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Canadian Hearing Report

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Vol. 3 No 3

Revue canadienne d'audition

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Modelling of the Auditory System

Founders of Our Profession: Dr. Harry Levitt

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MESSAGE FROM THE EDITOR-IN-CHIEF

I am pleased to announce that *Canadian Hearing Report* (*CHR*) is welcoming a new editor-in-chief to succeed in the role I have proudly occupied for the past two years. Marshall Chasin, a well-known clinician, mentor and author will be bringing some new blood and fresh ideas to *CHR* and it is with great enthusiasm that I look forward to Marshall's contributions for years to come. Those who have studied at the University of Western Ontario are likely more familiar with Marshall's involvement in academics through his Seminars on Hearing, an annual event held for students, where some of the foremost authorities in audiology are flown in to London to inspire future audiologists. Those who have studied in other areas of the country may be more familiar with Marshall's articles or his book, *Musicians and the Prevention of Hearing Loss*. While his accomplishments are numerous, what I most admire are his dedication, integrity and down-to-earth personality. Welcome aboard Marshall!

While I will stay on the editorial board of *CHR*, it is with some reluctance that I have resigned from my position as editor-in-chief. Embarking on new clinical and humanitarian ventures, while keeping busy with teaching and research, have inadvertently left me with little time to lead the important project that has become *CHR*. Nevertheless I look back at the two last years of development of our journal with much satisfaction and pride. After years of publishing the now retired CAA newsletter, the CAA now produces a comprehensive media which includes scientific articles, industry and professional news, as well as a variety of advertisement packages. The editorial board is also at work ensuring the evolution of the publication so that it is a useful and efficient tool to a growing number of readers both in Canada and abroad. And while *CHR* may be destined for great things internationally, we also want to ensure that the publication remains true to its mandate of promoting our profession and our academy.

I would like to thank the board of directors for their dedication and support despite my often unrelenting demands for materials just prior to deadlines. I would like to give special thanks to Glen Sutherland who was instrumental in writing columns and developing some of the styles and sections of *CHR*. I would also like to thank the management and staff of Andrew John Publishing Inc. for their patience. I am certain that it was often not an easy task to work with an editor-in-chief who was also on the executive of CAA and who needed to make demands to develop a journal to meet the strategic plans of an academy. Furthermore, I would also like to thank the boards of directors of the past two years for providing me with the opportunity to develop this rewarding project. And finally, I would like to thank all the readers of the *Canadian Hearing Report* and for the constructive comments I have received from you over the years. It is my sincere hope that you will continue to send your letters and contributions to help build the publication into an interactive vehicle for the exchange of knowledge and thought.

Thank you sincerely for this wonderful experience.

André Marcoux, PhD

MESSAGE DU L'ÉDITEUR EN CHEF

Il me fait plaisir d'annoncer que la Revue canadienne d'audition (RCA) accueille un nouvel éditeur en chef pour me succéder dans le rôle que j'ai fièrement occupé au cours des deux dernières années. M. Marshall Chasin, un clinicien de renom, mentor et auteur, apportera du sang neuf et des idées nouvelles à la RCA, et c'est avec beaucoup d'enthousiasme et d'impatience que j'attends la contribution de Marshall pour les années à venir. Ceux qui ont étudié à l'Université Western Ontario en connaissent probablement davantage sur la participation de Marshall dans le milieu académique, par le biais de ses séminaires sur l'audition, un événement annuel destiné aux étudiants et dans le cadre duquel quelques-unes des plus grandes sommités en audiologie se déplacent jusqu'à London pour inspirer de futurs audiologistes. Ceux qui ont étudié ailleurs au Canada peuvent être plus familiers avec les articles de Marshall ou son livre, *Musicians and the Prevention of Hearing Loss*. Bien que ses réalisations soient nombreuses, ce que j'admire le plus est son dévouement, son intégrité and sa personnalité terre-à-terre. Bievenue à bord Marshall!

Bien que je demeure membre du comité éditorial de la RCA, c'est un peu à contrecœur que je démissionne du poste d'éditeur en chef. Le fait de me lancer dans de nouvelles entreprises cliniques et humanitaires, tout en demeurant actif dans les domaines de l'enseignement et de la recherche, ne me laisse malheureusement peu de temps pour diriger un projet important comme l'est devenu la RCA. Néanmoins, je ressens de la satisfaction et de la fierté quand je pense aux deux dernières années de la revue. Après plusieurs années de publication du bulletin de l'ACA (maintenant défunt), l'ACA produit maintenant une publication générale qui comprend des articles scientifiques, des nouvelles de l'industrie et de la profession ainsi qu'une gamme variée d'annonces publicitaires. Le comité éditorial s'emploie aussi à assurer l'évolution de la publication de façon à ce qu'elle constitue un outil utile et efficace pour le nombre croissant de lecteurs à la fois au Canada et ailleurs dans le monde. De plus, bien que la RCA puisse être destinée à de grandes réalisations sur la scène internationale, nous voulons aussi nous assurer que la publication demeure fidèle à son mandat de promouvoir notre profession et notre académie.

J'aimerais remercier le comité de direction pour leur dévouement et leur appui malgré mes demandes souvent acharnées visant à obtenir du matériel juste avant une date limite. Je remercie particulièrement M. Glen Sutherland, qui a contribué à la rédaction de chroniques et au développement de certains modèles et sections de la RCA. J'aimerais aussi remercier la direction et l'équipe de Andrew John Publishing Inc. pour leur patience. Je suis convaincu qu'il n'a pas toujours été facile de travailler avec un éditeur en chef qui était un membre exécutif de l'ACA et qui devait aussi formuler des demandes afin de produire une revue permettant d'atteindre les objectifs stratégiques de l'académie. En outre, j'aimerais remercier le comité de direction des deux dernières années pour m'avoir offert l'occasion de faire progresser ce projet enrichissant. Finalement, je remercie tous les lecteurs de la Revue canadienne d'audition, notamment pour les commentaires constructifs que j'ai reçu de leur part au fil des ans. Je souhaite sincèrement que vous continuerez à transmettre du matériel et des commentaires pour contribuer à faire de la publication en un outil interactif pour l'échange de savoir et de réflexions.

Merci infiniment pour cette merveilleuse expérience.

André Marcoux, PhD

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Revue canadienne d'audition
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The business of running a national association from day to day is a daunting task. When that association is required to respond effectively to the issues that affect its members and to advocate on their behalf, it requires a fine balance of coordination, administration, and an understanding of the profession at hand.

The Canadian Academy of Audiology began 12 years ago in response to a demand for educational events and an advocating body that could serve audiologists. As has been said many times, the CAA is "by audiologists, for audiologists," and this is a very literal descriptor. It is one thing to form such an association and another thing entirely to ensure that the administrative aspects are in place to support a board of directors whose responsibility is to fulfill the needs of the members.

In the early years, the focus of the CAA was on the development of a world-class conference. In order to run a conference, venues must be arranged as well as speakers, events, exhibits, and all the associated details. Suppliers must be contracted and paid, and the coordination of the entire event requires an experienced touch. In terms of the association itself, membership must be managed, dues collected, financial records kept, all in accordance with regulations and bylaws. As an association grows, so too does the administrative workload, in an exponential manner. Since the early days of the association, the CAA has contracted both conference management and administrative structure from a company experienced in providing these functions and supports for the board of directors.

Our current secretary, Monica Pozer, recently stated "I am only an audiologist." She was referring to our limited collective experience with legal aspects that impact our daily operations. A board of directors comprised entirely of professionals represented by the association can only work to the limits of their expertise. As audiologists, few of us are also chartered accountants, marketing specialists, financial advisors, or conference management professionals. We depend on external specialists to deal with the needs of the association and to advise the board on policy and direction. Since its inception, the Board of Directors of the Canadian Academy of Audiology has been very much a working board. We have developed marketing and membership recruitment strategies, we have responded to national, provincial, and regional issues that affect the profession as we have taken on tasks required to move the association forward. But, there must come a time in this process where a working board can no longer function effectively in terms of advocating on a national scale.

There has been significant change in the CAA over the past 12 years. Our membership has grown to represent the profession across Canada. The conference has expanded to a point where space demands limit our choice of venue. The issues that affect the profession of audiology have become numerous and increasingly complex. Regulation of the profession is changing with the inception of the Canadian Alliance of Regulators. The AuD degree will have a significant impact on audiologists

Diriger une association nationale au jour le jour est une tâche ardue. Quand cette association doit résoudre efficacement les problèmes auxquels ses membres font face et militer en leur faveur, elle doit veiller à assurer un bon équilibre entre la coordination et l'administration ainsi qu'à bien comprendre la profession.

L'Académie canadienne d'audiologie a vu le jour il y a 12 ans en réponse à une demande d'organisation d'évènements pédagogiques et de création d'un organisme de défense des intérêts des audiologistes. Comme cela a été dit à maintes reprises, l'ACA a été crée « par les audiologistes et pour les audiologistes », et ceci constitue une description très littérale. Créer une telle association est une chose, mais veiller à ce que les aspects administratifs soient en place pour appuyer un comité de direction responsable de la satisfaction des besoins des membres en est une toute autre.

Au cours des premières années, le centre d'intérêt de l'ACA était d'organiser une conférence d'ordre international. Pour tenir une conférence, il est nécessaire de prendre les dispositions nécessaires quant aux lieux de rencontre, aux conférenciers invités, aux évènements et expositions prévus et à tout autre détail connexe. Il faut retenir et payer les services de fournisseurs, et la coordination de l'évènement requiert de l'expérience. Sur le plan de l'association elle-même, il faut diriger les membres, percevoir les cotisations et tenir des rapports financiers tout en respectant les règlements applicables. Au fur et à mesure qu'une association croît, il en va de même de la charge administrative et ce, de façon exponentielle. Depuis ses tous débuts, l'ACA a confié la gestion des conférences et de la structure administrative à une entreprise qui a de l'expérience à l'égard de ces fonctions et du soutien du comité de direction.

Notre secrétaire actuelle, Mme Monica Pozer, a récemment déclaré : « Je ne suis qu'une audiologiste. » Elle faisait référence à notre expérience collective limitée en ce qui a trait aux facteurs juridiques qui ont une incidence sur nos activités quotidiennes. Un comité de direction composé entièrement de professionnels représentés par l'association peut travailler uniquement dans les limites de l'expertise de ses membres. En tant qu'audiologistes, très peu d'entre nous sont aussi des experts-comptables, des spécialistes en marketing, des conseillers financiers, ou des professionnels de l'organisation de conférences. Nous comptons sur des spécialistes externes pour combler les besoins de l'association et pour conseiller le comité quant aux politiques et à la direction. Depuis sa formation, le comité de direction de l'ACA a principalement été un conseil d'administration. Nous avons élaboré des stratégies de marketing et de recrutement de membres, nous avons résolu des problèmes nationaux, provinciaux et régionaux touchant la profession et nous avons pris les mesures nécessaires pour assurer la progression de l'association. Toutefois, il vient toujours un moment dans ce processus où un conseil d'administration n'est plus en mesure de défendre efficacement ses membres à l'échelle nationale.

Il y a eu des changements importants au sein de l'ACA au cours des douze dernières années. Notre effectif a augmenté afin de représenter la profession à la grandeur du Canada. La conférence a pris suffisamment d'ampleur pour que l'espace requis limite notre choix des lieux de rencontre. Les problèmes qui touchent la profession de l'audiologie sont maintenant nombreux et d'une complexité croissante. La réglementation de la profession est en train de changer avec la venue de l'Alliance canadienne des organismes de réglementation. Le doctorat clinique, l'Au.D. aura des répercussions importantes sur tous les audiologistes au pays.

nationwide. The increase of other hearing health care practitioners and their scope of practice and regulation are of concern to the CAA. These issues require an association "by audiologists, for audiologists" to take a leading advocacy role. In order to assume that role, the "working board of directors" needs to evolve into a board that can separate itself from daily operations and concentrate on action and responses to the issues at hand. Additionally, the "face" of the association needs to be someone from the profession who understands firsthand the issues facing audiologists and can act on behalf of the association regardless of the structure of the elected board. In other words, the Canadian Academy of Audiology has reached a point where some very fundamental changes to the administration of the association need to be made in order for further growth to ensue.

Of course, such fundamental changes are not made easily. And, as I mentioned earlier, "I am only an audiologist." Much of the past year has been consumed by discussion, meetings, and strategic planning regarding the necessary changes and how they should be implemented. In most aspects, the board of directors of the CAA were able to carefully evaluate the current issues and make changes to components of the operations. In some areas, our lack of experience made change difficult, resulting in long days, evenings, weekends, and significant lack of sleep! In the end, however, I can say that the Canadian Academy of Audiology has made some huge and positive steps and the association is poised to enter a new era.

You, as a member will notice some changes over the next few months. The CAA is in the process of hiring a new executive director to represent the association. We will be launching a new web-based membership database and forum that will allow audiologists to register online for membership and for events as well as renew membership and communicate with other professionals across the country. We have streamlined our financial procedures and are looking toward better marketing practices. The conference planning and management is changing as well, looking to efficiently move to new and larger venues while continuing to provide the same excellence in delivering a top notch conference for members and colleagues from across the country.

As excited as your board is about the future, we cannot do the work of the association without the commitment of the membership. A call for nominations to the board of directors has been made. I urge you all to consider a position with the board, to bring your expertise and experience to work for the profession as a whole. The meaning of "I am only an audiologist" will now take on a new context! In fact, being "only an audiologist" is now the best thing that your board of directors can be.

William Campbell, MClSc, Audiologist
President

L'augmentation du nombre d'autres praticiens de la santé auditive, de même que leur champ de pratique et leur réglementation, préoccupent l'ACA. Ces questions font en sorte que l'association « par les audiologistes et pour les audiologistes » doit jouer un rôle de chef de file dans la défense des intérêts. Afin d'assumer ce rôle, le conseil d'administration des directeurs doit devenir un comité qui peut se dissocier des activités quotidiennes et se concentrer sur la gestion et la solution des problèmes rencontrés. De surcroît, la figure de proue de l'association doit être un membre de la profession qui a une expérience directe des problèmes auxquels les audiologistes font face et qui peut agir au nom de l'association sans tenir compte de la structure du comité élu. En d'autres mots, l'ACA a atteint un point où son administration doit faire l'objet de changements fondamentaux pour qu'elle puisse continuer à croître.

Bien entendu, de tels changements fondamentaux ne sont pas faciles à apporter. Comme je l'ai mentionné précédemment : « Je ne suis qu'un audiologiste. » Une bonne partie de la dernière année a été consacrée à des discussions, à des réunions et à la planification stratégique dans le contexte des changements nécessaires et de leur mise en oeuvre. Dans la plupart des cas, le comité de direction de l'ACA a pu évaluer soigneusement les enjeux actuels et apporter des changements à des composantes des activités. Dans certains domaines, notre manque d'expérience a rendu les changements difficiles et a donné lieu à de longues journées, soirées et fins de semaine de travail ainsi qu'à un grand manque de sommeil! En bout de ligne toutefois, je peux affirmer que l'ACA a fait des progrès énormes et qu'elle est prête à passer à une nouvelle ère.

En tant que membre, vous remarquerez quelques changements au cours des prochains mois. L'ACA est à la recherche d'un nouveau directeur exécutif pour assurer sa représentation. Nous lancerons bientôt une nouvelle base de données des membres et un forum sur le web qui permettront aux audiologistes de s'inscrire en ligne, soit pour devenir membre de l'association ou pour participer à des évènements, de renouveler leur inscription et de communiquer avec d'autres professionnels au pays. Nous avons simplifié nos procédures financières et nous tentons de mettre au point de meilleures pratiques de marketing. La planification et la gestion de la conférence évoluent également, et nous tentons de trouver de nouveaux lieux de réunion plus vastes tout en maintenant le niveau d'excellence de la conférence pour les membres et collègues partout au pays.

Quelque soit l'enthousiasme de votre comité de direction à l'égard de l'avenir, nous ne pouvons pas faire le travail de l'association sans l'engagement de ses membres. Un appel de candidatures pour le comité de direction a été lancé. Je vous exhorte tous à considérer un poste au sein du comité, de mettre à contribution votre expertise et votre expérience pour le bien de la profession dans son ensemble. L'expression « je suis seulement un audiologiste » prendra maintenant un tout nouveau sens! En effet, être « seulement un audiologiste » est maintenant la meilleure chose que les membres de votre comité de direction peuvent être.

William Campbell, M.Cl.Sc., Audiologiste
Président


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Publicity Ideas for National Audiology Week

October 20 to 26, 2008

Effective publicity for National Audiology Week events is essential in order to gain community awareness and participation. The following is a list of ideas that may be used to increase the reach and impact of important messages.

Media

- Appearing on local radio programs
- Appearing on local access television programs
- Getting the local television station to do a story on National Audiology Week
- Inviting media to shadow an audiologist for a day
- Publishing newspaper articles, Letter to the Editor, and advertisements
- Placing special inserts in local newspapers
- Running radio public service announcements
- Organize a television or radio interview with an adult in your community living with a hearing problem
- Set-up a call-in radio show with an audiologist to let the public "talk to the experts."

Partnering with Organizations

- Events cosponsored with organizations and companies to promote good hearing health, etc.
- Mall events, such as displays
- University events (schools of audiology), education and communication can help plan campus-wide events; students may be able to get university credit for volunteering to help with hearing health promotion activities; faculty may give generously of their time; (plan this early)
- Hold a career presentation at a local high school, college, or university to introduce our professions to students
- Display National Audiology Week posters on bulletin boards throughout your community – at work, local schools, shopping centres, community centres, or churches, etc.
- Offer an information session to members of the community who wish to find out more about audiology and hearing
- Provide National Audiology Week colouring/activity sheets to be put in your waiting room, doctors' offices, etc.
- Supply your local pharmacies/grocery stores with audiology and hearing literature and ask them to include it in the bag with each customer's purchase
- Hold an open house or health fair where co-workers, clients, community members, and the general public are invited to visit your facilities
- Offer hearing screenings and demonstrate equipment such as FM amplification systems, assistive listening devices, etc.
- Participation of local legislators; for example, health screenings of legislators at municipal, provincial, and federal levels
- Church bulletin inserts
- Create a speakers bureau consisting of audiologist (offer to give workshops to local businesses, schools)
- Display a National Audiology Week poster in the lobby of your hospital
- Do a presentation about audiology and hearing at the Chamber of Commerce Luncheon, social clubs, etc.

Other Ideas

- Restaurant table tents
- Banner
- Fridge magnets
- Luncheon and breakfast placemats
- Proclamation
- Create sticker or stamp announcing the National Audiology week to put on outgoing mail

National Audiology Week Promotional Materials May Be Distributed to:

Local businesses, Local malls, Local restaurants, Health clubs, Schools, Libraries, Local grocery stores, Laundromats, Movie theaters, Daycare, centers, Youth centers, Banks, Hair salons, Hospitals, Medical, optometrist, and dental offices, Senior citizen homes, Public health departments, and health organizations and clubs (Red Cross, Lions Clubs, etc.).


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Idées publicitaires pour la Semaine nationale de l'audiologie

20 au 26 octobre 2008

Pour sensibiliser la communauté et obtenir sa participation, il faut une publicité efficace des activités prévues au cours de la Semaine nationale de l'audiologie. La liste suivante comprend des options pouvant être utilisées pour augmenter la portée et l'impact des messages importants.

Médias

- Passer à la radio locale
- Passer à la télévision locale
- Demander à la chaîne de télévision locale de faire un reportage sur la Semaine nationale de l'audiologie
- Inviter les médias à observer le travail d'un audiologiste pendant une journée
- Faire paraître des articles dans les journaux, une lettre au rédacteur en chef et des annonces publicitaires
- Insérer des encarts spéciaux dans les journaux locaux
- Faire diffuser des messages d'intérêt public à la radio
- Organiser une entrevue à la télévision ou à la radio avec un adulte de votre communauté aux prises avec un problème auditif
- Organiser une émission de radio téléphonique avec un audiologiste pour que le public puisse parler aux « experts »

Partenariat avec des organismes

- Activités de promotion de la santé auditive, etc. coparrainées avec des organismes et entreprises
- Activités dans les centres commerciaux, telles expositions
- Activités dans les universités (écoles d'audiologie) – les services d'éducation et de communications peuvent aider à planifier des activités sur le campus; les étudiants peuvent obtenir des crédits universitaires en participant volontairement aux activités faisant la promotion de l'audition; les membres de la faculté peuvent donner généreusement de leur temps (commencer tôt la planification)
- Faire un exposé d'initiation aux carrières à une école secondaire, au collège ou à l'université de votre région pour faire connaître la profession aux élèves et étudiants
- Mettre des affiches de la Semaine nationale de l'audiologie sur les tableaux d'affichage dans votre communauté – au travail, dans les écoles, centres commerciaux, centres communautaires, églises, etc.
- Offrir une séance d'information aux membres de la communauté qui désirent en savoir davantage sur l'audiologie et l'audition
- Placer des feuilles à colorier et des feuilles d'activités sur la Semaine nationale de l'audiologie dans votre salle d'attente, les cabinets de médecin, etc.
- Donner de la documentation sur l'audiologie et l'audition aux pharmacies et épiceries de votre région et leur demander de la mettre dans le sac d'épicerie de chaque client
- Tenir une journée portes ouvertes ou une foire sur la santé et inviter vos collègues de travail, membres de la communauté et le grand public à visiter vos installations, etc.
- Organiser une activité de dépistage auditif et faire une démonstration de l'équipement comme système de diffusion MF, dispositifs techniques pour malentendants, etc.
- Faire appel à la participation des élus municipaux, provinciaux et fédéraux, en leur faisant subir un dépistage auditif par exemple
- Mettre des encarts dans les bulletins paroissiaux
- Créer un service de conférenciers formé d'audiologistes (offrir de donner des ateliers aux entreprises, écoles locales)
- Mettre une affiche de la Semaine nationale de l'audiologie dans le hall d'entrée de votre hôpital
- Faire un exposé sur l'audiologie à un dîner de la chambre de commerce locale, aux clubs sociaux, etc.

Autres idées

- Cartes-chevalets dans les restaurants
- Bannière
- Aimants de réfrigérateur
- Napperons pour dîner et déjeuner
- Proclamation
- Création d'auto-collants ou d'un timbre annonçant la Semaine nationale de l'audiologie pour le courrier à expédier

Le matériel promotionnel de la Semaine nationale de l'audiologie peut être distribué comme suit :

Entreprises locales, Centres commerciaux locaux, Restaurants locaux, Clubs de santé, Écoles, Bibliothèques, Épiceries locales, Buanderies, Cinémas, Garderies, Centres de jeunes, Banques, Salon de coiffure, Hôpitaux, Cabinets de médecin, d'optométriste et de dentiste, Foyers pour personnes âgées, Services de santé publique, Organismes de santé et clubs sociaux (Croix-Rouge, clubs des Lions, etc.)

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Take the first step

Dr. Harry Levitt

In conversation with Marshall Chasin

Dr. Harry Levitt is a distinguished professor emeritus at the City University of New York and among many other awards, is the recipient of the 2006 Jerger Career Award for Research in Audiology from the American Academy of Audiology, and the 2001 Lifetime Achievement Award through the American Auditory Society. Dr. Levitt is well known for his work on adaptive methods in psychoacoustics (*JASA*, 1971) as well as for his engineering and basic research into the development of digital hearing aids. He is a well-respected teacher and supervisor of many PhD audiologists currently working in the field. Dr. Levitt is in conversation with Marshall Chasin, editor-in-chief of the *Canadian Hearing Report*.

Marshall Chasin (MC): When we first met years ago, you had commented that your training in electrical engineering was more in trying to understand what you are doing from a solid theoretical background rather than from a practical "circuit building" perspective. Do you think that that was the correct orientation in your education, and do you feel that it has ramifications for the study of audiology?

Harry Levitt (HL): Yes and yes. In undergraduate engineering we did physics, math, applied math, and chemistry for three years. It was actually not until the third year that our professors started to talk about circuits. As soon as I graduated I got a job and it was to design certain circuits. I really didn't know how, but after studying some manuals and thinking about it, I was able to do the necessary designing. If you want to improve the quality of audiology, I think that that educational approach would be very worthwhile. It is very important for audiology students, when they begin their studies, to develop a solid understanding of the theoretical underpinnings of audiology, the nature of auditory impairment, and what can be done to address the problem. Once the student has acquired this understanding, learning how to use modern audiological techniques will come very easily. The field of audiology is continually expanding with new methods and sophisticated new instrumentation being introduced at a fast pace. Audiologists with a strong theoretical background will have little difficulty in understanding and keeping up with these ongoing rapid advances in the field.

I took a sabbatical in the 1970s and went to Australia. I was very impressed with the work and level of clinical expertise that I saw there. At that time they did not have an undergraduate degree in audiology. In order to become an audiologist, one took courses at the post-graduate level followed by an extensive practicum. Most of the audiologists I met on my sabbatical had undergraduate degrees in the sciences, such as physics or experimental psychology. This educational background was clearly extremely helpful in their research and practice of audiology. It obviously paid off because some of the biggest names in the field such as Dennis Byrne and Harvey Dillon, came through the Australian educational model of audiology.

MC: You are also known as a wonderful teacher and doctoral supervisor. As a professor in the City University of New York, I understand that you supervised over 50 doctoral students, either as the primary supervisor or as a committee member.

HL: I did supervise many students who have gone on to do some very important work and have had excellent careers of their own. Every year I supervised two or three students either directly or indirectly and I did this for over 30 years. I tried to instill in them an appreciation of the importance of a sound theoretical basis for their work and this was similar to that of my own training.

MC: In 1971 you had published a very interesting article in *JASA* entitled "Transformed up-down methods in physchoacoustics" (JASA, 49, 467-477) and this became the standard of doing psychophysical work for the last generation of audiologists, including many forms of testing – so much so, that we are surprised that it was not always done that way. Is that technique the most efficient one?

HL: I was doing a study in lateralization and I wanted to get a quick answer. I came up with a method of bracketing and went to the statistics department who were very helpful since a similar technique was also being used in other areas. There are many variations of the technique and the purpose of the paper in 1971 was to develop a general approach to techniques of that type. With respect to the issue of what is the most efficient technique, it turns out that there is no single technique that is uniformly better or more efficient than any other technique. The most efficient technique for a given application is often critically dependent on the underlying assumptions. In the real world, the underlying assumptions are not always entirely valid, so it can be a treacherous situation. Unless you are absolutely sure of the validity of the underlying assumptions, it is wiser to use a technique that is slightly less efficient but highly robust; i.e., it is not dependent on restrictive assumptions that may not be true. The technique described in the 1971 paper is almost as efficient as the theoretically "most efficient" technique for the kinds of conditions encountered in audiological testing or psychoacoustics in general, but unlike the "most efficient" technique it is a robust procedure that will not break down even if the underlying assumptions are only approximately true.

MC: Let's talk about your involvement with digital technology and digital hearing aids. I understand that it goes back to the 1960s.

HL: In the late 1950s and early 1960s, methods for digitizing audio signals were developed and in the 1960s we were starting to develop software to analyze and process digitized audio signals. The software was actually very advanced for the time and it could be used to process signals for people with hearing loss. That was my introduction to what later would become a digital hearing aid. Of course, everything was done off-line at that time; the processing, the signal conversion, and so on. And then when I started the Communications Research Laboratory at the City University of New York in 1969 we got a small computer (one of the PDP-8 series that most of us over 50 will recall from our graduate years). We were then able to do some interesting signal processing that may make speech more intelligible and to try to extract speech out of noise – for example, Mary Joe Osberger, who was a doctoral student with me at the time, used digital signal processing to modify the speech of deaf children to make it more intelligible and to develop more effective speech training programs. Mary Joe won an award for that work.

One of my colleagues was interested in doing work with hearing aids so in 1972 we applied for a research contract to evaluate a programmable, wearable hearing aid that had been developed by the (USA) National Institutes of Health. It was an analog hearing aid that used plug-in modules to adjust the frequency-gain characteristic and compression characteristics. I developed a multivariate adaptive fitting procedure for that project which served as a basis for our subsequent research on hearing aid fitting. The technique was published in the Danavox Symposium in 1978. At that point, I put "2 and 2" together – it was a tremendous amount of work to plug and unplug the various modules in the analog hearing aid. Why couldn't we just have a digital hearing aid with a computer to do the work of adjusting the hearing aid? We applied for and got funding from the National Institutes of Health to do this.

An important development at that point was a new kind of computer called an array processor. It allowed us to do many calculations simultaneously thereby increasing computational speed substantially. Unlike a traditional computer which did one calculation at a time, the array processor, as its name implies, processed huge arrays of numbers simultaneously, thereby allowing us to process speech signals in real time. That was a big technological breakthrough. Using this technology we developed a "digital master hearing aid" (also known as an "array processor computer hearing aid," Levitt, H, 1982, ASHA, (abstract, 24, 805). This first paper on a digital hearing aid was actually given in Canada at the ASHA convention in Toronto. .

Dr. Harry Levitt

A paper of mine on the history of digital hearing aids recently appeared in *Trends in Amplification* called, "A Historical Perspective on Digital Hearing Aids: How Digital Technology has Changed Modern Hearing Aids" (March 2007, 11, 7–24). A shorter historical account marking the 25th anniversary of this ASHA paper also appeared in The *ASHA Leader* (Dec. 26, 2007, pp. 28–30) titled "Digital Hearing Aids: Wheelbarrows to Ear Inserts." In this article the word "wheelbarrow" refers to the needed size of the container of the hearing aid back then. That hearing aid used a wireless connection between an ear-level unit containing the microphone and receiver and the computer which did the signal processing. This allowed the hearing-aid wearer to walk around freely without any connecting wires. However, the system picked up a lot of electromagnetic interference from other devices, such as when someone dialed a telephone number in a nearby office. This was a precursor of a problem we have today, that of interference in hearing aids from digital telephones. We eventually resorted to using a hard-wire connection in our experiments in order to avoid this electromagnetic interference.

The basic design of our digital hearing aid was used for a number of years including several more advanced versions. Two digital units were used. One was a high-speed signal processor (the array processor in our first digital hearing aid); the other was a smaller control unit. The control unit provided instructions to the processor unit which did the hard work of processing audio signals in real time. We used to refer to this arrangement as the "husband and wife" team. One provided the instructions and the other did the work. This arrangement has also been used extensively in the early hybrid or "digitally controlled" hearing aids. These were analog hearing aids that were controlled by a small digital unit.

MC: Early on, I understand that you had consulted with some hearing aid companies.

HL: I have done a lot of consulting over the years – sometimes paid, and sometimes not. I had to be careful because on occasion I was consulting with more than one company. I have worked on the Phoenix project as well as the AT&T project at Bell Labs (with Edgar Villchur, Jont Allen, Fred Waldhauer, and several of the company's top engineers). Eventually the AT&T hearing aid division was sold off. This had nothing to do with the excellent work of the people on the project. AT&T had a very bad year in their personal computer division, and some of the other smaller divisions needed to be pruned away, and this included the hearing aid group, which was relatively small. The AT&T hearing aid was picked up and developed further by ReSound. This resulted in what was probably the best hearing aid in the world at that time.

MC: Since the infancy of digital hearing aids, there has always been a debate about the sophistication of the various digital platforms.

HL: The first two commercially succesful true digital hearing aids – brought out by Widex and Oticon – used the basic architecture and design based on analog hearing aids, multiband compression amplification. The architecture was essentially the same as that of the analog hearing aids. It's interesting to note that when Bell Labs started to use digital audio signal processing, the first few generations of software were designed to to simulate the processing of existing analog devices. Similarly, the first digital hearing aids were designed to simulate existing analog hearing aids. It was only later that digital hearing aids (and digital audio in general) were designed to make use of the really big advantages offered by digital technology; i.e., employing new forms of signal processing that could not be implemented with analog technology.

Whereas early digital hearing aids were only slightly better than analog hearing aids, modern digital hearing aids are substantially superior to both analog hearing aids and the older generation of digital hearing aids.

MC: A more flexible digital design also had its drawbacks in that it was often more difficult to program and made it more difficult for the audiologist to select the appropriate electro-acoustic parameters for their patients.

HL: That is true, and progress is being made to make it easier to program digital hearing aids. It's like a car. Years ago, if one wanted to drive a car, one needed to know about the clutch, how a choke was used, and which gear to begin with. Today, one simply turns on the ignition and drives. The same is true of digital hearing aids. As the technology advances, it becomes easier to use. Today's motor cars are much more sophisticated than in the past and are much easier to drive. Similarly, modern digital hearing aids are very sophisticated instruments. They are also easier to program than the previous generation of digital hearing aids and, if the trend continues, the next generation of digital instruments will be even easier to program.

MC: It was once said that if enough time, money and energy was spent, there is no reason why an analog hearing aid could not be as good, and do everything, that a digital hearing aid could do. Do you agree with this statement?

HL: I don't agree. There are fundamental differences between digital and analog systems. A key characteristic of digital systems is its all-or-none mode of operation and, as a consequence, these operations are perfectly repeatable. Analog systems process signals with a range of possible values. The precision of processing, however, is limited by the internal random noise of the system. Every analog component, even a simple resistor, has some internal random noise, even though it may be extremely small. As a consequence, there is some uncertainty in every analog operation and perfect repetition of analog processing is not possible. Digital systems also have internal noise (e.g., quantization errors, rounding errors), but this noise is not random, although it can be extremely complex and may appear to be random. The lack of perfect reproducibility of analog operations is a fundamental limitation with important practical consequences. For example, one can record a digital signal again and again indefinitely with no difference between the first and last recorded signals. This is not possible with analog recording.

Digital systems also have fundamental limitations, such as those introduced by the sampling process and the discrete quantization of the digital signal. Both technologies have their limitations and neither technology is superior to the other for all situations. A well engineered system thus uses digital technology for those applications in which digital techniques are superior and analog technology where the latter is superior. There is no digital hearing aid that is 100% digital. It is only in the signal processing stage of a hearing aid that digital technology has proven to be superior.

MC: What do you think will be the next breakthrough with digital hearing aids? Will it be architecture with a larger number of bits; increased sampling rate, or something else?

HL: When it comes to bit rate you are still thinking with an analog bias. I think that the next big step will be in using logical operations (by means of "and" "or" gates) which may help to seperate speech from noise. There has been a lot of research on the factors affecting speech intelligibility. We have learned a lot about what makes speech intelligible, and how to process speech. We have also learned a lot about automatic speech recognition and there may be useful applications of this technology in improving speech recognition for people with hearing loss. For example, high-frequency fricatives are often not heard by a hard of hearing person. These fricatives, however, can be identified with good accuracy by an automatic speech recognition device. It is also possible to synthesize an easier-to-hear version of high frequency fricatives so that this combination of automatic speech recognition and selective speech synthesis could help improve speech intelligibility. Frequency lowering of high frequency sounds has been tried in the past for individuals with severe to profound hearing losses. The introduction of digital signal processing in hearing aids has revived interest in this approach with greater use being made of research findings in automatic speech recognition. Also, you can use techniques developed for automatic speech recognition to recognize the acoustic structure of background noise and then process the speech plus noise so as to improve speech intelligibility in certain noisy situations.

MC: My final question is whether "Harry Levitt is related to Larry Revit"?

HL: Actually Larry is a good friend, and he and I have occasionally considered writing a joint paper. It would be something like: Speech Rythm to Spoonerism by Levitt & Revit.

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Modelling of the Auditory System

By Lorienne Jenstad, PhD, Associate Editor

The focus of this issue's review in Spotlight on Science is on modelling of the auditory system.

No, wait, don't turn the page!

If you glance through publications such as the *Journal of the Acoustical Society of America*, or *IEEE Transactions on Speech and Audio Processing*, you may see articles with titles that include phrases such as "auditory model" or "computational model of the auditory system." Modelling of the auditory system is not new and building models, in general, is part of the scientific method. Auditory models have been published for many years, back to the days of Fletcher (1920s), S.S. Stevens (1950s), and earlier founders of our field from long before the days when "Audiology" was even a word, but there seems to be an increase lately in theoretical interest in the area.

So, what are these models and why should we care? I'm going to don my prophetic hat here for a moment. As we understand more and more about the auditory system and as our technology for both diagnostics and intervention improve, audiologists will have the tools necessary to match hearing instrument processing with the specific auditory deficits of individual patients.

Many models are developed to provide a framework to hold together neurophysiological and perceptual data from many different types of studies and findings, explaining data from both normal hearing listeners and hearing-impaired listeners. They are simply ways of unifying the existing data. Once the data are gathered into the framework of a model, the model can then be used to generate hypotheses for further experiments.

Modelling the auditory process is a complex and challenging task, because of the many nonlinearities inherent in the auditory system. In listeners with normal hearing, the nonlinearities are good, because, for example, they increase the large dynamic range of signals to which we can respond. We take advantage of the inherent nonlinearities in our diagnostic testing: the presence of otoacoustic emissions in a normal functioning cochlea is the by-product of the nonlinear process.

> The presence of otoacoustic emissions in a normal functioning cochlea is the by-product of the nonlinear process.

Beyond unifying data and generating hypotheses, though, models can become working models to allow for computation of hearing instrument processing targets. This is an exciting area that I think holds great possibility for audiology and hearing instrument fitting in the near future.

If we can successfully model the processes in the normal auditory system, and identify how the system "breaks down" with hearing loss, we should know what processing is needed to restore (as much as possible) normal hearing. For individual patients, this may mean performing additional measurement procedures to allow us to quantify the changes with hearing loss and incorporate the results of these measures into our prescriptions.

The process should sound familiar: we already do this when fitting hearing instruments. For example, wide-dynamic range compression processing has been used in hearing instruments in response to a model of the loss of cochlear nonlinearity that occurs with sensory hearing loss. With the loss of nonlinearity, we see elevated thresholds but only slightly elevated loudness discomfort levels, and therefore a reduced dynamic range of hearing. Wide dynamic range compression serves to "squish" the dynamic range of inputs into the dynamic range of the hearing-impaired listener. This is already the use of an auditory model in daily clinical work.

> Wide dynamic range compression serves to "squish" the dynamic range of inputs into the dynamic range of the hearing-impaired listener.

Auditory models are continually developing as we gather more data about processing with the auditory system, so they're becoming significantly more complex than the model of reduced dynamic range with loss of nonlinearity.

The advantage of auditory modeling is that the newer models incorporate many levels of the auditory system, beginning with the acoustic transforms inherent in the pinna and ear canal, moving through middle ear transmission, adding in the effects of cochlear and neural processing, up to cognitive and language processes (e.g., Müsch and Buus 2001a; 2001b; 2004). When we fit hearing instruments, we deal with all of these levels at the same time, so it is important to incorporate all the elements into a single computational system.

The advantage of auditory modeling is that the newer models incorporate many levels of the auditory system.

For example, just published in July 2008, in the *Journal of the Acoustical Society of America*, Jepsen, Ewert, and Dau present "A computational model of human auditory signal processing and perception." Their model still includes our familiar concept of compression, along with outer and middle ear acoustic transforms. In addition, they include a mathematical model of transduction from the hair cells to the auditory nerve, internal noise, and a higher level "decision maker."

Any model then needs to be put to the test. Testing models of the auditory system can be difficult, because there are so many possible parameters that could vary. That is, if you test the whole model and don't get the predicted results, this doesn't mean that the model is fatally flawed and must be rejected in entirety. However, it's impossible to know which part of the model failed by only examining a single, global outcome. On the other hand, testing every possible parameter of the model would require a prohibitively large research study. As a way to deal with this, Jepsen and colleagues tested their model in two ways: (1) by comparing predictions of the model computation to existing data sets and (2) by collecting additional data to compare to the model's predictions. The dual sources of data allowed them to test many of the assumptions of their model without having to collect all new behavioural data.

The types of phenomena Jepsen and colleagues examined to put their model to the test were intensity discrimination, masking paradigms, and modulation detection. The variety of stimuli and levels tested allowed for a broad range of predictions of the model to be investigated. For example, intensity discrimination was well-predicted by the model for broadband signals, and for pure tones at high presentation levels, but not for pure tones at low presentation levels. This distinction provides important information about which aspects of the model need to be modified.

In general, it was found that the model was an improvement over a previous version of the same model (Dau et al 1997), by being able to predict more of the variance in the observed data. However, there were other aspects of the data that were not fully predicted by the model, such as noted above, intensity discrimination for pure tones at low presentation levels.

The ability to model the physiology and behaviour of the auditory system is continually improving. The current model of Jepsen and colleagues, reviewed here, provides good insight into the workings of the auditory system. As the authors note, although the model is an improvement over its previous incarnation, more factors need to be accounted for in the model.

What to Look for In the Literature

Watch for more improvements in this auditory model and others. As we come closer to being able to define and describe the normally functioning auditory system, and then the impaired system, it will be much easier to define desired hearing instrument processing to fill in the deficit.

Watch the literature for applications of these models to hearing instrument processing. There are possibilities for some very exciting developments in processing and our ability to match processing with individual hearing impairments based on measured deficits.

Finally, watch the literature for evidence of whether a "normalization of function" approach is the best way to approach hearing loss remediation. We have seen trends in the past of trying to restore normal loudness function through wide dynamic range compression, with a subsequent call to caution, that loudness normalization may not be the ultimate goal in hearing instrument fitting (Byrne, 1996). Whether or not more extensive auditory models will lead us to evidence-based hearing instrument fittings remains to be seen, but I suspect we will see data emerging in this area soon, with direct clinical application.

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Industry Insider

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The sponsorship deal is part of Widex' ongoing support of sports and involves the Widex Marathon Team 2008, which is made up of 100 hearing care professionals from around the world, competing in the marathon in New York on 2nd November 2008.

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For several years, Widex has organized marathon races for hearing aid users and hearing care professionals. The Widex Marathon Teams have competed in the Berlin Marathon and the Great Wall Marathon in China and aim to create awareness about hearing related issues. By supporting values linked to an active lifestyle, Widex hopes to break down prejudices associated with hearing aids

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The Canadian Hard of Hearing Association offers employment services to hard of hearing persons who meet the eligibility criteria under the Opportunities Fund for Persons with Disabilities program. Services are currently offered in the Okanagan Valley, Edmonton, Ottawa, and St. John's, Newfoundland. To find out more about the services and to contact our regional Employment Facilitators please visit www.chha.ca.

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Widex Seminar on Paediatric Audiology

Widex will be hosting a pan-Arabic seminar on paediatric audiology. The seminar takes place from November 5 to 8, 2008 in Antalya, Turkey.

The aim is to facilitate increased sharing of knowledge and best practice within newborn hearing screening and hearing aid fittings across the Arabic speaking world.

Leading audiologists and ENT doctors from more than 10 Arabic speaking countries are expected to participate. Contemporary research and case studies within neonatal hearing screening will be presented by scientists from Turkey and the Arabic speaking region.

In addition, participants will learn about the latest news from Widex within hearing aid technology and fitting software.

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2008 Oticon Focus on People Awards: Call for Nominations of Outstanding Individuals with Hearing Loss

Oticon, Inc. is seeking nominations of outstanding individuals with any degree of hearing loss for the 2008 Oticon Focus on People Awards. The national awards program, created by Oticon, Inc. in 1996, honours hearing impaired students, adults, and advocacy volunteers whose accomplishments demonstrate that hearing loss does not limit a person's ability to make a difference in their families, their communities or the world. By spotlighting people with hearing loss and their achievements and contributions, Oticon aims to change outdated stereotypes that discourage people from seeking professional help for their hearing loss. Now in its 11th year, the program has awarded more than $130,000 to deserving individuals and the not-for-profit causes of their choice.

"We know that people with hearing loss make incredible contributions in all walks of life," states Peer Lauritsen, President of Oticon, Inc. "But for many, negative stereotypes persist. We believe these hurtful stereotypes influence the more than 80% of individuals who hesitate to seek help for their hearing loss. Through this program, Oticon hopes to motivate people to speak with hearing care professionals about the new technologies that can enable them to live the lives they want with the hearing they have."

This year the program offers awards in five categories:

Student: For young people with hearing loss, ages 6 to 21, who are full-time students

Adults: For people with hearing loss, ages 21 and above

Advocacy: For adults with hearing loss, ages 21 and above who actively volunteer their time in advocacy or support efforts for the hearing impaired and deaf community (full-time students in advocacy should apply for the Student category)

Practitioner: A special award for hearing care professionals who are currently in practice

Pediatric Practitioner: A special award for hearing care professionals in school or clinical settings

Winning nominations will be announced in October. First place category winners will receive a $1,000 award and a $1,000 donation by Oticon to a not-for-profit cause of their choice. Second place winners will receive $500 and third place winners will receive $250. All nominees, regardless of whether they are selected as category winners, will receive a Certificate of Recognition.

People may nominate themselves or other individuals with a hearing loss for the Oticon Focus on People Awards. Nominators complete a simple form that asks for a brief description of the nominee's accomplishments and contributions that distinguish them as role models for all - but especially for others who struggle to overcome the stigma of hearing loss.

To complete an application, please visit oticonusa.com, Professionals section and click on the Oticon Focus on People Awards link. The deadline for award nominations is September 8, 2008.

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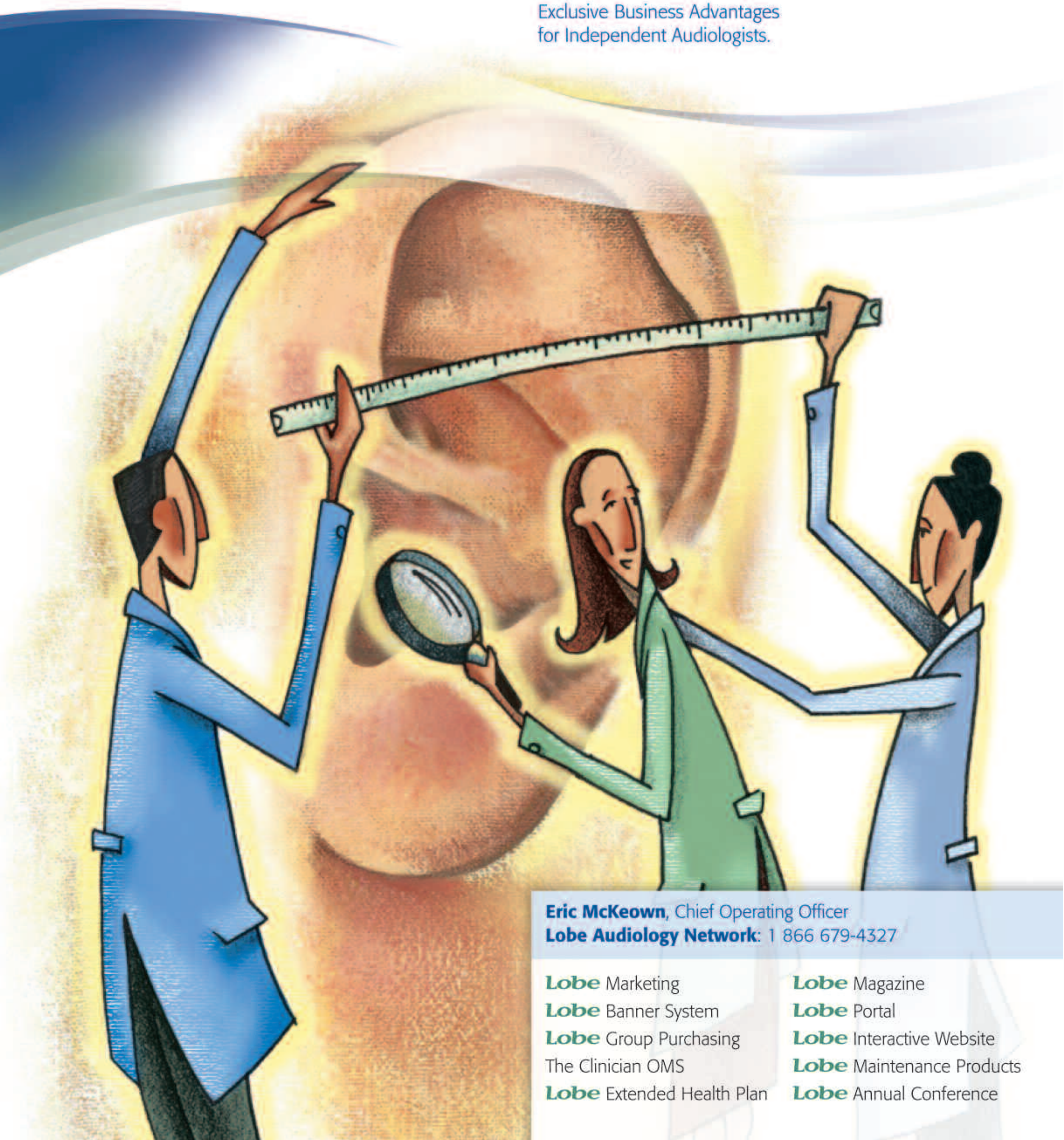

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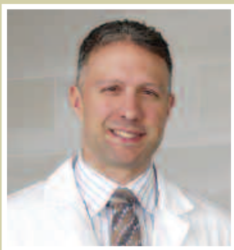
Influence of Microphone Position during FM Transmission

André M. Marcoux, PhD



About the Author
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Abstract

There are a variety of recommendations for the optimal fitting of a composite system, comprising a Frequency Modulation (FM) wireless receiver coupled to a hearing aid for hearing impaired listeners. Current fitting methods attempt to provide an acceptable signal-to-noise ratio benefit while avoiding excessive outputs in the ear of the listener. Often, these fitting methods are recommended without consideration for the various types of microphones used with FM systems. This study simultaneously measured frequency and intensity characteristics of speech discourse at microphone positions common to the FM transmitter. Results indicate the long term average speech spectrum will be different at each of the microphone positions in relation to a reference microphone position. Attenuation below 500 Hz and above 800 Hz is reported for a chest-level microphone while amplification between 100 and 800 Hz is noted for a boom-type microphone. These results suggest that the position of the FM microphone should be considered prior to fitting and subsequent use.

Introduction

Acoustic propagation of a speech signal in a medium will typically cause two important modifications of that signal which may have a negative effect on its perception by the listener. First, the level of speech will decrease as the distance between the source of speech (i.e., talker) and the listener is increased. This will potentially decrease the audibility of the speech signal and this effect will be magnified for a listener who is hearing-impaired (Olsen, 1988). Secondly, the intelligibility of speech is typically reduced in reverberant environments or situations with competing noise. The contribution of reverberation and competing noise on the degradation of the speech signal will be greater as the distance between the sound source and the listener is increased. For these reasons, wireless transmission by means of Frequency Modulation (FM) systems is used for hearing-impaired listeners, so that they may be able to effectively communicate in adverse listening situations (Berger and Millin 1989; Ross 1992). FM transmission permits the delivery of acoustic characteristics of distant sound sources to the ear of the hearing-impaired individual. In classroom situations, the FM system enables the reception of a dedicated sound source (i.e., teacher's voice) in a variety of adverse listening situations (Ross 1992).

FM systems can be used as stand-alone units. However they are commonly coupled to a hearing aid by means of its direct audio input. A student in a classroom situation may require the use of the FM transmitter microphone as well as the hearing aid microphone, so as to be able to monitor self-voicing (Maxon 1993). Elsewhere, it may be preferable to use the FM transmitter microphone exclusively to reduce interference from noise sources located near the listener.

In a composite system (FM system + hearing aid), the frequency shaping and other processing features of the hearing aid are applied to the FM input. In so doing, certain properties of the overall FM transmission (level and frequency response measured from the hearing aid receiver when input is presented at the microphone of the FM transmitter microphone) should be observed to ensure a satisfactory performance from the composite system. The output or gain required for an FM system is often the result of the recommended fitting procedure, such as the equal gain method (ASHA 1994), the +10 dB advantage method (ASHA 2000), or the equal output method (Seewald et al. 1993). According to their objectives, these procedures each prescribe a different intensity relationship in output from inputs independently reaching the microphones of the composite system. These procedures also attempt to describe the SNR benefit from the composite system, assuming a constant level of background noise. It has been argued that a single prescription of gain from FM transmission might not be suitable in all listening situations (ASHA 2000; Rowson and Bamford 1995). Therefore, while fitting strategies may potentially promote an acceptable performance of the composite system during a defined set of listening situations, any single strategy may not ensure the same result under other conditions. This can be emphasized when considering the change in spectral shape of the Long Term Average Speech Spectrum (LTASS) based on the change in position of the FM transmitter microphone relative to the talker's mouth (Cornelisse et al. 1991; Dunn and Farnsworth 1939). Traditionally, FM transmitter microphones have either been worn on the chest or fastened at the lapel or around the neck. In recent years, boom microphones as well as central conference table microphones have also been used. It therefore appears unlikely that the prescription of gain deemed optimal when a microphone is worn at the chest position will also be deemed optimal for a boom microphone positioned near the talker's cheek.

Fitting procedures assume that the speech level at the FM microphone will exceed the level at the hearing aid microphone by 15 dB (ASHA 1994, 2000, 2002). This difference reflects the fact that the FM microphone is typically much closer to the talker in comparison to the hearing aid microphone. Furthermore, these same procedures assume that signals at the microphones of the composite system will have an identical spectral shape. Considering the variety of microphones used in conjunction with the FM system and the distance of the listener from the talker, it is seems unlikely that real-life inputs will always be 15 dB more intense and with identical spectral shape at the FM microphone in comparison to the hearing aid microphone.

The purpose of the present study is to compare the LTASS measured at a reference position with spectra simultaneously recorded at positions representative of the FM transmitter microphone. These comparisons will attempt to provide evidence of the possible effect of microphone position on the provision of gain for FM transmission. Furthermore, data will be compared to previous estimations of the LTASS at specific microphone locations (Cornelisse et al. 1991; Dunn and Farnsworth, 1939).

Methods

SUBJECTS

Five female and five male subjects ranging in age between 29 and 58 years participated in this study. Subjects were native speakers of Danish. Note, that LTASS of Danish is very similar to the international LTASS (Byrne et al. 1994).

MICROPHONE POSITIONS

Four miniature microphones (Knowles FG 3629) were positioned at specific coordinates in relation to the listener. First, the position of a reference microphone was determined to reflect the conditions of the composite system's fitting procedure. Hearing aids are fitted with the purpose of achieving optimal audibility and intelligibility when speech is produced by a person facing the listener, speaking clearly and with a normal or slightly raised vocal effort. Complete consensus does not exist with regard to the level of this speech or the related distance between the talker and the listener (Byrne et al. 1994). According to ANSI S3.5-1997 (American National Standards Institute, 1997), speech produced with a "normal" vocal effort described in ANSI S3.5-1997 (American National Standards Institute 1997) has its RMS specified as 62.4 dB SPL at a distance of one meter in front of the talker's lips. Slightly higher values have been reported (Dillon 2001, p. 67). Based on this, it is realistic to assume that the RMS level of speech at the position of the listener corresponds to approximately 65 dB SPL at a distance somewhat less than 1 metre. Since the distance law will estimate an increase of 2.5 dB upon reducing the distance from 1 metre to 0.75 metres, this definition is a good estimation of the standard and also reconciles most studies from the literature. We will therefore define the typical listening situation of a hearing-impaired person as one where the talker and the listener with hearing aids, are facing each other and the listener is positioned at a distance of 0.75 metres directly in front of the talker's lips and speaking clearly with a normal effort resulting in a speech spectrum with an RMS of 65 dB SPL. Following the directive mentioned above, the equivalent real-life distance of the FM microphone assumed with most fitting recommendations can be calculated. Using the ASHA approach we can then determine where the FM microphone is placed to observe an RMS of 15 dB more than that reaching the hearing aid. As a result of impinging the microphone of the FM system with inputs 15 dB greater than at the hearing aid microphone, it could be deduced that these fitting methods assume that the FM microphone is roughly placed at 13 cm from the talker's mouth, as calculated with the equation from the inverse square law.

$$65 \text{ dB} + 20\log(75 \text{ cm}/x) = 80 \text{ dB}$$

$$x \sim 13 \text{ cm}$$

While some may argue that a distance of 0.75 metres, and subsequently an input to the hearing aid of 65 dB SPL, may not be the only listening situation in which a speaker will provide speech input to a person or student wearing a composite system, it has been chosen to create a reference position which is supported by the literature with respect to long term speech spectra and, furthermore, with inputs (i.e., 65 dB SPL) which are similar to what is used to verify the performance of composite systems (ASHA 1994, 2000, 2002). These values also assume that there is no effect from the reverberant field at these distances in the FM setting environment (i.e., a testing chamber) and that the inverse square law can be used to calculate the effect of distance on SPL.

Fitting procedures also recommend presenting spectra with identical spectral shape to both the hearing aid and FM microphones. Dunn and Farnsworth (1939) have documented the effect of elevation and azimuth of the speech spectrum of a male talker. This reveals that changes in elevation or azimuth of the recording microphone can significantly change the spectrum of the recorded speech. Since the spectral shape of the signal which reaches the FM transmitter and hearing aid microphones during a fitting procedure is identical (ASHA 2000), it is conceivable that such a procedure assumes that both microphones are located at an equal elevation and azimuth from the talker. ANSI S3.5-1997, specifies an elevation of 0° and an azimuth of 0° from the talkers lips and thus similar values can be assumed to represent the spectrum which impinges the FM microphone during a fitting procedure.

The position of the FM microphone during fitting procedures therefore corresponds to a distance of 13 cm with an elevation of 0° and an azimuth of 0° from the speaker's lips, as defined by the coordinates (0.13, 0, 0). These coordinates were used to represent a reference position used to observe relative differences in intensity and spectrum with other microphones at different coordinates.

In addition to the on-axis reference microphone position (0.13, 0, 0), another on-axis position was chosen (0.75, 0, 0) to represent the approximate position of a conference podium-type FM microphone position. Two off-axis positions were also chosen: one placed at coordinates of (0.07, 45, 0) which represents a typical position of a boom microphone, located at a distance of 0.07 m from the talker's mouth with an azimuth of 45° and an elevation of 0° and another placed at coordinates of (0.20, 0, –80) which represents the typical position of a chest-level microphone, located at a distance of 0.20 metres from the talker's mouth with an azimuth of 0° and an elevation of –80°. A conservative calculation of the critical distance of the room, the distance inside which recordings are not influenced by reverberant energy, was calculated using the following formula:

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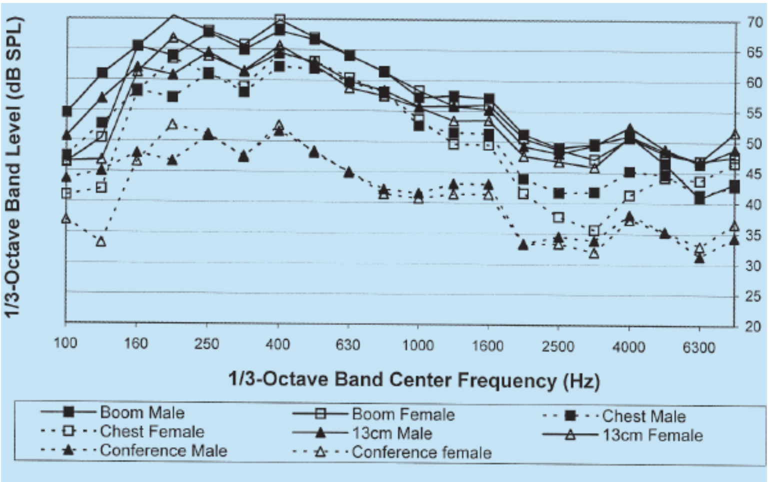

Figure 1. 1/3-octave band levels of the speech spectrum obtained at different microphone positions for male and female subjects.

Table 1. Mean and standard deviations of overall SPL of male and female discourse measured at four different microphone positions.

Microphone Position	Males (dB)	Females (dB)
Boom	75.5 (4.0)	76.3 (3.0)
Chest	69.7 (3.5)	70.6 (1.4)
13 cm (Reference)	72.7 (3.2)	72.1 (2.1)
Conference	59.4 (2.7)	59.6 (1.1)

Critical Distance

$= \sqrt{[(\text{Directivity}*\text{RoomVolume})/}$
$= (100\pi*\text{RT60})]$
$= \sqrt{[(2*21.3)/(100*\pi*0.2)]} = 0.8234$

Therefore, all microphones will lie within the far field, where the inverse square law applies and where recordings will not be affected by reverberant energy.

TESTING EQUIPMENT

Recordings were made in a 2.85 m by 3.40 m semi-reverberant sound-treated room with a reverberation time of 0.25, 0.24, 0.24, 0.21, 0.19, 0.18 at 125, 250, 500, 1000, 2000, 4000 Hz respectively. In order to observe the influence of microphone positioning on the transfer characteristic (difference between spectral shape of the speech spectrum at a reference microphone position and a typical microphone position for FM use) of the FM transmitter microphone, a recording technique was developed to permit simultaneous recordings at various microphone positions. Microphones were kept in the desired positions relative to the mouth using a metal wire support mounted at the talker's head to minimize the effect head movements. A wind screen covered the boom microphone in order to minimize the effect of turbulence in proximity of the speaker's mouth. Recordings were sampled with a resolution of 16 bit and stored digitally in the Random Access Memory (RAM) of a specially designed digital signal processing unit. After each recording session the content of the RAM was transferred to the hard disk of a PC, and stored for further editing.

PROCEDURE

Prior to each recording, microphone positions were adjusted relative to the individual talker. All microphones were individually calibrated and calibration curves were later used to correct the recorded spectra in the frequency range between 50 to 10,000 Hz within one dB.

Five female and five male subjects were required to stand on a demarcation and read a passage of Danish text. The text appeared in large print on a page of paper placed approximately 1 metre in front of the talker's eyes. Talkers were instructed to minimize movements while reading and to disregard any speech production error. Talkers were asked to read the text twice, where the first attempt was to familiarize the talker with the text and technique.

Results

The average duration of the recorded passage was 27 seconds with a standard deviation of 1.3 seconds. The recorded signals were sampled with a frequency of 32 kHz and their long-term average amplitude spectrum was calculated by using a 2048 point FFT with a moving Hanning window with 50% overlap. The resulting spectra were transformed to dB SPL using the individual calibration for each microphone and averaged separately for female and male talkers.

Statistical analyses consisted of a two-way mixed-design analysis of variance (ANOVA), where a repeated measures variable was utilized to demonstrate the effect of microphone position on the overall level of the LTASS. A between-groups variable of gender was also added. There was no significant interaction between talker gender and microphone position ($F = 0.3$, ns), indicating that the microphone position had a similar effect on the overall LTASS level with both male and female talkers. Because overall levels for each microphone position and level differences between microphone positions were statistically similar for both males and females, post-hoc 1/3-octave analyses were conducted by grouping all subjects into a single group. This does not imply that 1/3-octave levels are equal for male and female talkers, as mainly seen below 160 Hz in Figure 1, but reflects the similar effect of microphone position on various recordings. The four recorded speech samples for each male and female talker were analyzed to determine a significant effect of microphone position on the overall speech level. A Newman-Keuls procedure was utilized for this purpose. Separate analyses were conducted on male and female subgroup data as well as on the overall group data. Significance was established at the .05 level. Recordings for the male and female talkers, averaged over all four microphone positions, were of similar overall SPL (i.e., SPL averaged over the total duration of each speech recording) with male talkers ($M = 69.2$, $SD = 1.1$) and with female talkers ($M = 69.8$, $SD = 1.1$), ($F = 0.09$, ns). Changing the position of the microphone had a significant effect on the overall SPL, ($F = 380.8$, $p < .001$). For both males and females, the overall level, expressed in dB SPL, was highest at the boom microphone position (Males: $M = 75.5$, $SD = 4.0$; Females: $M = 76.3$, $SD = 3.0$), followed by the reference microphone (Males: $M = 72.7$, $SD = 3.2$; Females: $M = 72.8$, $SD = 2.1$), followed by the chest microphone (Males: $M = 69.7$, $SD = 3.5$;

Females: M = 70.6, SD = 1.4) and finally by the conference microphone (Males: M = 59.4, SD = 2.7; Females: M = 59.6, SD = 1.1). These values are reported in Table 1.

To demonstrate the effect of microphone position on the overall LTASS at various frequencies, 1/3-octave band levels were compared between the reference microphone and all other microphone positions. Paired *t*-tests were performed at 1/3-octave band levels between 100 and 8,000 Hz. The level of significance was modified to $p < .0025$ with a Bonferroni correction to control error associated with multiple comparisons. The results from a comparison of 1/3-octave levels between various microphone positions are reported in Table 2. Results indicated that the LTASS measured at the reference position 13 cm from the mouth differed significantly from the LTASS measured at the conference position microphone across the frequency spectrum. Visual inspection of the 1/3-octave band LTASS confirms that changing the position from the reference position to the conference position results in a significant reduction in level similarly in all frequency regions. Results further indicated that the LTASS measured at the boom and the reference position differed significantly between 100 Hz and 800 Hz but not for the frequency region above 800 Hz. Thus the effect of changing the position of the recording microphone from the reference position to the boom microphone position is mostly one of increase in level in the low frequency region. Results further indicated that the LTASS measured at the chest microphone and that measured at the reference position differed significantly across most of the frequency spectrum, except for the frequency region between 500 and 800 Hz. Thus changing the position of the microphone from the reference position to the chest position is mainly one of decrease in level except for the frequency region between 500 and 800 Hz. Lastly, the difference between the reference and conference microphones is one of significant decrease in level across frequencies. Results from a comparison of 1/3-octave levels between the reference position of the FM microphone, boom, chest level and conference microphone positions are illustrated in Figure 2.

Discussion

By examining the LTASS of recordings obtained at various microphone positions, as shown in Figures 1 and 2, it is clear that a change in FM microphone position will have

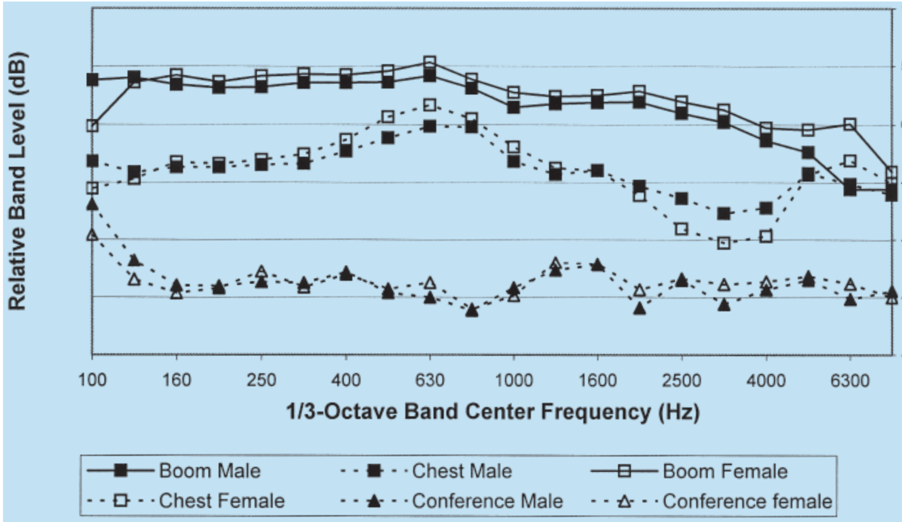

Figure 2. Difference in 1/3-octave band levels of the speech spectrum obtained at different microphone positions and the 13 cm reference position.

Table 2. Mean and standard deviations of 1/3-octave band SPL of averaged male and female discourse measured at four different microphone positions.

Frequency (Hz)	Boom (dB)	13 cm (dB)	Chest (dB)	Conference (dB)
100	50.5	48.7	44.3	40.3
	(9.3)	(9.7)	(10.1)	9.6
125	55.6	51.8	47.4	39.2
	(10.9)	(11.9)	(12.0)	(11.3)
160	65.4	61.6	58.1	47.3
	(4.5)	(4.4)	(3.8)	(4.9)
200	67.2	63.8	60.3	49.6
	(5.8)	(4.8)	(4.9)	(4.7)
250	67.9	64.2	60.9	51.0
	(2.8)	(2.4)	(1.8)	(1.8)
315	65.3	61.4	58.4	47.4
	(4.7)	(4.3)	(4.3)	(3.0)
400	69.0	65.0	63.2	52.1
	(4.5)	(4.1)	(4.0)	(3.1)
500	66.8	62.7	62.4	48.2
	(4.1)	(3.4)	(3.6)	(2.9)
630	64.0	59.3	60.0	44.9
	(3.6)	(2.8)	(2.9)	(3.2)
800	61.4	57.9	58.0	41.8
	(4.0)	(2.9)	(2.9)	(3.1)
1,000	57.8	55.7	53.1	41.1
	(5.0)	(3.5)	(3.5)	(4.1)
1,250	56.7	54.6	50.5	42.2
	(3.7)	(3.0)	(3.4)	(2.6)
1,600	56.6	54.4	50.4	42.2
	(3.6)	(2.2)	(3.3)	(2.4)
2,000	50.9	48.5	42.7	33.3
	(3.3)	(2.3)	(5.2)	(2.2)
2,500	48.9	47.4	39.7	34.0
	(3.4)	(1.8)	(5.4)	(1.3)
3,150	48.4	47.7	38.7	32.9
	(2.9)	(3.4)	(5.4)	(2.6)
4,000	50.9	51.7	43.3	37.7
	(5.4)	(4.0)	(6.6)	(1.2)
5,000	47.3	48.6	44.4	35.3
	(4.9)	(46.6)	(4.7)	(3.7)
6,300	43.9	46.6	42.5	32.1
	(5.9)	(4.2)	(4.1)	(3.7)
8,000	45.4	50.2	44.7	35.5
	(5.7)	(4.1)	(4.4)	(3.9)

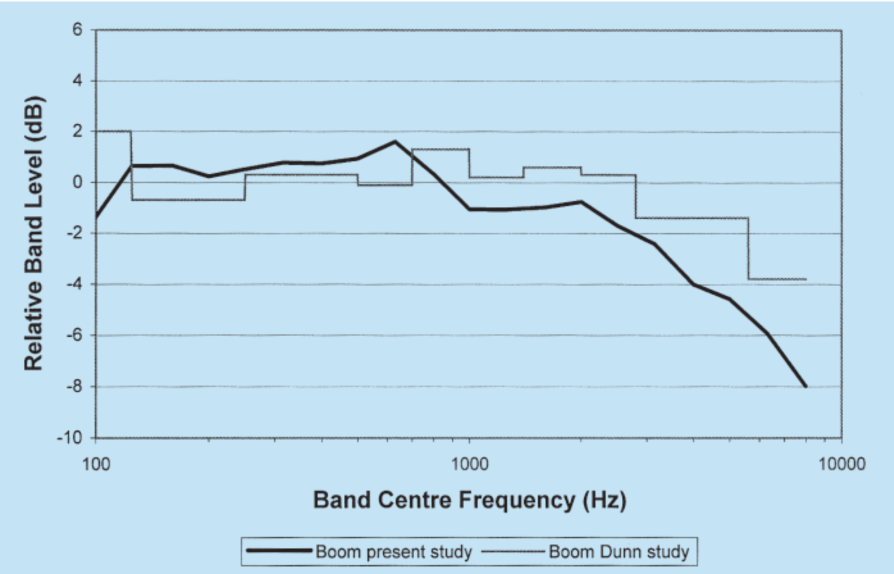

Figure 3. Comparison of transfer functions in 1/3-octave band levels for a boom microphone position from the present study and a single male (Dunn & Farnsworth, 1939).

a significant effect on the intensity and frequency of measured inputs.

Data from the present study was also compared to prior reports from the literature. A comparative approach was based on a report of relative speech spectra rather than using LTASS. This approach was chosen because of the different microphone coordinates reported in the literature, at which LTASS was measured. For example, Dunn and Farnsworth (1939) report the LTASS obtained for a single male speaker at coordinates that are different from those used for both the boom and chest microphones in this study. On the other hand, Cornelisse et al. (1991) report a chest-level microphone LTASS for a group of female talkers with identical coordinates as those reported here. The advantage of using relative spectra, expressed in dB relative to the overall RMS value of the LTASS, is that the resulting value remains constant with changes in distance of the microphone from the talker. In so doing, the author could attempt a comparison between relative spectra from various studies and contend with small discrepancies in the reported azimuth and elevation coordinates without the additional concern of having to contend with reported discrepancies in the distance coordinate. Also, a difference in relative spectra; the transfer function, can be calculated to reveal the change in spectral shape of the LTASS resulting from a change in microphone position from a defined reference position. Accordingly, in this study, transfer functions were calculated by subtracting the relative spectrum at the typical position of an FM microphone (i.e., boom, chest-level or conference microphone position) from the relative spectrum at the implied reference position.

The boom microphone coordinates used in the present study (0.07, 45, 0) did not exactly correspond that those reported by Dunn and Farnsworth. Their closest coordinates of (0.05, 45, 0) were therefore selected for comparison. As can be observed in Figure 3, close agreement is observed between the relative speech spectrum for the boom microphone from the present study and the Dunn and Farnsworth data at coordinates (0.05, 45, 0) up to approximately 1,000 Hz. The subsequent high-frequency attenuation appears slightly more prominent for the present study. Considering the proximity to the point source, a slight deviation in elevation from either study could account for this slight discrepancy.

At the chest position, the coordinates chosen for the present study (0.20, 0, – 80) corresponded exactly to those of Cornelisse et al. (1991). Data from the present study was therefore compared to that from Cornelisse et al. using a group of 10 young adult females. A comparison with Dunn and Farnsworth (1939) is also provided although their closest coordinates for comparative purposes (0.15, 0, – 90) are slightly different, which may slightly blur a direct comparison. A comparison of normalised spectra for the chest microphone, as it appears in Figure 4, reveals a close agreement with Cornelisse et al., (1991). There is also close agreement with the Dunn and Farnsworth (0.15, 0, – 90) coordinates except in the frequency region exceeding 4,000 Hz. This discrepancy may be due to the slight difference in elevation between the present study, as well as the Cornelisse et al. study (1991) and the Dunn and Farnsworth (1939) report. In general and across studies a similar mid-frequency amplification is noted in the frequency region between 800 and 1,000 Hz with a subsequent attenuation in the frequency region above 1,000 Hz.

An interesting observation was that the overall SPL at this microphone position was close to 5 dB lower that that predicted by ANSI S3.5-1997 using the inverse square law. This observation would indicate that the speakers used in this study produced softer speech than those who participated to elaborate ANSI S3.5-1997. Although dissimilar, the purpose of the current study was to note relative spectral change between microphone positions which were defined using assumptions from verification strategies which are performed in anechoic conditions. Given that the microphones used in this study were all placed within the critical distance of the room, the relative spectral changes would be similar to those obtained with more slightly more intense speech.

The effects documented here exemplify why identical input spectra with a constant 15 dB difference should not be presented to the microphones of the composite system during the fitting procedure. As long as current fitting procedures (ASHA 1994, 2000; Seewald et al. 1993) imply that the FM microphone is placed directly in front of the mouth at a distance close to 13 cm, the resulting audibility and SNR of a fitting procedure will be dependant on the actual FM microphone position and will differ from that predicted by the fitting procedure. This statement is based on findings from the present study which document the significant effect on LTASS resulting from a change of the microphone position from the implied reference position to actual positions of the FM microphone, and which is not considered during current fitting procedures. The present author realizes that the exact positions provided in this study for each FM transmitter microphone type are a general approximation of their position in the real-life situation. For example, a boom microphone may not necessarily be placed at 7 cm away from the centre of the speaker's mouth, but may also be placed closer or further. Nonetheless, the

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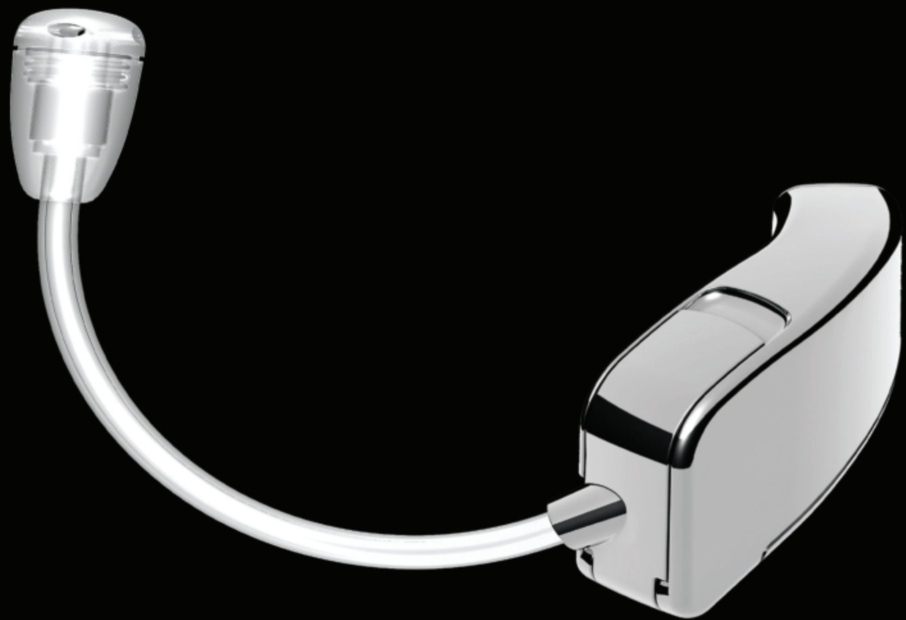

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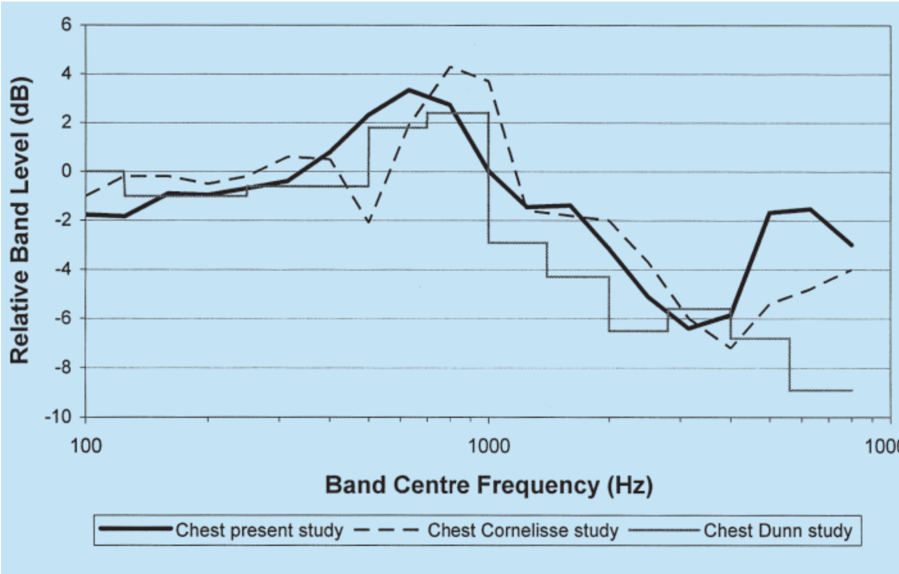

Figure 4. Comparison of transfer functions in 1/3-octave band levels for a chest-level microphone position from the present study, a group of adult females (Cornelisse et al. 1991) and a single adult male (Dunn and Farnsworth, 1939).

general arguments of the present study remain the same.

Based on the simultaneously recorded data from the present report, along with the close agreement with other individual recordings, it can be suggested that future fitting strategies for fitting composite systems should consider the effect described herein. Recommendations are offered for fitting strategies to more accurately predict the audibility and SNR provided by a composite system during everyday use. One possibility would be to utilize LTASS that are representative of a signal recorded at a position similar to where the FM transmitter microphone will be placed during everyday use. This strategy is exemplified in Cornelisse et al. (1991) which calculate the LTASS for the chest-level microphone by correcting the LTASS used for hearing aid microphone measurements (Cox and Moore 1988) with their chest-level relative speech spectrum as well as with a correction for vocal effort used by people speaking to the hearing-impaired. Hence, a verification system should allow for the selection of speech spectra which attempt to mimic that measured at FM-transmitter positioned either at the chest, boom or conference positions during the verification procedure.

A second possibility would be for a multi-channel digital hearing to account for the approximate position of the FM transmitter microphone and ensure that inputs received by the hearing aid's auxiliary input (i.e., FM inputs) are manipulated in order to restore the change of spectral density caused by the FM transmitter microphone position. In so doing, FM inputs across the frequency spectrum (as determined by the number of channels available in the hearing aid) would receive an identical output to that intended by the fitting procedure. These strategies should also consider the various characteristics inherent to FM transmission such as output limiting. Hawkins and Schum (1985) have documented that the input-output characteristics of a composite system cannot be unambiguously depicted by the independent input-output characteristics of the FM system or hearing aid. Therefore fitting strategies should provide a valid methodology to ensure the performance and benefit of a particular composite system. More precise details should be explored but are beyond the scope of this report.

Conclusion

The present study provides a comprehensive set of simultaneous recordings at microphone positions relevant to FM transmission. Significant differences in intensity and frequency are noted with changes in microphone position relative to the position of the listener. Results suggest that the position of the FM transmitter microphone configured during its normal use should be considered during the fitting process of a composite system. Current fitting procedures may not acknowledge the effect of the FM microphone position and predictions of the performance from the composite system may differ from that provided in real-life situations.

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Hearing Loss Is in the Ear, But Hearing Problems Are In The Brain

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Abstract

While the cochlea is the source of audiometric hearing loss, the brain is involved with hearing problems. The important role of the acoustic environment in causing or preventing maladaptive changes in the brain that are at the source of problems such as loudness recruitment and tinnitus, are emphasized. The role of well-fitted hearing aids to provide that needed acoustic environment is stressed.

Peripheral

The inner ear structures transduce the airborne sound vibrations, transmitted by the middle ear to the cochlear fluids, into electrical signals. This is done in several steps; first the basilar membrane that separates fluid filled compartments vibrates as a result of the vibrations of the fluid. But it does so with some sort of selectivity for the vibration frequency. Because the membrane is stiffer at the basal end (close to the stapes) and more flaccid near the apex of the cochlea, high frequency vibrations only move the basal part of the basilar membrane and low frequencies move the apical part most easily. This is the crude frequency analysis that was highlighted in the stroboscopic observations of basilar membrane movements in dissected ears by von Békésy in the mid 1920s. This earned him the first, and so far only, Nobel prize for auditory research in1961.

The cochlea contains two types of hair cells: the inner hair cells and the outer hair cells. Both act as microphones that convert mechanical movement into an electric voltage change. The voltage changes follow the changes in movement of the basilar membrane, and thus ultimately those of the eardrum. The voltage changes are brought about because movements of the basilar membrane result in movements of the stereocilia on top of the hair cells. Movement of the stereocilia in one direction results in the opening of gates at the tip of the stereocilia through which positively charged potassium ions flow into the hair cells. This depolarizes the hair cell. These potassium ions are pumped out of the hair cell very rapidly during the movement of the stereo cilia in the other direction. The result is that the voltage in the hair cell follows that of the sound pressure; this changing voltage is also known as the cochlear microphonic.

In addition to their microphone action, the outer hair cells act as mechanical amplifiers by their motor action. When the outer hair cell's interior becomes less negative (depolarization) the hair cell contracts along its length, thereby pulling up the basilar membrane in phase with its movement. Compare this to a swing that gets pushed at the right time. The stereocilia movement is also amplified. This results in an amplification of the basilar membrane movement by about 40 dB over the sound level range of 0–40 dB SPL; for higher sound levels the amplification slowly decreases to zero. This motor action is very fast so that the amplification works for our entire audible frequency range. As a result of the amplification of the basilar membrane movement, the output of the inner hair cells is greatly enhanced at low to moderate sound levels.

The combination of the low quality frequency analysis of the unaided basilar membrane combined with the positive feedback produced by the outer hair cells results in a superbly increased selectivity of sound frequency and corresponding distribution of sound across an array of inner hair cells. Sometimes the positive feedback can be so large that local basilar membrane oscillations develop spontaneously. These can set the surrounding fluid and consequently the stapes into oscillatory motion, which also results via the middle ear bones into vibration of the eardrum. Placing a sensitive microphone into one's ear canal allows recording of these vibrations. They are called spontaneous oto-acoustic emissions that have a level of typically less than 15 dB SPL and are inaudible to the person that emits them.

There are two major ways to destroy the amplification by the outer hair cells; one is to damage them by exposure to loud sound, the second is to administer aspirin. Aspirin interferes with the molecules that cause the motor action, however, without destroying the outer hair cells. Destruction of the motor action of the outer hair cells produces a 40–50 dB hearing loss.

Noise-induced hearing loss results from both hair cell damage and neurotoxic effects. The outer hair cells in the basal turn of the cochlea are the most sensitive to noise-exposure, whereas the inner hair cells are generally more resistant. Outer hair cell damage as a result of noise trauma initially is generally confined to a narrow frequency range (e.g., 4–8 kHz). The neurotoxic effects of exposure to loud sounds result from the excessive release of the neurotransmitter glutamate by the inner hair cells in the basal turn of the cochlea. This continuously depolarizes the synaptic terminal from the auditory nerve fibres, and as a result there is a large influx of calcium ions into the nerve fibre and this cause damage to the nerve side of the synapse with the hair cells. This damage can be reversible under appropriate conditions; a process that takes about five days (Puel et al. 1998). This temporary hearing loss in the high frequencies, including the region with outer hair cell loss, is part of the temporary threshold shift.

Loss of outer hair cells, e.g., due to noise trauma, thus results in a localized hearing loss (result from the reduced amplification provided by outer hair cells) and a corresponding loss in frequency selectivity. So even if the inner hair cells are not affected by exposure to noise or other hearing loss-inducing agents the cochlea or parts thereof will not function properly. One can somewhat compensate for that hearing loss, but not for the reduction in frequency selectivity. One of the immediate consequences is that understanding speech in noise becomes much more difficult and that (social) communication can break down substantially.

Central

Hearing loss typically produces an imbalance between the neural activity in auditory nerve fibres across the range of characteristic frequencies (CFs). Nerve fibres in the hearing loss range generally fire less, both spontaneously and in response to sounds than do their normal counterparts at lower CFs. As a result, both the excitatory input to the central nervous system as well as the inhibitory input, via inhibitory interneurons, decreases. It appears that the result is a disturbance of the normal balance between excitation and inhibition in structures such as the inferior colliculus, thalamus, and cortex, and likely also in the dorsal cochlear nucleus. This imbalance appears to be temporary, and lasts approximately one month in experimental animals. It is during this critical period after noise trauma that large changes happen in the frequency-place representation (the tonotopic maps) in the thalamus and cortex, in the excessive response to loud sounds (recruitment) in the midbrain, thalamus and cortex, and in the spontaneous firing (tinnitus) from the cochlear nucleus to the cortex. After the critical period, these changes appear ingrained in the working of the central nervous system, and any therapy becomes tedious.

Changes in Tonotopic Maps

There is a gradual change in the response of the basilar membrane to low-level tones with different frequencies. High frequencies (>10 kHz) produce maximal basilar membrane vibration near the base, whereas low frequencies (<200 Hz) mostly vibrate the basilar membrane near the apex, with each octave being up to 4 mm further along the basilar membrane. This cochlear frequency map is copied along the auditory pathway up to the primary auditory cortex on Heschl's gyrus. In the cat, five of the 13 auditory cortical areas have such a tonotopic organization; the one in the primary auditory cortex has been studied the most intensely. Exposing an adult cat to a 1/3 octave band of noise with a center frequency of 5 kHz for two hours at 120 dB SPL, which after about three weeks produces a permanent change in the representation of CFs along the surface of the primary auditory cortex. Let us assume that the induced hearing loss, as measured by ABR, is about 40 dB for frequencies above 8 kHz (as is on average the case). It now appears that the region of cortex that normally was most sensitive to 8–40 kHz, is now most sensitive to frequencies of about 6 kHz, the highest frequency which still has a near-normal hearing threshold. Thus the neurons in a large area of cortex now have CFs equal to 6 kHz. Similar tonotopic map changes can be found in the auditory thalamus, but are not as clear in the inferior colliculus, and are not present at all in the cochlear nucleus. This will be different when neonatal animals are noise exposed, where tonotopic map changes have been clearly demonstrated in the inferior colliculus, and may occur at brainstem locations as well. Do these map changes provide any benefit? One would expect that having more neurons available tuned to 6 kHz would allow one better frequency discrimination around this frequency. This appears to be the case but the effect is minimal, albeit statistically significant. One would also expect that the excess of neurons tuned to 6 kHz might contribute to recruitment at that frequency.

Changes in Loudness Representation

It appears that the central effects of noise trauma, i.e., causing the imbalance between neural excitation and inhibition, are mostly negative. One of these negative aspects is the emergence of loudness recruitment. We all have learned that the presence of loudness recruitment is a diagnostic indicator for a cochlear sensorineural hearing loss. This is of course correct, but it does not mean that the recruitment phenomenon is generated in the cochlea. Loudness recruitment has been equated with an abnormally steep increase in loudness with increase in stimulus level. Thus, neuroscientists (Heinz et al. 2005; Salvi et al. 1983; Wang et al. 2002) started to look at the firing rate-level functions for individual neurons and for compound action potentials and other auditory evoked potentials. For individual auditory nerve fibres there was no evidence for steeper rate-level functions after noise trauma, nor was there in the amplitude-level functions for the compound action potential of the auditory nerve (equivalent to wave I in the ABR). The local field potentials in the rat's cochlear nucleus also did not show steeper amplitude-level functions, and in fact were comparable to those for the auditory nerve. However, the local field potentials in the inferior colliculus showed the expected steep and over-recruiting amplitude-level functions. The same was found in the auditory cortex. Thus, under the assumption that loudness recruitment is the result of increased firing rate (or amplitude)-level functions, the phenomenon clearly originates only at the level of the auditory midbrain and higher. It is therefore a central nervous system phenomenon and not a cochlear one.

Preventing Maladaptive Changes in the Brain

Assume, as we did above, that the changes in the cortical tonotopic map are the result of an imbalance in central excitation and inhibition, resulting from reduced spontaneous and stimulus-induced activity in auditory nerve fibres after noise trauma. Then ameliorating that difference by either amplifying sound in the hearing loss range, or, as we had to do in the cats, providing continuous ambient sound in the frequency range of the hearing loss, should prevent tonotopic map changes. This is indeed what happened. Immediately after the noise trauma (5 kHz, 120 dB SPL, 4 hours) we put the animals in a room with 4–20 kHz dynamic multi-frequency sound presented at 80 dB SPL (about 40 dB above the estimated hearing loss) for 24 hours/day, 7 days/week, and for at least 3 weeks. The hearing loss in the 6–8 kHz range due to hair cell loss remained, whereas the hearing loss in the higher frequencies resulting from neurotoxic effects disappeared completely. Despite the remaining hearing loss of about 40 dB in the 6–8 kHz range the tonotopic map was normal (Noreña and Eggermont, 2005). This indicates that it is the balance of excitatory and inhibitory activity that induces these central changes, not the hearing loss in itself. It also suggests that sound at modest level is needed as soon as possible after noise trauma to prevent maladaptive changes in cortical activity. This sound should have a frequency range that matches the hearing loss-low frequency sound matching the normal hearing part of the audiogram did not have any effect. It is not yet determined if a gradual accumulation of hearing loss would result in tonotopic map changes.

Latent Effects of Juvenile Exposure: An Age-noise Interaction.

Age-related and noise-induced hearing losses in humans are potentially potentiating each other. Kujawa and Liberman (2006) addressed this in an animal model by comparing noise-induced and age-related hearing loss in groups of mice exposed to a one octave (8–16 kHz) noise band at 100 dB SPL for two hours but at different ages (4–124 weeks) and held with unexposed mice for 2–96 weeks post exposure. When evaluated two weeks after exposure, maximum threshold shifts in young-exposed animals were 40–50 dB; older-exposed animals showed essentially no shift at the same post exposure time. In addition, when young-exposed animals were held for long post exposure times, they also showed ongoing deterioration of cochlear neural responses, without change in hair cell activity, but with evidence of primary neural degeneration throughout the cochlea. This was not evident in the older-exposed mice. This suggests that pathologic changes initiated by early noise exposure render the inner ears significantly more vulnerable to aging. It also suggests that young ears are much more vulnerable to noise-induced hearing loss than adult ones.

Age-related hearing loss often diminishes the ability to discriminate speech signals, especially in noise. This is attributable, in part, to a loss in temporal resolving power and ability to adjust the dynamic range of the neurons. Circuits in the adult dorsal cochlear nucleus (DCN) can preserve signals in the presence of background noise. The major DCN output neurons receive excitatory input from auditory nerve fibres as well as inhibitory inputs from other cells in the DCN. This inhibition normally results in decreased tone-evoked activity as sound level is increased at frequencies adjacent to the CF. The output of the DCN to the midbrain is determined by this inhibition. Caspary et al. (2005) investigated the impact of aging on this processing in the DCN. They compared the response properties of DCN output cells in young and aged rats. In aged animals there were significantly higher maximum discharge rates to CF tones compared to young-adult animals. In addition there was a tendency for increased spontaneous firing rates in aged rats. These findings suggest an age-related reduction in inhibitory neurotransmitter function.

Thus, aging effects can be demonstrated in the auditory nerve and cochlear nucleus and may potentiate pre-existing changes in the cochlea. In particular the loss of inhibition in the DCN may set up a chain of changes in more central parts of the auditory system that may be enhancing loudness as well as spontaneous activity. This may lead to over recruitment and tinnitus.

Brain Plasticity and Dealing with Hearing Loss.

Homeostatic mechanisms in the adult brain tend to keep the average firing rate of a given neuron approximately constant. If the input from parts of the auditory periphery is reduced, e.g., by noise-induced hearing loss, the gain of the relevant synapses is increased. Applying a hearing aid, increases activity in nerve fibres innervating inner hair cells in the hearing loss range, and also will induce changes in the gain of neurons in the central auditory system. The adult auditory system changes its gain to simple interferences such as plugging the ears for a few weeks or exposing to low-level noise continuously for a few weeks as Formby et al. (2003) demonstrated. In the first case, the central gain was increased and all sounds now were rated louder than before the introduction of ear plugs. In the second case the opposite effect was noted, sounds were now rated as less loud than before the low-level noise exposure. It is thus not surprising that changes in the auditory environment as produced by hearing loss or hearing aids will cause slow changes in the central auditory system. There is likely not the same plasticity in all patients and the ability to adapt may also be age dependent.

Tinnitus

Is tinnitus in the ear or in the brain? Tinnitus sensations associated with hearing loss are nearly always localized towards the affected ear(s). Does this mean that tinnitus is generated in the ear? This somewhat contentious issue, which has great implications for the types of treatment that should be developed, and can only be resolved in animal models that are conditioned to signal the presence of tinnitus following application of either salicylate or excessive noise. Tinnitus resulting from head and neck injury also localizes to the ipsilateral ear and obviously there are no changes in that ear. Early on, in cases of truly debilitating tinnitus, a common surgical procedure was to cut the auditory nerve from the tinnitus ear in order to abolish tinnitus. However, the tinnitus sensation in most cases persisted after section of the auditory nerve. This suggests that localizing the source of tinnitus it is not so simple. In most cases it is indeed initiated by processes in the ear, and this is likely also the case for the very short transient forms of tinnitus and potentially also in some temporary forms lasting less than a few weeks. However, most chronic tinnitus is of central origin and its generation site has shifted to the brain.

Tinnitus is generally attributable to a phantom sensation and not unlike that related to those sensations or pains experienced after losing a digit or more severely a limb. Itch on a non-existent part of the body is truly annoying and so is tinnitus. The pitch of tinnitus corresponds, when there is a hearing loss, to the frequency region of that hearing loss. In case of low-frequency hearing loss (as in Ménière's disease) the tinnitus is low pitched, and in the more frequent cases of high-frequency hearing loss the pitch of the tinnitus corresponds to a high ringing or hissing sound. The brain "hears" the sound of the missing frequencies in the ear: a true phantom sensation.

Not all persons with sensorineural hearing loss have tinnitus or do complain about tinnitus. In other words, cochlear damage does not always result in tinnitus. It is likely that differences in central auditory processing are at the origin of this finding. Conversely, not all persons with tinnitus have a hearing loss; about 70 to 80% of tinnitus patients have "significant hearing difficulties." This suggests that the phantom sound idea does not universally work and that tinnitus is not a unitary concept. There may be various underlying pathologies that all result in some form of tinnitus; identifying these various causes is the first step in tailoring appropriate and effective treatments.

We found that providing an enhanced acoustic environment (4–20 kHz, see above) not only prevented changes in the tonotopic map, but also prevented the increase in spontaneous firing rate that is commonly found after noise trauma and that one generally considers a biological substrate of tinnitus (Noreña and Eggermont, 2006). Thus, the imbalance of excitation and inhibition is important for the initiation of tinnitus as

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well. Consequently, providing a hearing aid that provides output in the frequency range of the hearing loss (including the high frequencies up to 12 kHz if needed) will first of all mask the tinnitus to some extent, secondly will provide a more balanced input to the brain so that plastic changes may be initiated. These changes will be more difficult to effectuate the longer the tinnitus exists, but relief could still be attainable.

Things to Think About

It should be noted that the research mentioned in this paper was with animals and extrapolation to humans may not be valid. Paying attention to the fact that most complaints of persons with hearing loss are central in origin can be beneficial for counselling and treatment. Plastic changes in the adult brain usually take some time to manifest themselves, so do not expect optimal responses to a treatment for hearing loss or hearing problems to occur within the first three months. The universal influence of the acoustic environment for successful treatment puts more emphasis on the use of appropriate hearing aids: these need likely be differently fitted for aiding speech in noise, for listening to music, and for the alleviation of tinnitus.

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