing loss interferes with effective communication, may disrupt work performance, compromise safety, impact interpersonal relations, and lead to depression. Because the number of older adults is expected to double in size over the next 20 years, and will represent roughly 20% of the United States population,[2] the preservation of hearing is a national health concern. Already, the number of people in the world, ages 65 and older, increases at an average rate of 870,000 each month.

Presbycusis is a peripheral and/or central auditory decrement over time.[3] For years, hearing loss was expected to decline with age, starting at around age 30. It is well known that noise exposure accelerates the loss of hearing acuity and after varying periods of time, causes a permanent noise-induced hearing loss. Additionally, a common finding is the great individual variation in hearing change among older adults of the same age. However, studies of different cultures and cohorts have shown that depending on where and when one lives often determines the amount of noise exposure and hearing loss. Recent experiments have reported that hearing loss is caused by the general effects of a variety of factors,[4] some within and some outside of a person's control. For example, the presence or absence of regulatory legislation requiring the reduction of noise exposure in the workplace, individual access to hearing protective equipment, use of ear bud headphones, or even knowledge about the consequences of noise exposure, may influence both the amount of noise and behaviour that ultimately affect hearing conservation.[4]

METHODS

Primary sources from peer-reviewed literature investigating multiple factors associated with presbycusis and noise-induced hearing loss were consulted in this review. Assessment of hearing sensitivity focuses on pure tone threshold (PTT) and temporary threshold shift (TTS). PTT is considered an objective criterion to establish hearing ability based on a person's response to pure tone stimuli at different frequencies. TTS is a short-term hearing decrement caused by brief noise exposure. Hearing thresholds typically recover from TTS after brief noise exposure. While intensity, duration, and frequency of noise exposure are key determinants of this phenomenon, other factors independent of these noise characteristics may also influence this effect. For example, underlying correlates such as psychological profiles,[4] body temperature,[5] physical exercise,[6] and variations in middle ear impedance and acoustic reflex properties[7] have been shown to influence susceptibility to TTS. A reduction of blood flow through the inner ear as a result of generalized peripheral vasoconstriction which occurs in response to loud noise may also be an underlying determinant of TTS.[8] The cardiovascular system is believed to play a significant role in regulating hearing sensitivity. Current concepts in auditory physiology include active mechanisms that serve to counteract the effects of trauma and stress. The effect of simultaneous noise exposure and cardiovascular responses to exercise has come under scrutiny in both leisure and work environments. This review begins with a discussion of underlying correlates of permanent hearing loss in addition to the role of cardiovascular health in regulating hearing sensitivity, first reported by Alessio and Hutchinson in 1991.[9]

ENVIRONMENTAL NOISE

The effect of environmental noise, referred to as sociocusis, is known to influence the progression of presbycusis depending on the amount of time and level of noise exposure at work, leisure or home settings. In some settings, sociocusis is negligible. For example, hearing loss is rare in Mabaans, a population indigenous to central Africa, where individuals have little to no exposure to industrial noise in this area of Southeast Sudan. The fact that the perceptual hearing loss of Mabaan adults over 60 years of age is indistinguishable from young adolescents suggests a correlation between auditory capabilities and the healthy and active lifestyle of the Mabaan people.[10] Many people who live in industrialized countries are exposed to environmental noise unfamiliar to the Mabaans and do not typically live active lives that include regular harvesting and hunting. Despite the typical industrial, musical, entertainment, and motorized sounds, noise exposure is moderated in most developed countries through work regulations, educational efforts, and safety precautions including mufflers and earplugs required in noisy workplaces. Additionally, many people use hearing protection during routine activities (e.g., lawn mowing) that involve loud noise.

In contrast, recent popularity of listening to music via ear bud headphones has caused young individuals to suffer premature hearing loss, resulting in hearing sensitivity levels equivalent to individuals who are decades older.[11] Exposure to noise through music performance is another potential mediating factor that contributes to hearing loss. Axelsson and Lindgren[12] found that pure tone thresholds among 59 of the 139 musicians tested showed more hearing loss than would be expected with age, worsening at age 60. Similarly DiSalvo[13] and Deatheradge[14] investigated hearing sensitivity among 33 younger instrumentalists and vocalists and found no definitive evidence indicating whether a young adult who plays a musical instrument or spends considerable time exposed to music has a greater risk of hearing loss compared to a group of 33 non-musicians. Physical fitness levels were similar in both groups and results included only young adults. Nevertheless, the use of specialized earplugs by professional musicians may assist in protecting hearing sensitivity, especially over time.

GENETICS

Hearing loss results from a number of causes and can be characterized as congenital or acquired. Approximately six of every 1,000 newborns have a significant hearing problem at birth, and more than 4,000 babies are born with hearing loss each year.[2] Advances in genetics have led to the identification of genes that cause hearing loss; as many as half of individuals with hearing loss may have a genetic origin. For example, the connexin 26 (CX26) genetic disorder causes disruption of potassium flow in the inner ear with subsequent hearing loss.[15] Genetic factors play a major role in onset and progression of hearing loss, susceptibility to hearing loss due to noise exposure, and responsiveness to intervention, although the environment and disease processes may contribute to the degree and severity of hearing loss.[15]

BEHAVIOURAL FACTORS

A common finding in audiology research is that the same noise exposure may result in different levels of either temporary or permanent threshold shifts among similar-aged individuals. This variability complicates the ability to draw conclusions about a cause-and-effect of noise and hearing loss. A study by Ickes et al.[16] on stress reaction indicated that individuals who had higher intensive reactions to stress ended up with prolonged peripheral blood vessel constriction, which in turn may have reduced blood circulation in the inner ear. When sorted into type A (coronary-prone) and type B (non-coronary prone) personality types, and exposed to 100 dB SPL noise, type A persons demonstrated increased vasoconstriction compared with persons categorized as type B. Without direct measurements of hearing sensitivity, the authors of this study could only hypothesize that the effects of prolonged vasoconstriction in type A would likely result in higher risk for TTS.

TTS and blood pressure were assessed by Dengerink et al.[17] who concluded that hearing sensitivity was related to an individual's general stress response to noise. The link between personality and hearing sensitivity appeared to be mediated by blood pressure and circulation. Hutchinson and Alessio[18] investigated the interaction of personality, noise, and hearing sensitivity with a group of individuals categorized as coronary prone, according to the Myers-Briggs test, which consistently identifies sensing/judging (SJ) pre-

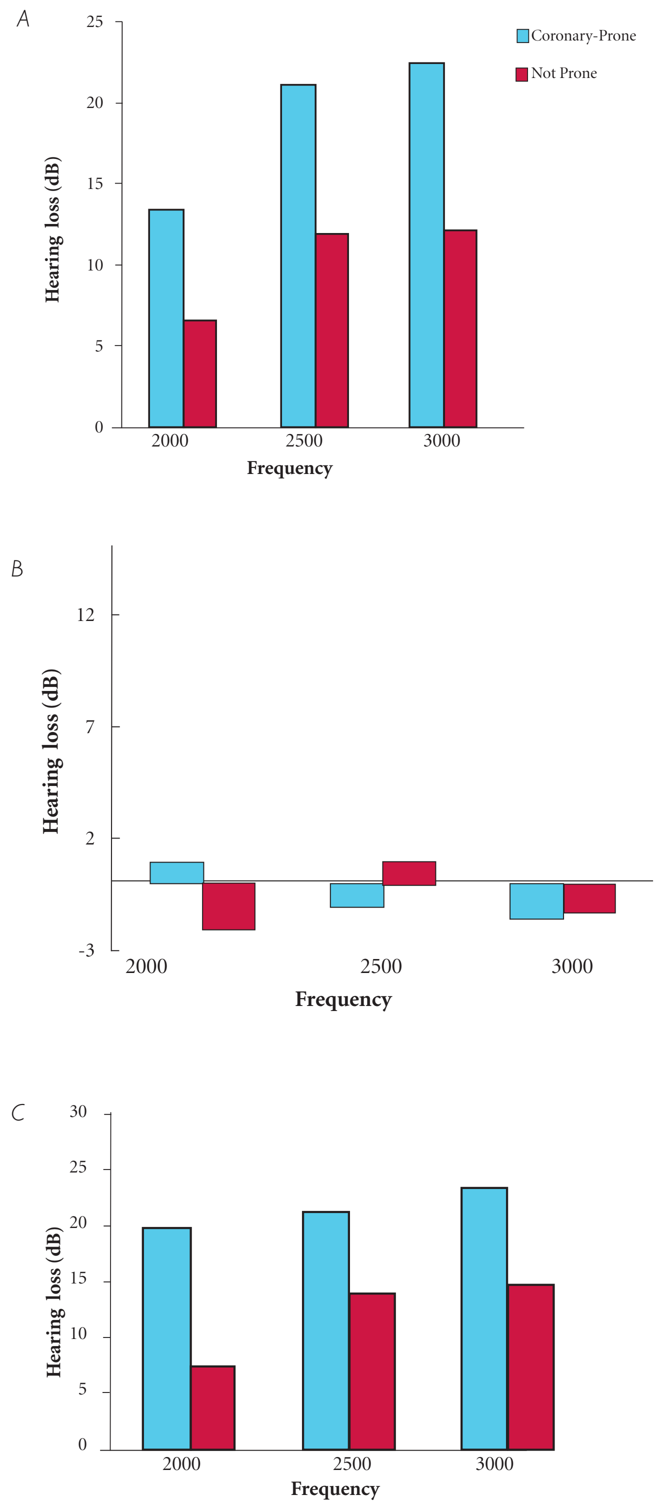


Figure 1 Hearing levels in dB HL at 2000, 2500, and 3000 Hz in coronary-prone and noncoronary-prone groups following 10 minutes of noise *(A)*, exercise only *(B)*, and noise and exercise *(C)*.

ferences within the type A behaviour complex. When compared with a control group of noncoronary-prone individuals, the coronary prone group had worse hearing levels at 2000 Hz following 10 minutes of noise (13.7 ± 5.1 vs. 6.5 ± 2.4 dB) and following 10 minutes of noise accompanied by exercise (19.7 ± 4.4 vs. 7.4 ± 2.4 dB; $p < .05$). Evidence of TTS following either noise or noise and exercise in the coronary-prone group occurred independently of differences in circulatory and heart rate measures compared with a control group, indicating other stress mechanisms besides cardiovascular reactivity that contribute to temporary hearing loss (Figure 1).

EXERCISE: ACUTE VERSUS CHRONIC

Study of the effects of exercise on hearing sensitivity, has produced intriguing results over the years. In 1971 Saxon and Dahle[19] tested a traditional activation theory by assessing auditory thresholds at 1000 Hz during rest and following a stressor. The authors chose acute exercise, which consisted of a 2.5 minute step test, as the stressor. They reported that auditory threshold sensitivity was significantly reduced following exercise-induced high heart rate compared with rest; supporting a contention that acute and intense arousal impairs hearing sensitivity. This study was the first to recognize a relation between cardio-vascular adjustments to acute exercise and hearing loss.

Shortly after Saxon and Dahle's 1971 publication, Ismail et al.[20] investigated the impact of chronic exercise on hearing sensitivity. Sixty-four adults between 23 and 62 years of age took part in an eight-month study. After measuring cardiovascular fitness levels, 54 of the 64 adults were equally divided into low, medium, or high physical fitness categories and 10 control subjects were also sorted into an appropriate fitness group. Then, over eight months, the experimental group participated in thrice-weekly hour-long supervised conditioning activities, which included 20 minutes of calisthenics followed by running, and team sports, according to individual preferences. Before and following the conditioning program, PTT, and TTS following noise exposure

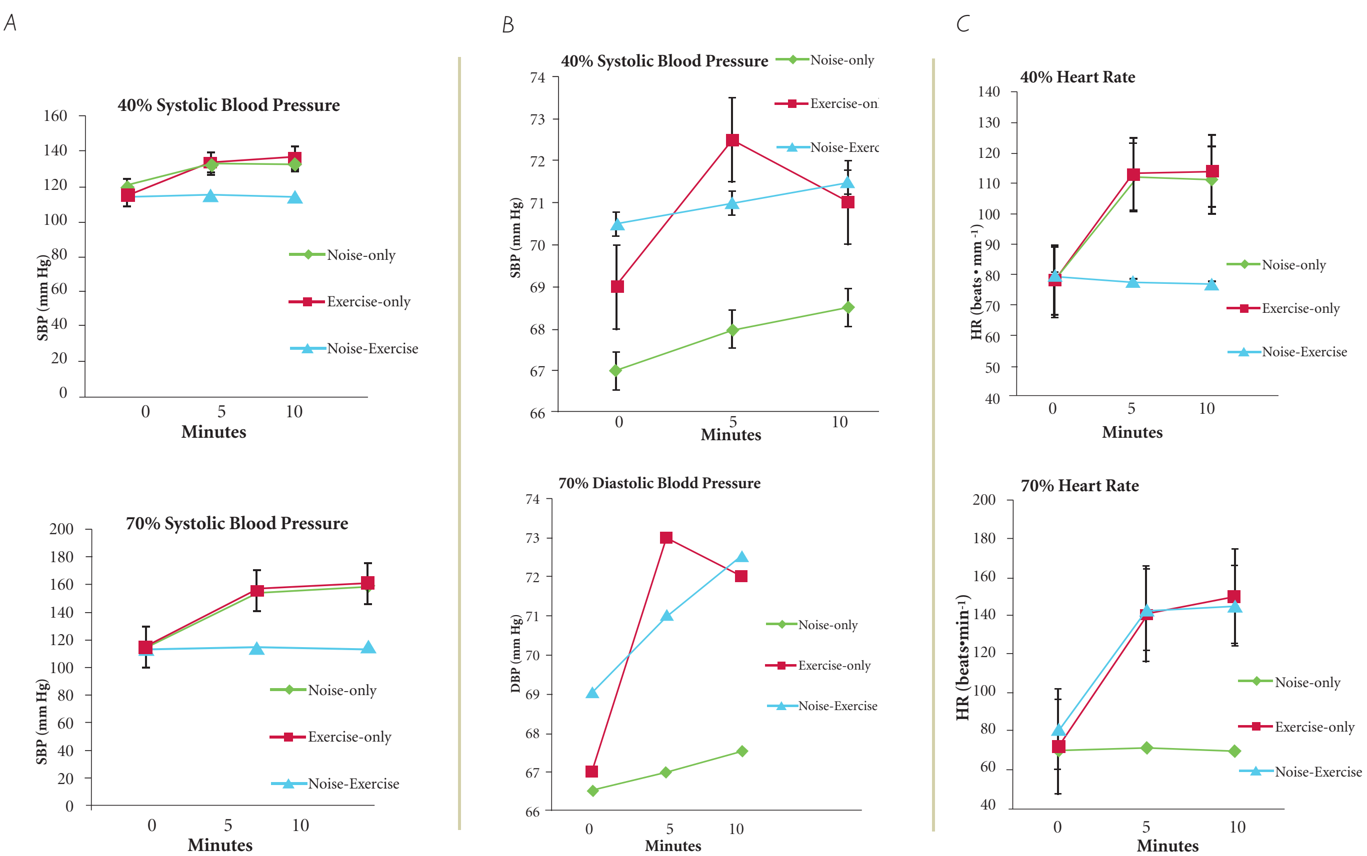
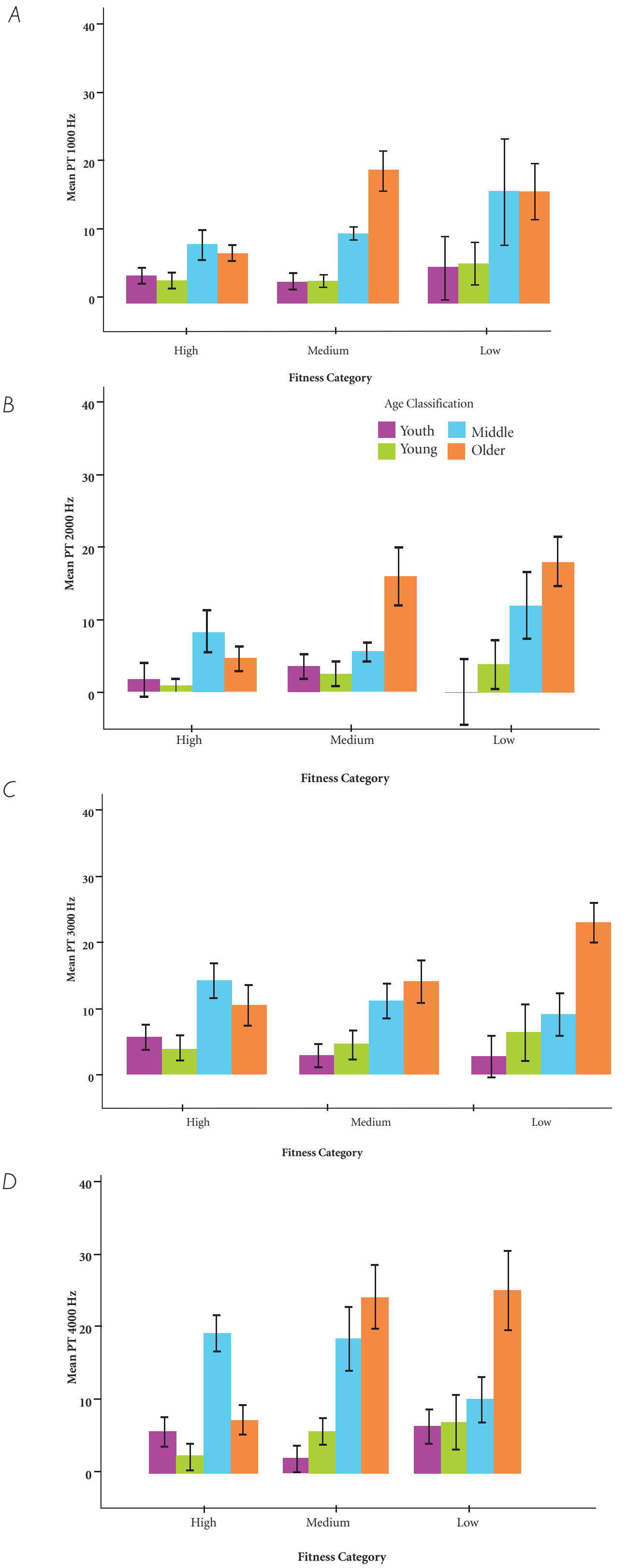


Figure 2. Systolic blood pressure (SBP) during 40% and 70% of VO2 max with and without noise *(A)*, Diastolic blood pressure (DBP) during 40% and 70% exercise with and without noise *(B)*, Heart rate (HR) during 40% and 70% exercise with and without noise *(C)*.



Figures 3A–D. Mean pure tone threshold (PTT) at 1000, 2000, 3000, and 4000 Hz (± SD) in dB HL by fitness level and age classification. The population was separated into four age groups: 10–19, 20–27, 28–48, and 49–78 years, each of similar group size.

were compared in all individuals as well as a number of health-related physio-logical variables. Results from Ismail's study indicated that chronic exercise was successful in improving biomarkers of cardiovascular fitness, including percent lean body weight, resting, submaximal, and maximal heart rate. Maximum oxygen uptake (VO_2 max) the benchmark assessment for cardio-vascular health and fitness, also improved 21% after 8 months of participating in regular exercise. In contrast, the control group reported no changes in any health-related variables after eight months. Although pure tone thresholds did not improve in the experimental group, individuals in the experimental group were less susceptible to temporary threshold shifts, indicating that the individuals who exercised recovered faster from auditory fatigue following the eight-month conditioning program. This was the first report that associated cardiovascular fitness with enhanced auditory function.

The beneficial role of exercise in mediating hearing sensitivity was questioned in a 1981 study. Sanden and Axelsson[21] reported temporary hearing loss in young adults who exercised for 10 minutes at 40% of VO_2 max while simultaneously listening to 104 dB SPL noise. The authors hypothesized that elevated blood temperature associated with acute exercise compromised cochlear reserve and function and caused TTS. The authors cautioned against participating in aerobic exercise activity that included vigorous and bouncy movements accompanied by loud music, by placing blame on the exercise activity more than the noise exposure. The same caution appeared in a brief magazine report by Navarro,warning readers of the risk of hearing loss from exercising to loud music. The Sanden and Axelsson study and brief report by Navarro both referred to the potential harm from combining vigorous exercise and noise exposure, but surprisingly, both considered exercise rather than noise to be the cause of hearing loss.

Hutchinson and Alessio[23] questioned the assertion that either PTT or TTS could be influenced by noise combined with exercise and physiological responses to exercise, regardless how vigorous, to a greater extent than actual noise exposure. They compared the effect of low (40% of VO_2 max) and high (70% of VO_2 max) intensity exercise with and without 104 dB SPL of noise on TTS. Figure 2 shows that heart rate, blood pressure, and core temperature increased in proportion to exercise intensity and were not changed above resting levels by noise exposure alone[23–25] TTS occurred following noise exposure only, with and without exercise of either intensity. These results refuted Sanden and Axelsson and Navarro's concerns that exercise contributes to temporary hearing loss when performed with noise exposure.

Hutchinson and Alessio noticed a surprising trend among participants in the early studies (1991, 1992, 1994, and 1996): the more physically fit subjects tended to perform better on the audiology tests than less physically fit subjects. This finding led to further investigations of hearing sensitivity among low, medium, and highly fit adults. Results indicated that high cardiovascular fitness correlated with better hearing sensitivity while low cardiovascular fitness correlated with worse hearing sensitivity.[25–28] These findings (Figure 3) were particularly evident among adults, age 50 and older, indicating that cardiovascular (CV) fitness may have a protective effect on hearing loss with age.[27, 28] Other health factors related to CV fitness and health were similarly examined in relation to hearing sensitivity, including muscle strength and blood pressure. Only CV health remained as a positive predictor of improved hearing sensitivity across age levels.

Table 1. Characteristics of four subject groups (mean ± SEM) comparing effects of muscle strength and cardiovascular fitness on pure tone threshold

Group	Number	Age (years)	Total Strength (kg)	VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$)	Body Mass Index	Body Composition (percent fat)
Low CV-Low MS	15	21.2 ± .57	404 ± 37.9	30.06 ± 0.97**	23.85 ± 1.10	21.51 ± 1.69††
High CV-Low MS	10	21.0 ± .89	497 ± 45.6	42.97 ± 2.49	22.49 ± .56	13.18 ± 1.65
Low CV-High MS	7	20.85 ± .94	612 ± 73.3*	29.68 ± 1.7**	27.24 ± 1.99†	19.35 ± 3.9
High CV-High MS	11	20.27 ± .50	523+ 51.3	41.8 ± 1.6	23.16 ± 1.05	15.64 ± 2.1

*Significant difference ($p<.05$) between Low CV-High MS and Low CV-Low MS and High CV-Low MS.
**Significant difference ($p<.05$) between both groups with low CV and both groups with high CV.
† Significant difference ($p<.05$) between low CV-high MS and other three groups.
†† Significant difference ($p<.05$) between low CV-low MS and high CV-low MS and high CV-high MS.

The cardiovascular system has been found to play a crucial role in regulating hearing sensitivity. TTS, a short term worsening of hearing thresholds, results from noise exposure; chronic noise exposure may result in PTS. One widely held theory is that a reduction in blood flow through the inner ear causes temporary TTS and subsequent short-term hearing loss. Generalized peripheral vasoconstriction, which occurs in response to loud noise, may be an underlying determinant of TTS.[8] Variations in cochlear blood flow may affect the availability of oxygen and glucose, which is more rapidly metabolized during sound stimulation.[6] A decline in blood flow through the inner ear is attributed to increased peripheral blood pressure or decreased oxygen tension in the cochlear endolymph and vasoconstriction, especially of the stria vascularis. Reduction in blood circulation through the inner ear can also cause reduced hearing acuity over time and lead to TTS and permanent hearing loss. Metabolism and blood flow are directly related to the vascular pattern of the cochlea. If one's circulation is compromised, blood flow through the cochlea may also be reduced. The impact of the cardiovascular system on hearing sensitivity is therefore theorized to be related to changes in blood circulation to the hearing mechanism as a result of exercise; it is hypothesized that regular exercise reduces PTS by an increase in blood flow and oxygen delivery in a healthy cardiovascular system.

Additional descriptive information about the association between hearing sensitivity and health-related components was studied by examining combined muscle strength and cardiovascular fitness.[26] Muscle strength was determined by performing leg curls, leg extensions, and bench press on a Nautilus machine (Nautilus Inc., Deland, Fl) and a hand grip using a standard dynamometer. Subjects also underwent skin fold testing, testing for blood lipids and glucose, and a 48-hour diet and physical activity recall. Distortion product otoacoustic emissions (DPOAE) testing was performed to assess cochlear integrity. Baseline PTTs were also determined.

Participants in the study were split into four groups for comparison, based upon their level of cardiovascular (CV) fitness and muscle strength (MS): low CV-low MS, high CV-low MS, low CV-high MS, and high CV-high MS (Table 1). As expected, the group with both high CV and high MS had the best hearing sensitivity. The group exhibiting the worst hearing sensitivity was the low CV fitness and high MS group. Equally surprising was the finding that that when muscular strength was accompanied by high cardiovascular fitness, individuals demonstrated better PTTs; high muscular strength alone was negatively correlated with PTTs.[26] Once again, hearing sensitivity was associated with cardiovascular health. It is unclear why muscle strength has a negative correlation with hearing sensitivity. Nevertheless, as long as high muscle

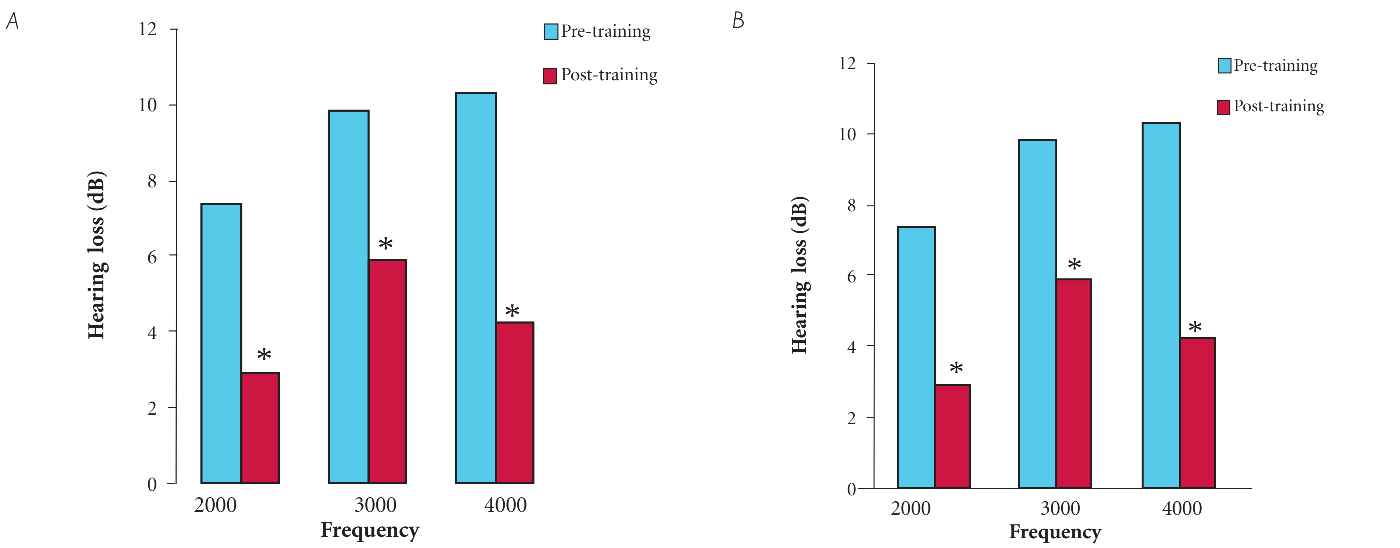


Figure 4. Temporary threshold shift in dB HL pre- and post-exercise training for experimental group *(A)* that exercised (*$p < .05$) and control group *(B)*.

strength was combined with high cardiovascular fitness, then hearing sensitivity was better.

EFFECTS OF EXERCISE TRAINING ON HEARING ABILITY

Although cardiovascular responses to exercise in combination with noise do not appear to influence the level of hearing sensitivity,[23–25] findings indicate that chronic cardiovascular adaptations to physical training might attenuate the level of hearing loss from noise exposure, thus preserving hearing sensitivity.[29] By comparing hearing ability among low and moderately fit people before and after the completion of an eight-week aerobic exercise training program, Cristell et al.[25] found that an increase in cardiovascular fitness (15–25% increase in VO_2 peak) resulted in less susceptibility to TTS at all frequencies (Figure 4) and an improvement in baseline hearing levels at some frequencies (Figure 5). This increase in VO_2 peak was similar to the increase reported by Ismail et al.[20] Although results suggest that exercise training may be used as a preservative measure against loss in hearing sensitivity the increased in VO_2 peak must achieve at least a level of fitness considered to be moderate. In our laboratory, low fit individuals who improved their VO_2 peak, but still did not attain a level of fitness that met or

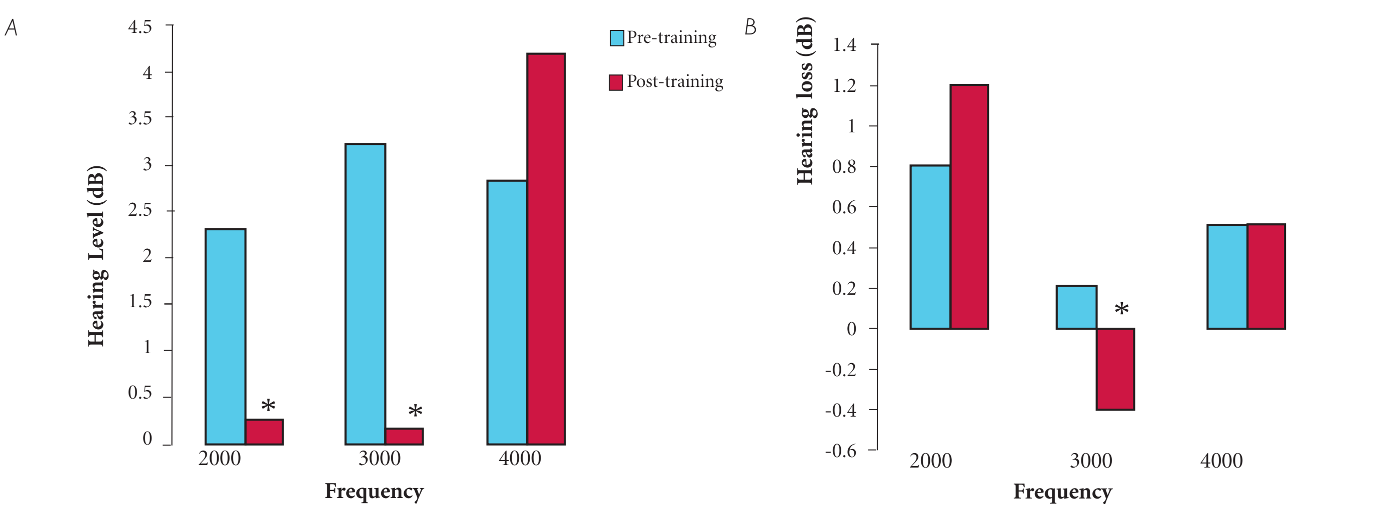


Figure 5. Pure tone thresholds in dB HL pre- and post-exercise training for experimental group *(A)* that exercised (*$p < .05$) and *(B)* control group.

exceeded moderate fitness level for their age group, did not demonstrate improved hearing sensitivity.

CROSS-SECTION STUDY OF CARDIOVASCULAR HEALTH ON HEARING SENSITIVITY

As demonstrated throughout this review, while declining PTTs is considered a normal age-related change, other factors, such as cardiovascular health, can play a role in the rate and intensity of these changes and may even conserve hearing at some frequencies. Hutchinson and Alessio et al.[27]confirmed these findings in two studies, the first of which examined the results of baseline PTTs and VO_2 peak determination using a maximal or submaximal graded exercise test on a Monark bicycle ergometer. Heart rate and blood pressure were also taken during testing. At 2000 Hz, 3000 Hz, and 4000 Hz, pure-tone hearing was positively influenced by cardiovascular fitness. The variable, Decade* VO_2 peak, which relates to the effect of one's age and health on overall hearing, was statistically significant ($p<.01$), suggesting a difference in hearing for differing levels of VO_2 peak in relation to age. Data suggests that age 50 is the separation point, after which fitness level and age are related in a statistically significant way, with high fitness being positively related to better hearing sensitivity (Table 2). Across the age groups, people with low cardiovascular health exhibited the worst hearing thresholds.[12]

In a similar study, PTTs and distortion product otoacoustic emissions (DPOAE) measures were evaluated in a representative sample of over 100 participants.[28] DPOAE testing was performed in this study in addition to pure-tone threshold testing, as it allowed the researchers to obtain information regarding cochlear function and integrity. Similar to the previous study, VO_2 peak was used to determine the level of cardiovascular fitness; heart rate response, blood pressure, and respiratory gases were monitored throughout the test. After data collection, participants were split into four age categories containing 22 to 26 participants for analytic purposes (youth, 10 to 19 years; young, 20 to 27 years; middle, 28 to 48 years; older, 49 to 78 years). Multivariate analysis using the fitness level as a factor (i.e., VO_2 peak), and PTTs as dependent variables indicated significantly better thresholds for the high versus low fit participants at 1000 Hz. Although PTTs worsened in persons in all cardiovascular fitness categories with age, multivariate ANOVA performed using both age and fitness level as factors showed that those with low cardiovascular fitness in the old age group had significantly worse pure-tone hearing at 2000 and 4000 Hz.[28] The PTTs of the old high fit group were consistently better than the mean thresholds of the low fitness levels in the same age group. These results confirm previous studies by Hutchinson and Alessio (1998, 2000, 2005, and 2010) demonstrating the positive benefits of cardiovascular health on hearing sensitivity among adults. Furthermore, these results are particularly strong among aging populations; cardiovascular fitness seemingly acts as a mechanism of preservation for hearing sensitivity.

Table 2. Pure tone hearing levels in dB HL by decade age groups, fitness level and frequency

Age	2000 Hz			3000 Hz			4000 Hz		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
Teens	3.5	3.4	4.0	3.0	4.1	.25	2.0	2.2	.75
20s	2.0	3.2	1.8	8.3	4.5	3.7	6.6	4.8	2.3
30s	4.0	4.4	0.0	1.0	2.1	6.5	10.6	3.7	12.0
40s	7.7	7.1	4.8	5.5	8.5	5.2	6.0	11.7	6.8
50s	9.7	4.8	2.7	9.2	8.0	8.5	13.5	11.3	13.0
60s–80s	20.0	16.4	12.2	29.2	17.7	17.2	34.5	21.2	14.2

HEARING LOSS AND DIABETES

Given the microvascular abnormalities that underlie cardiovascular health and disease, it is reasonable to postulate that similar mechanisms associated with diabetes, particularly type 2 diabetes, may be associated with hearing loss. Type 2 diabetes is the most common form of diabetes. In type 2 diabetes, the cells do not recognize insulin and since insulin's main role is to facilitate the transfer of glucose from blood into cells, diabetics are at risk of being deprived of glucose that can be used by cells for energy. If this happens, glucose builds up in the blood instead of going into cells, and this leads to a number of diabetic complications including hypertension, heart attacks, and kidney failure. Whether or not the microvascular changes that occur in diabetics may be associated with microvascular changes that influence hearing loss, has been examined in several large scale studies. In a five-year population-based survey in Australia, age-related hearing loss was present in 50% of diabetic participants (n = 210) compared with 38.2% of non-diabetic participants (n = 1,648) after adjusting for multiple risk factors.[30] A large scale cross-sectional study was used to examine the secular change of the prevalence of hearing impairment over three decades in US adults with and without diabetes. After adjustment for age, sex, race, and education, the prevalence of hearing impairment in the National Health and Nutrition

Examination Surveys (NHANES) 1 (1971–1973) and 2 (1999–2004), respectively, was 24.4% and 22.3% for adults without diabetes compared with 28.5% and 34.4% for adults with diabetes. The results indicated that persons with diabetes have a higher prevalence of hearing impairment than persons without diabetes.[31]

The link between diabetes and hearing loss was investigated further in order to determine possible causal factors. In the National Health and Nutrition Examination Survey (NHANES) study, 1,508 participants, aged 40–69 years, who completed audiometric testing during 1999–2004 were studied to determine whether controlling for vascular or neuropathic conditions, cardiovascular risk factors, glycemia, or inflammation influenced the association between diabetes and hearing sensitivity. Bainbridge et al (2010) concluded that mechanisms related to neuropathic or microvascular factors, inflammation, or hyperglycemia mediate the association of diabetes and hearing impairment.[32]

CONCLUSION

This review has described the chronological progression of research on major factors, other than age, that influence hearing sensitivity. The incidence of hearing loss may increase with age in many parts of the world; however, presbycusis does not occur in all persons at one particular age point. When exposed to noise, temporary hearing loss typically occurs regardless of age; yet factors other than age significantly influence one's hearing sensitivity. Compared to lower fit individuals, TTS recovery is much quicker in moderate and high fit individuals. Cardiovascular fitness is directly associated with hearing sensitivity while muscular fitness is not, however, the combination of high muscle strength and high cardiovascular fitness was associated with the most sensitive hearing. When cardiovascular fitness is improved in lower fit adults, hearing sensitivity also improves, yet the improvement has to reach a level of fitness considered as moderate or higher. When exercising to music, any temporary hearing loss that may occur is due to the level of noise and is not exacerbated by the exercise. After age 50, individuals with high cardiovascular fitness experienced significantly better hearing sensitivity than low fit individuals, who demonstrated a typical age-associated decline in hearing. Evidence suggests that a personality type affiliated with coronary prone behaviour is associated with compromised hearing. Twenty-five years of research supports the importance of health and lifestyle in maintaining hearing sensitivity over the life span.

ACKNOWLEDGEMENTS

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CONFLICTS

None declared.

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Helmholtz Resonators: They Are Everywhere!

By Scott Lake, Westone Laboratories

About the Author

Scott Lake is employed by Westone Laboratories, Inc. as an engineer. He was previously employed for 20+ years in the automotive industry as an acoustics engineer, where he concentrated on full-vehicle, sub-system, and component sound quality. He is also a hobbyist composer, guitarist, and keyboardist. He can be reached at Westone Laboratories by e-mail at: scottl@westone.com.

It is a beautiful warm day, and you are driving down the road. The nice weather stirs your desire for some fresh air, and you move to roll down the window down. Rather than rolling down your driver side front window, you inadvertently roll down a rear window. Your ears and chest are assaulted by that annoying and familiar "whup, whup, whup," and instantly, you correct your mistake. What you have just experienced is the sensation of being inside of a Helmholtz resonator. It's the same kind of resonance you studied in school – just on a grander scale geometrically.

This article will introduce you to some basic examples of Helmholtz resonance in areas of life other than audiology, yet deal with the same equations and the same physics. In my past career in the automotive industry, I worked on vehicle acoustics and sound quality, specializing in those topics during my graduate degree studies. It is encouraging to me that the same physics equations and characteristics apply to the acoustics of the ear as well.

I happened across Marshall Chasin's article, "What Your Mother Never Taught You about Earmold Acoustic Formulae," in *Hearing Review*. As I read the first formula in the article for Helmholtz resonance as it pertains to venting a hearing aid, I realized that this formula was relatively unchanged from the formulas I studied in my past career as an acoustician in the automotive industry. A Helmholtz resonance basically boils down to an acoustic analogy of what happens when you put a mass on a spring, hold onto the spring, then pull down on the mass and let it go. It oscillates at a specific frequency.

You might be saying to yourself: "But, there's no mass involved with air. And, where's the spring?" Both mystery objects are alive and well in Helmholtz resonators, even though they are not visible to the naked eye.

HELMHOLTZ RESONATORS

Perhaps the most familiar Helmholtz resonator with which nearly everyone has interacted is a partially full or empty soda bottle. Who hasn't delighted in blowing across the top of an empty soda bottle to hear what kind of tone results? If you are like me, you've annoyed friends and family alike with this simple joy. Let's analyze the soda bottle in relation to its critical Helmholtz resonator elements. Critical elements are shown in Figure 1.

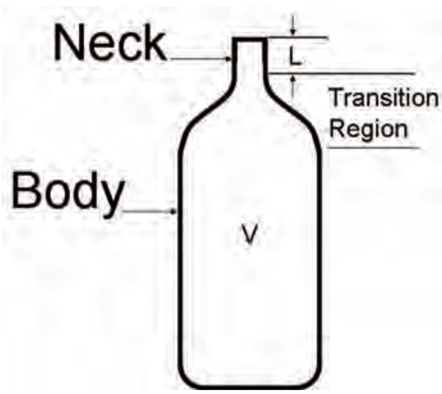

Figure 1. Soda bottle cross-section

There are three critical elements of any simple mechanical resonating system: a mass, a spring, and something to set the mass into motion.

In the case of the soda bottle, the mass is the air contained in the neck of the bottle and the spring is the air trapped inside the rest of the bottle. More specifically, the spring is the mechanical property of what is called the "bulk modulus" of the air in the bottle. The force that sets the air in the bottle's neck into motion is the vacuum created by blowing across the top of the bottle. (Remember the Bernoulli principle from speech acoustics?) The action of blowing makes the air in the neck want to escape, but the elasticity of the air in the rest of the bottle basically says to the air in the neck, "Get back here! You'll have to come back inside!" Then it pulls on that mass of air in the bottle neck back toward the bottle's interior. Once the air in the neck goes past its initial starting position before the blowing started, it begins pushing against the spring property of the trapped air and starts to get forced back the other way – towards the exit – where the process repeats itself. It oscillates. As a result, the oscillating mass disturbs the exterior air near the top of the bottle at the oscillating frequency and that pleasant sounding tone is heard as those disturbances travel acoustically to your ear.

As is the case in most areas of audiology, equations accompany this behaviour to calculate the natural frequency of a basic Helmholtz resonator:

frequency = (v/2pi)*(A/V*L)^0.5

where:
v = the speed of sound in air
A = cross sectional area of the interior of the neck of the bottle
V = the volume of the air in the main part of the bottle
L = Length of the neck of the bottle

This formula will calculate the frequency in Hz, with which we are all familiar. Right off the bat (or in Canadian, right off the hockey stick), it can be seen that the empty soda bottle (large volume) has a lower Helmholtz resonant frequency than a fuller bottle (smaller volume). This agrees nicely with our intuition.

My opinion is that it's always better to undergo a bit of experimentation than to simply trust equations. Locate an empty soda bottle – I suggest a one liter bottle (or litre – sorry, I forgot for a moment this is a Canadian publication!), because it's rather easy to imagine where the neck is versus the large volume of the bottle. Some readers may be disappointed to read that it is harder to discern where the dividing line is between neck and larger volume on beer and wine bottles.

I personally am using an empty 1L sparkling water bottle for my calculations. This bottle isn't a perfect example; it has the funny shaped bottom like a 2L bottle, and there's a 5 cm length of bottle where the transition occurs from the neck portion to the body of the bottle. After taking some rough measurements of the neck and body of the bottle, I have recorded the following data:

- The diameter of the neck is 2.2 cm
- The length of the neck is 3.2 cm
- The height of the body section of the bottle up to the transition portion is roughly 18 cm
- The circumference of the bottle is approximately 26 cm.

Our equation asked us for the neck area, which calculates to be about 3.9×10^{-4} m^2. The equation also needs the volume of the bottle, which I calculate to be 1.1×10^{-3} m^3. The length of the neck was already measured, but converted to meters, it is .032 m. Using this data, the equation indicates that my 1L bottle should have an empty resonance of about 187 Hz.

Using spectral analysis software (Audacity or Adobe Audition have this capability), I recorded the tone and measured the frequency as 138 Hz. So, where did the error occur? There are several places where error was perhaps introduced. First, I used 340 m/s for the speed of sound in air. Here in Colorado Springs, where I made my recording, the elevation is 2,073 meters. This has an effect on the air density and ultimately affects the speed of sound in the air. Using a calculator I found on a NASA website, at 2,073 m elevation, the speed of sound approximates 332 m/s rather than 340. So there's one overestimation. But, it hardly accounts for the large error.

What else could have gone wrong? There are several remaining factors. First, my measurements of everything besides the cross-sectional area of the neck were crude. I could have overestimated the volume of the body of the bottle, and my length calculation for the neck of the bottle could be off as well. As it turns out, both of these measurements are probably culprits. What was not shown in the basic Helmholtz equation were "fudge factors" that are used for what we acousticians call "end effects."

End effects account for the difficulty that the "mass" of air in the neck has moving back and forth. The air inside and outside of the bottle is actually part of a continuum of air. Some of that air is moving in concert, but other air in the vicinity does not really want to move. There is therefore an amount of surface tension between the air and the inside and outside of the bottle. Because this air is perfectly happy sitting right next to the bottle neck on the outside, and on the inside, it pulls on the air in the neck when that air "slug" wants to move. Another way to think about it is that the slug of air seems heavier than it actually is. Newton's first law is force = mass × acceleration. The additional force of the air nearby the neck pulling on the air in the neck makes the mass appear heavier than it is.

To account for this additional force, we can turn to the Helmholtz resonator and look at both ends of the neck to see what the surrounding environment looks like. Figure 2 shows a generic Helmholtz resonator and two generalized end conditions. An open-ended condition is called "unbaffled," but if the neck terminates in a wall or similar surface, it is called "baffled." This is similar to the "open" and "closed" conditions with ¼ and ½ wavelength resonators. Both hearing aids and the vocal tract have wavelength and Helmholtz resonators.

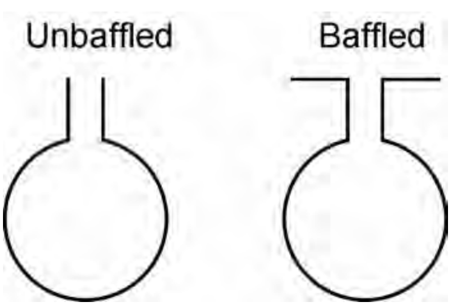

Figure 2. Helmholtz resonator end conditions.

Let's now take a look at what an open bottle looks like on both ends of the neck. The top of the bottle opens into space – what we would call an "unbaffled" end condition. The air moving in and out of the neck also has to convince the air that's immediately near the neck of the bottle on the outside to bend and move. That air, however, doesn't want to go anywhere. So, there's a fairly large resistance to the air moving. This can be generalized to add effective length to the neck by a factor of 0.85 × the radius of the neck. On the inside of the bottle, there's a smoother transition; represented more by a baffled condition. There is still resistance to move, but the generalized effective length addition in the baffled condition is 0.6 × radius of the neck. For this bottle, we need to add these two corrections to the length. Where we first had a length of 0.032 m, we can add 1.45 × radius of the neck. In our case, the effective length of the neck is now 0.048 m, rather than the original 0.032 m. We thus added 50% extra length to the neck. If we plug that corrected length into our equation above, we get a resonant frequency of the bottle at around 146 Hz, which is much closer to the measured value of 136 Hz. We likely underestimated the volume of the bottle as well, which would slightly overestimate the resonant frequency. This is actually quite similar to how the eardrum (which is quite compliant) adds several mm of acoustic length to the ear canal. In other words, the acoustic or effective length of the ear canal is about 31 or 32 mm, even though its physical length is only about 28 mm.

HELMHOLTZ RESONATORS AND OUR NOISY CAR

Now that you have an understanding of the resonator in thinking about a soda bottle, the same thing is happening as you drive along in a car with an open rear window. The frequency in this case is down in the sub-sonic range, perhaps 10 Hz at most. The "whup, whup, whup" sound is audible because what you really hear is the shearing of the air back and forth in the open window frame. This phenomena can also occur with some sunroofs when fully opened. Another potential reason for hearing the individual events (though unconfirmed) results from your hearing system's natural compression function of the muscle on the oval window with the large pressure excursions happening in the cabin of the car.

Why does this effect only happen with these particular vehicle openings and not the front windows? This relates to the forcing function involved. With the open sunroof or open rear window conditions, the leading edge of the open space is perpendicular to the direction of airflow. It's thus very easy for an air vortex to form along that leading edge. The vortex causes a local pressure drop, which the air in the open window frame moves to fill. But then the bulk modulus of the air in the cabin (that's the "spring" effect of the air in the car) says, "Get back in here!" and pulls that mass of air back toward the interior. Of course, that air can only go so far before it's pushing on that very same trapped air. Just like the mass on the spring, it oscillates back and forth. All the while, vortices of air are making sure that the whole thing keeps going and going. With the front windows, the leading edge is not perpendicular, and the vortex that provides the tweaking of the mass on the spring cannot be formed easily. Thus, the vortex is not perpendicular to the airflow, which breaks up the vortex.

Besides rolling up that rear window up or closing the sunroof, what can possibly be done to reduce the irritating noise? We can use the mass and spring analogy to provide some guidance. If you take the end of the spring that's attached to the ground and remove it from the ground, the spring becomes incapable of pushing or pulling on the mass that is attached to it. In the vehicle, how could we remove the air "spring" connection to the ground? A simple resolution is to just slightly open a front window, causing the trapped air inside the body of the vehicle to no longer be trapped. Depending on the strength of the resonance, it may take only a small 2 cm opening, but perhaps a bit more. You can also change the speed of the vehicle – by slowing down. But don't slow down too much or people will start looking for retirement community stickers on your vehicle's window or bumper!

With sunroofs, most that are factory installed employ some kind of spring loaded air deflector that pops up when the sunroof is opened, which forces the vortex shedding to re-attach to the main part of the vehicle behind the open sunroof location. This prevents the vortex from actually setting the resonance into motion. In this case, you can sometimes cause the "whup, whup, whup" to occur by simply pulling down on that air deflector at cruising speeds of perhaps 40–60 km/h.

WHEN HELMHOLTZ RESONATORS ARE USED TO REMOVE SOUND OUTPUT

Keeping with the automotive terminology, we are going to "shift gears" here and talk about some practical applications of Helmholtz resonators where they are used to remove or cancel irritating sounds.

EXHAUST SYSTEM MUFFLER

A relatively familiar example of how a Helmholz resonator can be used to remove sound are some of the chambers in an exhaust system muffler. These chambers are specifically designed to function as Helmholtz resonators effectively cancelling particular strong frequencies in the exhaust system. Below is a cross-sectional diagram of a "tri-flow" muffler, which has an end of the muffler dedicated specifically to a Helmholtz resonance (Figure 3).

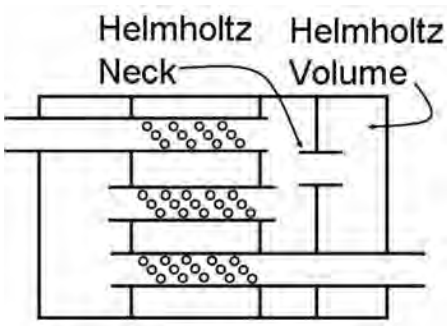

Figure 3. Cross-sectional diagram of a "tri-flow" muffler.

In this case, the presence of the Helmholtz resonator provides an impedance mismatch to the exhaust sound waves at the tuned frequency of the resonator. At that frequency, the sound waves are reflected back toward the engine, rather than passing through the muffler and out the tailpipe.

Intake System Tuner

On the intake of the vehicle, there is also usually some kind of a "muffler" system, but it is not referred to in that way, and these days it's usually made from plastic. At large throttle openings, a considerable amount of the sound heard emanating from a vehicle is actually radiating out of the intake system – a sort of "out through the in door" situation. Besides providing air filtration, the intake system often has a Helmholtz resonator in a branch configuration off of the main air duct. This helps prevent sound of a certain frequency from passing out of the front of the vehicle.

Architectural Acoustics

Yet another area where Helmholtz resonance comes into play is with the design of some cinder blocks. The typical cinder block we've all seen and employed for various non-construction purposes has two chambers that are not visible in a finished wall. These cavities, however, can be used as the body of a Helmholtz resonator if given an opening to the room where sound needs to be controlled. This type of design has been in place for many years; for example, perhaps you have seen it employed in some school gymnasium or cafeteria walls where you see open vertical "slots" in the cinder-block wall. More recently, the Proudfoot Company has employed several interesting acoustic design principles into the humble cinder block. Their blocks feature Helmholtz resonance for low-frequency control in a room, angled surfaces on the exterior of the block to serve a diffraction function, and absorbent material inside the block's cavity to provide some damping of the resonance peak and to provide some high frequency sound absorption. Below is a photo of the Soundcell cinder block product from the Proudfoot Company laying on its side (Figure 4).

The port for the resonator in this case is the slot, which is easiest to see in the upper left corner of the block. The blocks have to be laid in a specific pattern so that this slot is not obstructed. The fibrous absorptive material can provide both a damping of the Helmholtz resonance frequency response; thus broadening the resonance across a wider frequency range and directly absorb higher

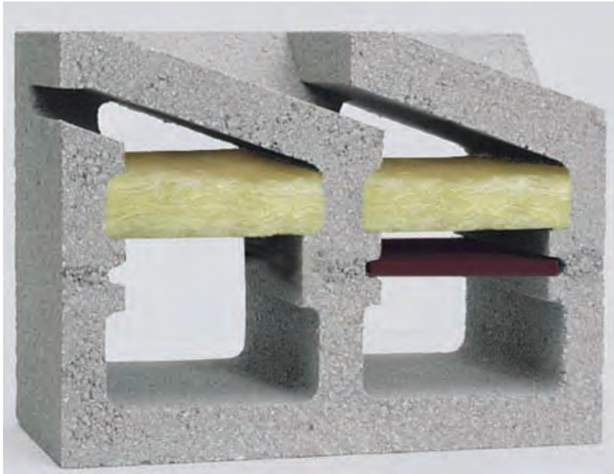

Figure 4. Soundcell cinder block product from the Proudfoot Company laying on its side. Image courtesy of the Proudfoot Company (http://theproudfootcompany.com/)

frequency sound. The angled surfaces formed by the slot/neck provide an acoustically diffracting surface for higher frequency waves.

WHEN HELMHOLTZ RESONATORS ARE USED TO ENHANCE SOUND OUTPUT

Now that we've covered some territory where Helmholtz resonators are used to reduce irritating frequencies, we'll shift gears again and discuss when Helmholtz resonators are used to enhance acoustic output. Aside from hearing aid acoustic tuning, we find these examples mostly in the musical instrument world.

Acoustic Stringed Instruments

Any acoustic stringed instrument that has a body and a port to the exterior of the instrument has Helmholtz resonance as part of its acoustic signature. Instruments that likely come to mind immediately are acoustic guitars, orchestral stringed instruments (those f-holes on the top of the instruments constitute for the port), mandolins, bouzoukis, certain lutes and zithers, autoharps, etc. Note that banjos did not make the list. (This is nothing against banjos; they just don't have the Helmholtz "cool" factor.) Banjos use a drum-head as the primary resonating device, whereas these other instruments use both resonating body panels and the Helmholtz resonator to radiate sound. Of course, these instruments, like our vocal chords also have ½ wavelength resonators (strings held tightly at both ends), which results in integer multiple harmonics of the fundamental frequency. For our purposes, we'll look specifically at acoustic guitars and orchestral stringed instruments.

Acoustic Guitar

Of the list of stringed instruments using Helmholtz resonance, it's probably safe to say that the flattop acoustic guitar is the most well-known. Even if you aren't currently a guitar player, you have probably tried strumming an acoustic guitar at some point in your life. If you've looked into the hole of an acoustic guitar, you know that the "neck" doesn't really seem to exist – it's just a hole in the thin top of the guitar. Recall that the end correction factors introduced some additional length and that they were related to the radius of the neck. In this case, the radius of the "neck" is many times larger than the length of the neck. The end correction factors thus dominate the actual length of the neck. The end conditions can be considered to be a baffled condition on both ends of the neck. The frequency at which this Helmholtz resonator radiates sound dominates the low frequency character of the sound of acoustic guitars. Several different body styles of acoustic guitars and different sizes of port holes account for some of the different sounds of different types of guitars, including other factors such as the choice of wood, strings, and myriad other factors that acoustic guitar aficionados will debate ad infinitum. Indeed, the acoustic guitar does not have a dominant frequency because the actual thin layered top, and to some extent the back and sides of the guitar, also have specific vibration modes that radiate sound and higher acoustic cavity modes that contribute to the frequency signature. There's an excellent scholarly treatment of this topic in Chapter 9 of *The Physics of Musical Instruments* by Fletcher and Rossing. In the immediate vicinity of the soundhole, the radiated sound is dominated by the Helmholtz resonance frequency. This is the reason it's generally recommended to avoid placing a microphone directly in front of the soundhole when amplifying or recording acoustic guitar. Acoustic guitar design and construction technology changes rather slowly because tradition tends to dominate designs. Some relatively recent trends, however, promise to keep the debates alive and well for many years to come. Some of these recent trends involve changing the shape of the soundhole to move it away from the traditionally recognized central location. Tacoma Guitar Company, for example, has made this design a feature of most of their acoustic guitars and mandolins. (www.tacomaguitars.com/products). Another trend seen for some years in boutique acoustic guitar manufacturers is to put an additional, yet typically smaller hole in the side of the guitar. Some guitar builders that have adopted this trend are McKnight Guitars (http://www.mcknightguitars.com/soundports.html) and Charles Fox Guitars

Figure 5. Acoustic guitar with the O-Port superimposed. Image courtesy of Dare Music Group.

(http://www.charlesfoxguitars.com/intro_design.html).

O-Port Modification

A new product on the market that specifically aims to change the Helmholtz resonance of an acoustic guitar is the O-Port from Dare Music Group (http://www.dmg-austin.com). Whereas the typical acoustic guitar has a relatively shallow hole "neck," the O-Port aims to increase the length and end conditions of the acoustic guitar neck directly. Below is a photo of the side of an acoustic guitar with the O-Port superimposed as if the side of the guitar was translucent and one could view the O-Port internally mounted in the port of the guitar.

With the O-Port, the flared design of the port reminds one of similar efforts in bass-reflex speaker design. Bass reflex is the phenomenon where a trapped mass of air (sometimes referred to as an inertance) oscillates as a single unit and creates a Helmholtz resonance. The vent associated resonance in hearing aids is an example of a bass reflex system.

Orchestral Stringed Instruments

The other well-known family of stringed instruments employing Helmholtz resonance includes the violin, viola, cello, and contrabass. With these instruments, the ports are commonly known as "f-holes," due to their shape resembling a lower-case letter "f." These holes have been shown in scholarly articles to provide more than just the port for Helmholtz resonance, because they also significantly change the stiffness of the top of the instrument. Whereas acoustic guitars with wood tops use a bracing pattern to provide the necessary stiffness to withstand the tension of the strings, the stiffness of the top of a violin is provided by the curvature of the top itself. This is also true for archtop acoustic guitars (which also employ f-hole type ports). So the placement, size, and shape of the f-holes affect more than just the Helmholtz resonance of the instrument. Nevertheless, efforts to control the thickness of the top at the f-hole locations, the size and shape of the f-hole, and the smoothness of the f-hole's edges are all design factors that the luthier takes into consideration in designing these instruments.

Cajon (percussion instrument)

Constructing the cajon is fairly simple. Cajon is a Spanish word for "box," and the instrument is basically a box with a few cool design elements that allow it to have several different "voices." Pertinent to our discussion is the side port that many cajons use to provide a Helmholtz resonance. This allows the box to resonate with a low and rich tone when the player wants a bass or kick drum type sound. Other design factors include a loose side to "slap" or strings mounted on the interior of the cajon to provide a more "snare" like sound. LP Percussion has a new take on the cajon side port, with a sliding cover for the port hole, which allows an adjustable Helmholtz resonance frequency. This sliding port cover is available on their Kevin Ricard model. This instrument can be seen at http://www.lpmusic.com/Product_Showcase/Whats_New/kevin-ricard-cajon.html.

Djembe (percussion instrument)

The djembe uses Helmholtz resonance in yet another unique way. Djembe construction is somewhat typical of drums in general, but where this design varies from a drum-kit drum, is that the

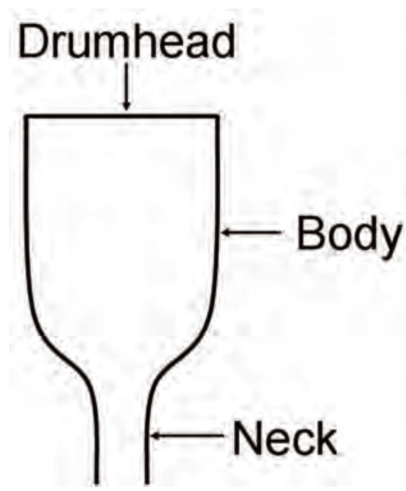

Figure 6. A cross sectional diagram of a djembe showing the trapped volume, the drumhead, and the port/neck.

body of the djembe that narrows down to a neck section. Below is a cross sectional diagram of a djembe showing the trapped volume, the drumhead, and the port/neck (Figure 6).

Some djembe players will take advantage of the dual-tone (open port versus closed) capability of the djembe by holding the drum between their knees and lifting the drum, though most keep the drum up off of the floor at all times to take advantage of the resonance.

SUMMARY

I hope you have enjoyed this romp through the garden of Helmholtz resonance and can spot other instances of this most useful acoustic tuning device in your day-to-day life. We've covered the basic physics of how these resonators work, and how they are employed to both reduce irritating sound, and enhance desirable sound in automotive, architectural and musical acoustics. Hopefully the next time you tune a vent in a hearing aid earpiece, you'll remember your unique connection to other acousticians applying the same principle across very different industries.

CONFLICTS

None declared.

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Noise and Chemicals: Workers Are Losing Their Hearing

A study carried out by Spanish researchers has shown that the presence of chemical contaminants can interact with noise and modify, for good or for bad, the way in which work-related "deafness" - which is increasingly common among young people - manifests itself. Noise-related hearing loss is the most common occupational disease in Europe.

http://www.physorg.com/news204902069.html

Reinventing the Road

Sound absorbing asphalt being used in repaving some California freeways highway noise by as much as 6 dB, compared to dense asphalt, according to a story in the July 20 issue of the *San Jose Mercury News*. The new asphalt, developed at the University of California’s Pavement Research Center, is applied in three layers, the top layer of which is open-graded asphalt with sound-absorbing air pockets. It is backed by a layer of rubberized asphalt to provide durability.

www.mercurynews.com