Volume 2 • Number 4 • December 2012 ISSN 2083-389X

# Journal of Hearing Science®

Editor-in-Chief
**Prof. Henryk Skarzynski, M.D., Ph.D., Dr. h.c.**

**In this issue:**



***With contributions from the Presbycusis Research Meeting, Munich, January 2012***



INSTITUTE OF SENSORY ORGANS www.journalofhearingscience.com

# Journal of Hearing Science®

**Journal of Hearing Science®** is an international, peer-reviewed scientific journal that publishes original articles in all areas of Otolaryngology, Audiology, Phoniatrics, and Rhinology. JHS is issued 4 times per year in printed form and in electronic form at www.journalofhearingscience.com. JHS is issued primarily as an electronic open access (OA) journal.

The JHS editors endorse the principles embodied in the **Declaration of Helsinki** and expect that all investigations involving humans will have been performed in accordance with these principles. For animal experimentation reported in the journal, it is expected that investigators will have observed the **Interdisciplinary Principles and Guidelines for the Use of Animals in Research, Testing, and Education** issued by the New York Academy of Sciences Adhoc Committee on Animal Research. All human and animal studies must have been approved by the investigator's Institutional review board.

• **Review process.** Manuscripts are evaluated on the basis that they present new insights to the investigated topic, are likely to contribute to a research progress or change in clinical practice or in thinking about a disorder. It is understood that all authors listed on a manuscript have agreed to its submission. The signature of the corresponding author on the letter of submission signifies that these conditions have been fulfilled.

Received manuscripts are first examined by the JHS editors. Manuscripts with insufficient priority for publication are rejected promptly. Incomplete packages or manuscripts not prepared in the advised style will be sent back to authors without scientific review. The authors are notified with the reference number upon manuscript registration at the Editorial Office. The registered manuscripts are sent to independent experts for scientific evaluation. We encourage authors to suggest the names of possible reviewers, but we reserve the right of final selection. The evaluation process usually takes 1–3 months. Submitted papers are accepted for publication after a positive opinion of the independent reviewers.

• **Conflict of interests**. Authors of research articles should disclose at the time of submission any financial arrangement they may have with a company whose product figures prominently in the submitted manuscript or with a company making a competing product. Such information will be held in confidence while the paper is under review and will not influence the editorial decision, but if the article is accepted for publication, the editors will usually discuss with the authors the manner in which such information is to be communicated to the reader.

Because the essence of reviews and editorials is selection and interpretation of the literature, the Journal expects that authors of such articles will not have any financial interest in a company (or its competitor) that makes a product discussed in the article.

Journal policy requires that reviewers, associate editors, editors, and senior editors reveal in a letter to the Editor-in-Chief any relationships that they have that could be construed as causing a conflict of interest with regard to a manuscript under review. The letter should include a statement of any financial relationships with commercial companies involved with a product under study.

• **Permissions.** Materials taken from other sources must be accompanied by a written statement from both author and publisher giving permission to the Journal for reproduction. Obtain permission in writing from at least one author of papers still in press, unpublished data, and personal communications.

• **Patients confidentiality.** Changing the details of patients in order to disguise them is a form of data alteration. However authors of clinical papers are obliged to ensure patients privacy rights. Only clinically or scientifically important data are permitted for publishing. Therefore, if it is possible to identify a patient from a case report, illustration or paper, JHS Editors ask for a written consent of the patient or his/her guardian to publish their data, including photograms prior to publication. The description of race, ethnicity or culture of a study subject should occur only when it is believed to be of strong influence on the medical condition in the study. When categorizing by race, ethnicity or culture, the names should be as illustrative as possible and reflect how these groups were assigned.

• **Copyright transfer.** Upon acceptance, authors transfer copyright to the Journal of Hearing Science. Once an article is accepted for publication in JHS, the information therein is embargoed from reporting by the media until the mail date of the issue in which the article appears.

Upon acceptance all published manuscripts become the permanent property of the Institute of Sensory Organs, the Publisher of the Journal of Hearing Science, and may not be published elsewhere without written permission from the Publishing Company.

• **Disclaimer.** Every effort is made by the Publisher and Editorial Board to see that no inaccurate or misleading data, opinion or statement appear in the Journal of Hearing Science. However, they wish to make it clear that the data and opinions appearing in the articles and advertisements herein are the responsibility of the contributor, sponsor or advertiser concerned. Accordingly, the Publisher and the Editorial Board accept no liability whatsoever for the consequences of any such inaccurate of misleading data, opinion or statement. Every effort is made to ensure that drug doses and other quantities are presented accurately. Nevertheless, readers are advised that methods and techniques involving drug usage and other treatments described in this Journal, should only be followed in conjunction with the drug or treatment manufacturer's own published literature in the readers own country.

• **Publishing model**. The submission, peer-review, and publishing of manuscripts is free of charge.

**MANUSCRIPTS**

Editorial Board takes under consideration for publication original articles with the understanding that neither the manuscript nor any part of its essential substance, tables or figures have been published previously in print form or electronically and are not taken under consideration by any other publication or electronic medium. Copies of any closely related manuscripts should be submitted to the Editor along with the manuscript that is to be considered by the Journal. The Journal discourage s the submission of more than one article dealing with related aspects of the same study.

Each submission packet should include the statement signed by the first author that the work has not been published previously or submitted elsewhere for review and a copyright transfer.

**Criteria for Manuscripts may be found at our website**
***http://www.journalofhearingscience.com***

Volume 2 • Number 4 • December 2012 ISSN 2083-389X

# Journal of Hearing Science®

Editor-in-Chief

**Prof. Henryk Skarzynski, M.D., Ph.D., Dr. h.c.**

INSTITUTE OF SENSORY ORGANS www.journalofhearingscience.com

Volume 2 ▪ Number 4 ▪ December 2012

# Table of contents:

## Editorial



## Original articles



## Case Report



## Extended Abstracts

## Reports

Volume 2 ▪ Number 4 ▪ December 2012

Dear Colleagues,

This issue of the *Journal of Hearing Science* is to large extent devoted to the Presbycusis Research Meeting that was held in Munich on 13–14 January 2012.

Our understanding of the biological underpinnings of presbycusis is still at an early stage. Although the majority of hearing impairments in older adults include a cochlear component – similar to that seen in many younger adults – the auditory systems of older people may be damaged in ways that are not typical of the young. Moreover, hearing involves top–down influences, including cognitive elements of attention, memory, motivation, emotion, and learning. This means that older people have a higher prevalence of both cochlear and cognitive impairments. Damage at multiple sites – peripheral and central – will contribute to differences in auditory processing that affect listening, comprehending, and communicating.

In order to design, configure, and deliver interventions suitable for older adults, we must therefore advance our understanding of how both auditory and non-auditory aspects of ageing come together to alter how a person listens, comprehends, and communicates – functions that are crucial for participating in daily life. Towards this end, the Presbycusis Research Meeting covered a broad range of topics: population characteristics; anatomy and physiology of the aged ear; evaluation methods and current treatment of older adults; cognitive contributions to hearing in older people; genetics and presbycusis; and social aspects and other health considerations. The meeting concluded with a round table on future directions in presbycusis research, with panelists Helge Rask-Andersen, Blake Wilson, Jane Opie, Christoph von Ilberg, and Marty Woldorff.

I especially recommend a paper "Hearing and psychophysics: implications for individuals with presbycusis considering cochlear implantation" by René H. Gifford and colleagues. This insightful work is followed by extended abstracts from other participants at the meeting.

I express my gratitude to Jane Opie for her help in preparing this issue of JHS.

With kind regards and greetings,

*Prof. Henryk Skarzynski, M.D., Ph.D., Dr.h.c.*

# Original articles

# HEARING, PSYCHOPHYSICS, AND COCHLEAR IMPLANTATION: EXPERIENCES OF OLDER INDIVIDUALS WITH MILD SLOPING TO PROFOUND SENSORY HEARING LOSS

**René H. Gifford[1], Michael F. Dorman[2], Chris Brown[3], Anthony J. Spahr[1,4]**

[1] Vanderbilt University, Department of Hearing and Speech Sciences, Nashville, TN 37232, U.S.A.
[2] Arizona State University, Department of Speech and Hearing Science, Tempe, AZ 85287, U.S.A.
[3] University of Pittsburgh, Department of Communication Science and Disorders (CSD), Pittsburgh, PA 15260, U.S.A.
[4] Advanced Bionics, Department of Research and Technology, Valencia, CA 91355, U.S.A.

**Corresponding author:** René H. Gifford, Vanderbilt University, Department of Hearing and Speech Sciences, Nashville, TN 37232, U.S.A., e-mail: rene.h.gifford@vanderbilt.edu

**Abstract**

In a previous paper we reported the frequency selectivity, temporal resolution, nonlinear cochlear processing, and speech recognition in quiet and in noise for 5 listeners with normal hearing (mean age 24.2 years) and 17 older listeners (mean age 68.5 years) with bilateral, mild sloping to profound sensory hearing loss (Gifford et al., 2007). Since that report, 2 additional participants with hearing loss completed experimentation for a total of 19 listeners. Of the 19 with hearing loss, 16 ultimately received a cochlear implant. The purpose of the current study was to provide information on the pre-operative psychophysical characteristics of low-frequency hearing and speech recognition abilities, and on the resultant postoperative speech recognition and associated benefit from cochlear implantation. The current *preoperative* data for the 16 listeners receiving cochlear implants demonstrate: 1) reduced or absent nonlinear cochlear processing at 500 Hz, 2) impaired frequency selectivity at 500 Hz, 3) normal temporal resolution at low modulation rates for a 500-Hz carrier, 4) poor speech recognition in a modulated background, and 5) highly variable speech recognition (from 0 to over 60% correct) for monosyllables in the bilaterally aided condition. As reported previously, measures of auditory function were not significantly correlated with pre- or post-operative speech recognition – with the exception of nonlinear cochlear processing and preoperative sentence recognition in quiet ($p$=0.008) and at +10 dB SNR ($p$=0.007). These correlations, however, were driven by the data obtained from two listeners who had the highest degree of nonlinearity and preoperative sentence recognition. All estimates of postoperative speech recognition performance were significantly higher than preoperative estimates for both the ear that was implanted ($p$<0.001) as well as for the best-aided condition ($p$<0.001). It can be concluded that older individuals with mild sloping to profound sensory hearing loss have very little to no residual nonlinear cochlear function, resulting in impaired frequency selectivity as well as poor speech recognition in modulated noise. These same individuals exhibit highly significant improvement in speech recognition in both quiet and noise following cochlear implantation. For older individuals with mild to profound sensorineural hearing loss who have difficulty in speech recognition with appropriately fitted hearing aids, there is little to lose in terms of psychoacoustic processing in the low-frequency region and much to gain with respect to speech recognition and overall communication benefit. These data further support the need to consider factors beyond the audiogram in determining cochlear implant candidacy, as older individuals with relatively good low-frequency hearing may exhibit vastly different speech perception abilities – illustrating the point that signal audibility is not a reliable predictor of performance on supra-threshold tasks such as speech recognition.

**Key words:** cochlear implant • older • aging • psychoacoustic function • low-frequency hearing • bimodal • frequency resolution • temporal resolution • speech recognition

## AUDICIÓN, PSICOFÍSICA E IMPLANTES COCLEARES: EXPERIENCIAS DE INDIVIDUOS MAYORES CON PÉRDIDA AUDITIVA SENSORIAL DE LEVE A PROFUNDA

**Resumen**

En un artículo anterior, informamos de la selectividad de frecuencia, la solución temporal, el procesamiento coclear no lineal y el reconocimiento de voz en silencio y en ruido para 5 oyentes con audición normal (edad media de 24,2 años) y 17 oyentes mayores (edad media de 68,5 años) con pérdida auditiva sensorial bilateral de suave a profunda (Gifford et al., 2007). Desde ese informe, 2 participantes adicionales con pérdida auditiva completaron la experimentación llegando a un total de 19 oyentes. De los 19 con pérdida auditiva, 16 recibieron finalmente un implante coclear. El propósito del actual estudio era informar sobre las

características psicofísicas preoperatorias de la audición de baja frecuencia y las capacidades de reconocimiento de voz, así como sobre el reconocimiento postoperatorio de voz resultante y el beneficio asociado de los implantes cocleares. Los actuales datos preoperatorios de los 16 oyentes que recibieron un implante coclear demuestran: 1) un procesamiento coclear no lineal reducido o ausente a 500 Hz, 2) una selectividad de frecuencia disminuida a 500 Hz, 3) una resolución temporal normal a un índice de modulación bajo para una portadora de 500 Hz, 4) un reconocimiento de voz pobre en un fondo modulado, y 5) un reconocimiento de voz altamente variable (desde 0 hasta más del 60% correcto) para monosílabos en condiciones de ayuda bilateral. Como se informó anteriormente, las mediciones de la función auditiva no estaban significativamente correlacionadas con el reconocimiento de voz preoperatorio y postoperatorio, a excepción del procesamiento coclear no lineal y el reconocimiento preoperatorio de frases en silencio (p=0.008) y a +10 dB SNR (p=0.007). Sin embargo, estas correlaciones estaban motivadas por los datos obtenidos de dos oyentes que tenían el grado más alto de no linealidad y reconocimiento preoperatorio de frases. Todas las estimaciones de rendimiento del reconocimiento de voz postoperatorio fueron significativamente más altas que las estimaciones preoperatorias tanto para el oído donde se colocó el implante (p<0.001) como para la condición con la ayuda más adecuada (p<0.001). Podemos concluir que los individuos mayores con pérdida auditiva sensorial de suave a profunda tenían muy pocas o ninguna función coclear no lineal residual, lo que resultó en una selectividad de frecuencia disminuida y un reconocimiento de voz pobre en ruido modulado. Estos mismos individuos exhiben una mejora significante en el reconocimiento de voz tanto en silencio como en ruido después de colocar el implante coclear. Para los individuos mayores con pérdida auditiva sensorial de suave a profunda que tienen dificultades para reconocer la voz con audífonos debidamente ajustados, hay poco que perder en cuanto al procesamiento psicoacústico en la región con baja frecuencia y mucho que ganar en cuanto al reconocimiento de voz y los beneficios generales en la comunicación. Estos datos corroboran la necesidad de considerar otros factores diferentes al audiograma para determinar los candidatos a un implante coclear, ya que los individuos mayores con una audición de baja frecuencia relativamente buena muestran capacidades de percepción de la voz enormemente diferentes, ilustrando el punto de que la audibilidad de las señales no permite predecir de manera fiable el rendimiento en tareas de supraumbral como el reconocimiento de voz.

## СЛУХ, ПСИХОФИЗИКА И КОХЛЕАРНАЯ ИМПЛАНТАЦИЯ: ОПЫТЫ С УЧАСТИЕМ СТАРШИХ ЛЮДЕЙ – ИМЕЮЩИХ ОТ ЛЕГКОГО СНИЖЕНИЯ ДО ПОЛНОЙ СЕНСОРНОЙ ПОТЕРИ СЛУХА

### Резюме

В предыдущей исследовательской работе мы описывали частотную селективность, разрешающую способность по времени, нелинейную кохлеарную обработку и распознавание речи в тишине и при шуме у 5 слушателей с нормальным слухом (средний возраст 24,2 лет) и 17 старших слушателей (средний возраст 68,5 лет) с билатеральным легким снижением и с полной сенсорной потерей слуха (Гиффорд et al., 2007). С тех пор закончило эксперимент два дополнительных участника с потерей слуха, всего – 19 слушателей. 16 из 19 с потерей слуха в конечном итоге получили кохлеарный имплант. Цель нынешнего исследования – дать информацию относительно предоперационной психофизической характеристики восприятия звуков низкой частоты, способностей распознавания речи, в последствии постоперационного распознавания речи и связанных с этим преимуществ кохлеарной имплантации. Актуальные предоперационные данные относительно 16 слушателей, получающих кохлеарные импланты, показывают: 1) пониженную или отсутствующую нелинейную кохлеарную обработку при 500 Гц, 2) ослабленную частотную селективность частоты при 500 Гц, 3) нормальную разрешающую способность по времени при низких уровнях модуляции несущей 500 Гц, 4) слабое распознавание речи на модулированном фоне и 5) высоко изменчивое распознавание речи (правильное - от 0 до более 60%) для односложных слов с билатеральным вспомоганием. Согласно предыдущему докладу, измерения слуховой функции не имели значительной связи с пред- или постоперационным распознаванием речи – за исключением нелинейной кохлеарной обработки и предоперационнго распознавания предложений в тишине (p=0.008) и при +10 дБ SNR (p=0.007). Однако эти соотношения были вызваны данными, полученными от двух слушателей, у которых имелась нелинейность самого высокого уровня и предоперационное распознавание предложений. Все оценки постоперационного распознавания речи были значительно выше, чем предоперационные оценки для уха, в которое был вставлен имплант (p<0.001) и в состоянии с самыми лучшими вспомогательными устройствами (p<0.001). Можно сделать выводы, что старшие люди с легким снижением и с полной сенсорной потерей слуха имеют очень незначительную или отсутствующую остаточную нелинейную кохлеарную функцию, что ведет к ослабленной частотной селективности, а также к слабому распознаванию речи при модулированном шуме. У этих людей, вследствие кохлеарной имплантации, наступило очень значительное улучшение распознавания речи в тишине и при шуме. Старшим людям, имеющим от легкого снижения до полной сенсонейронной потери слуха, у которых были проблемы с распознаванием речи с соответственно вставленными слуховыми вспомогательными устойствами, нечего терять, имея в виду психоакустическую обработку в низкочастотной области, но они могут много выиграть, учитывая распознавание речи и общие коммуникационные преимущества. Эти данные еще более подтверждают необходимость рассмотрения факторов за пределами аудиограммы для определения кандидатур на кохлеарную имплантацию, так как старшие люди с относительно хорошим низкочастотным слухом могут проявлять очень разные способности распознавания речи – иллюстрируя проблему сигнальной аудиоспособности, которая не является достоверной предпосылкой выполнения надпороговых заданий, таких как распознавание речи.

## Background

Individuals with considerable low-frequency hearing are receiving cochlear implants at an increasing rate. Current U.S. Food and Drug Administration (FDA) labeled candidacy indications include individuals with moderate sloping to profound sensorineural hearing loss. Thus it is logical that greater attention has been placed on understanding and describing the psychoacoustic properties of low-frequency hearing (e.g., Gifford et al., 2007, 2010; He et al., 2008; Brown and Bacon, 2009; Peters and Moore, 2002) since individuals are combining electric and acoustic hearing either across ears (bimodal hearing) or within the same ear in cases of hearing preservation with cochlear implantation.

Psychophysical estimates of frequency selectivity obtained by deriving auditory filter (AF) shapes using the notched-noise method (Patterson et al., 1982) have shown frequency selectivity to be negatively correlated with audiometric threshold at the signal frequency ($f_s$) (e.g., Peters and Moore, 1992). Thus for individuals with even mild to moderate hearing loss in the lower frequency region, impaired frequency selectivity is not unexpected. Broadened auditory filters associated with impaired frequency selectivity can result in broadened auditory filters, which smear speech spectra across adjacent filters resulting in significantly poorer speech intelligibility, particularly in the presence of background noise (e.g., Baer and Moore, 1994; Moore and Glasberg, 1993).

Audiometric threshold is also negatively correlated with nonlinear cochlear processing. In other words, increases in sensory hearing loss are associated with greater dysfunction and/or destruction of outer hair cells – which are responsible for the active or nonlinear cochlear mechanism. Individuals with mild to moderate hearing loss are expected to demonstrate reduced nonlinear cochlear processing, a mechanism responsible for high sensitivity, broad dynamic range, sharp frequency tuning, and enhanced spectral contrasts via suppression. Thus, any reduction in the magnitude of the nonlinearity may result in one or more functional deficits, including impaired speech recognition.

Given the known relationships between hearing loss, active cochlear mechanics, and spectral resolution, one might hypothesise that individuals with hearing loss rely more heavily upon temporal resolution for speech and sound recognition. Research has shown that temporal resolution in the apical cochlea of individuals with relatively good low-frequency hearing should be comparable to that of a normal-hearing listener under conditions of the same restricted listening bandwidth (e.g., Bacon and Viemeister, 1985; Bacon and Gleitman, 1992). Thus, it is reasonable to believe that when combining acoustic and electric hearing in bimodal listening, normal or near-normal low-frequency acoustic temporal resolution will be associated with high speech recognition performance.

Speech recognition in the presence of a temporally modulated background noise (as compared to a steady-state noise) provides an estimate of the degree of masking release or the listener's ability to *listen in the dips*. Past research has shown that listeners with hearing loss (e.g., Bacon et al., 1998) and listeners with cochlear implants (e.g., Nelson et al., 2003) demonstrate either a reduced or an absent masking release relative to listeners with normal hearing. It is believed that the degree of masking release represents a functional measure of temporal resolution. In particular, the masking of speech by 100% modulated noise is probably dominated by forward masking (e.g., Bacon et al., 1998) – for which temporal resolution will impact performance. Qin and Oxenham (2003) examined the effects of simulated cochlear-implant processing on speech perception in quiet, steady-state maskers and in temporally fluctuating maskers. They found that even with a large number of processing channels, the effects of simulated implant processing were more detrimental to speech intelligibility in the presence of the temporally complex masker than in the steady-state masker. Thus, speech perception measures in a temporally fluctuating background may provide a more realistic description of the listening and recognition difficulties experienced by cochlear implant recipients.

In a previous study, we reported on the psychophysical measures of frequency selectivity, temporal resolution, nonlinear cochlear processing, and speech recognition in quiet and in noise, for 5 listeners with normal hearing (mean age 24.2 years) and 17 listeners (mean age 68.5 years) with bilateral sensory hearing loss with audiograms that would have qualified for the North American clinical trial of Med El's electric and acoustic stimulation (EAS) device or the Nucleus Hybrid implant (Gifford et al., 2007). Since that report, 2 additional participants with hearing loss completed experimentation, for a total of 19 listeners. Of the 19 with hearing loss, 16 ultimately received a cochlear implant. Thus the purpose of the current project was to provide, for these 16 older individuals with mild sloping to profound sensory hearing loss, information on the pre-operative psychophysical characteristics of low-frequency auditory function and speech recognition, and on the resultant postoperative speech recognition and associated benefit from cochlear implantation.

## Methods

### Participants

Exactly 16 participants (12 male, 4 female) with hearing loss were evaluated. The participants had been previously recruited for a preoperative study examining psychophysical function of low-frequency hearing (Gifford et al., 2007). All preoperative estimates of psychoacoustic function were obtained monaurally in the ear to be implanted as per the referenced 2007 study. These listeners then went on to receive a cochlear implant which allowed for a comparison of pre- and post-implant auditory function. The mean age was 67.7 years with a range of 48 to 85 years. All participants were paid an hourly wage for their participation. Figure 1 displays, for all participants, individual and mean preoperative audiometric thresholds for the implanted and non-implanted ears. The preoperative low-frequency pure tone average (LF PTA, mean threshold for 125, 250, and 500 Hz) in the ear to be implanted is also shown in Table 1. Preoperative inclusion criteria for the study required that all participants meet

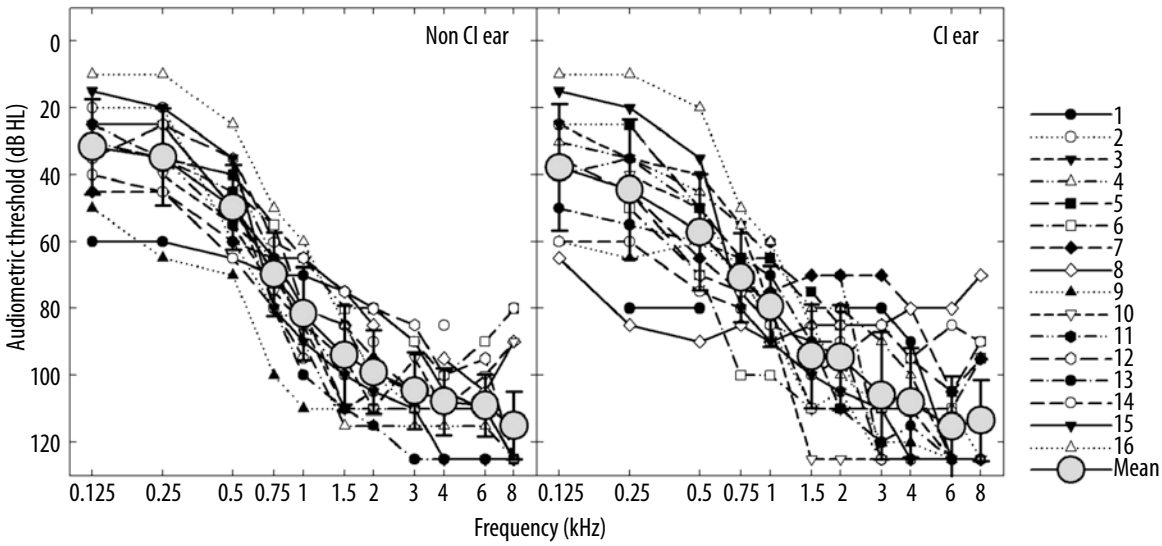



**Figure 1.** Individual and mean preoperative audiometric thresholds, in dB HL, for the ear to be implanted as well as the non-implanted ear. Error bars represent ±1 standard deviation.

audiometric threshold criteria for inclusion in the North American clinical trial of EAS as outlined by Med El Corporation (e.g., Gifford et al., 2007) or for the Nucleus Hybrid S8 device as outlined by Cochlear Americas (Gantz et al., 2009) for at least one ear. It is important to note, however, that although the listeners had EAS-qualifying audiograms, they did not undergo hearing preservation surgery with the EAS or the Hybrid device. Rather all study participants chose to undergo conventional cochlear implantation with a standard long electrode. Participant demographic data including age at implantation, device implanted, and months experience with implant at testing point are shown in Table 1.

## General laboratory procedures

Recorded speech recognition stimuli were presented in the sound field via a single loudspeaker placed in front of the subject (0° azimuth) at a distance of 1 meter. The calibrated presentation level for the speech recognition stimuli was 70 dB SPL (A weighted). Stimuli used in the measurement of low-frequency acoustic processing were presented monaurally via Sennheiser HD250 stereo headphones. All psychophysical testing utilised an adaptive, three-interval, forced-choice paradigm with a decision rule to track 79.4% correct (Levitt, 1971). Stimuli were generated and produced digitally with a 20-kHz sampling rate. All gated stimuli were shaped with 10-ms $\cos^2$ rise/fall times. All test stimuli were temporally centered within the masker. Interstimulus intervals were 300 ms in all masking experiments. Testing was completed in a double-walled sound booth.

## Stimuli and conditions

### *Frequency resolution*

As discussed in Gifford et al. (2007), frequency resolution was assessed by deriving auditory filter (AF) shapes using the notched-noise method (Patterson, 1976) in a simultaneous-masking paradigm. Each noise band (0.4 times $f_s$) was placed symmetrically or asymmetrically about the 500-Hz signal (Stone and Moore, 1992). The signal was fixed at 10 dB above absolute threshold [or 10 dB sensation level (SL)], and the masker level was varied adaptively. The masker and signal were 400 and 200 ms in duration, respectively.

### *Temporal resolution*

Temporal resolution was assessed via both amplitude modulation (AM) detection and speech recognition in temporally modulated noise. Amplitude modulation detection was assessed for modulation rates from 4 to 32 Hz, in octave steps. The 500-Hz carrier was fixed at 20 dB SL and gated with each 500-ms observation interval. Modulation depth was varied adaptively. Level compensation was applied to the modulated stimulus (Viemeister, 1979).

Speech recognition in temporally modulated noise was assessed via speech reception threshold (SRT) for the Hearing in Noise Test (HINT; Nilsson et al., 1994) using sentences in both steady-state (SS) and 10-Hz square wave (SQ, 100% modulation depth) noise. The noise spectrum was shaped to match the long-term average spectrum of the HINT sentences. The noise was fixed at an overall level of 70 dB SPL and the sentences were varied adaptively to achieve 50% correct. The SRT was achieved by concatenating two 10-sentence HINT lists that were presented as a single run. The last six presentation levels for sentences 15 through 20 were averaged to provide an SRT for that run. Two runs were completed per condition and the SRTs were averaged to yield a final SRT for each listening condition. Prior to data collection, every subject was presented with a trial run of 20 sentences for task familiarisation in both the bimodal and best-aided EAS listening conditions. The difference in the thresholds for the SS and SQ noises provides a measure of masking release or the listener's ability to "listen in the dips" to obtain information about the speech stimulus and is

**Table 1.** Individual and mean demographic data including age at implantation, device implanted, months experience with implant at test point, and preoperative low-frequency pure tone average (LF PTA) in the implanted ear, in dB HL. Also displayed are individual and mean psychoacoustic estimates of frequency selectivity [equivalent rectangular bandwidth (ERB) of the auditory filter in Hertz], nonlinear cochlear function (Schroeder phase effect, SPE, in dB), amplitude modulation (AM) detection thresholds [average of 16 and 32 Hz in dB (20 log m)], and the speech reception threshold (SRT, in dB SNR) for steady-state (SS) and square-wave (SQ) noise. All psychoacoustic data were obtained preoperatively in the ear to be implanted. A horizontal line indicates that auditory filter shape could not be derived. See results section for additional detail.

| Subject | Age at CI (yrs) | Device | Months experience | Pre-CI LF PTA (dB HL) | ERB (Hz) | SPE (dB) 500 Hz | Mean AM detection threshold 16–32 Hz | SRT (dB SNR) SS, SQ |
|---|---|---|---|---|---|---|---|---|
| 1 | 55 | CI24RE(CA) | 7 | 61.7 | – | –0.8 | –16.6 | >20, >20 |
| 2 | 78 | HR90K 1j | 8 | 33.3 | 276 | –1.5 | –17.7 | >20, >20 |
| 3 | 77 | CI24RE(CA) | 6 | 33.3 | 199 | 2.8 | –15.5 | 17, >20 |
| 4 | 85 | HR90K 1j | 6 | 35.0 | 235 | 2.0 | –17.4 | >20, >20 |
| 5 | 84 | HR90K 1j | 7 | 37.5 | 236 | 7.0 | –23.9 | 17.3, 16.0 |
| 6 | 80 | CI24RE(CA) | 5 | 36.7 | 259 | 2.8 | –16.7 | >20, >20 |
| 7 | 67 | CI24RE(CA) | 18 | 50.0 | 134 | 13.9 | –22.1 | 14.7, 11.7 |
| 8 | 47 | CI24RE(CA) | 39 | 33.3 | 232 | 5.6 | –18.5 | >20, >20 |
| 9 | 70 | CI24RE(CA) | 28 | 61.7 | – | 1.2 | –19.8 | >20, >20 |
| 10 | 77 | HR90K 1j | 12 | 47.5 | 222 | 0.5 | –21.3 | 16.3, 9.7 |
| 11 | 75 | HR90K 1j | 7 | 51.7 | 281 | 0.2 | –21.6 | >20, >20 |
| 12 | 64 | HR90K 1j | 18 | 31.7 | – | 5.0 | –20.9 | 8.0, 8.0 |
| 13 | 62 | HR90K 1j | 23 | 35.0 | 229 | 5.7 | –22.6 | 17.0, 13.0 |
| 14 | 62 | CI24RE(CA) | 20 | 50.0 | 178 | 2.7 | –24.0 | 15.7, 12.7 |
| 15 | 48 | CI24RE(CA) | 70 | 23.3 | – | –3.5 | –22.6 | >20, >20 |
| 16 | 52 | CI24RE(CA) | 15 | 15.0 | 338 | 15.8 | –18.7 | 10.7, 7.7 |
| Mean | 67.7 | N/A | 18.1 | 39.8 | 234.9 | 3.7 | –20.0 | 14.6, 11.3 |
| St dev | 12.5 | N/A | 16.8 | 12.9 | 52.2 | 5.2 | 2.8 | 3.4, 3.0 |

thought to reflect a measure of temporal resolution (e.g., Bacon et al., 1998).

### *Nonlinear cochlear processing*

Nonlinear cochlear processing was assessed via masked thresholds for 500-Hz signals in the presence of both positively scaled (m+) and negatively scaled (m–) Schroeder phase harmonic complexes (e.g., Schroeder, 1970; Lentz and Leek, 2001). The m+ and m– Schroeder phase harmonic complexes have identical flat envelopes as they are simply time-reversed versions of one another. However, the m+ complexes tend to be less effective maskers. Researchers have hypothesised that the difference in masking effectiveness results from the m+ complexes producing a more peaked response along the BM, coupled with fast-acting compression (e.g., Carlyon and Datta, 1997; Recio and Rhode, 2000; see also Oxenham and Dau, 2001) – an effect which is maximised when the phase curvature of the harmonic complex is equal, but in opposition to the phase curvature of the auditory filter in which the complex is centered. Masker overall level was fixed at 75 dB SPL (63.9 dB SPL per component) and signal level was varied adaptively. The masker spectrum ranged from 200 to 800 Hz with a fundamental frequency of 50 Hz. The durations of the masker and signal were 400 and 200 ms, respectively. The signal was placed in the temporal center of the masker.

### *Estimates of speech recognition in quiet and in noise*

Preoperative speech recognition was assessed for all participants for words, sentences, and sentences in noise in the sound field at a calibrated presentation level of 70 dB SPL. Word recognition was assessed using one 50-item list of the consonant-nucleus-consonant (CNC, Peterson and Lehiste, 1962) monosyllables. Sentence recognition was assessed using two 20-sentence lists of the AzBio sentences (Spahr et al., 2012) presented in quiet as well as at +10 and +5 dB SNR (4-talker babble). The same metrics and presentation levels were used for all listeners both pre- and post-implant.

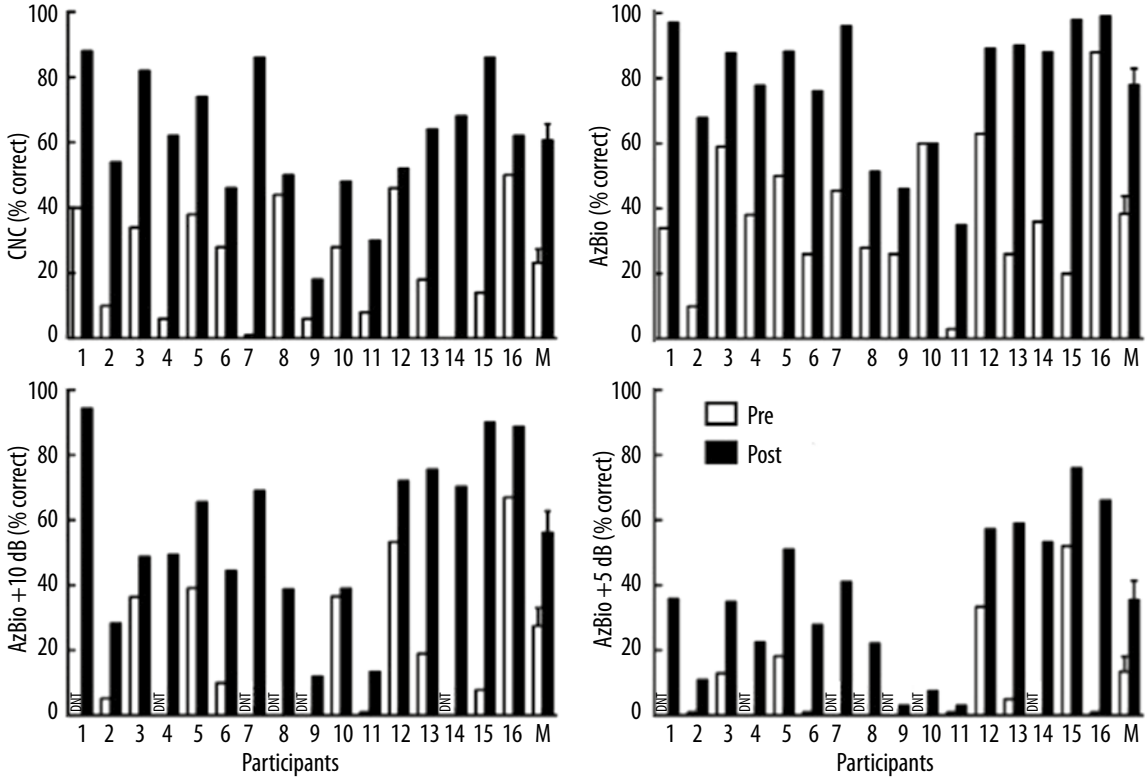



**Figure 2.** Individual and mean speech recognition scores for the ear that was implanted in the preoperative (unfilled bars) and postoperative (filled bars) conditions for CNC monosyllabic words, and AzBio sentences in quiet, at +5 dB, and at +10 dB SNR. Error bars represent ±1 standard error.

## Results

### Psychophysical estimates of auditory function

Auditory filter (AF) shapes were derived using a roex (*p,k*) model (Patterson et al., 1982) and the bandwidth was characterised in terms of equivalent rectangular bandwidth [(ERB), Glasberg and Moore, 1990]. The individual and mean preoperative AF bandwidth values for the implanted ears are shown in Table 1. AF shapes could not be derived for four of the participants (#1, 9, 12, and 15) given that the probe could not be masked for the widest notch condition at the highest allowable masker spectrum level (50 dB SPL); for these four listeners, the ERB values were listed as horizontal dashed lines indicating that the AF shape and corresponding ERB could not be determined. The mean AF width, and associated standard deviation, was 234.9 and 52.2 Hz, respectively (with a range of 134 to 338 Hz). As reported by Gifford and colleagues (2007), mean AF width for young listeners with normal hearing on this same task was 104 Hz with a range of 78 to 120 Hz. Thus even preoperatively, the participants with EAS-qualifying audiograms – who had relatively good low-frequency hearing – exhibited impaired frequency selectivity.

Individual and mean modulation detection thresholds for the temporal modulation transfer function (TMTF) averaged across 16 and 32 Hz are listed in Table 1. The mean modulation detection threshold averaged across 16 and 32 Hz was –20.0 dB with a range of –24.0 to –15.5. As reported in Gifford et al. (2007), the mean TMTF threshold averaged across 16 and 32 Hz for the normal-hearing listeners was –18.5 with a range of –23.2 to –11.8. Consistent with what was reported in our prior work, temporal resolution – as determined by modulation detection at relatively low rates – was normal in this population of hearing-impaired listeners.

Individual and mean SRTs for the preoperative HINT in both the steady-state (SS) and square-wave (SQ) background noises are listed in Table 1. Within the hearing-impaired group, there were 8 listeners who could not achieve 50% correct even at +20 dB SNR – these listeners' SRTs are displayed as >20. Mean SRTs for the 8 listeners who were able to complete the task for the SS noise and the 7 listeners able to complete the task for the SQ noise were 14.6 and 11.3 dB SNR, respectively. For the listeners with normal hearing reported in Gifford et al. (2007), mean SRTs were –2.7 and –17.5 dB SNR for the SS and SQ noises. Thus the normal-hearing listeners exhibited considerable temporal release from masking or the ability to listen in the dips. As compared to the listeners with normal hearing, the hearing-impaired listeners showed little to no benefit from listening in the dips of a modulated noise masker.

Estimates of nonlinear cochlear processing, as defined by the peak-to-valley threshold differences for the m+ and m– Schroeder-masked thresholds, are shown in Table 1 for individual participants as well as for the mean.

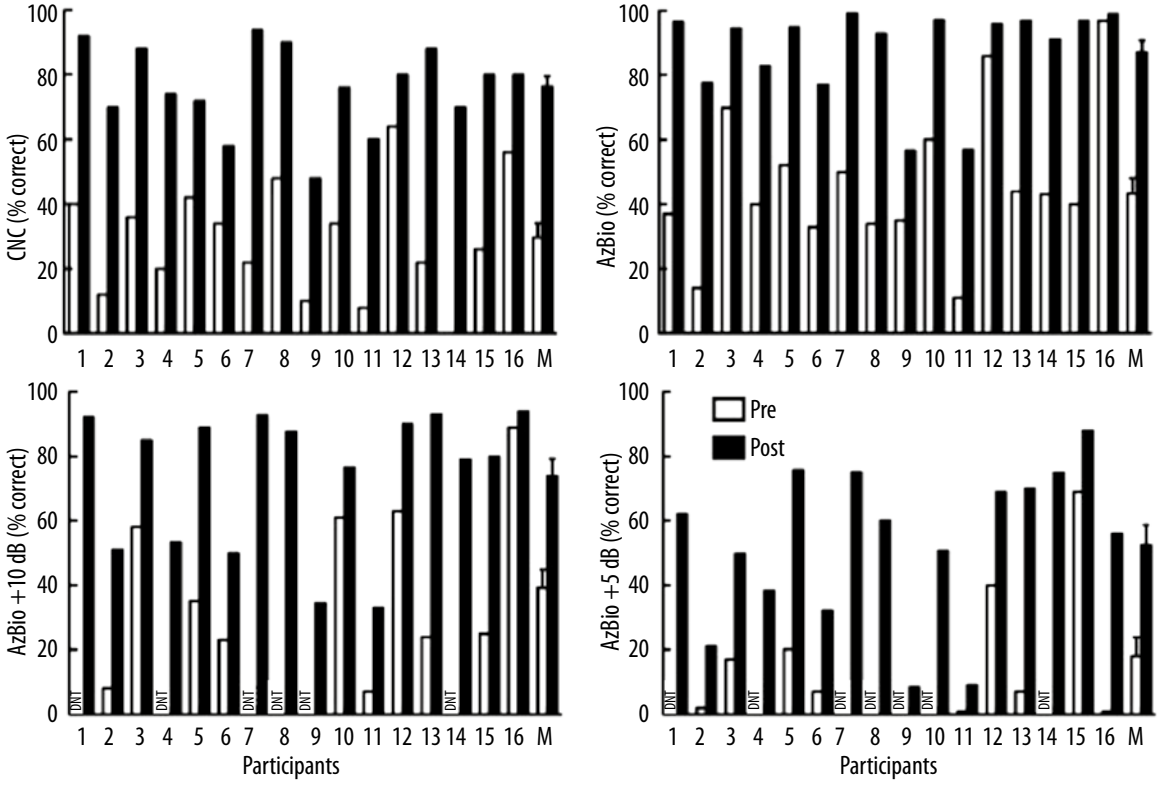



**Figure 3.** Individual and mean speech recognition scores for the best aided condition in the preoperative (unfilled bars, bilaterally aided) and postoperative (filled bars, bimodal hearing) conditions for CNC monosyllabic words, and AzBio sentences in quiet, at +5 dB, and +10 dB SNR. Error bars represent ±1 standard error.

The mean Schroeder phase effect (SPE) was 3.7 dB with a range of –3.5 to 15.8 dB. For the individuals with normal hearing in Gifford et al. (2007), the mean SPE was 18.0 with a range of 14.5 to 21.5 dB. Thus the majority of individuals with hearing loss exhibited little to no residual nonlinear cochlear function.

## Speech recognition

Individual and mean speech recognition scores for both the pre- and post-implant conditions are displayed in Figures 2 and 3 for the ear that was implanted as well as for the best-aided condition, respectively. For any given measure administered preoperatively, there was considerable variability across listeners, with inter-subject differences up to 85 percentage points for CNC word recognition. This variability represents nearly the entire range of possible scores for a group of individuals who had relatively similar preoperative EAS-like audiograms. Postoperatively, all participants exhibited improvement in performance for both the implanted ear as well as in the best-aided condition. At the group level, postoperative performance was significantly higher than preoperative performance for all measures tested. A two-way analysis of variance was completed with metric and test point (pre- *versus* post-implant) as the variables. The analysis revealed a highly significant effect of test point ($F_{(1,15)}$=53.5, $p$<0.001) such that postoperative performance was significantly higher than preoperative performance. There was also an effect of metric ($F_{(1,3)}$=31.1, $p$<0.001) which was not unexpected given that performance levels differ across word recognition, sentence recognition in quiet, and in various levels of background noise. There was no interaction between test point and metric ($p$=0.51) such that postoperative performance was higher than preoperative scores and that did not vary as a function of the administered speech metric.

Individual speech recognition performance was assessed using a binomial distribution statistic for a 50-item list of monosyllabic words (Thornton and Raffin, 1978) and the AzBio sentences (Spahr et al., 2012). At the individual level, postoperative CNC word recognition was significantly higher for all but 4 listeners (#6, 10, 12, and 16) in the implanted ear and all but 1 listener (#12) for the best-aided condition. For AzBio sentences in quiet, individual performance was significantly higher in the ear that was implanted for 14 of the 16 listeners (excluding #9 and 10); note that post-implant performance for participant #9 was 20-percentage points higher in the implanted ear, but did not reach significance for 2-list administration (Spahr et al., 2012). Comparing the best-aided conditions pre- and post-implant, AzBio sentence recognition was significantly better for all 16 listeners postoperatively. For AzBio sentences at +10 dB SNR, 14 of the 16 listeners (excluding #3 and 10) exhibited significantly higher postoperative performance as compared to preoperative listening in the ear that was implanted. In a comparison of the best-aided conditions, all but 1 listener (participant #10) exhibited statistically significant improvement

in performance for AzBio sentences at +10 dB – despite exhibiting a 17-percentage point improvement in performance. For AzBio sentence recognition at +5 dB SNR, all individuals exhibited significant improvement in performance for both the ear that was implanted as well as the best-aided condition.

In an attempt to relate speech recognition performance to psychophysical function, correlational analyses were completed. The psychophysical metrics used for correlation were AF width in ERBs, AM detection threshold in dB (20 log m) averaged across 16 and 32 Hz, degree of masking release in dB, and SPE in dB. Each of the four psychophysical metrics was compared to performance on the preoperative and postoperative measures of speech recognition in the ear that was implanted. For the majority of Pearson product moment correlation analyses, there were no significant correlations between the psychophysical metrics and speech recognition performance. The exceptions were SPE *versus* preoperative AzBio sentence recognition in quiet ($r$=0.64, $p$=0.008) and at +10 dB SNR ($r$=0.79, $p$=0.007). These correlations, however, were primarily driven by data for two participants (#7 and 16) who exhibited the highest SPE as well as the highest preoperative speech recognition performance. No correlations were found to be significant in preoperative measures of psychoacoustic function and postoperative speech recognition in the same ear.

## Conclusions

The primary goal of this analysis was to revisit data collected for 16 individuals with EAS-qualifying audiograms describing psychoacoustic function for low-frequency hearing (Gifford et al., 2007) in the preoperative condition as compared to postoperative performance for standard clinical measures of speech recognition. As reported by Gifford et al. (2007) there were significant impairments noted in frequency selectivity, masking release (the difference in SRT between the SS and SQ conditions), and nonlinear cochlear processing for the individuals with EAS-qualifying audiograms in the preoperative listening condition. Temporal resolution at low modulation rates was essentially equivalent to that observed in young normal-hearing listeners.

Exactly 14 of the original 17 individuals with hearing loss reported in Gifford et al. (2007) went on to receive a cochlear implant and 2 additional participants were recruited for pre- and post-implant testing. Thus these data offer a unique look at pre-implant estimates of psychoacoustic function as well as pre- and post-implant speech recognition abilities for individuals with EAS-like audiograms.

Preoperative speech recognition performance was highly variable across the listeners and in some conditions the range of performance covered nearly the entire possible range of scores. This range was observed in individuals who all had EAS-qualifying audiograms. Thus these data support the need to consider factors beyond the audiogram, as signal audibility is not a reliable predictor of performance on supra-threshold tasks such as speech recognition. Further, the range of preoperative scores were, in some cases, much higher than expected for a traditional implant candidate. Despite having relatively good sentence recognition abilities, all individuals in the current study reported considerable difficulty with everyday communication (which precipitated an appointment for preoperative cochlear implant candidacy evaluation). Further, nearly all listeners exhibited significant improvement in speech recognition performance when considering individual subject performance using a binomial distribution statistic, and all listeners demonstrated an improvement in raw performance scores.

The current results suggest that individuals with EAS-like hearing loss have little to lose in terms of psychoacoustic low-frequency function and much to gain in terms of speech understanding – representing a highly favorable assessment of risk *versus* benefit. Further, there is a lack of correlation between preoperative measures of pre-implant tonal detection (i.e. audiometric thresholds), frequency resolution, and temporal resolution as related to post-implant speech recognition. Thus it is critical to consider the whole patient when determining implant candidacy, as neither the audiogram nor pre-implant speech recognition will accurately predict the degree of postoperative benefit with a cochlear implant. These data also provide further evidence for the expansion of adult cochlear implant criteria to include individuals with low-frequency thresholds in even the near-normal range, as significant postoperative benefit is noted for speech understanding.

## Acknowledgements

This work was supported by NIDCD grants F32 DC006538 (RHG), R01 DC009404, and DC00654 (MFD). A portion of these data were presented at the 2012 Med El Presbycusis Meeting in Munich.

## References:

1. Bacon SP, Opie JM, Montoya DY: The effects of hearing loss and noise masking on the masking release for speech in temporally complex backgrounds. J Speech Lang Hear Res, 1998; 41: 549–63
2. Bacon SP, Gleitman RM: Modulation detection in subjects with relatively flat hearing losses. J Speech Lang Hear Res, 1992; 35: 642–53
3. Bacon SP, Viemeister NF: Temporal modulation transfer functions in normal-hearing and hearing-impaired listeners. Audiology, 1985; 24: 117–34
4. Baer T, Moore BCJ: Effects of spectral smearing on the intelligibility of sentences in the presence of interfering speeck. J Acoust Soc Am, 1994; 95: 2277–80
5. Brown CA, Bacon SP: Low-frequency speech cues and simulated electric-acoustic hearing. J Acoust Soc Am, 2009; 125: 1658–65
6. Carlyon RP, Datta J: Excitation produced by Schroeder-phase complexes: Evidence for fast-acting compression in the auditory system. J Acoust Soc Am, 1997; 101: 3636–47
7. Gantz BJ, Hansen MR, Turner CW et al: Hybrid 10 clinical trial: preliminary results. Audiol Neurotol, 2009; 14(Suppl.1): 32–38

8. Gifford RH, Dorman MF, Spahr AJ, Bacon SP: Auditory function and speech understanding in listeners who qualify for EAS surgery. Ear Hear, 2007; 28: 114S–18S
9. Gifford RH, Dorman MF, Brown CA: Psychophysical properties of low-frequency hearing: implications for perceiving speech and music via electric and acoustic stimulation. Adv Otorhinolaryngol, 2010; 67: 51–60
10. Glasberg BR, Moore BCJ: Derivation of auditory filter shapes from notched-noise data, Hear Res, 1990; 47: 103–38
11. He NJ, Mills JH, Ahlstrom JB, Dubno JR: Age-related differences in the temporal modulation transfer function with pure-tone carriers. J Acoust Soc Am, 2008; 124: 3841–49
12. Lentz JJ, Leek MR: Psychophysical estimates of cochlear phase response: masking by harmonic complexes. J Assoc Res Otolaryngol, 2001; 2: 408–22
13. Levitt H: Transformed up-down methods in psychoacoustics. J Acoust Soc Am, 1971; 49: 467–77
14. Moore BCJ, Glasberg BR: Simulation of the effects of loudness recruitment and threshold elevation on the intelligibility of speech in quiet and in a background of speech. J Acoust Soc Am, 1993; 94: 2050–62
15. Nelson PB, Jin SH, Carney AE, Nelson DA: Understanding speech in modulated interference: cochlear implant users and normal-hearing listeners. J Acoust Soc Am, 2003; 113(2): 961–68
16. Nilsson MJ, Soli SD, Sullivan J: Development of a hearing in noise test for the measurement of speech reception threshold. J Acoust Soc Am, 1994; 95: 1085–99
17. Oxenham AO, Dau T: Reconciling frequency selectivity and phase effects in masking. J Acoust Soc Am, 2001; 110: 1525–38
18. Patterson RD: Auditory filter shapes derived with noise stimuli. J Acoust Soc Am, 1976; 59: 640–54
19. Patterson RD, Nimmo-Smith I, Weber DL, Milroy R: The deterioration of hearing with age: frequency selectivity, the critical ratio, the audiogram and speech threshold. J Acoust Soc Am, 1982; 72: 1788–803
20. Peters RW, Moore, BCJ: Auditory filter shapes at low center frequencies in young and elderly hearing-impaired subjects. J Acoust Soc Am, 1992; 91(1): 256–66
21. Peterson GE, Lehiste I: Revised CNC lists for auditory tests. J Speech Hear Disord, 1962; 27: 62–70
22. Qin MK, Oxenham AJ: Effects of envelope-vocoder processing on F0 discrimination and concurrent-vowel identification. Ear Hear, 2005; 26: 451–60
23. Recio A, Rhode WS: Basilar membrane responses to broadband stimuli. J Acoust Soc Am, 2000; 108: 2281–98
24. Schroeder MR: Synthesis of low peak-factor signal and binary sequences with low autocorrelation. IEEE Transactions on Information Theory, 1970; 16: 85–89
25. Spahr AJ, Dorman MF, Litvak LL et al: Development and Validation of the AzBio Sentence Lists. Ear Hear, 2012; 33: 112–17
26. Stone MA, Glasberg BR, Moore BCJ: Simplified measurement of impaired auditory filter shapes using the notched-noise method. Br J Audiol, 1992; 26: 329–34
27. Thornton AR, Raffin MJ: Speech discrimination scores modeled as a binomial variable. J Speech Hear Res, 1978; 21: 507–18
28. Viemeister NF: Temporal modulation transfer functions based upon modulation thresholds. J Acoust Soc Am, 1979; 66: 1364–80

# ELECTRIC AND ACOUSTIC DYNAMIC RANGES AND LOUDNESS GROWTH FUNCTIONS: A WITHIN-SUBJECT COMPARISON IN COCHLEAR IMPLANT PATIENTS

**Katrien Vermeire[1,2,*], Dewey Tull Lawson[3]**

[1] C. Doppler Laboratory for Active Implantable Systems, Institute of Ion Physics and Applied Physics, University of Innsbruck, Technikerstrasse 25, A-6020 Innsbruck, Austria
[2] University Department for Otorhinolaryngology and Head and Neck Surgery, University Hospital Antwerp, University of Antwerp, Wilrijkstraat 10, 2650 Edegem, Belgium
[3] Duke University, Department of Physics, Physics Building, Science Drive, Box 90305, Durham, NC 27708, U.S.A.
* Current affiliation: University College Thomas More, Jozef De Bomstraat 11, 2018 Antwerpen, Belgium

**Corresponding author:** Katrien Vermeire, University College Thomas More, Jozef De Bomstraat 11, 2018 Antwerpen, Belgium, e-mail: katrien.vermeire@lessius.eu

**Source of support:** This research was supported by RTI International and Med-El GmbH, Innsbruck, Austria

**Abstract**

**Objectives:** (1) To estimate the dynamic range (DR) for electric stimulation by means of acoustic and electric loudness matching; (2) to characterize loudness growth as a function of electric stimulus amplitude across the DR.

**Design:** Prospective study.

**Study Design:** Three cochlear implant subjects, with normal hearing in the contralateral ear, participated in this study (ME-28, ME-29, ME-30). For each electrode, the upper limit of electric stimulation was loudness matched to three different types of pitch-matched acoustic stimuli. Within the electric DR, the 25%, 50%, and 75% points were loudness matched to the acoustic stimuli to create loudness growth functions.

**Results:** ME-28's DRs for electric stimulation were constant at 17–18 dB across electrodes. ME-29's and ME-30's DRs were narrower, at around 10 dB. For ME-28 and ME-30, none of the corresponding DRs for matched acoustic stimuli exceeded 50 dB. Only one of ME-29's DRs exceeded 35 dB. Loudness growth functions showed a tendency for basal electrodes to have gentler overall slopes. For relatively high proportions of the DR, the three different types of acoustic stimuli tend to have similar loudness growth slopes. However at low levels, the fewer harmonics, the steeper the loudness growth.

**Conclusions:** There is qualitative and quantitative agreement but patterns of variation can also be observed.

**Key words:** cochlear implant • single-sided deafness • dynamic range • loudness growth

## GAMAS DINÁMICAS ELÉCTRICAS Y ACÚSTICAS Y FUNCIONES DE CRECIMIENTO DE LA INTENSIDAD SONORA: UNA COMPARACIÓN INTRASUJETO EN PACIENTES CON IMPLANTE COCLEAR

**Resumen**

**Objetivos:** (1) Estimar la gama dinámica (GD) para la estimulación eléctrica mediante la igualdad de la intensidad acústica y eléctrica; (2) caracterizar el crecimiento de la intensidad como una función de la amplitud de un estímulo eléctrico a lo largo de la GD.

**Plan:** Estudio prospectivo.

**Plan del estudio:** Tres sujetos con implante coclear, con audición normal en el oído contralateral, participaron en el estudio (ME-28, ME-29, ME-30). Para cada electrodo, el límite superior de estimulación eléctrica era la intensidad igualada a tres tipos diferentes de estímulos acústicos con igualdad de tono. Dentro de la GD eléctrica, los puntos al 25%, 50% y 75% fueron igualados en intensidad a los estímulos acústicos para crear funciones de crecimiento de intensidad.

**Resultados:** Las GD para la estimulación eléctrica de ME-28 estuvieron constantes a 17–18 dB a través de los electrodos. Las GD de ME-29 y ME-30 fueron más reducidas, alrededor de 10 dB. Para ME-28 y ME-30, ninguna de las GD correspondientes para los estímulos acústicos igualados superó los 50 dB. Solo una de las GD de ME-29 superó los 35 dB. Las funciones de crecimiento de intensidad mostraron una tendencia de los electrodos basales a tener pendientes más suaves en general. Para proporciones relativamente altas de la GD, los tres tipos diferentes de estímulos acústicos tienden a tener pendientes de crecimiento de intensidad similares. Sin embargo, en los niveles bajos, cuanta menos armonía hay, más inclinado es el crecimiento de intensidad.

**Conclusiones:** Hay una concordancia cualitativa y cuantitativa, pero también se pueden observar patrones de variación.

**Palabras clave:** implante coclear • sordera unilateral • gama dinámica • crecimiento de intensidad

## ЭЛЕКТРИЧЕСКИЕ И АКУСТИЧЕСКИЕ ДИНАМИЧЕСКИЕ ДИАПАЗОНЫ И ФУНКЦИИ УВЕЛИЧЕНИЯ ГРОМКОСТИ: ВНУТРИ ПРЕДМЕТНОЕ СРАВНЕНИЕ У ПАЦИЕНТОВ С КОХЛЕАРНЫМИ ИМПЛАНТАМИ

### Резюме

**Цели:** (1) Оценить динамический диапазон (ДД) электростимуляции с помощью выравнивания акустической и электрической громкости; (2) схарактеризовать рост громкости как функцию электрической стимулирующей амплитуды на динамическом диапазоне.

**Конструкция:** Предполагаемые изучения

**Построение исследования:** Три человека по кохлеарной имплантации с нормальным слухом в контралатеральном ухе, которые взяли участие в этом исследовании (ME-28, ME-29, ME-30). Для каждого электрода верхний лимит электростимуляции – это громкость, приспособлена к трем разным видам акустических стимулов, настроеных на высоту тона. В электрическом динамическом диапазоне, точки 25%, 50%, и 75% имели громкость, приспособленную к акустическим стимулам, чтобы вызвать функции увеличения громкости.

**Результаты:** Динамические диапазоны ME-28 электростимуляции были неизменные при 17–18 дБ на электродах. Динамические диапазоны ME-29 и ME-30 были уже – приблизительно на 10 дБ. В случае ME-28 и ME-30 ни один из соответствующих динамических диапазонов для отрегулированных акустических стимулов не превысил 50 дБ. Только один из динамических диапазонов ME-29 превысил 35дБ. Функции увеличения громкости показали склонность основных электродов к более плавным общим снижениям. В случае относительно высоких пропорций динамического диапазона, три разные виды акустических стимулов имели тенденцию к подобным снижениям увеличения громкости. Однако на низких уровнях - чем меньше гармония, тем более крутой рост громкости.

**Заключение:** Имеется качественное и количественное соответствие, но можно также проследить примеры отклонения.

**Ключевые слова:** кохлеарный имплант •односторонняя глухота • динамический диапазон • увеличение громкости

## Background

Cochlear implant (CI) speech processors compress a wide dynamic range (DR) of sounds into a much smaller electric DR. The DR of CI recipients is markedly reduced compared with that of normal hearing individuals. Specifically, the psychophysical DR of CI recipients is much smaller (6 to 30 dB HL) compared to that of normal hearing listeners, which is approximately 120 dB HL for acoustic stimuli. The discrepancy between acoustic and electric DRs requires that signal processing maps the amplitude of the acoustic signal onto the more limited electric DR. Potential implications of such compression are suboptimal speech recognition, particularly in noise, and negative effects on sound quality. Currently there is little agreement on the shape of the loudness growth function in electric hearing. If the acoustic-to-electric amplitude mapping fails to maintain appropriate loudness growth within each electrode, important speech cues may be lost. Previous studies have shown that the best speech recognition occurs when a normal loudness growth function is restored (Holden et al., 2007; Davidson et al., 2009). Distortions to the normal loudness growth function result in a moderate, but significant drop in speech perception performance (Boëx et al., 1997; Fu & Shannon, 1998). In all current clinical systems, the default conversion of acoustic amplitude to electric stimulus amplitude (loudness mapping) is done by mapping functions using a logarithmic shape, and the same mapping law is applied to all channels.

One approach to estimate the optimal acoustic-to-electric amplitude mapping is to directly compare acoustic and electric loudness growth functions. CI users who have residual hearing in the ear contralateral to the implanted ear provide a good model for comparisons of acoustic-to-electric amplitude mapping. Eddington et al. (1978) balanced

**Table 1.** Information on the three experimental subjects.

| Subject | Age at surgery [yrs: mo] | Duration of deafness at surgery [yrs] | Aetiology | Implant | Side | PTA of the non-implanted ear [dB HL] | Duration of implant use [mo] |
|---|---|---|---|---|---|---|---|
| ME-28 | 38: 2 | 2.5 | Labyrinthitis | COMBI 40+ M | Left | 17 | 21 |
| ME-29 | 59: 1 | 5.5 | Hydrops | PULSARCI100 FLEXSOFT | Left | 17 | 7 |
| ME-30 | 22: 11 | 2.5 | Sudden hearing loss | PULSARCI100 FLEXSOFT | Right | 13 | 18 |

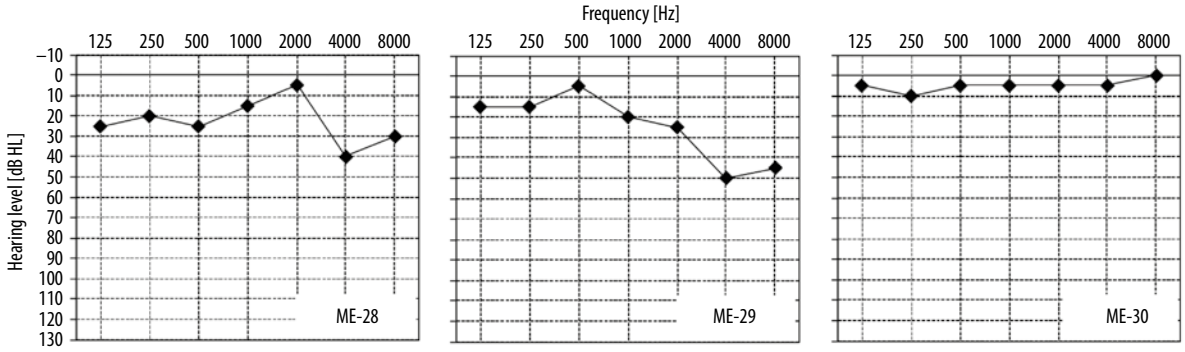



**Figure 1.** Individual audiograms showing unaided hearing in the non-implanted ear.

loudness between acoustic and electric stimulations in a unilaterally deaf Ineraid CI patient (the device was previously manufactured by Symbion, Inc., of Salt Lake City, UT, and then by Smith & Nephew Richards, Inc., of Bartlett, TN, but it is no longer manufactured). They found that the acoustic level (in dB SPL) was linearly related to the electric amplitude in mA. A similar logarithmic relation was also observed in another Ineraid user with hearing thresholds less than 50 dB HL for frequencies less than 500 Hz (Dorman et al., 1993). The same was observed in three auditory brainstem implant recipients who had substantial acoustic hearing in one ear (Zeng & Shannon, 1992). Zeng & Shannon argued that this logarithmic acoustic–electric loudness relation is due to the loss of the implanted cochlea´s normal logarithmic compression. Based upon this linear relationship between acoustic amplitude (in dB SPL) and electric current (in mA), Zeng and Shannon proposed an exponential model of loudness growth in electric stimulation. The data from these previous studies suggest that loudness growth in CIs could be described by a power function for lower frequencies and an exponential function for high frequencies (Zeng & Shannon, 1994). However, Hoth (2007) showed that CI recipients demonstrate no systematic dependence of the shape and the steepness of the growth function on electrode position.

The current study evaluates electric-acoustic amplitude mapping in a unique subject group with normal hearing in the non-implanted ear. The fact that these subjects have normal hearing in the non-implanted ear makes them especially suitable for comparing electric-acoustic stimuli, as there is little or no influence of hearing impairment in the non-implanted ear.

## Methods

### Subjects

Three subjects were included in this study. All three participated in a larger study investigating the effectiveness of cochlear implantation in treating unilateral tinnitus (Van de Heyning et al., 2008). All subjects were adults with unilateral severe tinnitus concurrent with ipsilateral sensorineural deafness. It is worth noting that the tinnitus treatment was highly successful and subjects did not suffer from tinnitus during these experiments. Subjects were instructed to notify the experimenter if tinnitus were to resume during the experiment. When this occurred, the experiment was paused. The experiment was resumed when the tinnitus had disappeared. Background information for the three subjects is provided in Table 1. Clinical pure-tone audiograms for the non-implanted normal ear are shown in Figure 1.

### Materials

All subjects received Med-El cochlear implants (Med-El GmbH, Innsbruck, Austria). ME-28 had the COMBI 40+ with M electrode array and ME-29 and ME-30 had the $PULSAR_{CI}^{100}$ with $FLEX^{SOFT}$ electrode array. Both electrode arrays have 12 contacts which are numbered E1 to E12 from apex to base. For both arrays E1 has a distance of 30.4 mm from the marker ring which indicates full insertion into the cochlea. The inter-electrode distance of the M electrode is 1.9 mm which creates a distance of the most basal electrode to the marker ring of 9.4 mm, in contrast to 3.9 mm with the $FLEX^{SOFT}$ electrode array with a 2.4 mm inter-electrode spacing.

**Table 2.** Mean matched tone pitch (in Hz) with Electrode Position using 3 types of acoustic matching tones: fundamental only (pure tone), complex tone with odd harmonics 1–9, and complex tone with all harmonics 1–9.

| Electrode | ME-28 | | | ME-29 | | | ME-30 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Pure tone | Odd | All | Pure tone | Odd | All | Pure tone | Odd | All |
| 1 | 350 | 330 | 300 | 465 | 440 | 440 | 255 | 197.5 | 190 |
| 2 | 400 | 360 | 300 | 405 | 410 | 380 | 425 | 377.5 | 260 |
| 3 | 450 | 430 | 415 | 435 | 410 | 420 | 435 | 347.5 | 315 |
| 4 | 520 | 515 | 430 | 415 | 410 | 390 | 560 | 500 | 465 |
| 5 | 630 | 630 | 610 | 395 | 430 | 390 | 640 | 600 | 530 |
| 6 | 860 | 710 | 730 | 395 | 430 | 390 | 830 | 695 | 690 |
| 7 | 900 | 965 | 780 | 370 | 410 | 370 | 870 | 737.5 | 660 |
| 8 | 1140 | 1080 | 980 | 387.5 | 410 | 370 | 880 | 695 | 685 |
| 9 | 1240 | 1130 | 1180 | 385 | 370 | 330 | 1150 | 1100 | 820 |
| 10 | 1400 | 1390 | 1340 | 365 | 330 | 310 | 1850 | 1735 | 1740 |
| 11 | 1600 | 1600 | 1850 | 370 | 310 | 290 | 1750 | 1705 | 1755 |
| 12 | 3600 | 3900 | 3300 | 377.5 | 310 | 290 | 3100 | 2710 | 2075 |

All three subjects were fitted with a TEMPO+ clinical speech processor. The processing strategy used was the CIS+ speech-coding strategy, using 26.7 µs/phase (ME-28) or 24.2 µs/phase (ME-29 and ME-30) biphasic pulses. The overall bandwidth was 300 to 8500 Hz.

## Stimuli

All electric pulse-burst stimuli were generated in the subjects' implanted receiver-stimulators, under the control of a laboratory interface that in turn received instructions from a digital laboratory processor. Instructions and power were transmitted to the implanted electronics from external antenna coils that were part of the laboratory interfaces. None of the clinical external electronics were involved. Two different interfaces were used, one to control ME-28's Med-El COMBI 40+ implanted electronics and the other to control the Med-El $PULSAR_{CI}^{100}$ implanted electronics of the ME-29 and ME-30.

The electric stimuli consisted of constant-amplitude pulse trains of 500 ms duration and a constant pulse rate of 1515 Hz. The pulse duration was 27 µs (ME-28) or 24 µs (ME-29 and ME-30). All electric stimuli were delivered in monopolar mode with the reference electrode under the temporalis muscle, as is standard in the COMBI 40+ and $PULSAR_{CI}^{100}$. Before the experiments, each subject's electric thresholds and maximum comfortable level (MCL) were checked and loudness balanced.

The acoustic test stimuli consisted of tones with frequencies that were matched to the electric stimuli. This matching was done prior to the experiment and the results are presented in Table 2. For the matching procedure, the subject listened alternately to the electric stimulus and to a loudness-balanced pure tone acoustic stimulus, and adjusted the frequency of the acoustic stimulus to match the pitch of the electric one. Each trial ended when the subject reported that an exact match had been achieved, and 10 trials were conducted for each electrode with various initial settings of the acoustic stimulus. The starting frequencies for matching acoustic tones were varied widely (i.e. the starting point was well below or above the expected match). The acoustic stimuli were 500 ms in duration. All stimuli were digitally synthesized by laboratory computers, recorded as .wav digital audio files. Stimuli were delivered via an IBM PC compatible computer, using a standard PC sound card and connected to an audiomixer (Mackie Micro Series 1402-VLZ; 14-channel mic/line mixer). Stimuli were presented to the subjects over circumaural headphones (Sony MDR-V600). Three types of acoustic stimuli were used in the loudness-matching studies: pure tones (fundamental alone), complex tones with odd harmonics 1 through 9 only, and complex tones with all harmonics 1 through 9. For all the complex tones, the relative amplitude of the $n$-th harmonic was proportional to $1/n^2$. Pure tones (fundamentals only) were included as the simplest pitched stimulus and as a stimulus certain not to cause complex interactions between adjacent processor analysis bands. Versions with only odd harmonics were included to provide some of the additional cues present with all harmonics, but with larger spacing between adjacent partials to decrease such complex interactions between adjacent processor analysis channels.

## Procedure

Throughout the experiment, subjects were asked to adjust the loudness of the acoustic stimulus while the level of the electric stimulus was kept constant. The electric stimulus was delivered first, followed by the acoustic stimulus presentation. The subject was instructed to indicate if the acoustic stimulus was softer, louder, or equally loud compared to the electric stimulus. The level of the acoustic stimulus was varied by the experimenter in response to the subject's response, in a staircase procedure. The start value for each loudness match was randomized, with one starting point well below the match, one starting point above. Two loudness matches were obtained for each electric–acoustic

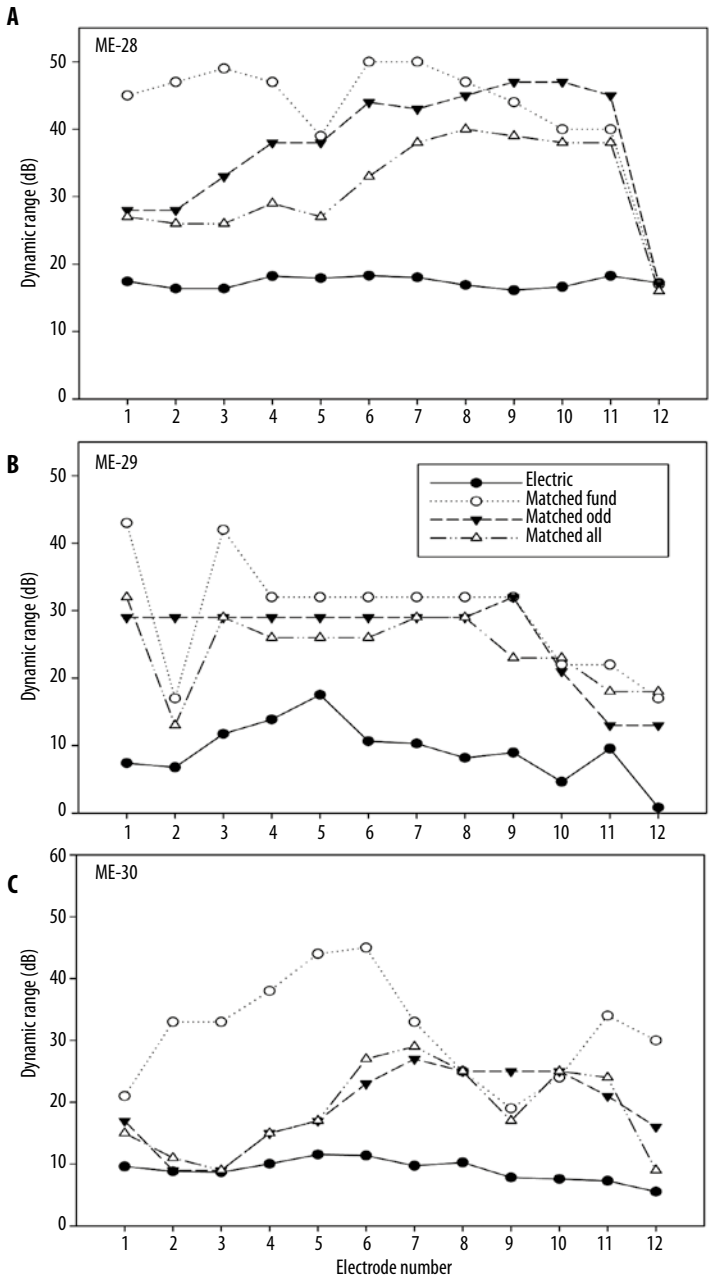



**Figure 2.** DRs for Subject ME-28 (**A**), ME-29 (**B**), ME-30 (**C**). Open and filled symbols show DR mean values.

combination. For calculation of the DRs, all 12 electrodes were tested. DR for electric stimulation was determined by the difference between the electric current amplitude levels corresponding to threshold and MCL for each electrode. DR for matched acoustic stimuli was determined by the difference between the subject´s acoustic thresholds (Figure 1) and MCL at each pitch-matched frequency. For the detailed studies of loudness growth, one relatively apical, one middle, and one basal electrode were chosen for each subject on the basis of the DR measurements. For ME-28, electrode 4 was chosen as representing a large overall dynamic range variation fairly evenly spread across the acoustic stimulus types. Electrode 8 provided a different distribution among types for a similar overall dynamic range variation. Electrode 12 was selected on the basis of its uniqueness in terms of equal dynamic ranges for electric and all three acoustic stimuli. For the same reason, electrodes 3, 5, and 12 were chosen for ME-29 and electrodes 3, 8, and 12 for subsequent studies with ME-30.

Within the electric DR, the 25%, 50%, and 75% points were loudness matched to the acoustic stimuli to create loudness growth functions.

## Results

### Dynamic range

Figure 2A–C show the DRs for the three subjects. The three types of acoustic stimuli (fundamentals, odd harmonics 1–9, and all harmonics 1–9) are included, as well as the DRs for the current amplitudes of the matched electric stimulus pulses.

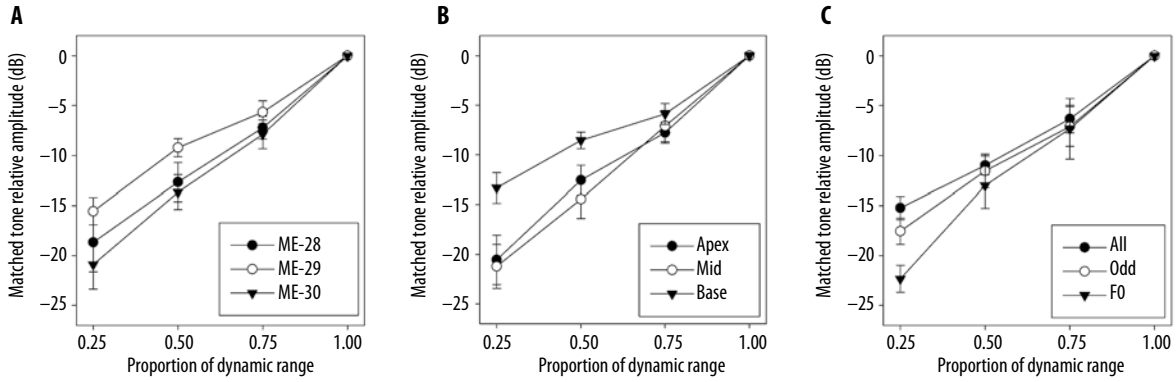



**Figure 3.** Loudness growth across dynamic range, by subject (**A**), by electrode position in array (**B**), and by matching tone type (**C**).

ME-28's DRs for electric stimulation were roughly constant at 17–18 dB across electrodes (Figure 2A). The corresponding DRs for matched acoustic stimuli did not exceed 50 dB, and many were much less. There was a substantial difference in matched DR depending on the type of acoustic stimulus, with the DR for pure tone stimuli (43 dB) tending to be greater than for odd harmonic complex tones (38 dB), and both of those greater than for complex tones including all harmonics (31 dB). The large drop in ME-28's pure tone DR for electrode 5 was reproducible. The electrode 5 dip in DR was verified by repeating the measurements for electrodes 4, 5, and 6 on a later date. Test-retest reliability was within 3 dB for all 3 electrodes. For ME-28's electrode 12, all the DRs for the matched acoustic stimuli dropped to equal the 17 dB DR for electric stimulation.

As seen in Figure 2B, ME-29's DRs for electric stimulation were generally narrower and more variable across electrodes than those observed for ME-28. They varied between 1 and 18 dB. Only two of ME-29's corresponding DRs for matched pure tone stimuli exceeded 35 dB, and some were much less. There was less variation in matched DR with the different types of acoustic stimulus than for ME-28. The rather dramatic drop in the pure tone DR for electrode 2 was reproducible, similar to what was found for electrode 5 in the case of ME-28. Also here, the DR was verified by repeat measurements on a later day.

ME-30's DRs for electric stimulation were roughly comparable to those of ME-29 at around 10 dB, but with less variation across electrodes (Figure 2C). Only one of the corresponding DRs for matched acoustic stimuli approached 50 dB, and some were much less. These DRs were generally narrower than those observed for ME-28, and wider than those observed for subject ME-29. Figure 2C shows more variation in matched DR across the different types of acoustic stimulus for ME-30. The DRs for pure tone stimuli tended to be greater than for odd and all harmonic complex tones, especially for the more apical electrodes.

### Loudness growth

In Figure 3A–C, loudness growth curves are displayed as relative amplitude levels of acoustic stimuli of three types (Fundamental only, Odd harmonics 19–, and All harmonics 19–), matched to current amplitudes corresponding to 25%, 50%, and 75% of the DRs of each of the three electrodes selected for each of the three subjects. The curves were normalized to matched MCLs in each case. Across all three subjects, the goal was to include choices representing a variety of locations and magnitudes of DRs. As a relatively apical location, electrode 4 was included for ME-28 and electrode 3 for ME-29 and ME-30. As a relatively medial location in the array, electrode 8 was included for ME-28 and ME-30 and electrode 5 for ME-29. The most basal electrode, number 12, was included for all three subjects.

The plots in Figure 3A–C allow the opportunity to look for correlations in terms of several variables that might be expected to influence loudness growth. ME-28 and ME-30 show steeper slopes than ME-29 (Figure 3A). A tendency of relatively basal electrodes to have gentler overall loudness growth slopes could be observed (Figure 3B). For relatively high proportions of the dynamic range, the three different types of acoustic stimuli tend to have similar loudness growth slopes. However at low levels, the fewer harmonics, the steeper the loudness growth (Figure 3C).

## Discussion

We quantified the DRs of electric stimulation in three subjects. These DRs were roughly between 10 dB (ME-29 and ME-30) and 20dB (ME-28) (Figure 2). This is in agreement with what is reported in literature (Simmons, 1966; Eddington et al., 1978; Shannon, 1983). Shannon (1983) found that DR is dependent on the stimulation rate, with the DR of high rate stimulation (1000 Hz) being narrower than the DR at lower stimulation rates (250 Hz) (18–25 dB *vs.* 30–40 dB). Seeing that in the experiment described here a high rate stimulation (1515 Hz) is used, this could explain why the DRs that were found are at the lower end of what is reported in the literature, DRs for electric stimulation between 6 and 30 dB.

The DRs found for electric stimulation were matched to acoustic stimulation. This was done in terms of the levels of simple and complex pitch- and loudness-matched acoustic tones heard in the contralateral normal ear. Clearly, the range of loudness experienced by the subjects over the full DR of their electric stimulation did not correspond to a perceptual range of loudness similar to that of

normal hearing (DR equal to 43 dB-30 dB-32 dB for the pure tone stimuli). This finding is in agreement with but slightly smaller than the finding by Zeng and Shannon (1992). They obtained loudness balance values between electric and acoustic stimulation in three auditory brainstem implant listeners who had substantial, even normal, acoustic hearing in the contralateral ear. Their subjects showed a matched DR between 35 and 60 dB. Dorman and colleagues (1993) estimated loudness balance in one Ineraid subject with residual hearing up to 500 Hz. They found a loudness balance value of about 60 dB when balancing a 250 Hz acoustic pure tone and an electric 250 Hz sine signal on electrodes 1 and 2. A reason for this discrepancy with the present data could be the fact that they used low-rate analog stimulation (250 Hz) whereas in the present experiment a high-rate pulsatile stimulation burst was used (1515 Hz). Although the loudness balancing data are reproducible in each condition, substantial variability was seen across subjects, electrodes and their associated pitches, and acoustic tone types. Especially in the case of ME-28 (and also ME-30), there was substantial variation in matched DR depending on the type of the acoustic stimulus involved. A possible explanation for this finding could be that a complex tone including all harmonics has more energy and therefore sounds louder than a complex tone including only odd harmonics and certainly more than pure tone stimuli. In previous reports, loudness balancing experiments were always conducted with acoustic sinusoidal stimuli (Dorman, 1993).

The second part of the current experiment was loudness growth. For that, loudness growth across the DR, as a function of relative amplitude of electric stimulation, was characterized quantitatively. This was done in terms of the levels of simple and complex pitch- and loudness-matched acoustic tones heard in the contralateral normal ear. Results showed that almost half of the 27 measured curves indicated relatively smooth, uniform loudness growth across the full measured range. In roughly one-third of the curves, loudness growth is more rapid at one end of the range than the other, more often at relatively high levels. Only about one-fifth of the curves were more complex, typically including a region of slower growth in the middle of the DR. All of the more complex curves except one were associated with subject ME-30. Hoth (2007) investigated loudness growth functions for electric stimulation in 15 adult Nucleus CI22 or CI24 users. He found that 5 general types of growth functions could be distinguished: (1) a linear growth over the whole DR, (2) a smooth initial growth (positive curvature) followed by a linear growth, (3) an *S*-shaped function starting with positive curvature, (4) an *S*-shaped function starting with negative curvature, and (5) a two-step growth. He could not find any systematic dependence of the shape and steepness of growth function on electrode position. This is not in agreement with the present study. In the present data, relatively basal electrodes tended to have gentler overall loudness growth slopes compared to more medial and apical electrodes (Figure 3B). In a study by Fu (2005), loudness was balanced at apical and basal electrodes across the electrical dynamic range for both low rate (100 Hz) and high rate (1000 Hz) stimuli in six Nucleus CI22 subjects. At the lower stimulation rate of 100 Hz, 2 of the 6 subjects demonstrated a non-linear relationship between the loudness growth functions for the apical and basal electrodes. However, all subjects demonstrated a linear relationship between the loudness growth functions for the apical and basal electrodes at the higher stimulation rate of 1000 Hz. In our experiment, (which stimulated at 1515 Hz), we found that the loudness growth function differed between apical and basal electrodes. The explanation for the differences between the results of our experiment and Fu's experiment are unknown. One hypothesis for the difference is that our subjects haved better neural survival in the apex relative to the base, while the neural survival for the patients in Fu's experiments was more homogenous. Fu's subjects haved been deafened for longer duration than ours. Two out of three of our subjects have had a shorter duration of deafness (2.5 years) than the minimum duration of implant use for Fu's subjects. It is safe to assume that Fu's subjects haved been deafened for a greater duration than their implant use.

## Conclusions

Many reproducible measurements have been made based on loudness matching of stimuli between electrically stimulated and normal hearing ears. Consistency has been seen across subjects and patterns of variation across electrode position have been observed. We have confirmed that the electric dynamic range is smaller relative to acoustic dynamic range. We have demonstrated that the loudness growth function is linear across the dynamic range, although the slope may depend on the cochlear location. Research using matching techniques will allow better informed design of processing strategies for auditory prostheses.

## Acknowledgments

We would like to thank the three subjects for their generous and conscientious participation in these studies. We would also like to acknowledge the involvement of colleagues Anne Jackson, Xiaoan Sun, and Robert Wolford in parts of the studies described in this paper, Prof. Paul Van de Heyning for providing the possibility to test the subjects, and Jane Opie and David Landsberger for assistance in preparing the paper. This research was supported by RTI International and Med-El GmbH. This research was approved by the Ethics Committee of the University Hospital Antwerp and the Institutional Review Boards of RTI International, and was carried out in accordance with the Declaration of Helsinki (approval No. OG085). All subjects gave written informed consent prior to participating in the study.

## References:

1. Boëx CS, Eddington DK, Noel VA et al: Restoration of normal loudness growth for CIS sound coding strategies. Abstract, Conference on Implantable Auditory Prostheses, 1997; 26
2. Davidson LS, Skinner MW, Holstad BA et al: The effect of instantaneous Input Dynamic Range setting on the speech perception of children with the Nucleus 24 implant. Ear Hear, 2009; 30: 340–49

3. Dorman MF, Smith L, Parkin JL: Loudness balance between acoustic and electric stimulation by a patient with a multichannel cochlear implant. Ear Hear, 1993; 14: 290–92
4. Eddington D, Dobelle W, Brackmann D et al: Auditory prosthesis research with multiple channel intracochlear stimulation in man. Ann Otol Rhinol Laryngol, 1978; 87(Suppl): 1–39
5. Fu Q-J, Shannon RV: Effects of amplitude nonlinearity on speech recognition by cochlear implant users and normal hearing listeners. JASA, 1998; 104: 2570–77
6. Fu Q-J: Loudness growth in cochlear implants: effect of stimulation rate and electrode configuration. Hear Res, 2005; 202: 55–62
7. Holden LK, Skinner MW, Fourakis MS, Holden TA: Effect of increased IIDR in the Nucleus Freedom cochlear implant system. J Am Acad Audiol, 2007; 18: 777–93
8. Hoth S: Indication for the need of flexible and frequency specific mapping functions in cochlear implant speech processors. Eur Arch Otorhinolaryngol, 2007; 264: 129–38
9. Shannon RV: Multichannel electrical stimulation of the auditory nerve in man. I. Basic psychophysics. Hear Res, 1983; 11: 157–89
10. Simmons FB: Electrical stimulation of the auditory nerve in man. Arch Otolaryngol, 1966; 84: 2–54
11. Van de Heyning P, Vermeire K, Diebl M et al: Incapacitating unilateral tinnitus in single-sided deafness treated by cochlear implantation. Ann Otol Rhinol Laryngol, 2008; 117: 645–52
12. Vermeire K, Van de Heyning PH: Binaural hearing after cochlear implantation in subjects with unilateral sensorineural deafness and tinnitus. Audiol Neurootol, 2009; 14: 163–71
13. Zeng F-G, Shannon RV: Loudness balance between electric and acoustic stimulation. Hear Res, 1992; 60: 231–35
14. Zeng F-G, Shannon RV: Loudness coding mechanisms inferred from electric stimulation of the human auditory system. Science, 1994; 264: 564–66

# Case Reports

# SINGLE TO MULTI-CHANNEL COCHLEAR REIMPLANTATION AFTER 21 YEARS: CASE REPORT

**Johannes Schnabl[1], Astrid Wolf-Magele[1], Viktor Koci[2], Volker Schartinger[1], Andreas Markl[1], Georg Sprinzl[1]**

[1] Department of Otorhinolaryngology, Innsbruck Medical University, Innsbruck, Austria
[2] Department of Hearing, Speech and Voice Disorders, Innsbruck Medical University, Innsbruck, Austria

**Corresponding author:** Georg Sprinzl, Department of Otorhinolaryngology, Innsbruck Medical University, Innsbruck, Austria, e-mail: georg.sprinzl@i-med.ac.at

**Abstract**

**Background:** In the literature cochlear reimplantation is described as a possible surgical procedure and the change from a single to a multichannel device is associated with audiological improvement.

**Material and Methods:** A 47 year old male caucasian patient presented after cochlear implantation 21 years ago. Lacking any benefit from the old single-channel implant over the last few years, the patient no longer used the device. The old cochlear implant was changed for a modern multichannel unit.

**Results:** The patient showed a great improvement in hearing threshold and his quality of life with the new device.

**Conclusions:** This case justifies the reimplantation of patients who have been implanted more than 20 years ago.

**Key words:** Cochlear reimplantation • ball electrode

## REIMPLANTACIÓN COCLEAR DE MONOCANAL A MULTICANAL DESPUÉS DE 21 AÑOS: INFORME DE UN CASO CLÍNICO

**Resumen**

**Antecedentes:** En la literatura, se describe la reimplantación coclear como un posible procedimiento quirúrgico y el cambio de un aparato monocanal a multicanal está asociado a la mejora audiológica.

**Materiales y métodos:** Se presentó a un paciente caucásico de 47 años al que se colocó un implante coclear 21 años antes. Como el implante monocanal no le había proporcionado beneficios durante los últimos años, el paciente ya no usaba el aparato. Se le cambió el implante coclear antiguo por una unidad multicanal moderna.

**Resultados:** El paciente mostró una gran mejora en el umbral auditivo y en su calidad de vida con el nuevo aparato.

**Conclusiones:** Este caso justifica la reimplantación de pacientes a los que se colocó un implante hace más de 20 años.

**Palabras clave:** reimplantación coclear • electrodo de bola

## ОТ ОДНО- ДО МНОГОКАНАЛЬНОЙ КОХЛЕАРНОЙ РЕИМПЛАНТАЦИИ ПОСЛЕ 21 ГОДА: СИТУАЦИОННЫЙ ДОКЛАД

**Резюме**

**Предпосылки:** В литературе кохлеарная реимлантация описана как возможная хирургическая процедура, а замена одно- на многоканальный аппарат связана с аудиологическими усовершенствованиями.

**Материалы и методы:** Представлен 47-летний пациент – белый мужчина после 21-летней кохлеарной имплантации. Не получая за последние несколько лет от старого одноканального импланта никакой пользы, пациент перестал пользоваться аппаратом. Старый кохлеарный имплант был заменен на современный многоканальный аппарат.

**Результаты:** У пациента с новым аппаратом произошло огромное улучшение порогов слуха и качества его жизни.

**Заключение:** Этот случай утверждает правильность реимплантации пациентов, которые были имлантированы более 20 лет назад.

**Ключевые слова:** кохлеарная реимплантация • шариковый электрод

## Background

Dr William House first introduced cochlear implantation 35 years ago as a treatment for patients with sensorineural hearing loss [1]. Since then, cochlear implants have developed from single-electrode devices to multi-electrode devices with complex digital signal processing. Previous studies have demonstrated huge benefits in speech recognition with multi-electrode devices compared to single channel devices [2,3]. We have been implanting cochlear implants (CIs) in our clinic since 1986. Due to the electronic nature of CIs, device failure can sometimes occur. In addition, continuous improvements to CI technology have resulted in substantially more sophisticated new implants. For these and other reasons, reimplantation is sometimes necessary and/or desirable.

The first study concerning CI reimplantation was published in 1985 [4]. Since then several reports about cochlear reimplantation have appeared in the literature [5–9]. All of these publications state that such surgery is possible in general, as well as the fact that the audiologic performance of reimplanted patients is equal to or better than it was before the failure occurred. Although the surgical technique for cochlear reimplantation is not markedly different than that of an initial CI, some complications, such as ossification, have been observed and should therefore be taken into consideration when attempting this procedure.

The aim of this case report is to show the surgical possibility of cochlear reimplantation and its audiological benefits with a multichannel CI after 21 years.

## Case Report

### History of the patient

A 47-year old patient presented with congenital or infantile acquired profound hearing loss. He began wearing conventional hearing aids at the age of 4 years, with marginal benefit. He studied sign language in a special school. In 1989 he was implanted with a two-channel cochlear implant (Vienna Implant; Med-El, Innsbruck, Austria). Postoperatively, the patient had problems with vertigo and headaches, and was disappointed with the audiological results of his first CI. He wore the speech processor only at home and not while working because of the adverse noise and subsequent headaches. This patient was ashamed of his speech and hearing disorders and therefore decided to retire. At the time he came to us, he did not wear his CI any more. The implant was still working but no new external speech processor able to stimulate the old implant was available and no spare parts to repair the old speech processor were available. He asked for a new, improved implant because of the disappointing audiological results with his old one.

Figure 1 presents the patient's audiogram from March 2010, showing profound hearing loss.

After performing a CT scan (Figure 2) and after the patient gave written informed consent, we decided to implant him with a new CI.

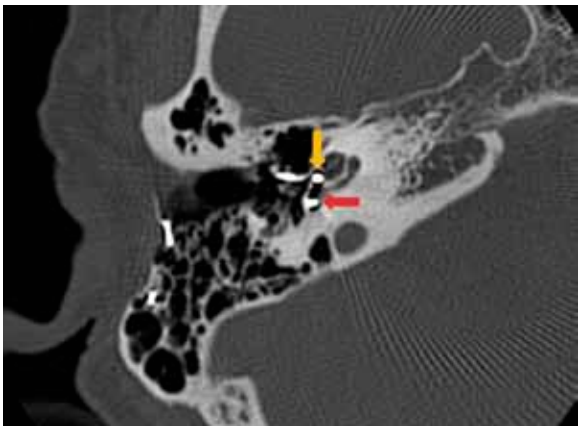


**Figure 2.** Preoperative, axial view CT scan of the right temporal bone with the ball electrode at the apex of the cochlea (yellow arrow) and near the round window (red arrow).

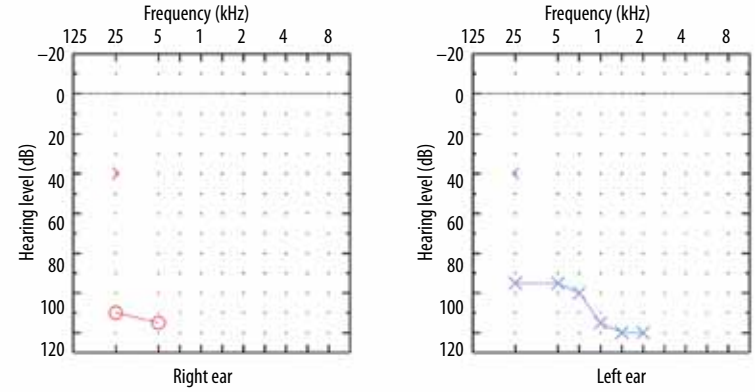



**Figure 1.** Preoperative audiogram.

**Figure 3.** Preoperative retroauricular photo of the old scar and implant.

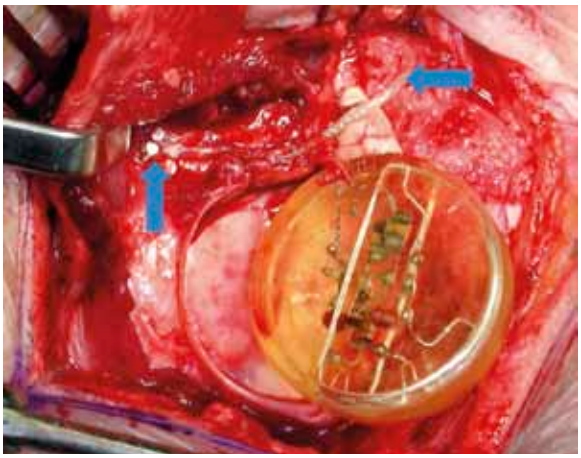


**Figure 4.** The old implant with the reference electrode (blue arrows).

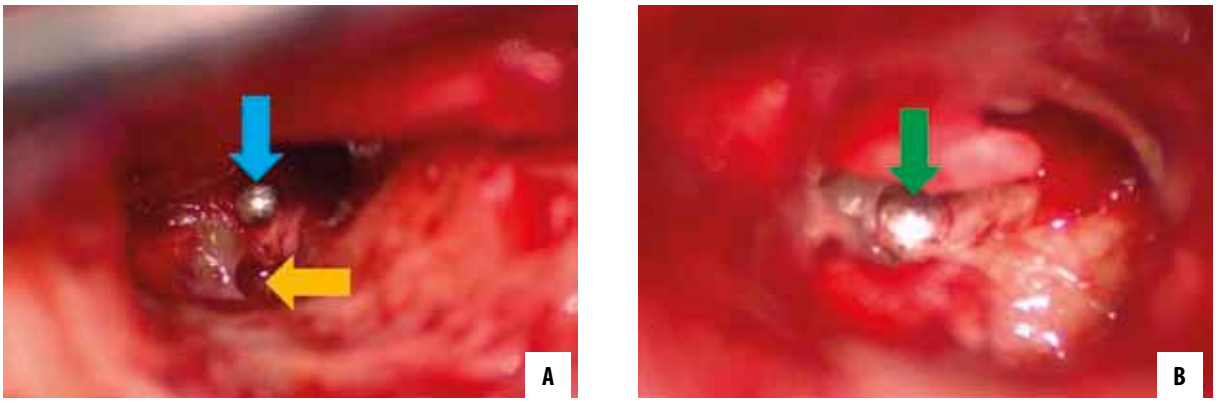



**Figure 5.** (**A**) The ball electrode (blue arrow) and its former placement niche (yellow arrow) on the promontorium. (**B**) The ball electrode at the apex of the cochlea.

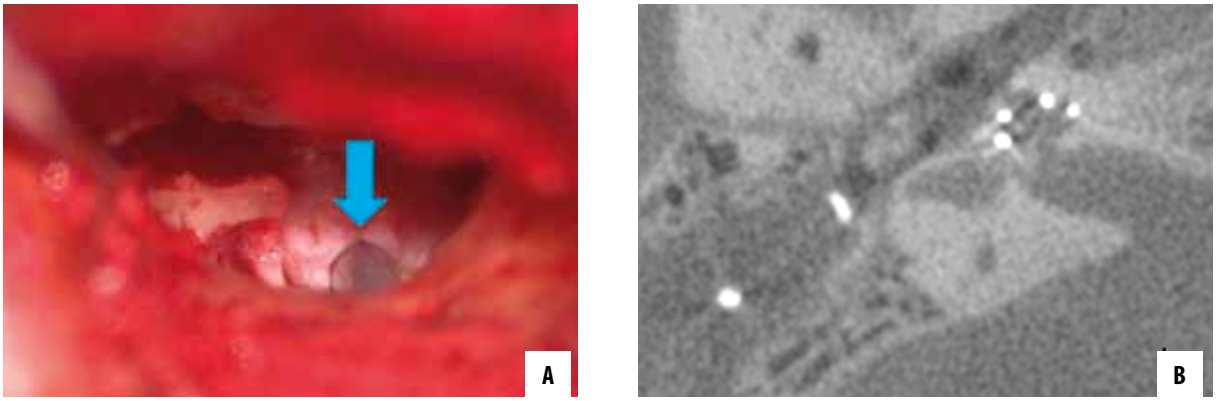



**Figure 6.** (**A**) The implanted electrode (blue arrow). (**B**) A DVT scan for postoperative monitoring of the electrode's position.

## Surgery

Under general anesthesia, the region of the old scar (Figure 3) was injected with local anesthetic. After opening the scar, the old implant was visualised. The reference electrode (Figure 4) from the Vienna CI (a two-channel implant in which one ball electrode is placed at the apex of the cochlea and another in the field of the round window) could be removed easily. The electrode was located at the epitympanon near the round window, whose membrane was intact (Figure 5A). The electrode placed at the apex of the cochlea (Figure 5B) could be removed after drilling the bone (due to extensive bone growth, the electrode was surrounded by bone).

A mastoidectomy and a posterior tympanotomy approach were then performed. After drilling a bed and placing the implant (Med-El Sonata, standard length) in it, we were able to fully insert the electrode through the round window (Figure 6A). Intraoperative measurements were found to be correct (the stapedius reflex could be activated and impedance audiometry and ARTs were in the

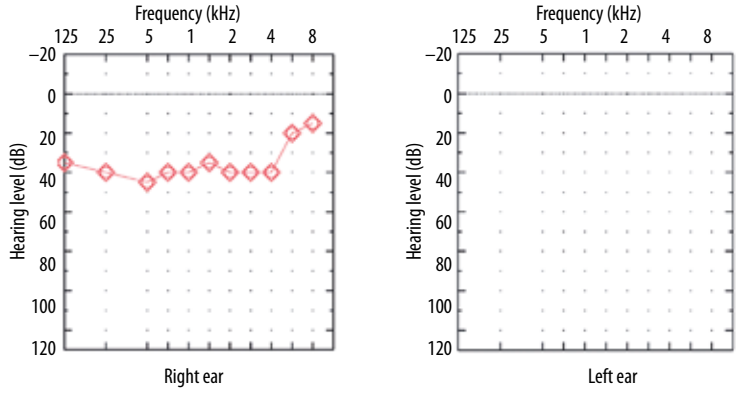



**Figure 7.** Aided, free-field hearing threshold.

normal range). At the end of the surgery, the wound was sutured.

Two days after surgery, a DVT scan was done to monitor the position of the electrode (Figure 6B).

### Audiological outcome

Six weeks after implantation, we activated the CI and initiated adjustments. Figure 7 shows the audiogram of the patient's aided hearing threshold in free field, 8 months after reimplantation. Pre- or postoperative speech audiometry was not possible due to severe prelingual hearing impairment and never-acquired speech (speech score was 0%).

### General outcome

The patient reported an enormous improvement in his quality of life. He is now able to receive new impressions like birds singing and chirping, the noise of the wind, and music. He is also better able to distinguish letters and sibilants, with the result being that he can now better control his own voice and is beginning to acquire speech.

## Discussion

Cochlear reimplantation is a practicable and potentially successful operation to help patients with non- or malfunctioning CIs. However, the surgical procedure can present challenges, particularly if structures are cicatrised or ossified [10]. In our case, the tricky part of the surgery involved the removal of the ball electrodes, since the electrode near the apex was nearly completely ossified.

The reasons for performing cochlear reimplantation include device failure, the desire to upgrade to a newer technology, and infection. Naturally, as CI technology has become more sophisticated, the relative number of device failures has also decreased.

Animal studies [11,12] involving explantation of a CI and subsequent reimplantation have suggested reimplantation is generally safe, with no significant additional damage to cochlear structures above that incurred from the first implantation. However, Jackler et al. [11] suggests that reimplantation should not be delayed after explantation of a CI.

Long-term retrospective studies [6,10,13–16] have shown postoperative performance following reimplantation to be equal to or better than performance with the initial implant before its failure. These studies also revealed reimplantation to be a safe procedure, with no damage to cochlear structures that would prevent the patient being provided with an upgraded device [6].

Our patient's audiologic outcome is astonishing and correlates with the audiologic outcomes described by Coté et al. [7]. We can conclude that cochlear reimplantation is an effective and safe procedure, even if the original implantation was done more than 20 years ago.

### Acknowledgement

We thank Noelani Peet for medical writing assistance.

### Conflict of interest

All authors declare that the manuscript has not been published previously nor under review by another journal. The paper has not been presented to any professional society. All authors declare that neither financial interests nor financial support by companies exist.

## References:

1. House WF: Cochlear implants. Ann Otol Rhinol Laryngol, 1976; 85(Suppl.27): 1–93
2. Rubinstein JT, Parkinson WS, Lowder MW et al: Single-channel to multichannel conversions in adult cochlear implant subjects. Am J Otol, 1998; 19: 461–66
3. Hamzavi JS, Baumgartner WD, Adunka O et al: Audiological performance with cochlear reimplantation from analogue single-channel implants to digital multi-channel devices. Audiology, 2000; 39: 305–10

4. Hochmair-Desoyer I, Burian K: Reimplantation of a molded scala tympani electrode: impact on psychophysical and speech discrimination abilities. Ann Otol Rhinol Laryngol, 1985; 94: 65–70
5. Gantz BJ, Lowder MW, McCabe BF: Audiologic results following reimplantation of cochlear implants. Ann Otol Rhinol Laryngol Suppl, 1989; 142: 12–16
6. Alexiades G, Roland JT Jr, Fishman AJ et al: Cochlear reimplantation: surgical techniques and functional results. Laryngoscope, 2001; 111: 1608–13
7. Cote M, Ferron P, Bergeron F et al: Cochlear reimplantation: causes of failure, outcomes, and audiologic performance. Laryngoscope, 2007; 117: 1225–35
8. Henson AM, Slattery WH, Luxford WM et al: Cochlear implant performance after reimplantation: a multicenter study. Am J Otol, 1999; 20: 56–64
9. Sorrentino T, Cote M, Eter E et al: Cochlear reimplantations: technical and surgical failures. Acta Otolaryngol, 2009; 129: 380–84
10. Orus DC, Venegas Pizarro MP, De Juan BJ et al: [Cochlear reimplantation in the same ear: Findings, peculiarities of the surgical technique and complications]. Acta Otorrinolaringol Esp, 2010; 61: 106–17
11. Jackler RK, Leake PA, McKerrow WS: Cochlear implant revision: effects of reimplantation on the cochlea. Ann Otol Rhinol Laryngol, 1989; 98: 813–20
12. Greenberg AB, Myers MW, Hartshorn DO et al: Cochlear electrode reimplantation in the guinea pig. Hear Res, 1992; 61: 19–23
13. Trotter MI, Backhouse S, Wagstaff S et al: Classification of cochlear implant failures and explantation: the Melbourne experience, 1982-2006. Cochlear Implants Int, 2009; 10(Suppl.1): 105–10
14. Yu LS, Chen F, Zheng HW et al: [Cochlear reimplantation]. Zhonghua Er Bi Yan Hou Ke Za Zhi, 2004; 39: 598–601
15. Woolford TJ, Saeed SR, Boyd P et al: Cochlear reimplantation. Ann Otol Rhinol Laryngol Suppl, 1995; 166: 449–53
16. Saeed SR, Ramsden RT, Hartley C et al: Cochlear reimplantation. J Laryngol Otol, 1995; 109: 980–85

# Extended Abstracts

# BILATERAL AND BIMODAL BENEFITS AS A FUNCTION OF AGE FOR ADULTS FITTED WITH A COCHLEAR IMPLANT

**Michael Dorman[1], Anthony Spahr[1], Rene H. Gifford[2], Sarah Cook[1], Ting Zhang[1], Louise Loiselle[1], JoAnne Whittingham[3], David Schramm[3]**

[1] Arizona State University
[2] Vanderbilt University
[3] University of Ottawa Faculty of Medicine

**Source of Support:** This research was supported by grants from the National Institute of Deafness and Other Communication Disorders (USA) to authors Dorman (R01 DC 010821), Gifford (R01 DC009404), Spahr (R03 DC 011052), Zang (F32 DC010937), and Loiselle (F31 DC011684-02).

**Corresponding author:** Michael F. Dorman, Ph.D., Department of Speech and Hearing Science, Arizona State University, Tempe, Arizona 85287-0102. Telephone: +1 480 965 3345. Fax: +1 480 965 8516, e-mail: mdorman@asu.edu

**Abstract**

**Background:** Both bilateral cochlear implants (CIs) and bimodal (electric plus contralateral acoustic) stimulation can provide better speech intelligibility than a single CI. In both cases patients need to combine information from two ears into a single percept. In this paper we ask whether the physiological and psychological processes associated with aging alter the ability of bilateral and bimodal CI patients to combine information across two ears in the service of speech understanding.

**Materials:** The subjects were 61 adult, bilateral CI patients and 94 adult, bimodal patients. The test battery was composed of monosyllabic words presented in quiet and the AzBio sentences presented in quiet, at +10 and at +5 dB signal-to-noise ratio (SNR).

**Methods:** The subjects were tested in standard audiometric sound booths. Speech and noise were always presented from a single speaker directly in front of the listener.

**Results:** Age and bilateral or bimodal benefit were not significantly correlated for any test measure.

**Conclusions:** Other factors being equal, both bilateral CIs and bimodal CIs can be recommended for elderly patients.

**Key words:** cochlear implant • presbycusis • bilateral • bimodal

## Background

Both bilateral cochlear implants (CIs) and bimodal (electric plus acoustic) CIs can provide better speech intelligibility than a single implant [1–5]. The two interventions, however, pose different information-extraction and central-integration challenges for CI patients. In the case of bilateral CIs, signals of the same kind, i.e., electric stimulation, are presented to the two ears. The signals, however, are not identical. The degree to which the inputs differ depends, at least, on the depth of electrode insertion, the number of activated channels for each ear, and the details of the ear-specific, input-amplitude to output-amplitude functions. The listener must construct a single percept from different information in the two ears. Bimodal stimulation poses a different problem for listeners. In this case, the information specified by low-frequency acoustic stimulation directed to one ear must be integrated with the information specified by wide-band electric stimulation directed to the other ear. Moreover, it is likely that the information in the low frequencies, e.g., in the range 250–750 Hz, is presented to different places in the electrically and acoustically stimulated cochlea.

In this paper we ask whether the changes in the physiological and psychological processing of auditory signals associated with aging [6,7] alter the ability of bilateral and bimodal CI patients to combine information across two ears in the service of speech understanding. To answer this question, we tested 61 bilateral CI patients and 94 bimodal CI patients with words in quiet, sentences in quiet, and sentences in noise. At issue was whether age was correlated with either bilateral benefit (bilateral score minus best-ear score) or bimodal benefit (bimodal score minus electric-only score).

## Material and Methods

### Subjects

The subjects were adult bilateral CI patients and bimodal CI patients tested at either Arizona State University; Mayo Clinic, Rochester; Vanderbilt University, or the University of Ottawa. The bilateral sample ranged in age, at time of testing, from 19 to 81 years. The majority of patients were between 40 and 70 years old. The mean duration of severe to profound hearing loss was 11.7 years. The mean duration of bilateral implant use was 3.8 years. The bimodal

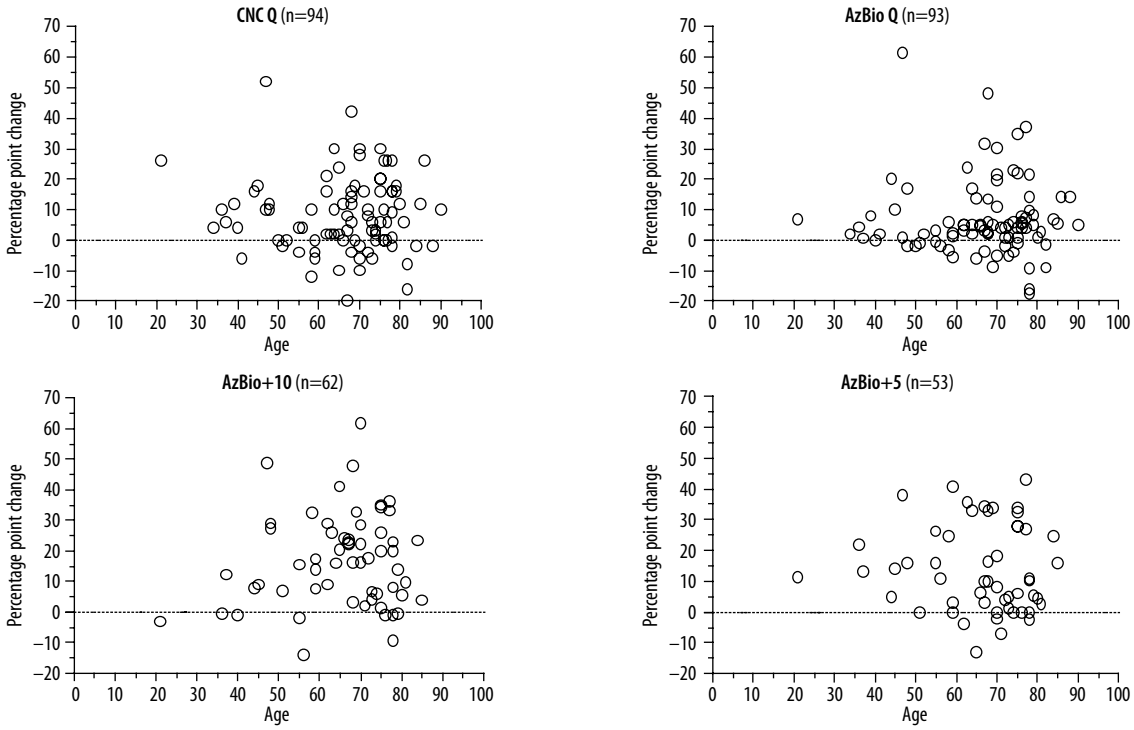



**Figure 1.** Bimodal benefit as a function of age.

sample ranged in age, at time of testing, from 21 to 90 years. The majority of patients were between 60 and 80 years old. The mean duration of severe to profound hearing loss was 17.8 years. The mean duration of bimodal use (CI plus hearing aid) was 3.4 years.

Testing took place over a number of years. For that reason not all patients were tested with all of the speech material: 53 bimodal patients completed all the tests and 26 bilateral patients completed all of them. The sample sizes for bimodal and bilateral patients tested with each type of speech material ranged from 94 to 27 and are shown in Figures 1 and 2. Patients were selected for testing based on their willingness to participate in research and, for some, their willingness to travel to Arizona State University for testing.

### Speech materials

The test battery was composed of monosyllabic words [8] presented in quiet and the AzBio sentences [9] presented in quiet, at +10 and at +5 dB signal-to-noise ratio (SNR). Most commonly the tests were administered on the same day.

### Listening environment

The subjects were tested in standard audiometric sound booths. Speech and noise were always presented from a single speaker directly in front of the listener with the speech signal at 60 dB SPL (a small number of patients were tested with speech at 70 dB SPL).

## Results

The results for bimodal patients are shown in Figure 1 where percentage changes in performance, i.e., benefit, are plotted as a function of age. Change scores were calculated as bimodal score minus electric-only score. Visual inspection suggests that patients in their 70s derived as much bimodal benefit as younger patients for each type of test material. Pearson's correlations showed no significant relationship between age and benefit for any test measure ($r$=–0.04 for CNC words; $r$=–0.01 for AzBio sentences in quiet; $r$=0.11 for AzBio sentences at +10 dB SNR; and $r$=–0.07 for AzBio sentences at +5 db SNR).

The results for bilateral patients are shown in Figure 2 where benefit is plotted as a function of age. Change scores were calculated as bilateral score minus best-ear score. Visual inspection suggests that patients in their 70s derived as much bilateral benefit as younger patients. Pearson's correlations showed no significant relationship between age and benefit for any test measure ($r$=–0.11 for CNC words; $r$=0.16 for AzBio sentences in quiet; $r$=0.33 for AzBio sentences at +10 dB SNR; and $r$=0.07 for AzBio sentences at +5 db SNR).

## Discussion and Conclusions

Aging is accompanied by decreases in function in multiple physiological, psychophysical, and psychological domains [6,7]. In this paper we have asked whether the accumulated consequences of decrements in these domains alter the ability of CI patients to extract and integrate speech-related information presented to the two ears. The answer to the question is relevant to health care systems as it is

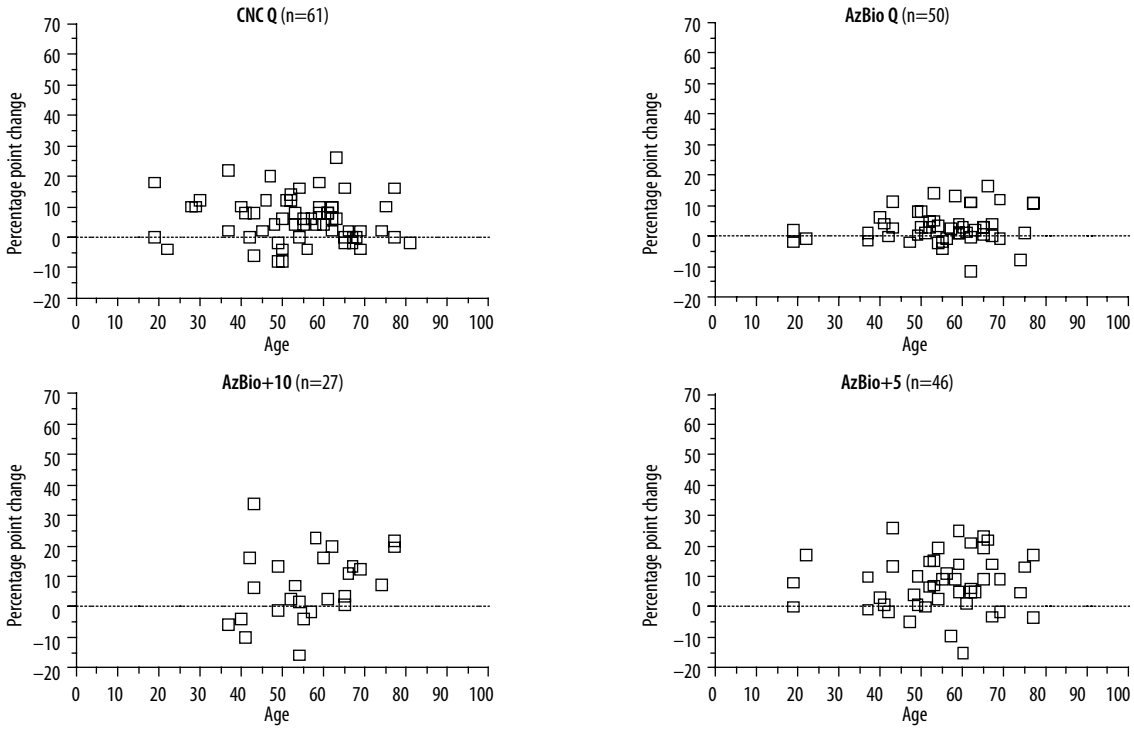



**Figure 2.** Bilateral benefit as a function of age.

likely that there is an upper age limit for the benefit to be gained from bilateral and bimodal CIs.

We find that patients in their 70s and 80s can benefit from both bimodal and bilateral stimulation. Although we do not have equal sample sizes in all age decades, it does not appear that 70 and 80 year olds are less likely to benefit than younger patients. Thus, it is reasonable to recommend both bilateral CIs and bimodal CIs to elderly patients.

## References:


1. Litovsky R, Parkinson A, Arcaroli J: Spatial hearing and speech intelligibility in bilateral cochlear implant users. Ear Hear, 2009; 30(4): 419–31
2. Buss E, Pillsbury HC, Buchman CA et al: Multicenter U.S. bilateral Med-El cochlear implantation study: Speech perception over the first year of use. Ear Hear, 2008; 29(1): 20–32
3. Shallop J, Arndt P, Turnacliff K: Expanded indications for cochlear implantation: Perceptual results in seven adults with residual hearing. J Speech-Lang Path & Applied Behavior Anal, 1992: 16: 141–48
4. Ching T, Incerti P, Hill M: Binaural benefits for adults who use hearing aids and cochlear implants in opposite ears. Ear Hear, 2004; 25: 9–21
5. Dorman M, Gifford R: Combining acoustic and electric stimulation in the service of speech recognition. Int J Audio, 2010; 49(12): 912–19
6. Gordon-Salant S, Frisina, R, Fay R, Popper A: The Aging Auditory System. Springer Handbook of Auditory Research, 34; 2010
7. Pichora-Fuller M: Processing speed and timing in aging adults: psychoacoustics, speech perception, and comprehension. Int J Audiol, 2003; 42: S59–67
8. Peterson GE, Lehiste I: Revised CNC lists for auditory test. J Speech Hear Disord, 1962; 27: 62–70
9. Spahr A, Dorman M, Litvak L et al: Development and validation of the AzBio sentence lists. Ear and Hearing, 2012; 33(1): 112–17

# THE IMPORTANCE OF HEARING FOR OLDER ADULTS: A GERIATRICIAN'S PERSPECTIVE

**Michael Lerch[1], Mechthild Decker-Maruska[2]**

[1] Geriatric Department, Protestant Hospital, „Bethanien", Iserlohn, Germany
[2] Geriatric Department, St. Barbara Hospital, Attendorn, Germany

**Corresponding author:** Dr Michael Lerch, MD, MBA, Abt. für Akutgeriatrie und Frührehabilitation, Ev. Krankenhaus Bethanien Iserlohn, Hugo-Fuchs-Allee 6, 58644 Iserlohn, Germany, e-mail: m.lerch@eks-schwerte.de

**Abstract**

**Background:** In providing medical care to senior citizens, the impact of demographic change has not been widely recognised. Whereas dementia and cognitive decline have become major concerns in caring for the elderly, sensory loss – especially decline of auditory function (in spite of its prevalence) – are still stigmatised by society and health care professionals. Although hearing aids have poor acceptance, elderly persons need them to maintain communication and social competency. Self-sufficiency in old age is the ultimate therapeutic goal in geriatrics, and so mobility, stability, emotional equilibrium, continence, nutrition, and cognition need to be targeted by multiprofessional teams. Often professionals do not recognise the prevalence of presbycusis and the options for its treatment and care, and elderly patients often ignore the symptoms of auditory decline. As a result, oral communication, as the basis of therapeutic interaction, becomes brittle. This could lead to frequent misunderstandings and behavioral changes (reduced compliance, inadequate reactions towards demands, lack of interest, social retreat, total isolation), as often experienced in dementia.

**Results:** All geriatric staff, as well as the caregiver, need to be educated about presbycusis (it has a prevalence of 52%; Lerch & Decker-Maruska 2008) and the need for handicap-adjusted communication skills.

**Conclusions:** Since hearing impairment carries a relative risk factor of 2.4 for the development of dementia, differentiating cognitive and auditory decline (or their comorbidity) in the elderly becomes crucial. Therefore geriatric patients should be screened for hearing impairment before any cognitive testing is done (Lerch & Decker-Maruska 2009). From a geriatric perspective, staff education, increase of awareness, early screening, and the most suitable augmentation of hearing (hearing aid, EAS, cochlear implant), matched with age-adapted audiotherapy, will bring benefits in terms of geriatric care and rehabilitation to the elderly.

**Key words:** geriatrics • communication • presbyacusis • elderly • dementia

## Background

Communication is the essence of receiving or processing information. It establishes and maintains social contacts and allows one to act and react appropriately in a given situation. But what if this communication becomes brittle and the information received is no longer clear? A growing number of citizens, more than 600 million worldwide (Institute of Hearing Research 2005), are experiencing gradual breakdown in communication.

According to Cordes et al. (2000), senior citizen are particularly affected (>70 yrs, ≥54%). In Germany alone, more than 13 million citizens suffer impaired hearing, more than 8 million of which are over the age of 70. But despite considerable progress in signal processing, fitting, and amplification, the use and acceptance of hearing aids among the elderly is still very poor. Some 600,000 of these 8 million senior citizens are equipped with a hearing aid, but only about 300,000 wear them on a regular basis; the rest remain in the drawer only to be used on "special occasions" like the visit of the grandchildren.

Why are these numbers so high? First of all, medical reasons should be considered. There is a high prevalence of under diagnosis, partly due to a lack of awareness of the problem among health professionals. In addition, there is still the stigma of hearing impairment and being considered "of advanced age", and the reduced accessibility of medical services due to a declining mobility. Also, the majority of senior citizens mention financial reasons: e.g. hearing aids are too expensive or insufficiently subsidised by the social security system.

Primarily, though, reluctance to use a hearing aid is due to denial of having a hearing affliction and worries about aesthetics. Those who actually wear hearing aids also frequently complain about insufficient age- and handicap-adjusted audio training. Unlike the correction of a visual impairment with prescription lenses, a hearing aid will not restore normal hearing, and so re-training of hearing and continual adjustment of the hearing device is needed.

## Results

In a 2003 survey, the British Royal Institute for Deaf People looked into the consequences of hearing impairment. They categorised them as social (problems at work, lack of concentration, loss of intimacy, problems participating in social life, withdrawal, and isolation); physical (tiredness,

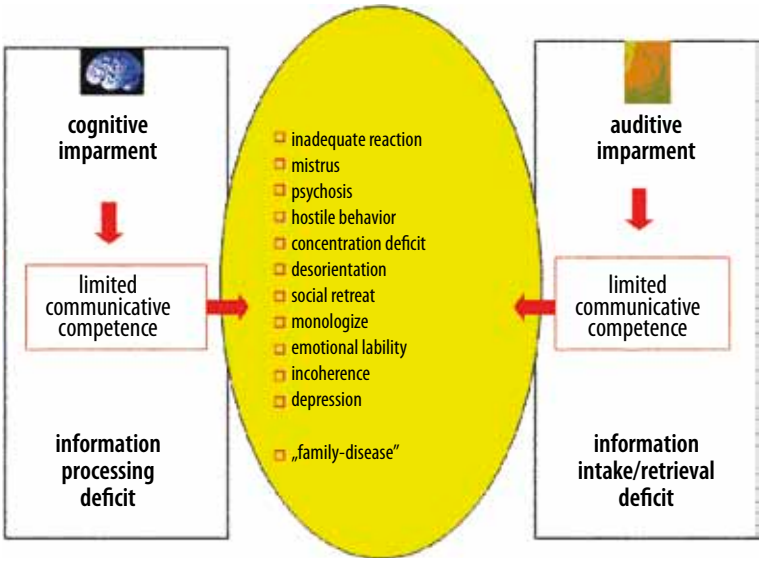



**Figure 1.** Similarity between auditory and cognitive impairment.

vertigo, eating and sleeping problems, elevated blood pressure, and sexual problems); and psychological (shame, guilt, anger, embarrassment, sadness, depression, anxiety and suspiciousness, self-criticism, low self-esteem). When considering the psychological impacts, a similarity between auditory and a cognitive impairment is obvious (Figure 1), and a hearing test preceding a cognitive test becomes imperative (Strouse et al. 1995, Lin et al. 2011).

Hearing impairment is a contributing factor in the development of cognitive dysfunction (Uhlmann et al. 1989, Lin et al. 2011), and has been identified as an independent risk factor (2.4) for developing dementia (Pouchain et al. 2007). This is in the same range as hypertension and diabetes mellitus. Gates et al. (1996) even viewed "central auditory dysfunction" as a probable marker for senile dementia because in a significant number of cases it preceded the dementia.

In contrast to the major health risks – like dementia, depression, and falls – the comorbidity due to hearing impairment is still not recognised either by the public or by most of the medical profession. This is shown by the fact that, in the UK in 2010, £49.71 million went into cardiovascular research and £21.3 million into diabetes research, but only £1.34 million was spent on hearing loss (Hearing Matters 2011).

The lack of public and professional awareness is costly. The social and economic cost of a hearing impairment range from €2,200 (mild hearing loss) up to €11,000 (severe hearing loss) per person per year (not including lost income, lost tax revenues due to unemployment, or early retirement because of hearing loss). This imposes a significant financial burden on many countries: e.g. Germany €30.2 billion, France €22.4 billion, UK €22 billion, Italy €21.3 billion, and Spain €16.3 billion (Hear-it AISBL 2006).

The World Health Organization (WHO) predicts that by 2030 adult-onset hearing loss will be in the top 10 disease burdens in the UK and other high or middle income countries, above cataracts and diabetes. The treatment costs of comorbidities like dementia, depression, and falls – due directly to untreated hearing impairment – will rise steadily for healthcare management organisations (HMOs) over the next four decades, with demographic changes being an accelerator for this process (IfG 2011).

The benefits of an early screening for seniors, adjusted for the demographic changes, can be considerable. If one adds expected savings in the treatment of co-morbidities to the expected preventable loss of economic value, and then subtracts the expected additional cost for the HMOs, a saving between €297 million in 2015 and €571 million in 2050 can be expected. Therefore screening for and treating hearing impairment in the elderly is not only sound medical practice, but economically sensible.

## Conclusions

To achieve these benefits there must be a paradigm change. Hearing impairment must not be seen as a necessity of old age. The geriatric profession in particular, as an advocate of the senior patient, needs to recognise hearing impairment as a major health risk; it should promote early detection and include a hearing test in basic geriatric assessment. It is especially important to differentiate between dementia and pseudo-dementia due to auditory impairment. Patient-targeted questionnaires like the HHIES or the ALOHA (Decker-Maruska/Lerch 2012) as well as bedside screening tests like the HEARCOM triple digit test (Smits et al. 2004) or the speech understanding in noise (SUN) test (Paglialonga et al.) could be valuable tools in geriatrics.

Age-adjusted accessibility to hearing aids (binaural) and age-related audio training, as well as structured allocation of financial resources, should also be major targets in this change process.

Apart from that, good communicational skills in dealing with the elderly hearing impaired should be a priority in geriatric care at all levels and in all professions. To achieve good levels of awareness and communicational skills, they need to be introduced into everyday working practice. To

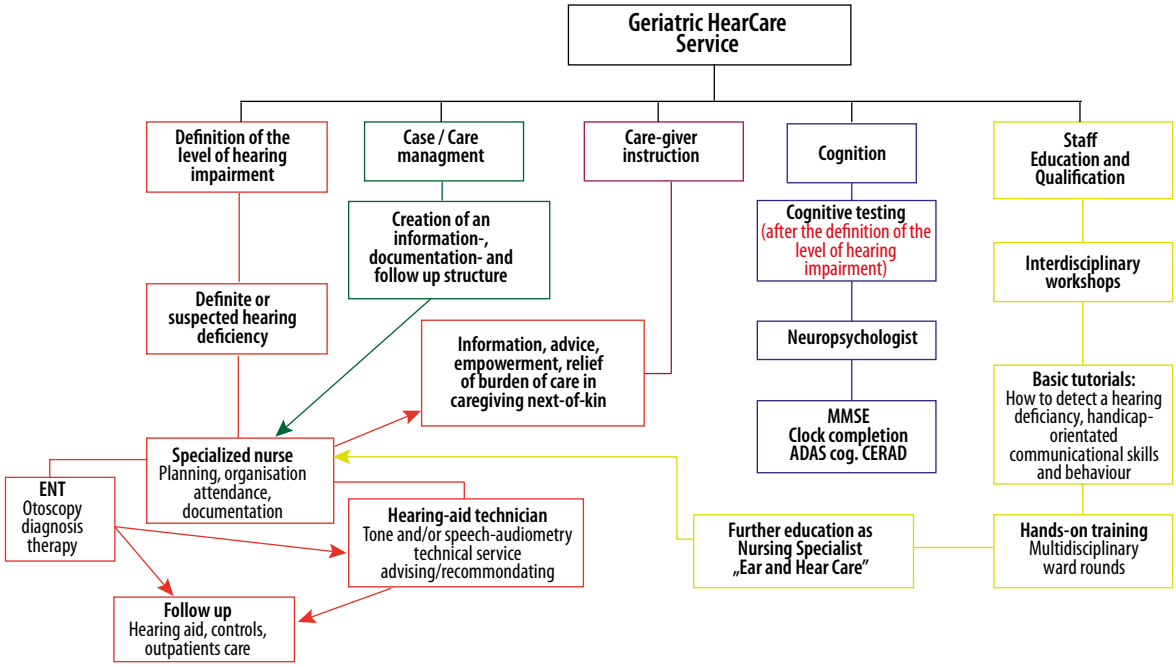



**Figure 2.** Geriatric HearCare Service (Lerch/Decker-Maruska 2009).

act as a "blue print" for such a transfer, possibilities include the five columns of the "Geriatric HearCare Service", staff education and qualification, cooperation with an ENT specialist and an audiologist, hearing-adjusted cognitive testing, case management, and care-giver empowerment (see Figure 2) (Lerch/Decker-Maruska 2009).

In summary, hearing impairment is an increasing health risk, a fact that needs to be emphasised in medical and nursing education. Public opinion also needs to be targeted so as to prevent health deterioration, rising health costs, and declining quality of life in the elderly.

## References:


1. Cordes E: Forum Schwerhörigkeit in Deutschland- Hörscreening Studie. In: DSB Report Nr. 3/2000. Hrsg. Deutscher Schwerhörigenbund, Kornel Mierau Verlag, 2000 [in German]
2. Gates GA, Cobb JL, Linn RT et al: Central auditory dysfunction, cognitive dysfunction, and dementia in older people. Arch Otolaryngology Head Neck Surg, 1996; 122: 161–67
3. Hearing Matters, Action on Hearing Loss, 2011
4. Hear-it AISBL; Evaluation of the Social and Economic Costs of Hearing Impairment, October, 2006
5. Lerch M, Decker-Maruska M: Dementia and impaired hearing – a comorbidity. Eur J Neurol, 2008; 15(Suppl.3): 32–221
6. Lerch M, Decker-Maruska M: Dementia and hard-of hearing – a co morbidity often overlooked in geriatrics. Journal of the American Geriatric Society, 2009; 57(4) Suppl.: 191–92
7. Lerch M, Decker-Maruska M: Case und Care Management in der Geriatrie – Versorgung schwerhöriger Patienten. European Journal of Geriatrics, 2009; 11(3–4): 196–97 [in German]
8. Lerch M, Decker-Maruska M: Best practice in Geriatric HearCare – a concept badly needed. Journal of Nutrition, Health and Aging, 2009; 13(Suppl.1)
9. Lin FR, Ferrucci L, Metter EJ et al: Hearing loss and incident dementia. Arch Neurol, 2011; 68(2): 214–20
10. Neubauer G, Gmeiner A: Institut für Gesundheitsökonomik (IfG): Volkswirtschaftliche Bedeutung von Hörschäden und Möglichkeiten zur Reduktion deren Folgekosten, 2011 [in German]
11. Pouchain D, Dupuy C, San Jullian M et al: La presbyacousie est-belle un facteur de risque de démence? Etude AcouDem. La Revue de Gériatrie, Tome 32, N°6 Juin, 2007 [in French]
12. Strouse AL, Hall JW III, Burger MC. Central auditory processing in Alzheimer's disease. Ear Hear, 1995; 16(2): 230–38
13. Smits C, Kapteyn TS, Houtgast T: Development and validation of an automatic speech-in-noise screening test by telephone. Int J Audiol, 2004; 43: 15–28
14. Uhlmann RF, Larson EB, Rees TS et al: Relationship of hearing impairment to dementia and cognitive dysfunction in older adults. JAMA, 1989; 261(13): 1916–19

# IS HEARING PRESERVATION COCHLEAR IMPLANTATION IN THE ELDERLY DIFFERENT?

**Hinrich Staecker, Sandra Prentiss**

Department of Otolaryngology Head and Neck Surgery, University of Kansas School of Medicine, MS 3010, 3901 Rainbow Blvd, Kansas City, KS 66160, U.S.A.

**Corresponding author:** Hinrich Staecker, Department of Otolaryngology Head and Neck Surgery, University of Kansas School of Medicine, MS 3010, 3901 Rainbow Blvd, Kansas City, KS 66160, U.S.A., e-mail: hstaecker@kumc.edu

**Abstract**

**Background:** Hearing preservation cochlear implantation has become commonplace, giving patients who are poor hearing aid candidates but who have significant residual hearing an opportunity to take part in the hearing world. Hearing preservation cochlear implantation has been extended into pediatric populations, but little attention has been paid to geriatric implantation.

**Material and Methods:** Cochlear implant candidates with residual low frequency hearing implanted between 2009 and 2011 were studied. Pure tone average was evaluated pre- and post-operatively and plotted against patient age.

**Results:** There was a statistically significant relationship between loss of hearing (PTA before and after implantation) and age.

**Conclusions:** Hearing preservation cochlear implantation is feasible in the elderly but there is a slightly larger change in hearing. We review factors that may affect hearing preservation outcomes in the elderly.

**Keywords:** cochlear implantation • hearing preservation • aging • presbycusis

## Background

Recognition that preservation of residual low frequency hearing improves cochlear implant (CI) function has been widely described (Gstoettner et al., 2004; Kiefer et al., 2004; Dorman and Gifford, 2010). Among patients, the elderly represent a population where down-sloping hearing losses with poor speech discrimination are common, and hence they are a group from which potential hearing preservation CI patients may be recruited. A key question is whether the elderly have the same outcomes in terms of hearing preservation as younger patients. To examine this we looked at changes in hearing after implantation as a function of age; we then examined the correlation between age and change in pure tone average. We also looked at cochlear implant outcomes as a function of age for hearing preservation patients. We discuss some of the potential causes of observed differences between the patient populations.

## Methods

### Subjects and outcomes measures

Informed consent was obtained prior to testing, and the protocol was approved by the University of Kansas Medical Center human subjects board. A total of 18 patients with residual hearing between 125 and 500 Hz (5 males and 13 females) were implanted between 2009 and 2011. Ages ranged from 26 to 84 with a mean age of 63.2 years. All candidates fell within Food and Drug Administration (FDA) or Medicare guidelines for implantation. Prior to implantation, all patients underwent blood testing to screen for autoimmune inner ear disease and had an MRI scan to rule out the presence of retrocochlear disease.

### Surgical approach

The extended round window approach was used in all cases. After performance of a mastoidectomy and facial recess (posterior tympanotomy) approach to the middle ear, all bone dust was irrigated out of the wound. Hemostasis was obtained and 0.5 ml of Decadron (10 mg/ml) was applied to the round window niche. The bony overhang of the round window niche was then carefully removed with a 1 mm diamond burr and the round window clearly visualised by testing the round window reflex. The wound was once again irrigated and Healon was used to cover the round window (RW). The RW was then opened with a small pick and the implant electrode carefully inserted. All patients were implanted with a Med-El medium (M) electrode array. Pure tone thresholds were obtained before surgery and 2 weeks post-operatively using insert earphones. The change in pure tone average (PTA) was calculated at 250, 500, and 750 Hz. Initial PTA immediately after surgery for all patients was less than 40 dB.

## Results

As seen in Figure 1 there was a linear relationship between age at implantation and change in hearing in the low frequencies ($r^2$=0.52; $p$<0.05). When arbitrarily divided at age 65, the average change in PTA for the younger patient group (average age =46.5) was 13.4 dB and the older patient (average age =74.5) group was 19 dB ($p$=0.12). As seen in the box plot of this data (Figure 2), the range

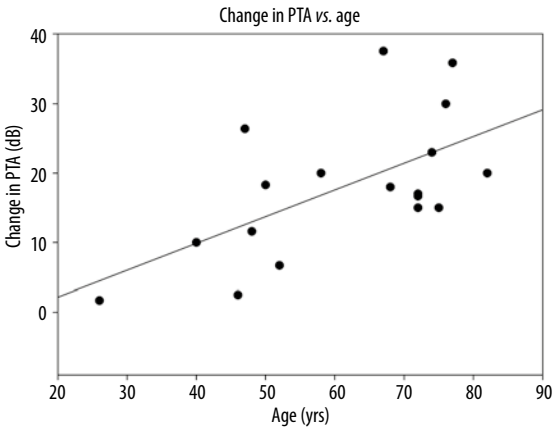



**Figure 1.** Scatter plot of change in pure tone average *versus* age. There is a linear relationship between patient age at time of implantation and degree of hearing preservation.

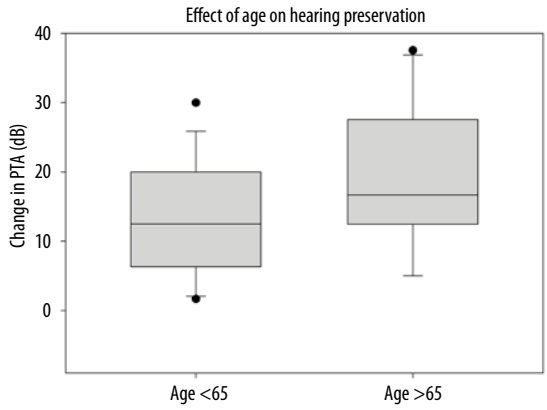



**Figure 2.** Box plot of average change in hearing for patient age less than and greater than 65. Younger patients tend to have slightly less change in hearing and older patients demonstrated a wider range in change in residual hearing after implantation; however, this was not statistically significant.

of data distribution is broader for the older age group, resulting in a large standard deviation.

## Discussion

The development of reliable approaches for hearing preservation cochlear implantation has led to a rapid expansion of cochlear implantation to novel patient populations (Skarzynski et al., 2010). The audiologic configuration that makes patient candidates for hearing preservation implantation is common in the elderly (Hoffman et al., 2012). A recent review of cochlear implantation in the elderly suggests that earlier implantation, when patients have less hearing loss, may result in better hearing outcomes (Lin et al., 2012). Successful expansion of hearing preservation implantation into this population thus represents an important goal.

Overall, our data suggest that hearing preservation is feasible in the elderly and that, on average, hearing preservation outcomes are similar to younger patients (Figure 2). However, when examining the data more closely, the range of hearing loss after implantation is higher in older patients and regression analysis does suggest that, as age increases, the amount of hearing loss after implantation also increases (Figure 1). As we have previously reported, we did not see any significant difference in implant function between our patients based on age (Prentiss et al., 2010); therefore, despite slightly increased loss of low frequency hearing, hearing preservation implantation is still a valuable intervention. Accumulation of patient numbers may in future allow us to divide patients into 10-year cohorts, allowing us to better stratify risk based on age.

The relationship between age and central auditory dysfunction has been well documented, but little is known about the effects of age on the cochlea's sensitivity to damage. A potential source of age-related sensitivity to damage is mitochondrial function within the inner ear. Damage to mitochondrial DNA has been documented to occur in all regions of the inner ear as age increases (Seidman et al., 2002; Yamasoba et al., 2007; Someya and Prolla, 2010; Crawley and Keithley, 2011). The accumulation of mitochondrial DNA damage can lead to sensitivity to further stress and subsequent induction of apoptosis (Fariss et al., 2005). This opens the possibility that completely different protective molecules that stabilise mitochondria could be applied to improve our hearing outcomes in the elderly.

## Conclusions

Hearing preservation cochlear implantation is feasible in the elderly although slightly higher rates of hearing loss may be observed compared to younger patients.

## References:

1. Crawley BK, Keithley EM: Effects of mitochondrial mutations on hearing and cochlear pathology with age. Hear Res, 2011; 280: 201–8
2. Dorman MF, Gifford RH: Combining acoustic and electric stimulation in the service of speech recognition. Int J Audiol, 2010; 49: 912–19
3. Fariss MW, Chan CB, Patel M et al: Role of mitochondria in toxic oxidative stress. Mol Interv, 2005; 5: 94–111
4. Gstoettner W, Kiefer J, Baumgartner WD et al: Hearing preservation in cochlear implantation for electric acoustic stimulation. Acta Otolaryngol, 2004; 124: 348–52
5. Hoffman HJ, Dobie RA, Ko CW et al: Hearing threshold levels at age 70 years (65-74 years) in the unscreened older adult population of the United States, 1959–1962 and 1999–2006. Ear Hear, 2012; 33: 437–40
6. Kiefer J, Gstoettner W, Baumgartner W et al: Conservation of low-frequency hearing in cochlear implantation. Acta Otolaryngol, 2004; 124: 272–80

7. Lin FR, Chien WW, Li L et al: Cochlear implantation in older adults. Medicine (Baltimore), 2012; 91: 229–41
8. Prentiss S, Sykes K, Staecker H: Partial deafness cochlear implantation at the University of Kansas: techniques and outcomes. J Am Acad Audiol, 2010; 21: 197–203
9. Seidman MD, Ahmad N, Bai U: Molecular mechanisms of age-related hearing loss. Ageing Res Rev, 2002; 1: 331–43
10. Skarzynski H, Lorens A, Piotrowska A, Skarzynski PH: Hearing preservation in partial deafness treatment. Med Sci Monit, 2010; 16(11): CR555–62
11. Someya S, Prolla TA: Mitochondrial oxidative damage and apoptosis in age-related hearing loss. Mech Ageing Dev, 2010; 131: 480–86
12. Yamasoba T, Someya S, Yamada C et al: Role of mitochondrial dysfunction and mitochondrial DNA mutations in age-related hearing loss. Hear Res, 2007; 226: 185–93

# "INFLAMMAGING" AND ITS MANAGEMENT IN PRESBYCUSIS

**Carl Verschuur**

Institute of Sound and Vibration Research, Faculty of Engineering and the Environment, University of Southampton, U.K.

**Corresponding author:** Carl Verschuur, Institute of Sound and Vibration Research, Faculty of Engineering and the Environment, University of Southampton, U.K., e-mail: cav@isvr.soton.ac.uk

**Abstract**

**Background:** From human studies there is little published evidence on the biological basis for presbycusis. We report a previously published study which tested the hypothesis that chronic inflammation in the elderly, known as "inflammaging" is a causal factor for presbycusis.

**Method and Results:** Analysis of biological and audiological data from a large population cohort showed an independent association between a range of inflammatory markers and mean hearing level.

**Discussion:** Our findings suggest that further investigation into the role of inflammation in causing presbycusis is warranted. We also discuss wider research plans, and argue for a greater understanding of the inter-relationship of systemic and cochlear inflammation and the role of inflammatory processes in causing a range of types of hearing loss.

## Background

The aim of the paper is to report and discuss previously published results – which show a relationship between age-related hearing loss (ARHL, or presbycusis) and chronic inflammation in a cohort of older people – and to discuss the wider implications for future management and research in this area. ARHL is one of the most common and debilitating conditions associated with ageing and is thought, world-wide, to affect more than half of all adults over the age of 75 and over a third of those over 65. The condition has a range of effects in terms of increased social isolation and reduced economic and social activity. Despite this widespread impact, treatment of presbycusis is primarily limited to management through hearing aids, and there are no clearly identified methods to prevent the onset or progression of the condition.

Our understanding of the biological basis for ARHL is limited, and largely based on cadaver studies or animal models. There is potential to exploit recent advances in the understanding of the biological basis for ageing and seek to apply this to understanding ARHL more specifically. There are currently a number of proposed mechanisms and theories of ageing, which may provide both competing and complementary explanations for senescence. An important proposed mechanism is immunosenescence [1], according to which the ageing immune system becomes less adept at down-regulating on-going production of inflammatory proteins after acute inflammatory events, leading to a chronic state of low-level inflammation known as "inflammaging" [2].

There is growing evidence that inflammaging is a causal factor, or at least associated with, a range of age-related or age-accelerated diseases, including atherosclerosis, cardiovascular disease, peripheral arterial disease, type II diabetes, and Parkinson's disease. It seems plausible that chronic changes in inflammatory state play a role in causing or accelerating ARHL. The cochlea has its own immune response [3,4] and is not immune-privileged, with evidence of interaction between systemic and local inner ear inflammation. Interestingly, a number of age-related conditions with an inflammatory element, including cardiovascular disease [5], Alzheimer's disease [6], and diabetes [7] are associated with markedly increased severity and prevalence of ARHL. In a recently published study, we sought to investigate the hypothesis that inflammaging could cause, or accelerate, long-term damage to the hearing system with age [8]. The hypothesis was based on a model of the effect of peripheral inflammation on CNS function which shows that acute and chronic inflammation interact in causing disease [9].

## Methods

We examined data from the Hertfordshire Ageing Study (HAS), a large birth cohort of individuals born in Hertfordshire, UK, between 1911 and 1948 [10,11]. Data from the HAS study were available on hearing level, inflammatory status, and a range of other physiological and medical variables that were measured during a cross-sectional data-sampling exercise undertaken in 1995. These data were analysed to determine the degree of independent association between inflammatory markers and hearing status, with additional lifestyle and demographic factors (e.g. gender, age, smoking, occupational and noise exposure history) taken into account. Data from blood samples taken during the data collection exercise included erythrocyte sedimentation rate (ESR) and white blood cell count, with differential numbers of neutrophils, lymphocytes, and monocytes. Stored serum was used subsequently to measure additional inflammatory markers using multiplex technology, including interleukins (IL-1, IL-6, and IL-10) and C-reactive protein (CRP). Audiometric thresholds measured by air conduction at four frequencies (500, 1000, 2000, and 4000 Hz) were also available.

## Results

After excluding data from subjects with possible conductive hearing loss or significant audiometric asymmetry, data were analysed on a final cohort of 343 men and 268 women aged 63 to 74. Results showed that older age, smoking, history of noise exposure, and male gender were associated with higher mean hearing threshold in the worse ear. After adjustment for these factors in multiple regression models, four measures of immune or inflammatory status were significantly associated with hearing threshold, namely white blood cell count, neutrophil count, IL-6, and C-reactive protein, i.e. for these inflammatory measures, higher serum levels were associated with worse hearing among this group of older people.

## Conclusions

Our findings are consistent with the hypothesis that inflammaging is a causative factor in ARHL. Findings also suggest, albeit indirectly, that there is a link between inflammatory markers measured via serum analysis and intra-cochlear inflammatory status. The latter issue is important, as direct measurement of cochlear inflammation via analysis of cochlear fluid is not practically possible. Interestingly, the association between hearing level and inflammatory markers was *continuous*, i.e. there was no threshold effect, exactly as predicted by the inflammaging hypothesis, which indicates a gradual variation in inflammatory status and co-existing morbidity, rather than a binary disease model of ageing.

It is worth noting that the identified association between inflammatory markers and hearing level was present despite a number of factors likely to dilute any such effect. Audiometric data were not available for frequencies above 4000 Hz and, although testing was undertaken by trained researchers using standardised audiometric methods, tests were undertaken in a community environment with the possibility of interference from background noise. Most crucially, the cohort were relatively young (mean age 67 years), thus at an early stage of presbycusis.

Finally, the data did not assess changes over time, which is crucial in determining a causal link between inflammaging and ARHL. The fact that, despite possible limitations in data collection methods, significant associations were identified between hearing loss and its known predictors (such as age and gender) and were also independently associated with levels of inflammatory markers, suggests that these associations are likely to be robust.

The findings raise a number of important questions requiring further investigation. One question is how systemic (particularly chronic) inflammation interacts with inflammation in the cochlea and related auditory structures, and what levels of inflammatory response are needed to produce either a gradual or sudden reduction in hearing threshold. Related to this is the question of what the mechanism might be, i.e. whether primary hair cell damage is implicated or whether other auditory structures, e.g. the stria vascularis [12], spiral ganglion cells, or auditory nerve [13] are affected. Addressing these questions, we are currently undertaking work to determine the causal relationship between systemic inflammation and damage to the auditory system in a mouse model of ARHL. We also plan to undertake a longitudinal study of inflammation *vs.* hearing in a cohort of older adults to optimise the sensitivity of both auditory measures and bio-markers of inflammation to better understand the relationship between inflammaging and ARHL.

The work has also been extended to hearing preservation in cochlear implant surgery, as inflammation is likely to be the key mediating factor in determining loss of residual hearing after surgery [14–16]. We suggest that a better understanding of the link between systemic and cochlear inflammation, and the role of different inflammatory processes as drivers of both acute and chronic cochlear (or auditory neural) damage, will be beneficial to understanding, preventing, and treating a range of different types of hearing loss, including ARHL.

## Acknowledgements

The work reported here was made possible by funding from Action on Hearing Loss flexi-grant F12 and the support of the Medical Research Council Lifecourse Epidemiology Unit. The reported study has been previously published in the journal Age and Ageing [8] and was a joint project with all the co-authors of that paper. The author would also like to thank Dr Tracey Newman and Professor Huw Cooper for scientific input to on-going work reported above and comments on the draft.

## References:

1. Larbi A, Franceschi C, Mazzatti D et al: Aging of the immune system as a prognostic factor for human longevity. Physiology (Bethesda, Md.), 2008; 23: 64–74
2. Hunt KJ, Walsh BM, Voegeli D, Roberts HC: Inflammation in aging part 1: physiology and immunological mechanisms. Biol Res Nurs, 2010; 11(3): 245–52
3. Harris JP, Ryan F: Immunobiology of the inner ear. Am J Otolaryngol, 1984; 5(6): 418–25
4. Satoh H, Firestein GS, Billings PB et al: Proinflammatory Cytokine Expression in the Endolymphatic Sac During Inner Ear Inflammation. J Assoc Res Otolaryngol, 2003; 4(2): 139–47
5. Gates GA, Cobb JL, D'Agostino RB, Wolf PA: The relation of hearing in the elderly to the presence of cardiovascular disease and cardiovascular risk factors. Arch Otolaryngol Head Neck Surg, 1993; 119(2): 156–61
6. Lin FR, Metter EJ, O'Brien RJ et al: Hearing loss and incident dementia. Arch Neurol, 2011; 68(2): 214–20
7. Frisina ST, Mapes F, Kim S et al: Characterization of hearing loss in aged type II diabetics. Hear Res, 2006; 211(1–2): 103–13
8, Verschuur CA, Dowell A, Syddall HE et al: Markers of inflammatory status are associated with hearing threshold in older people: findings from the Hertfordshire Ageing Study. Age Ageing, 2012; 41(1): 92–97

9. Holmes C, Cunningham C, Zotova E et al: Systemic inflammation and disease progression in Alzheimer disease. Neurology, 2009; 73(10): 768–74
10. a Ashfield T, Syddall HE, Martin HJ et al: Grip strength and cardiovascular drug use in older people: findings from the Hertfordshire Cohort Study. Age Ageing, 2010; 39(2): 185–91
11. Robinson S, Syddall H, Jameson K et al: Current patterns of diet in community-dwelling older men and women: results from the Hertfordshire Cohort Study. Age Ageing, 2009; 38(5): 594–99
12. Ohlemiller KK: Mechanisms and genes in human strial presbycusis from animal models. Brain Res, 2009; 1277(314): 70–83
13. Haake SM, Dinh CT, Chen S et al: Dexamethasone protects auditory hair cells against TNFalpha-initiated apoptosis via activation of PI3K/Akt and NFkappaB signaling. Hear Res, 2009; 255(1–2): 22–32
14. Chang A, Eastwood H, Sly D et al: Factors influencing the efficacy of round window dexamethasone protection of residual hearing post-cochlear implant surgery. Hear Res, 2009; 255(1–2): 67–72
15. James DP, Eastwood H, Richardson RT, O'Leary SJ: Effects of round window dexamethasone on residual hearing in a Guinea pig model of cochlear implantation. Audiol Neurootol, 2008; 13(2): 86–96
16. Dinh CT, Van De Water TR: Blocking pro-cell-death signal pathways to conserve hearing. Audiol Neurootol, 2009; 14(6) 383–92

# AUDITORY EVENT-RELATED POTENTIALS: A POSSIBLE OBJECTIVE TOOL FOR EVALUATING AUDITORY COGNITIVE PROCESSING IN OLDER ADULTS WITH COCHLEAR IMPLANTS

**Yael Henkin**

Hearing, Speech, and Language Center, Sheba Medical Center, Tel Hashomer, Department of Communication Disorders, Sackler Faculty of Medicine, Tel Aviv University, Israel

**Corresponding author:** Yael Henkin, Hearing, Speech, and Language Center, Sheba Medical Center, Tel Hashomer, Department of Communication Disorders, Sackler Faculty of Medicine, Tel Aviv University, Israel

**Abstract**

A wealth of research shows that aging adversely affects the morphology and physiology of the peripheral and central auditory system, resulting in a decline in auditory function. Moreover, age-related cognitive deficits in attention, working memory, and speed of information processing have been reported, augmenting the challenges involved in auditory rehabilitation of older adults.

With the growing number of older adults receiving cochlear implants (CIs) there is general consensus that substantial benefits can be gained. Nonetheless, variability in speech perception performance is high, and the relative contribution and interactions among peripheral, central auditory, and cognitive factors have not been fully delineated.

A possible objective means for assessing the benefits derived from CIs in older adults involves electrophysiological measures. In particular, auditory event-related potentials (AERPs), which allow evaluation of the time-course of cortical information processing from early perceptual to later cognitive, post-perceptual stages, could prove advantageous.

In the current report our experience with AERPs elicited by perceptual and higher order cognitive tasks in normal hearing listeners and in CI recipients is reported, and their implications for the evaluation of older adults with CIs is discussed. By varying task complexity and degree of cognitive load, AERPs can expose processing difficulties of older adults with a CI and gauge the contribution of bottom-up versus top-down processing. The suggested comprehensive, hierarchical AERP evaluation may contribute to the better understanding of the neural manifestations of age-related auditory/cognitive decline and its interaction with CIs. It may also lead to the development of CI strategies and rehabilitation procedures tailored specifically to this unique group.

## Background

A wealth of literature shows that aging adversely affects auditory system morphology and physiology [1]. Age-related changes result in decline in auditory function that include: decreased hearing sensitivity, especially in the high frequencies; decreased temporal and frequency resolution; decline in speech perception in non-optimal listening conditions; and reduced binaural processing [e.g. 2,3].

Deterioration of auditory function is accompanied by cognitive decline manifested by impairments in working memory, attention, and a reduced ability to inhibit processing of irrelevant information; there is also a general 'slowing down' of information processing [for review see 4].

Auditory rehabilitation of the older hearing-impaired adult is therefore a challenge. Nonetheless, with the growing number of older adults receiving cochlear implants (CIs), there is general consensus that substantial benefits can be gained. It is also agreed, however, that there is high variability in speech perception performance both in quiet and in noise, and the relative contribution and interactions among peripheral, central auditory, and cognitive factors are not fully understood. Behavioral speech perception studies show controversial results, with some suggesting similar performance of young and older adults [e.g. 5], and others indicating significantly poorer performance in older adults [e.g. 6]. It should be taken into account, however, that clinically-used speech perception tests are limited as they do not reflect cognitive aspects of speech understanding which affect the amount of attention, effort, and memory resources expended during communication. Moreover, they provide the 'end product' or 'outcome' of auditory processing but do not follow the sequence of events that lead to that outcome.

An objective means for assessing the benefits derived from CIs in older adults are electrophysiological measures. In particular, auditory event-related potentials (AERPs), which allow evaluation of the time-course of cortical information processing from early perceptual to later cognitive, post-perceptual stages, may prove advantageous [7]. The purpose of the current short review is to elucidate the potential use of AERPs for evaluating auditory/cognitive processing in older adults with CIs. By varying task complexity and degree of cognitive load, AERPs may expose processing difficulties of older adults with CIs and gauge the contribution of bottom-up *vs.* top-down processing.

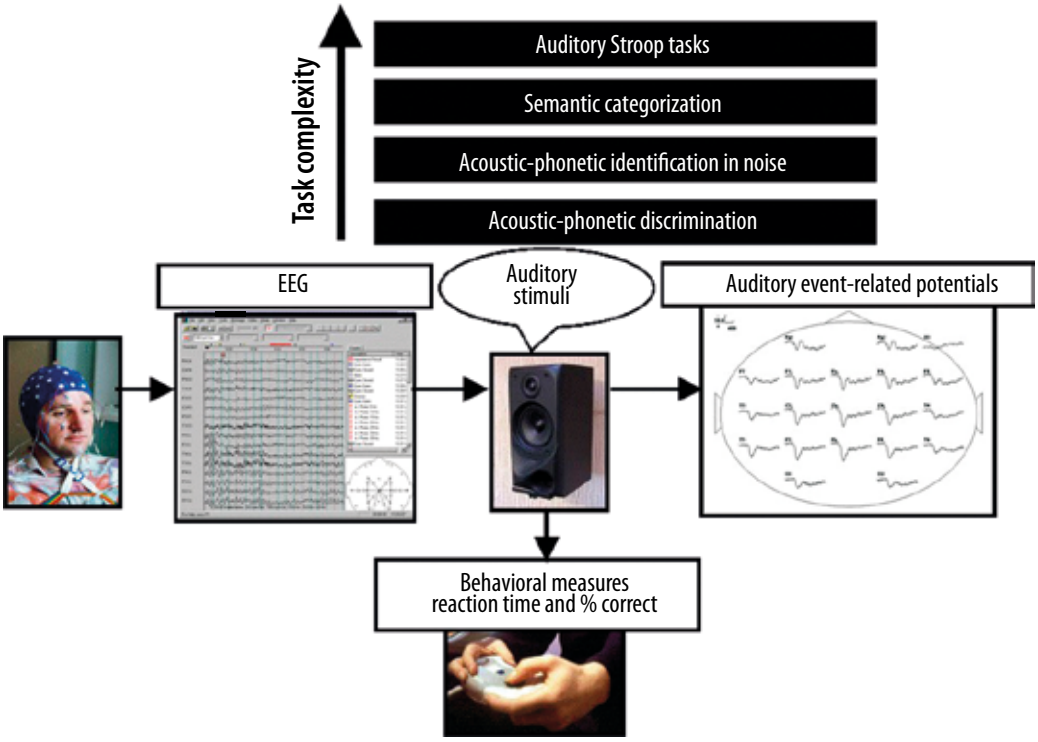



**Figure 1.** A schematic illustration of the recording of auditory event-related potentials to tasks of increasing complexity.

## Methods

In a series of studies we showed that valuable information regarding auditory processing can be gained by means of AERPs from healthy and clinical populations [8–11], and from CI recipients in particular [12–15]. In these studies we recorded the brain electrical activity from multiple electrodes by means of a Brain Performance Measurement (BPM) System (Orgil™) while subjects performed auditory tasks of increasing difficulty (for technical details see Henkin et al. [14]). The timing and strength of auditory processing was manifested by AERP's latencies and amplitudes, respectively, and the relationship with behavioral measures (e.g. performance accuracy and reaction time) was assessed.

## Results and Discussion

In a study designed to evaluate acoustic phonetic *discrimination* in post-lingual adult CI recipients, oddball tasks that included pairs of stimuli that differed by one phonetic feature were constructed [14]. We asked how increasing acoustic phonetic difficulty – from an easy 'vowel place' task (/ki/ *vs.* /ku/) to a difficult 'place of articulation' task (/ka/ *vs.* /ta/) – affects the P3 potential. Results in CI recipients indicated that, compared to NH controls, there was prolonged processing time and reduced synchrony, as reflected by longer P3 latency and reduced amplitudes. Furthermore, P3 was sensitive to acoustic phonetic difficulty in a hierarchical manner and differences between CI and NH subjects were more pronounced in the more difficult 'vowel height' task and place of articulation task.

Increasing task complexity in a group of normal hearing listeners, by using an acoustic phonetic *identification* task in noise, confirmed the advantage of AERPs for comparing bottom-up, perceptual processes *vs.* top-down cognitive processes [11]. In this study, subjects were required to identify the syllables /da/ and /ga/ presented in quiet and in signal-to-noise ratios (SNRs) ranging from +15 to –6 dB. Results indicated that N1 latency increased as SNR decreased from the most favorable SNR listening condition of +15 dB. In contrast, P3 latency was not altered in the favorable SNRs, and was prolonged only at SNRs equal to or less than 0 dB. The changes in N1, which is known to reflect the initial processing of the physical characteristics of the stimulus, reflect difficulty in bottom-up processing. Top-down processing left the higher order cognitive P3 unchanged in the favorable SNR; however, with increasing uncertainty, top-down processing could not compensate and indeed performance dramatically decreased.

Another means for increasing task complexity is by enhancing linguistic demand. For example, AERPs that were recorded during a semantic *categorization* task in which subjects were required to respond to stimuli from a targeted semantic category (names) and to ignore a non-target category (body parts) differentiated between healthy children and those with idiopathic generalized epilepsy who are prone to cognitive deficits [8,9]. In contrast, AERPs to tonal and easy acoustic phonetic discrimination tasks were comparable.

A task that is especially suitable for testing age-related decline in inhibitory processes and its effect on auditory/cognitive efficiency is the 'Stroop task'. In an auditory version of the task that we recently constructed [10], listeners were

required to classify word meaning or speaker's gender while ignoring the irrelevant (congruent or incongruent) speaker's gender or word meaning, respectively. A significant auditory Stroop effect was evident and manifested in prolonged reaction time and reduced performance accuracy to incongruent *vs.* congruent stimuli, as expected. Interestingly, the timing of neural events (latencies of N1, P2, N2, and N4) to congruent and incongruent stimuli did not differ, suggesting that auditory conflict processing was post-perceptual and located at response selection and execution stages. Nonetheless, reduced N1 amplitude to incongruent stimuli indicated a conflict processing signature at the initial stages of processing.

Taken together, the described hierarchical set of auditory tasks –characterized by increasing auditory/cognitive demand from simple acoustic phonetic discrimination to high-load cognitive Stroop tasks (summarized in Figure 1) – may prove advantageous for the evaluation of older adults with CIs. Such data may contribute to the better understanding of the neural manifestations of age-related auditory/cognitive decline and its interaction with CIs. Furthermore, it may lead to the development of CI device strategies and rehabilitation procedures tailored specifically to this unique group of patients.

## References:

1. Gordon-Salant S, Frisina RD: Introduction and overview. In: Gordon-Salant S, Frisina RD, Popper AN, Fay RR (eds.), The Aging Auditory System, Springer Handbook of Auditory Research, 2010; 34: 1–18
2. Fitzgibbons PJ, Gordon-Salant S: Behavioral studies with aging humans: hearing sensitivity and psychoacoustics. In: Gordon-Salant S, Frisina RD, Popper AN, Fay RR (eds.), The Aging Auditory System, Springer Handbook of Auditory Research, 2010; 34: 111–34
3. Pichora-Fuller MK, Souza PE: Effects of aging on auditory processing of speech. Int J Audiol, 2003; 42(Suppl.2): S11–16
4. Pichora-Fuller MK, Singh G: Effects of age on auditory and cognitive processing: implications for hearing aid fitting and audiologic rehabilitation. Trends Amplif, 2006; 10: 29–59
5. Budenz CL, Cosetti MK, Coelho DH et al: The effects of cochlear implantation on speech perception in older adults. J Am Geriatr Soc, 2011; 59(3): 446–53
6. Friedland DR, Runge-Samuelson C, Baig H, Jensen J: Case-control analysis of cochlear implant performance in elderly patients. Arch Otolaryngol Head Neck Surg, 2010; 136(5): 432–38
7. Martin BA, Tremblay KL, Stapells D: Principles and applications of cortical auditory evoked potentials. In: Burkard RF, Don M, Eggermont JJ (eds.), Auditory Evoked Potentials: Basic principles and clinical applications. Baltimore: Lippincott Williams & Wilkins, 2007; 482–507
8. Henkin Y, Kishon-Rabin L, Gadoth N, Pratt H: Auditory event related potential during phonetic and semantic processing in children. Audiol Neurotol, 2002; 7: 228–39
9. Henkin Y, Kishon Rabin L, Pratt H et al: Linguistic processing in idiopathic generalized epilepsy: an auditory event related potential study. Epilepsia, 2003; 44: 1207–17
10. Henkin Y, Yaar-Soffer Y, Gilat S, Muchnik C: Auditory conflict processing: behavioral and electrophysiological manifestations of the Stroop effect. JAAA, 2010; 21: 474–86
11. Kaplan-Neeman R, Kishon-Rabin L, Henkin Y, Muchnik C: Identification of syllables in noise: electrophysiological and behavioral correlates. JASA, 2006; 120: 926–33
12. Henkin Y, Kishon-Rabin L, Tetin-Schneider S et al: Low resolution electromagnetic tomography (LORETA) in children with cochlear implants: a preliminary report. Int J Audiol, 2004; 43: 48–51
13. Henkin Y, Kileny PR, Hildesheimer M, Kishon-Rabin L: Phonetic processing in children with cochlear implants: an auditory event-related potentials study. Ear Hear, 2008; 29: 239–49
14. Henkin Y, Tetin-Schneider S, Hildesheimer M, Kishon Rabin L: Cortical neural activity underlying speech perception in post-lingual adult cochlear implant recipients. Audiol Neurotol, 2009; 14: 39–53
15. Henkin Y, Givon L, Yaar-Soffer Y, Hildesheimer M: Cortical binaural interaction during speech processing in children with bilateral cochlear implant. Cochlear Implants Inter, 2011; 12: S61–65

# GENETICS AND PRESBYCUSIS – MONOGENIC FORM OF AGE RELATED HEARING IMPAIRMENT CAUSED BY *CDH23* MUTATIONS

**Shin-ichi Usami, Maiko Miyagawa, Nobuyoshi Suzuki, Shin-ya Nishio**

Department of Otorhinolaryngology, Shinshu University School of Medicine, Matsumoto, Japan

**Corresponding author:** Shin-ichi Usami, Department of Otorhinolaryngology, Shinshu University School of Medicine, 3-1-1 Asahi, Matsumoto 390-8621, Japan, e-mail: usami@shinshu-u.ac.jp

**Abstract**

**Background:** Presbycusis (age-related hearing impairment: ARHI) is believed to be a typical complex disorder associated with both genetic factors and environmental factors ("complex ARHI"). However, a small portion of patients with *CDH23* mutations exhibit an ARHI-like phenotype ("monogenic ARHI"). It is an interesting question as to the difference between the two types of ARHI from the clinical viewpoint as well as audiogram configurations.

**Subjects and Methods:** The detailed clinical courses of two cases of "monogenic ARHI" caused by *CDH23* mutations were evaluated. In addition, statistical classification of audiogram configurations was used to determine whether or not "monogenic ARHI" can be differentiated from the other clusters with high frequency involved hearing loss.

**Results:** Although onset age of the present two cases was somewhat earlier than commonly encountered in ARHI, clinical features were very similar to presbycusis, with slowly progressive high frequency involved hearing loss.

**Conclusions:** The present data strongly supports the view that there are at least two types of ARHI and a particular type of ARHI (late onset hereditary hearing loss) is monogenically inherited. It may be possible to differentiate those subtypes through statistical classification of audiogram configurations.

**Keywords:** age related hearing impairment • ARHI • presbycusis • *CDH23* • late onset • progressive • high frequency hearing loss • recessive • audiogram configuration

## Background

Presbycusis (age-related hearing impairment: ARHI) is the most common sensorineural impairment in elderly people and in developed countries, more than 30% of people over 65 years old are affected. ARHI is believed to be a typical complex disorder associated with both genetic factors and environmental factors ("complex ARHI"). However, some hereditary hearing loss patients showed late-onset hearing loss similar to presbycusis ("monogenic ARHI"). Recently we reported 52 probands with *CDH23* mutations among 1396 SNHL patients (Miyagawa et al., 2012), the majority of the patients showed congenital, high frequency involved, progressive hearing loss. However, among them, we have found a small portion of patients with *CDH23* mutations exhibiting ARHI-like phenotype (Miyagawa et al., 2012). Three out of 52 probands had "late-onset" hearing loss. Interestingly, two of the three patients are associated with a particular *CDH23* mutation (p.R2029W), indicating that some particular mutations cause late onset progressive high frequency involved hearing loss. In this paper, we report the detailed clinical course of "monogenic ARHI" caused by *CDH23* mutations and discuss the difference between the two types of ARHI from the viewpoint of audiogram configurations.

## Subjects and Methods

The detailed clinical courses of two cases of "monogenic ARHI" caused by *CDH23* mutations were evaluated. Audiogram configuration classification of high frequency involved hearing loss was carried out using 2846 patients (with ages ranging from 4 to 93 and an average age of 53.9) who visited the outpatient clinic of Shinshu University Hospital between 2001-2010. Using air conduction of seven frequencies, 0.125, 0.25, 0.5, 1, 2, 4, 8 kHz, K-means cluster analysis was conducted to classify the degree and shapes of pure tone audiometric data in SPSS v18 (SPSS Inc., Chicago IL). The cluster results were tested by ANOVA and the significance was estimated.

## Results

### Clinical courses of two cases of "monogenic ARHI" caused by *CDH23* mutations

As stated below, in these two cases, onset age was somewhat earlier than commonly encountered in ARHI, but their clinical features including late-onset and slowly progress nature of high frequency involved hearing loss were confirmed from the anamnestic evaluation and pronunciation, as well as pure tone audiogram.

*Case 1 (#2806)*

53 y.o. male.

The patient had not noticed any hearing loss in childhood and passed the annual school hearing screening (in Japan, mandatory hearing testing for 1000 Hz and 4000 Hz is performed annually in elementary and junior high school). However around age 40, his hearing loss was found in an annual company health check (in Japan, hearing testing for 1000 Hz and 4000 Hz is performed at most companies), and his hearing loss gradually progressed. The audiogram presented high frequency predominant hearing impairment (Figure 1). Incomplete pronunciation of consonants was not noted in this patient. He had tinnitus but did not have any vertigo nor any other associated symptoms. Caloric testing showed normal response. Mutation analysis identified homozygous for p.R2029W (p.[R2029W];[R2029W]) (Miyagawa et al., 2012).

*Case 2 (#3255)*

71 y.o. female.

The patient had not noticed any hearing problem in childhood and passed the annual school hearing screenings. However, she noticed her hearing loss around age 60, and it then gradually progressed. The audiogram presented high frequency predominant hearing impairment (Figure 1). She used hearing aids from age 70 due to progressiveness. Incomplete pronunciation of consonants was not noted in this patient. She had tinnitus but did not have any vertigo nor any other associated symptoms. Mutation analysis identified homozygous for p.R2029W (p.[R2029W];[R2029W]) (Miyagawa et al., 2012).

### Audiogram configuration classification of high frequency involved hearing loss

Audiograms of the patients could be divided into 12 groups by clustering (Figure 2), and the two cases with *CDH23* mutations were compatible with belonging to cluster 2.

## Discussion

### "Complex ARHI" *vs.* "monogenic ARHI"

It has been thought that any type of hearing loss is caused by (either or both) genetic factors and environmental factors, though the ratio of genetic/environmental influence is variable (Figure 3). For example, congenital hereditary hearing impairment is nearly 100% genetically determined disease, though injury or viral infection is caused by predominantly environmental factors. ARHI is situated between, and believed to be a typical complex disorder associated with both genetic factors and environmental factors ("complex ARHI"). The accumulated external and internal factors lead to degeneration and age-related changes in the cochlea. These environmental factors, including exposure to noise for a long time, ear disease, ototoxic drugs, circulatory disease, and diabetes mellitus, play important causative roles in presbycusis. The effect on the development of presbycusis of smoking and alcohol is controversial. Previous studies indicated heritability of ARHI phenotypes is estimated to be 0.35–0.55 and SNPs (single nucleotide polymorphisms) of many genes are reported to be risk factors for ARHI (see Liu and Yan 2007, for review).

On the other hand, some hereditary hearing loss patients showed late-onset hearing loss similar to presbycusis ("monogenic ARHI") (Figure 1). The present data from two cases with *CDH23* mutations strongly supported the view that the particular type of ARHI (late onset hereditary hearing loss) is monogenically inherited.

*CDH23* gene mutations are known to be responsible for both Usher syndrome type ID (USH1D) and non-syndromic hearing loss (DFNB12). Cadherin 23, part of the cadherin superfamily of cell surface adhesion proteins, conforms to the "Tip Link" structure of stereocilia important for hair-cell function. Therefore, it is conceivable that altered adhesion property or reduced stability of Cadherin 23 may confer susceptibility to ARHI.

Such late-onset phenotype is not surprising because a series of animal studies have shown that *Cdh23* mutation is involved in ARHI. C57BL/6 strain mice are known as

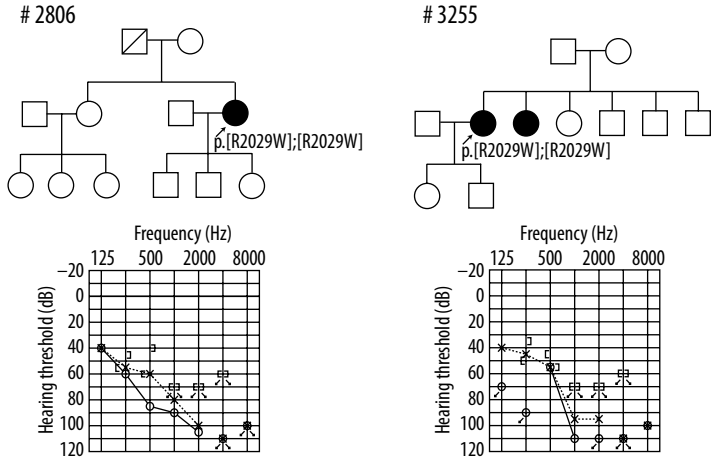



**Figure 1.** "Monogenic ARHI" caused by *CDH23* mutations. These two patients are associated with a particular *CDH23* mutation (p.R2029W). Some particular mutations cause "late-onset" hearing loss with residual hearing in low frequencies.

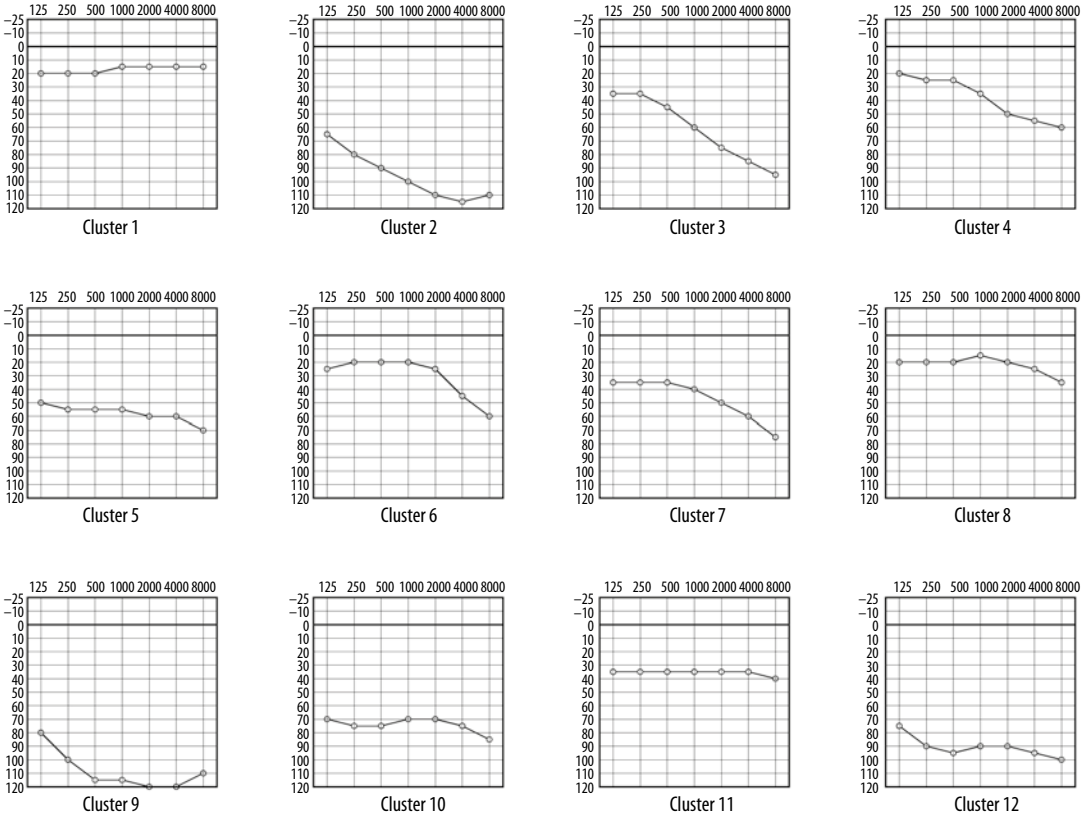



**Figure 2.** Audiogram configuration classification. Audiograms of the patients could be divided into 12 groups by clustering. Statistical analysis indicated that two cases with *CDH23* mutations ("monogenic ARHI") were compatible with belonging to cluster 2.

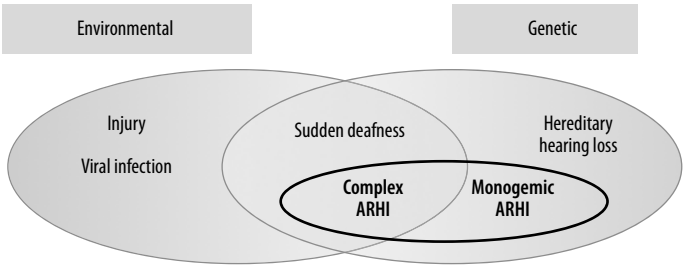



**Figure 3.** Etiology of presbycusis (age related hearing loss: ARHI). "Complex ARHI" is caused by both environmental and genetic factors, whereas "monogenic ARHI" is more genetically involved.

the most common model mice for ARHI. It has been reported that the 57BL/6 strain has *Ahl1* (Age-related hearing loss 1 gene) in chromosome 10 (Johnson et al., 1997). *Cadherin 23* was found to be the responsible gene at the *Ahl1* locus (Noben-Trauth et al., 2003).

## Audiogram configuration classification of high frequency involved hearing loss

It would be an interesting question whether audiograms of "monogenic ARHI" caused by *CDH23* mutations could be distinguished from those of "complex ARHI", because certain correlations between audiogram configuration and etiology have been suggested. We have tried to classify audiogram shapes statistically and looked at whether the two groups would belong to the different clusters. Clusters 4, 5, 6, 7, and 8 had one peak around the 60–70's with regard to age distribution (data not shown), suggesting they may be the commonest ARHI type ("complex ARHI") of audiogram configuration, whereas the two cases with *CDH23* mutations belonged to cluster 2. The mean age (32.8 y.o.) of cluster 2 was comparatively young and age distribution of cluster 2 has a peak around 1–10 years old, indicating this cluster may be predominantly involved with genetic causes. The present objective classification based on audiogram configuration successfully distinguished "monogenic ARHI" from the other groups with high frequency involved hearing loss, suggesting that such a classification together with genetic testing is helpful for better understanding of etiology.

## Future direction

High-throughput sequencing platforms using next generation sequencer have now been developed and are available for clinical study. With such new technologies, efforts to determine the genetic involvement for ARHL should be continued for clarifying the mechanism of ARHI, predicting individual risk, preventing progressiveness, and selecting suitable intervention.

## Acknowledgements

This study was supported by a Health Sciences Research Grant from the Ministry of Health and Welfare of Japan (SU).

## References:

1. Miyagawa M, Nishio S, Usami S: Prevalence and Clinical Features of Hearing Loss Patients with CDH23 Mutations: A Large Cohort Study. PLoS One, 2012; 7(8): e40366
2. Liu XZ, Yan D: Ageing and hearing loss. J Pathol, 2007; 211: 188–97
3. Johnson KR, Erway LC, Cook SA et al: A major gene affecting age-related hearing loss in C57BL/6J mice. Hear Res, 1997; 114: 83–92
4. Noben-Trauth K, Zheng QY, Johnson KR: Association of cadherin 23 with polygenic inheritance and genetic modification of sensorineural hearing loss. Nat Genet, 2003; 35: 21–23

# COCHLEAR IMPLANTS IN THE ELDERLY: THE BETTER HEARING PROSTHESIS?

**Uwe Baumann**

Klinikum der J.W. Goethe-Universität, HNO/Schwerpunkt Audiologische Akustik, Frankfurt a.M., Germany

**Corresponding author:** Uwe Baumann, Klinikum der J.W. Goethe-Universität, HNO/Schwerpunkt Audiologische Akustik, Theodor-Stern-Kai 7, 60590 Frankfurt a.M., Germany, e-mail: uwe.baumann@kgu.de

**Abstract**

**Background:** Cochlear implantation in the elderly (above the age of 70 years) as a treatment for profound sensorineural deafness is to some extent regarded with skepticism. First, the perception of sound transmitted by electrical stimulation is regarded as being generally too unfamiliar for elderly recipients to adapt to. Second, retrocochlear neural transduction and processing are supposed to underlie age-related degeneration and therefore a cochlear implant (CI) may give only poor outcomes in seniors.

**Materials and Methods:** Two cohorts of elderly people with hearing disabilities aged 60 years and above were studied. Retrospectively gained results in 129 hearing aid (HA) users (average age 72 years) and 115 CI recipients (average age 69 years, collected in our department) were investigated. Freiburger monosyllable scores were measured at 65 dB speech level in the best aided condition (FMS 65dB) and compared to the best monosyllable score (speech level set below uncomfortable loudness to achieve highest score) measured in the unaided condition with headphones.

**Results:** Verification of hearing aid fitting showed satisfying results in only 25% of all tests, whereas an average improvement of Freiburger monosyllable scores between 50% and 70% (range 5% to 100%) was found in the CI group, nearly independent of age, when compared to hearing aid results before surgery. Aided performance in the HA group was inferior compared to the CI group (FMS 65 dB: HA 52.7%, CI 62.8%). Additionally, age at surgery (range 60 to 84 years) showed no significant correlation to benefit after rehabilitation.

**Conclusions:** The results demonstrate a severe lack of fitting success in the group of seniors with hearing aids in this study. The seniors in the study fitted with a cochlear implant showed very good results, without any evidence of age-related problems. When deciding on cochlear implant surgery in seniors, the faster pace of progression of hearing loss with age should be considered.

## Introduction

To some extent, cochlear implantation in the elderly above the age of 70 years as a treatment for profound sensorineural deafness is regarded with scepticism. On the one hand, the perception of sound transmitted by electrical stimulation is regarded as being generally too unfamiliar for elderly recipients to adapt to (Labadie et al, 2000). On the other hand, retrocochlear neural transduction and processing are supposed to underlie age-related degeneration and therefore a cochlear implant (CI) may generate only poor outcomes in seniors (Welsh et al., 1985). The present study compares speech test results of hearing aid users to those of cochlear implant users, challenging the issue that seniors fitted with a cochlear implant may have age-related problems concerning adaptation and acclimatization to the unfamiliar hearing sensation with the cochlear implant

## Materials and Methods

A comparison of results obtained in two groups of elderly people with hearing disabilities aged 60 years and above was carried out by means of retrospectively gained results in 129 hearing aid users (average age 72 years, time span 2000–2011) and 115 CI recipients (average age 69 years, collected in our department from 1996–2011). The group of hearing aid users was recruited from patients who presented for testing their hearing aid settings in the Department of Otolaryngology and who were not eligible for cochlear implant treatment; the CI recipients were recruited from patients at the clinic who were examined as part of their regular implant check. The CI group included unilateral, bilateral, and bimodal cochlear implant users. CI recipients with asymmetric hearing loss or single-sided deafness were excluded from the study. The minimum experience of hearing with the cochlear implant was 3 months. Patients with clear signs and symptoms of dementia, Alzheimer's disease, and morbus Parkinson, as far as known, were excluded from the study.

The results of both groups were determined using the "Freiburger" speech test in quiet. This test includes a monosyllable word test. The metric was unaided *best monosyllable score (BMS)*. In addition, the monosyllable scores at 65 dB (free field-level condition [FMS 65 dB], distance 1.2 m to speaker) with hearing aid (HA) or cochlear implant were measured.

In binaural CI or HA fittings, the best result from either left, right, or both sides was used as a measure for the success of the patient. The subjects were divided into three age groups: 60–65, 66–73, >73 years. There were, respectively, 23/38, 51/38, and 56/39 (HA group / CI group) patients in the same age group.

## Results

The average unaided best monosyllable score (BMS) in the HA group was 57.9%, 79.4%, and 69.5%, depending on age group (60–65, 66–73, >73). With hearing aids, average FMS 65 dB score was 44.8%, 58.0%, and 49.7%, respectively. The difference between unaided BMS and aided FMS 65dB was significant in all age groups ($p<0.05$). On average, aided monosyllable scores were lower than the best scores obtained by headphone presentation, reflecting insufficient hearing aid fitting.

BMS in the unaided condition in over 50 subjects of the HA group was at least 90%, while roughly the same proportion of patients in the CI group achieved scores less than 10% in the unaided condition. The comparison of results obtained with HA (FMS 65 dB) and BMS in the unaided condition showed that only in 25% of all cases a satisfactory HA fitting was present (difference between BMS and FMS 65 dB ≤0%). In 25% of all patients in the HA group, a completely inadequate HA fitting was observed (difference BMS/FMS 65 dB ≥30%).

Prior to implantation, aided average FMS 65 dB in the different CI age groups was 9.6%, 12.4%, 9.2% (60–65, 66–73, >73), after respective fitting and rehabilitation scores as high as 67.9%, 63.1%, and 57.6% were reported. Differences between pre-op and post-op aided scores were highly significant in all age groups ($p<0.001$).

In comparison to the results of the HA-fitting before implantation, the CI-treated patients showed an improved FMS 65 dB score with averages between 50% and 70% (range between 5% and 100%). This effect could be observed nearly independent of age group.

The group of CI-treated patients with the lowest benefit with HA prior to implantation ($n$=87, FMS 65 dB with HA 0%) showed an improved FMS 65 dB score of almost 60% post-CI rehabilitation. Even patients with comparatively higher FMS 65 dB before surgery achieved a significant increase after rehabilitation.

A subgroup analysis of patients with recent implant and speech processor models ($n$=75) showed that 75% of patients in this group reached more than 60% FMS 65dB (median FMS 65 dB at 70%). The age (range 60–84 years) at CI surgery showed no significant correlation. However, a comparison of the age groups 60–65 years and older than 73 years revealed a significantly lower FMS 65 dB ($t$-test, $p<0.01$) in the group of older seniors.

## Discussion

Despite better hearing thresholds and higher unaided best monosyllable scores in the HA group (BMS average including all age groups HA 71.4%, CI 19.6%), aided performance in the HA group was inferior compared to the CI group (FMS 65 dB HA 52.7%, CI 62.8%). This result shows that careful optimisation of hearing aids is urgently required for the majority of elderly patients.

The seniors in the study fitted with a cochlear implant show very good results, without any evidence that age-related problems concerning adaptation and acclimatisation to the unfamiliar hearing sensation with the implant occur. Meanwhile, even patients beyond the 90$^{th}$ year of life were supported successfully with a cochlear implant. The assumption that an age-related degeneration of the auditory nerve prohibits satisfactory results with cochlear implants in the elderly seems refuted by the results of this study.

Other studies have shown that by improving the listening situation with cochlear implants, a significant increase in quality of life, a reduction of tinnitus distress, and a reduction of general stress can be achieved as well (Olze et al., 2012). The poor results in the hearing aid group of senior citizens may be distorted by the selection of subjects, since only patients with inadequate hearing success find their way to the University Hospital to check hearing aid fitting.

The present results have highlighted the lack of hearing aid fitting success in the group of seniors in this study. When deciding on cochlear implant surgery in seniors, the faster pace of progression of hearing loss with age should be considered.

## References:


1. Labadie RF, Carrasco VN, Gilmer CH, Pillsbury HC: Cochlear implant performance in senior citizens. Otolaryngol Head Neck Surg, 2000; 123: 419–24
2. Olze H, Grabel S, Forster U et al: Elderly patients benefit from cochlear implantation regarding auditory rehabilitation, quality of life, tinnitus, and stress. Laryngoscope, 2012; 122: 196–203
3. Welsh LW, Welsh JJ, Healy MP: Central Presbycusis. Laryngoscope, 1985; 95: 128–36

# COGNITIVE CONTRIBUTIONS TO HEARING IN OLDER PEOPLE

**David R. Moore, Christian Füllgrabe**

MRC Institute for Hearing Research, Nottingham, NG7 2RD, U.K.

**Corresponding author:** David R. Moore, MRC Institute for Hearing Research, Nottingham, NG7 2RD, U.K.

**Abstract**

**Background:** Hearing necessarily involves top-down influences on the sensory signals provided by bottom-up information from the ear. The top-down influences include elements of attention, memory, motivation, emotion, and learning, deriving from many regions of the cerebral cortex. They exert their influence via intra-cortical networks and auditory efferent pathways that extend back down the auditory system, right out to the ear. These 'cognitive' contributions to hearing affect sound detection, hearing-in-noise, and short- and long-term experiential modulation. Difficulty in speech perception in noisy environments (SiN) is the most common complaint that people of all ages and hearing levels make about their hearing. We review here aspects of those difficulties.

**Methods:** Studies considered recruited children and older adults with normal audiograms. Tests included speech-in-noise, cognition, and remote delivery via the internet. Interventions included wireless devices and training.

**Results:** For those with cochlear hearing loss, reduced sensitivity and broadened spectral and temporal processing contribute to poor speech perception in quiet and in noise. But for SiN, the nature of the noise is also important. Typically, able young adults can benefit from amplitude-modulated noise as it enables them to listen into the dips of the noise. They also benefit from a spatial separation between the target speech and the noise. However, those with reduced cognitive capabilities, notably children (especially those with learning difficulties), receive less benefit in these conditions. Older people have a high prevalence of both cochlear hearing loss and cognitive impairment. While these problems often occur together, and may be supra-additive and causally connected, they can also occur independently. We review studies showing that those (rare) older people with normal hearing sensitivity nevertheless have impaired SiN for both modulated and unmodulated noises, but older listeners show normal benefit from listening into the energetic minima of a fluctuating noise.

**Discussion:** Effective interventions to improve SiN in older people are likely to include reduction of room reverberation, instruction on viewing important sound sources, improved signal to noise (e.g. Bluetooth, FM), onset enhancement, directional microphones on hearing devices, and auditory training. Training should emphasise engagement with the target sound and is best achieved through the use of highly motivating exercises. These may involve the use of social engagement and salient signals (e.g. talk radio) that are also likely to enhance general cognitive well-being.

**Conclusions:** The reviewed studies – of development of hearing in children, of SiN perception in older adults, and of intervention – emphasise the role of top-down, cognitive factors in hearing, hearing impairment, and rehabilitation.

## Background

The audiogram is currently still considered the 'gold standard' index of a person's hearing abilities. However, it has been known for at least 50 years that pure-tone sensitivity only partially predicts other forms of hearing commonly used outside the sound chamber. In addition, the audiogram of any given individual is subject to significant variability depending on, for example, practice (Zwislocki et al., 1958) and assessment method (Marshall and Jesteadt, 1986). Hearing abilities also vary across individuals with similar audiograms and can deviate considerably from predictions based on audibility. For example, despite having normal hearing sensitivity, some middle-aged listeners experience difficulties understanding speech in noisy restaurants and bars in which younger people still seem to communicate quite happily (Leigh-Pfaffenroth and Elangovan, 2011).

While much work has been done on the perceptual consequences of peripheral hearing loss (for an overview, see Moore, 1995), our research has primarily focused on auditory processing deficits and listening difficulties in young and older listeners with normal or near-normal audiograms (i.e. < 20–25 dB HL). We (Moore et al., 2010; 2011) showed that many typically developing, normal-hearing children (≤12 y.o.) have poorer performance and/or sensitivity and greater variability on a variety of noise-masked detection and supra-threshold tests of hearing, compared both to adult controls and to what would be expected based on their audiograms. Many of those with learning difficulties (e.g. language and reading impairment, attention deficits, and autistic disorders) but normal audiograms, have additional auditory perception problems – for example, impaired pure-tone frequency discrimination. In adults, processing and listening difficulties probably also contribute to the subjectively reported reduction with age in speech-in-noise intelligibility, but are generally difficult to study due to the simultaneously occurring progressive age-dependent loss in audibility (Davis, 1995). Controlling for peripheral factors by recruiting only older listeners (>60 y.o.) with normal audiograms (i.e. ≤20 dB HL for frequencies ≤6 kHz), we (Füllgrabe et al., 2011) recently showed more difficulties with speech-in-noise

(SiN) perception in these listeners than in younger controls (<30 y.o.) with matched average thresholds. These results are discussed in more detail in the following sections, but first we consider briefly the potential underlying mechanisms of these difficulties.

Successful auditory perception depends on the sensory processing of sounds in the ear and 'conventional' central auditory nervous system (CANS; auditory nerve to auditory cortex), and the interpretation and modulation of those sensations by the auditory cortex and higher cortical areas (Moore, 2012). A specific feature of the CANS is the dense and extensive descending projection pathway, extending from the cortex right out to the cochlea and the middle ear. In children, accumulating evidence suggests that the sensory processing of sounds matures early in life (<2 y.o.), more than a decade before mature perception is achieved. We and others have argued that this mismatch between the maturation of sensation and perception is due to the later development of cognitive processing underlying auditory cognition. In adults, possibly as early as 40–50 years, when hearing sensitivity is generally still normal, there are the first signs of a decline in supra-threshold auditory processing (Füllgrabe, 2012) and cognitive (Singh-Manoux et al., 2012) abilities. Hearing loss in older persons has also been associated with cognitive decline and neurodegenerative disorders (Lin et al., 2011).

## Speech-in-Noise (SiN) Perception

The greatest challenge that people report with their hearing is listening in noise, and this is exacerbated for those with hearing loss. SiN identification is more cognitively demanding than tone detection, since it involves decoding a complex acoustic signal that must then be subject to further linguistic and language reconstruction. A feature of recent auditory research using SiN has been manipulations of the masking noise. The simplest masker is unmodulated flat-spectrum or speech-shaped Gaussian noise. When combined with simple words (e.g. the monosyllabic digits 0–9), speech detection thresholds (SDTs) for these SiN tests correlate highly with audiogram pure-tone averages. Maskers such as modulated noise or multi-talker speech (e.g. 'babble') provide a greater cognitive challenge, as they more closely resemble the target speech, leading to 'informational' masking. On the other hand, these maskers also provide an opportunity for the listener to 'glimpse' the target speech during the amplitude minima ('dips') in the masker (Füllgrabe et al., 2006).

It is surprising that, unlike the audiogram, there are no universally agreed measures of SiN identification. Obviously, such measures pose challenges across different languages and accents. Even cultural groupings could pose difficulties, for example, where nuanced use of certain words or phrases occurs. Nevertheless, closed-set lists of simple, commonly used ('high frequency' or 'high redundancy') individual words or syntactically legal sentences can address most of these challenges within a language or at a national level. In fact, with the advent of high-throughput SiN testing via the telephone and internet (Vlaming et al., 2011), there are now large corpora of data on two tests developed as part of the Hearcom EU project (www.hearcom.org), the Digit Triplets Test (Smits and Houtgast, 2005; Nachtegaal et al., 2012), and the Sentence Matrix Test (Hagerman and Kinnefors, 1995; Holube et al., 2010).

## Latest Findings

Several laboratory studies have recently attempted to investigate systematically the distinctive effect of age on speech identification in clinically normal hearing using various types of speech materials and interfering maskers (e.g. Füllgrabe et al., 2011). Based on the above considerations, we might predict that, with declining supra-threshold sensory processing *and* cognitive function, older listeners would have more difficulty with SiN than predicted based on pure-tone audiometry. This should be reflected in greater age-related decline in speech identification than in audiometric threshold. Indeed, while identification of speech-in-quiet did not differ across age groups, consonant identification in both stationary and amplitude-modulated speech-shaped noise, and sentence identification in interfering speech babble, were impaired in older listeners. Moreover, there was a strong positive correlation between speech identification in noise and performance on a variety of cognitive tasks (notably fluid intelligence and verbal working memory). While the poorer performance of the older listeners in the stationary noise supports the prediction, the finding that those same listeners benefitted as much as the younger listeners from modulation of the masker suggests that they did not experience additional informational masking and could receive as much benefit from the amplitude dips in the masker as the younger listeners. It is possible that undiagnosed or high frequency hearing loss, exacerbated at higher (supra-threshold) levels, influenced speech-identification performance in the older listeners in all masking conditions. However, the relation between speech identification and cognitive performance is more difficult to explain. For example, children with mild–moderate hearing loss tend not to show impairment on tests of non-verbal cognition (Briscoe et al., 2001).

## Implications for Rehabilitation

Borrowing again from our work with children, we (BSA, 2011; Moore et al., 2013) have recommended two primary forms of rehabilitation for impaired auditory perception. One is to increase signal-to-noise levels. This could involve very simple steps, improved listening strategies and environments, and wider use of the mushrooming number of wireless, remote microphone devices (e.g. ReSound Unite, Phonak iSense). Alternatively, training has shown convincing, clinically significant benefit in vision (acuity; Levi and Li, 2009) and memory (Holmes et al., 2009) studies. On the premise that perceptual learning is also closely related to, or primarily dependent on higher-order cognition (Amitay et al., 2006; Xiao et al., 2008), these results strongly suggest that a variety of forms of training could improve auditory perception and cognition. A number of computer-based training programs have been developed for the rehabilitation of hearing loss (e.g. 'LACE': Henderson-Sabes and Sweetow, 2007; Oba et al., 2011) or to improve listening skills (e.g. 'Phonomena': Moore et al., 2005; Halliday et al., 2012). However, while generally positive, the improvements achieved through training have been modest. There are many possible reasons for this, but much more extensive research in visual training (Li et al., 2011)

suggests that the duration of auditory training needs to be extended by an order of magnitude or more (i.e. to 100+ hours), relative to that used thus far, to achieve substantial and lasting impact. To effect this, it may be preferable to adapt everyday listening tasks that are especially engaging for different demographic groups than to rely solely on computer games.

**References:**


1. Amitay S, Irwin A, Moore DR: Discrimination learning induced by training with identical stimuli. Nature Neuroscience, 2006; 9: 1446–48
2. Briscoe J, Bishop DV, Norbury CF: Phonological processing, language, and literacy: a comparison of children with mild-to-moderate sensorineural hearing loss and those with specific language impairment. J Child Psychol Psychiatry, 2001; 42(3): 329–40
3. BSA (2011). Practice Guidance: An overview of current management of auditory processing disorder (APD). *http://www.thebsa.org.uk/images/stories/docs/BSA_APD_Management_1Aug11_FINAL_amended17Oct11.pdf,* pp 1–60
4. Davis AC: Hearing in adults: the prevalence and distribution of hearing impairment and reported hearing disability in the MRC Institute of Hearing Research's National Study of Hearing. London: Whurr, 1995
5. Füllgrabe C, Moore BCJ, Stone, MA: Speech-in-noise identification in elderly listeners with audiometrically normal hearing: Contributions of auditory temporal processing and cognition. British Society of Audiology annual conference abstracts. Nottingham, UK. Int J Audiol, 2011; (in press)
6. Füllgrabe C: Age-dependent changes in temporal-fine-structure processing in the absence of peripheral hearing loss. Am J Audiol, 2013; (in press)
7. Füllgrabe C, Berthommier F, Lorenzi C: Masking release for consonant features in temporally fluctuating background noise. Hear Res, 2006; 211: 74–84
8. Hagerman B, Kinnefors C: Efficient adaptive methods for measuring speech reception threshold in quiet and in noise. Scandinavian Audiology, 1995; 24(1): 71–77
9. Halliday LF, Taylor JL, Millward KE, Moore DR: Lack of generalization of auditory learning in typically developing children. J Speech Lang Hear Res, 2012; 55: 168–81
10. Henderson Sabes J, Sweetow RW: Variables predicting outcomes on listening and communication enhancement (LACE) training. Int J Audiol, 2007; 46(7): 374–83
11. Holmes J, Gathercole SE, Dunning DL: Adaptive training leads to sustained enhancement of poor working memory in children. Developmental Science, 2009; 12(4): F9–15
12. Holube I, Fredelake S, Vlaming M, Kollmeier B: Development and analysis of an International Speech Test Signal (ISTS). Int J Audiol, 2010; 49(12): 891–903
13. Levi DM, Li RW: Perceptual learning as a potential treatment for amblyopia: a mini-review. Vision Research, 2009; 49(21): 2535–49
14. Leigh-Pfaffenroth ED, Elangovan S: Temporal processing in low-frequency channels: Effects of age and hearing loss in middle-aged listeners. J Am Acad Audiol, 2011; 22: 393–404
15. Li RW, Ngo C, Nguyen J, Levi DM: Video-game play induces plasticity in the visual system of adults with amblyopia. PLoS Biology, 2011; 9: e1001135
16. Lin FR, Metter EJ, O'Brien RJ et al: Hearing loss and incident dementia. Arch Neurol, 2011; 68(2): 214–20
17. Marshall L, Jesteadt W: Comparison of pure-tone audibility thresholds obtained with audiological and two-interval forced-choice procedures. J Speech Hear Res, 1986; 29(1): 82–91
18. Moore BCJ: Perceptual Consequences of Cochlear Damage. Oxford: Oxford University Press, 1995
19. Moore DR: Listening difficulties in children: Bottom-up and top-down contributions. J Communi Disord, 2012; 45(6): 411–18
20. Moore DR, Cowan JA, Riley A et al: Development of auditory processing in 6- to 11-yr-old children. Ear Hear, 2011; 32(3): 269–85
21. Moore DR, Ferguson MA, Edmondson-Jones AM et al: Nature of auditory processing disorder in children. Pediatrics, 2010; 126(2): e382–90
22. Moore DR, Rosen S, Bamiou DE et al: Evolving concepts of developmental auditory processing disorder (APD): A British Society of Audiology APD Special Interest Group 'white paper'. Int J Audiol, 2013; 52(1): 3–13
23. Nachtegaal J, Festen JM, Kramer SE: Hearing ability in working life and its relationship with sick leave and self-reported work productivity. Ear Hear, 2012; 33(1): 94–103
24. Oba SI, Fu QJ, Galvin JJ III: Digit training in noise can improve cochlear implant users; speech understanding in noise. Ear Hear, 2011; 32(5): 573–81
25. Singh-Manoux A, Kivimaki M, Glymour M et al: Timing of onset of cognitive decline: results from Whitehall II prospective cohort study. BMJ, 2012; 344: d7622
26. Smits C, Houtgast T: Results from the Dutch speech-in-noise screening test by telephone. Ear and Hearing, 2005; 26: 89–95
27. Vlaming MSMG, Kollmeier B, Dreschler WA et al: HearCom: Hearing in the Communication Society. Acta Acustica United with Acustica, 2011; 97(2): 175–92
28. Xiao LQ, Zhang JY, Wang R et al: Complete transfer of perceptual learning across retinal locations enabled by double training. Curr Biol, 2008; 18(24): 1922–26
29. Zwislocki JJ, Maire F, Feldman AS, Rubin H: On the effect of practice and motivation on the threshold of audibility. J Acoust Soc Am, 1958; 30: 254–62

# Reports

# NHS 2012: BEYOND NEWBORN HEARING SCREENING. INFANT AND CHILDHOOD HEARING IN SCIENCE AND CLINICAL PRACTICE

**Anna Piotrowska[1,2], Paulina Kamyk[1,2], Anita Obrycka[1,2]**

[1] Institute of Physiology and Pathology of Hearing, Zgrupowania AK "Kampinos" 1, 01-943 Warsaw, Poland
[2] World Hearing Center, Mokra 17, Kajetany 05-830 Nadarzyn, Poland

**Correspoding author:** Anna Piotrowska, World Hearing Center, Mokra 17, Kajetany 05-830 Nadarzyn, Poland, a-mail: a.piotrowska@ifps.org.pl

Newborn Hearing Screening (NHS) conference takes place once every two years in Cernobbio, Lake Como, Italy. This year the conference was held on June 5th–7th. Specialists in audiology, otolaryngology, hearing sciences, communication disorders, neurosciences, neurology, psychology, genetics, biology, engineering, health care, epidemiology and other related areas from all over the world presented their work and exchange ideas during this international event. According to data provided by the organizers over 550 participants from 60 countries came together to attend the meeting. The Conference included Keynote Addresses, Special Session, oral communications with more than 140 platform presentations and Poster Sessions with 145 posters. Some of the topics being discussed in the field of NHS included models of early intervention, training and support, the importance of quality assurance, applications of telehealth, genetics of hearing loss, unilateral and mild hearing loss – risk factors and language development, new diagnostic techniques, evidence based NHS and data management.

Ann Geers, from USA, in her keynote lecture presented the results of two big studies of 60 children implanted at 1–2 years of age from 2001 to 2010 and 112 children who received a cochlear implant (CI) between 2 and 5 yrs of age implanted from 1996 to 2008 to answer the question: Can we expect children who receive a cochlear implant as infants to catch up with their normal hearing peers by elementary grades and to remain caught up when they graduate high school? The overall conclusions from the study were that CI at young age (to 24 months) was associated with most intelligible speech and age-related spoken language; all children with CI continued to show improved speech perception, speech production, language and reading skills through

their school years, improved phonological processing was associated with faster language development, social skills were age appropriate at both primary grades and high school.

Special Sessions on International Report on EHDI Programs was organized by the International Working Group on Childhood Hearing and the CDC/National Center on Birth Defects and Developmental Disabilities (EHDI Team). The session included the reports from Russia, UK, Belgium, Netherlands, Germany, Slovenia, Spain, Turkey, Cyprus, Palestine, Iran, Brazil, Singapore, Indonesia, New Zealand. Group from the Institute of Physiology and Pathology of Hearing in Poland presented European Consensus Statement on Hearing Screening of Pre-School and School-Age Children within EHDI Policies Session.

Considerable debate exists over the most effective method for detecting hearing loss post UNHS. Traditionally, targeted surveillance of at-risk infants using a risk factor registry, has been considered "best practice" to monitor hearing throughout early childhood. However, criticisms of these recommendations have been reported during the meeting and the limitations of the targeted surveillance program question the usefulness of this service delivery model. Preschool and school screening programs have been mentioned as one of the method recommended for early detection of delayed-onset hearing loss.

In Cernobbio Poland was represented by the group from the Institute of Physiology and Pathology of Hearing in Warsaw and Institute of Acoustic in Poznan. We reported on European Consensus Statement, mentioned above, the benefit of bilateral implantation in pre-school children

and development and application of the Pediatric Matrix Sentence Test. Prof. W. Sulkowski, who is European Federation of Audiology Societies' (EFAS) Auditor and its polish member participated in EFAS General Assembly (GA), which accompanied the Newborn Hearing Screening (NHS) conference. On the agenda of the EFAS GA, among other issues, was the report from the EFAS Working Group on School Hearing Screening. The establishment of the Working Group was the next step after the European Consensus Statement endorsement and the adoption of the "EU Council Conclusions on early detection and treatment of communication disorders in children, including the use of e-health tools and innovative solutions" (2011/C 361/04), at the end of Polish Presidency of the EU Council (December 2, 2011). Poland is represented in the EFAS Working Group by Prof. Henryk Skarżyński, state consultant in otorhinolaryngology and director of the Institute of Physiology and Pathology of Hearing.

The magic of Lake Como and its surroundings made these days truly an unforgettable experience. The meeting in 2014 will bring together hearing screening in newborns and adults (NHS and AHS) as HEaring Across the Lifespan (HEAL 2014).

# 11TH INTERNATIONAL CONGRESS OF THE EUROPEAN SOCIETY OF PEDIATRIC OTORHINOLARYNGOLOGY, 20–21.5.2012, AMSTERDAM, THE NETHERLANDS

**Monika Matusiak[1,2], Malgorzata Zgoda[1,2]**

[1] Institute of Physiology and Pathology of Hearing, Zgrupowania AK "Kampinos" 1, 01-943 Warsaw, Poland
[2] World Hearing Center, Mokra 17, Kajetany 05-830 Nadarzyn, Poland

**Correspoding author:** Monika Matusiak,World Hearing Center, Mokra 17, Kajetany 05-830 Nadarzyn, Poland, e-mail: m.matusiak@ifps.org.pl

The 11th International Congress of the European Society of Pediatric Otorhinolaryngology (ESPO) took place between 20 and 23 May 2012 in Amsterdam. The Society originated in 1994 when it was founded as a successor to the European Working Group in Pediatric Otorhinolaryngology. ESPO's main objectives are facilitating the dissemination of knowledge on otorhinolaryngologic disorders in children, enhancing scientific communication, promoting scientific and training programs, and creating new standards. The Congress was organised by Prof. Anne Schilder as a continuation of previous meetings which took place in Oxford, Athens, Paris, Budapest, and Pamplona. This year's meeting assembled about 800 participants from 63 countries ranging across Europe, North and South America, and Asia.

The scientific program included 5 plenary sessions, 11 roundtable sessions, 21 free paper sessions, and 11 workshops. The workshops covered a range of issues from practical aspects of pediatric otolaryngology to how to prepare a systematic review of scientific publications. Throughout the meeting there were electronic poster sessions that included 45-minute presentations on the results of independent research, analysis of materials, and descriptions of rare and interesting cases. The electronic form allowed all conference participants to receive a copy of the materials.

In the first plenary session, a lecture was delivered by Prof. Martin Burton. He stressed how important it was for patients to be fully informed about treatment options based on scientific facts, not the individual doctor's opinion. In this context, he pointed out that the patient must be involved in making decisions about treatment. Implants are currently the most intensively developing branch of pediatric otolaryngology, and were one of the dominant themes of the Congress. A major topic was simultaneous bilateral implantation in young patients with profound bilateral sensorineural hearing loss. Prof. Andrej Krall emphasised the importance of minimising the time between sequential implants due to the possibility of irreversible loss of activation of the two hemispheres. Attention was also focused on unilateral deafness in children and ways to treat it. The Med-El company unveiled a new solution in the field of bone conduction hearing – the Bonebridge. It is based on the concept of using a bone conduction implant such as BAHA, but instead of using the traditional transcutaneous implant screw it uses an external removable magnet speech processor. This strategy avoids common local skin reactions around the implant screw. The implant can be used in cases of congenital defects of middle and external ear, unilateral deafness of varying etiology, and radical ear surgery with persistent purulent persistent leaks.

An important discussion was on imbalances in children. It has been reported that 50–60% of children with sensorineural hearing loss have problems of this nature. Issues of diagnosis were raised, particularly in the youngest children, as well as the need to establish multidisciplinary teams to deal with vestibular disorders. It was recommended that rehabilitation be introduced to improve proper functioning of the sense organs and to avoid motor and other developmental problems (including coordination) related to the balance, especially in children who have undergone implant surgery.

During the meeting, otosurgery operations were broadcast live from the Department of Otolaryngology of the University of Utrecht and the Medizinische Hohschule in Hanover as part of the LION Foundation Programme. Surgeries included Bonebridge implantation and cochlear implantation from the suprameatal approach and the round window approach.

Other discussion sessions included hearing screening in different age groups, exudative otitis immunology, and genetics of hearing loss. Sessions were also devoted to oncology in pediatric otolaryngology, birth defects in children, immunology, and vaccination.

The next meeting in this series will take place in Dublin in 2014.

# OPENING OF THE WORLD HEARING CENTER AND AN ASSOCIATED INTERNATIONAL CONFERENCE, KAJETANY, POLAND, 11 MAY 2012

**W. Wiktor Jedrzejczak[1,2], Lech Sliwa[1,2]**

[1] Institute of Physiology and Pathology of Hearing, Zgrupowania AK "Kampinos" 1, 01-943 Warsaw, Poland
[2] World Hearing Center, Mokra 17, Kajetany 05-830 Nadarzyn, Poland

**Corresponding author:** W. Wiktor Jedrzejczak, Institute of Physiology and Pathology of Hearing, Zgrupowania AK "Kampinos" 1, 01-943 Warsaw, Poland, e-mail: w.jedrzejczak@ifps.org.pl

The World Hearing Center (WHC) – a new unit of the Institute of Physiology and Pathology of Hearing (IPPH) – was opened on 10 May 2012. It was especially designed as a center for the complex care of people with congenital and acquired hearing, voice, speech, and balance disorders. The opening was accompanied by an international scientific conference. The program included 21 invited lectures by distinguished scientists from all over the world: Blake Wilson (Durham, USA), Rene Gifford (Nashville, USA), Ad Snik (Nijmegen, The Netherlands), Frans Coninx (Solingen, Germany), Herman Jenkins (Aurora, USA), Nuri Ozgirgin (Ankara, Turkey), Timoleon Terzis (Athens, Greece), David McPherson (Provo, USA), Stavros Hatzopoulos (Ferrara, Italy), Andrew Bell (Canberra, Australia), Norbert Dillier (Zurich, Switzerland), Andrzej Czyzewski (Gdansk, Poland), Agnieszka Szczepek (Berlin, Germany), Joseph Attias (Haifa, Israel), Antonio della Vople (Naples, Italy), Sophia Kramer (Amsterdam, The Netherlands), Jose Padilla (Granada, Spain), Ewa Raglan (London, UK).

The conference was opened by Prof. Henryk Skarzynski who presented a lecture on partial deafness treatment (PDT) [1,2]. This topic was one of the fundamental issues that initiated the WHC project and made its development possible. In his presentation Prof. Skarzynski described the evolution of surgical techniques for cochlear implantation and how it changed with new electrode designs. Pre- and post-operative results, as well as follow up results of PDT patients, were shown.

This was followed by a presentation on evaluating the relative benefits of cochlear implantation according to the level of residual hearing. In the absence of Prof. Blake Wilson, the text of the talk was given by Dr Artur Lorens. An interesting result was that patients with high levels of residual hearing (PDT-EC levels) receive at least as much benefit from cochlear implantation as patients with lower levels of residual hearing. Moreover, age over 60 is not a contraindication for treatment. This latter finding has major implications for presbycusis treatment.

Most presentations related to cochlear and middle ear implants. Other topics covered were tomography and imaging methods in audiology and rhinology, multimodal human–computer interfaces, and the effect of psychosocial stress on gene expression in the auditory system.

An interesting occasion was the presentation by Andrew Bell. The talk was given from Australia via an internet

The live presentation by Dr Andrew Bell from Australia.


Group photo of the participants of the scientific conference.


Prof. Henryk Skarzynski and Prof. David McPherson unveil honorary plaques.

connection. Despite the distance, the audience was surprised by the very high quality of the audio and video. The topic was an alternative view of the role of the middle ear muscles in protecting the inner ear [3]. Standard theory says that stiffening of the joints and ligaments reduces sound transmission; the new theory suggests that sound reduction is brought about by the muscles increasing the pressure in the fluids of the cochlea.

In addition, there was a poster session that displayed various aspects of international collaborations by researchers from IPPH. Topics included partial deafness treatment, application of fMRI in studies of the hearing system, auditory brainstem responses, otoacoustic emissions, telemedicine, and computer-based systems supporting diagnosis and patient care.

At an appropriate interlude, Prof. Skarzynski and Prof. David McPherson unveiled honorary plaques on the wall of WHC which document collaborations with visiting researchers.

## References:

1. Skarzynski H, Lorens A, Piotrowska A, Skarzynski PH: Hearing preservation in partial deafness treatment. Med Sci Monit, 2010; 16(11): CR555–62
2. Skarzynski H: Ten years experience with a new strategy of Partial Deafness Treatment. Journal of Hearing Science, 2012; 2(2): RA11–18
3. Bell A: How do middle ear muscles protect the cochlea? Reconsideration of the intralabyrinthine pressure theory. Journal of Hearing Science, 2011; 1(2): RA9–23

# REPORT ON THE 9TH INTERNATIONAL CONFERENCE ON CHOLESTEATOMA AND EAR SURGERY

**Marek Porowski[1,2]**

[1] Institute of Physiology and Pathology of Hearing, Zgrupowania AK "Kampinos" 1, 01-943 Warsaw, Poland
[2] World Hearing Center, Mokra 17, Kajetany 05-830 Nadarzyn, Poland

**Corresponding author:** Marek Porowski, Institute of Physiology and Pathology of Hearing, Zgrupowania AK "Kampinos" 1, 01-943 Warsaw, Poland, e-mail: m.porowski@ifps.org.pl

An international conference on issues related to cholesteatoma was held in Nagasaki, Japan, between 3 and 7 June, 2012. In the main, the conference brought together Japanese and regional researchers, but there were also a large group of doctors from America and Europe. Professor Haruo Takahashi, of the Department of Otorhinolaryngology at the University of Nagasaki, was president and chief organiser of the conference. As well as cholesteatoma the conference also covered the epidemiology of different diseases around the world, pathophysiology, and surgical procedures in children and adults.

There were a relatively large number of presentations given to innate cholesteatoma; although the condition is rare, progress in diagnostic screening now increases the its detection rate. Dr Hun Yi Park of the Department of Otorhinolaryngology at Ajou University, Korea, presented data on more than 182 cases of congenital cholesteatoma. This is by far the largest group of patients with this disease collected from a single center. Other papers were devoted to surgical techniques including new developments in the reconstruction of the middle ear cholesteatoma after surgery. Noteworthy contributions were made by Alexander Hubers on "Ossiculoplasty in chronic ear surgery: omega connector, experimental and clinical results"; Jacob Tauris on "Ossiculoplasty longum crus of small defects with bone cement"; and Mehmet Ozuera on "Surgical outcomes in malleus to oval window prosthesis in revision stapes surgery". During the discussions Prof. Sennarogliu of Turkey highlighted the advantages of glass-ionomer cement in selected cases of middle ear disease, and a return to this way of surgical reconstruction.

The conference also delivered the latest information on the use of implantable devices for chronic otitis media and cholesteatoma states after its removal. Dr de Abajo from Spain presented work on "Vibrant Soundbridge for patients suffering chronic otitis media and severe hearing loss", and Adrian James from Canada spoke about implantable hearing aids in children with cholesteatoma ear infections, emphasising the advantages, indications, and limitations of implantable devices.

One interesting session, led by Prof. M. Sanna, was devoted to live audio-visual coverage of temporal bone surgery. Picture quality and sound was excellent, and 3D glasses allowed accurate spatial visualisation of the structures worked on by the surgeons. The session was accompanied by a very lively discussion on the usefulness of ear surgery and endoscopy.

To summarise, the conference was very successful in terms of content and experience gained. For more information about the conference visit *http://www.chole2012.jp/*

# 11TH HEARING PRESERVATION WORKSHOP, TORONTO, CANADA, 18–21 OCTOBER 2012

**Anna Piotrowska[1,2], Artur Lorens[1,2]**

[1] Institute of Physiology and Pathology of Hearing, Zgrupowania AK "Kampinos" 1, 01-943 Warsaw, Poland
[2] World Hearing Center, Mokra 17, Kajetany 05-830 Nadarzyn, Poland

**Correspoding author:** Anna Piotrowska, World Hearing Center, Mokra 17, Kajetany 05-830 Nadarzyn, Poland, a-mail: a.piotrowska@ifps.org.pl

Some 180 participants from all over the world attended the 11th Hearing Preservation Workshop in Toronto on 18–21 October 2012. It was a meeting of prominent specialists organized by the cochlear implant company, Med-El.

This year 35 papers were presented, 17 from Canada and the USA and 16 from Europe. Poland had an impressive share, with 5 papers coming from the Institute of Physiology and Pathology of Hearing, represented by Prof. Henryk Skarzynski, Dr Piotr H. Skarzynski, Dr Anna Piotrowska, and Dr Artur Lorens.

In an opening lecture Prof. H. Skarzynski presented longitudinal results of partial deafness treatment with cochlear implants. The lecture summarised the speech understanding of cochlear implant users who had had partial deafness and how they performed after implantation and up to 10 years later. Prof. Skarzynski drew the audience's attention to the paradox that "*in partially deafened patients we can, unfortunately, expect that, in the longer term, there will be a progression of inner ear problems and thus deterioration of natural hearing (both in the implanted and in the other ear). Hearing threshold tests confirm this. But what is particularly interesting is the fact that speech understanding in silence does not deteriorate in the long term, and in fact speech understanding in noise can even gradually improve*.

This observation demonstrates that in these patients deterioration of natural hearing may be compensated for by modifying the settings of the speech processor (nowadays called the audio processor), which is especially designed for cases of partial deafness. Prof. Skarzynski explained the paradox in terms of brain plasticity, so that progressive improvement in speech understanding in noise is due to the ability of certain structures in the brain responsible for understanding of speech to slowly change and improve in function.

The research presented by Prof. Skarzynski is the first clinical study to demonstrate the efficacy of partial deafness treatment using cochlear implants. Until now, other research has focused only on the experimental side of the efficacy or safety of this treatment method.

Evidence-based medicine as currently promoted recommends clinical management based on the best available research results on efficacy and safety. Evidence can come through both experiment and observations. The results presented by Prof. Skarzynski fill a gap in our knowledge of the partial deafness treatment method, confirming that the method if safe and effective and therefore recommended for clinical practice.

Other presentations from the Institute also focused on the topic of partial deafness. Dr. Piotr Skarzynski presented a study on the efficacy and safety of the partial deafness treatment method in children. The topic of hearing loss in children was continued by Dr Anna Piotrowska who gave a presentation on hearing screening in school-age children. Her presentation referred to two important documents initiated by Prof. H. Skarzynski and his team at the Institute: first, the *European Consensus on hearing, vision and speech screening in pre-school and school age children*, and secondly, *the EU Council Conclusions on early detection and treatment of communication disorders in children, including the use of e-Health tools and innovative solutions*.

Dr Artur Lorens presented preliminary results of innovative experimental research aimed at explaining the mechanisms involved in reception by the auditory system of information transmitted simultaneously in the acoustic (natural sound) and electrical (electrode stimulation) modes. This clinical study of patients with partial deafness involved joint electrical and acoustic stimulation of the same region of the auditory receptor. Preliminary results demonstrate the feasibility of using joint stimulation, showing that the information transmitted electrically does not disturb information transmitted acoustically, and vice versa.

Information about the partial deafness treatment method has been complemented by Dr Rene Gifford from Vanderbilt University, who presented a multicenter American-Polish research project in which Poland was represented by the Institute of Physiology and Pathology of Hearing. Study of simultaneous electric and acoustic stimulation, conducted on both Polish and American patients, showed significant improvement in speech understanding compared to electric-only and acoustic-only stimulation; this was particularly the case in difficult hearing conditions created experimentally by introducing sound reverberation (echo) and multiple disrupting signals from different directions.

The Toronto meeting was a unique occasion to exchange information and experiences, both from the clinic and in research settings. The wide range of topics covered by the workshop included not only surgical studies but reports from the fields of genetics, molecular biology, and biomedical engineering.

ReSound Verso™

# Empower users to tune in to life

Introducing ReSound Verso™, a new hearing solution that makes hearing feel instinctive again – like second nature.

**The only true support for binaural processing**
ReSound Verso features breakthrough Binaural Fusion™ technology that uses unique 2.4 GHz wireless device-to-device communication. It gives users a holistic sound picture with all the information they need to instinctively react and respond to what they want to hear – rather than the hearing aids deciding for them. Users get the best audibility and comfort, the best speech understanding in noise, plus a more natural sense of surroundings.

*Get the full ReSound Verso experience at www.resound.com/versopro.*
*Or call your ReSound representative at 1-800-XXX-XXXX.*

SURROUND SOUND by ReSound

ReSound
rediscover hearing

Innovation and Integration
in ORL-HNS

# IFOS Seoul 2013

## 20th World Congress of the International Federation of Oto-Rhino-Laryngological Societies

June 1-5, 2013 COEX Convention Center

### Important Dates

On-line Registration begins: January 2, 2012

Abstract Submission begins: January 2, 2012

Early Bird Registration by: September 30, 2012

Abstract Submission by: November 30, 2012

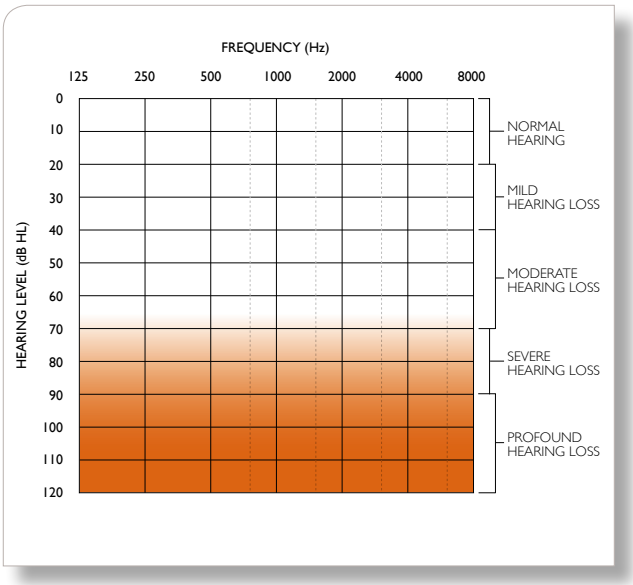
Call for Abstracts

www.ifosseoul2013.com

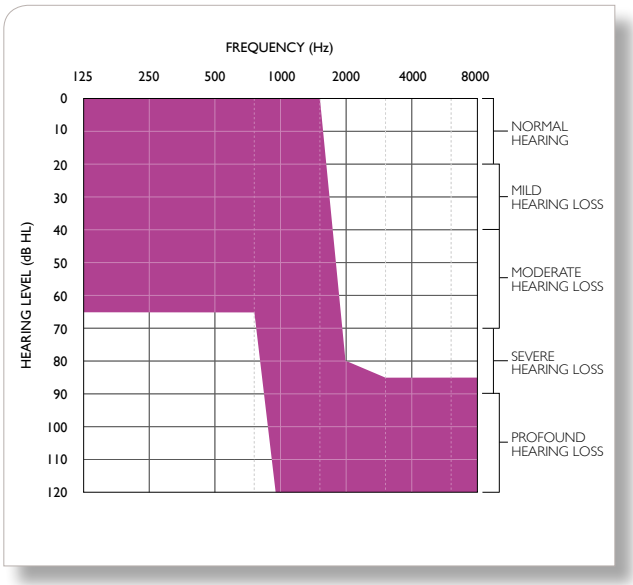
Tel 02-3476-7700 E-mail info@ifosseoul2013.com

# Exceptional Solutions
## for Hearing Loss

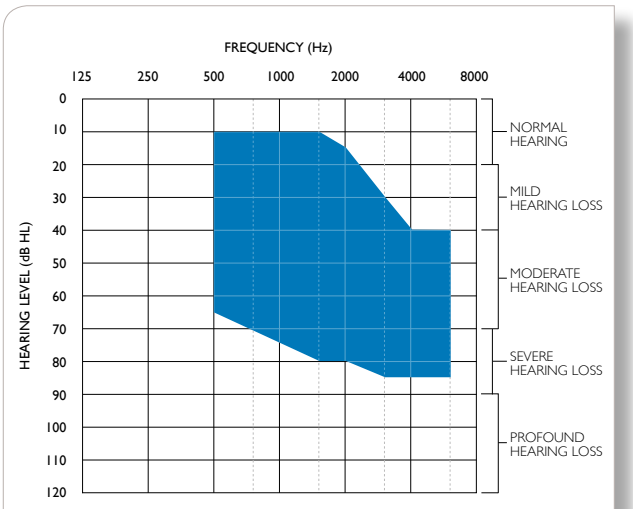
### MAESTRO™ Cochlear Implant System
Severe to Profound Hearing Loss




### EAS™ Hearing Implant System
Partial Deafness

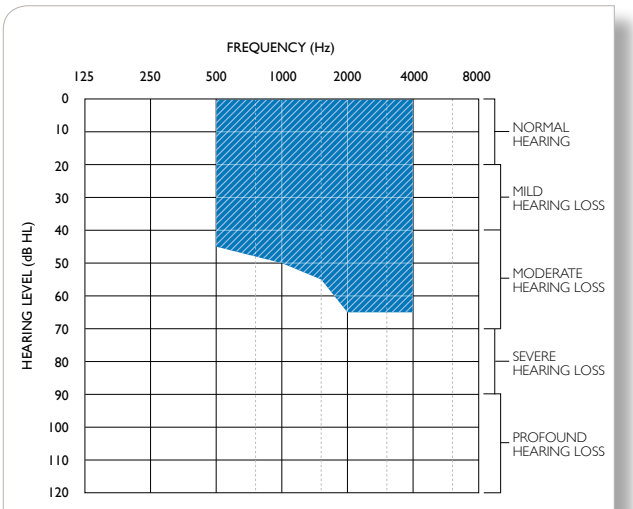



### VIBRANT SOUNDBRIDGE®
Sensorineural Hearing Loss




**Air-conduction** thresholds at or within the shaded region

### VIBRANT SOUNDBRIDGE®
Conductive and Mixed Hearing Loss




**Bone-conduction** thresholds at or within the shaded region

Pure-tone threshold criteria do not generally provide sufficient information to determine implant candidacy.

# 40-th Congress of Neurotology & Equilibriometric Society
# XL International NES Congress
## 18–20 April 2013, Bydgoszcz, Poland

**Scientific Comittee of the Congress:**
Prof. Dr. H. Kaźmierczak
Prof. Dr. C-F Claussen
PD Dr. Ales Hahn
Priv. Doz. Dr. Dieter Schneider
Prof. Dr. Katarzyna Pawlak-Osińska
Prof. Dr. M. Józefowicz-Korczyńska
Prof. Dr. W. Narożny
Prof. Dr. K. Orendorz-Frączkowska
Prof. Dr.J. Rzewnicki

**Program sections of the Congress:**

1. Modern Clinical Neurotology
2. Equilibriometry
3. Audiometry
4. Tinnitology
5. 0lfactometry
6. Gustametry
7. Neurosensorial degenerations in o/d age patients
8. Pharmacotherapy for neurotological patients.
9. Physica/ therapy for neurotological patients.
10. Free Papers

**Deadline of registration:** March 1, 2013
Presentation should be send before Jan. 1, 2013
e-mail: biuro@agora-konferencje.pl

Detail information:
**www.otoneuro2013.eu**

# World Hearing Center
of the Institute of Physiology and Pathology of Hearing

20th – 22nd February 2013 • Kajetany, Poland

# 5th International Course in the Endoscopic Sinus Surgery

## Chairman

**Prof. Henryk Skarżyński M.D., Ph.D.**
Institute of Physiology and Pathology of Hearing, Warsaw, Poland

## International Faculty

**Prof. Hans Rudolf Briner**
Hirslanden Klinik ORL Center, Zurich, Switzerland

**Prof. Piero Nicolai**
University of Brescia Otorhinolaryngology Clinic, Brescia, Italy

**Prof. Sergey Pukhlik**
Otorhinolaryngology Faculty, Odessa State Medical University, Ukraine

**Prof. Paweł Stręk**
Faculty and Clinic of Otolaryngology Collegium Medicum,
Jagiellonian University, Kraków, Poland

**Prof. Timoleon Terzis**
Athens Rhinology Center at Mediterraneo Hospital, Athens, Greece

## Scientific program includes

- Theoretical course: lectures of leading experts in the field and case studies presenting surgical techniques;
- Practical course: hands-on training in advanced surgical procedures on fresh frozen cadaver heads.

During the practical course participants will train the advanced techniques of the endoscopic sinus surgery performing procedures presented by instructors. There are 18 places available at the practical part, they will be assigned in order of application; practical experience in sinus surgery is mandatory.

Participants in the theoretical part will observe all procedures performed in the surgical room and in the laboratory with the instructor's commentary.

For more information, please visit website
**www.rynochirurgia.ifps.org.pl**

Contact:
World Hearing Center of the Institute of Physiology and Pathology of Hearing
Kajetany, 17 Mokra Str., 05-830 Nadarzyn, Poland
fess@ifps.org.pl

Organizers:

Institute of Physiology and Pathology of Hearing · STORZ Karl Storz – Endoskope · Institute of Sensory Organs · MEDIM Sztuka Współpracy

# Center of Hearing and Speech "MEDINCUS"

**PROPHYLAXIS, DIAGNOSTICS, TREATMENT AND REHABILITATION OF THE EAR, NOSE AND THROAT DISEASES**



**--> Center of Hearing and Speech "MEDINCUS" is a health care unit providing highly specialized services within the scope of:**

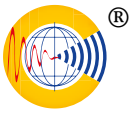
- Oto-rhino-laryngology (ENT)
- Audiology
- Phoniatrics
- Tinnitus
- Balance disorders
- Logopedy
- Rehabilitation
- Medical evaluation for hearing implants
- Physiotherapy
- Audio-psycho-linquistic stimulation
- Hearing aids fitting
- Hearing and speech rehabilitation
- Psychology
- Speech Therapy
- Comprehensive care for the patients after hearing implant surgery – subjective and objective examinations of electric hearing and fitting of the cochlear implants (including telefitting).


**--> Center of Hearing and Speech "MEDINCUS" provides comprehensive specialist consultations in a friendly atmosphere, all necessary examinations, hearing aids fitting and assistance to solve all hearing and speech problems.**

Odessa (Ukraine)

www.medincus.pl sekretariat@csim.pl

# Journal of Hearing Science®



Scope and Purpose: **Journal of Hearing Science®** is a peer-reviewed scientific journal that publishes original contributions to knowledge in all areas of **Otolaryngology**, **Audiology**, **Phoniatrics**, and **Rhinology**. The primary mission of this journal is to offer an international forum for professionals; a secondary aim is to assist hearing practitioners by providing important knowledge helpful to patients with hearing, voice, speech, and balance disorders.
JHS has a distinguished International Advisory Board and an impressive Editorial Board. Their high academic standing ensures that the journal produces multidisciplinary papers of the highest quality.
The broad international membership promotes fair and thorough assessment.
The journal is an open access type of publication which allows all readers around the world free access to articles. Moreover, we declare no publication fees or page charges.




**Publisher:**
Institute of Sensory Organs
1 Mokra Street, Kajetany
05-830 Nadarzyn, Poland



**Corresponding address:**
World Hearing Center
17 Mokra Street, Kajetany
05-830 Nadarzyn, Poland
Phone: +48 22 3560389 • Fax: +48 22 3560367
*office@journalofhearingscience.com*





*http://www.journalofhearingscience.com*

WORLD HEARING CENTER

The **World Hearing Center (WHC)** in Kajetany, near Warsaw, is a unit of the Institute of Physiology and Pathology of Hearing and has been established to provide comprehensive care for people with hearing, speech, and balance disorders.

The WHC complex is an extension of the International Center of Hearing and Speech, which has been operating at Kajetany since 2003. The World Hearing Center will include a modern hospital providing healthcare services at the highest international level as well as a superbly equipped research, education, and conference center.

The initiator and organizer of the World Hearing Center is Prof. Henryk Skarżyński, who is also the director of the Institute of Physiology and Pathology of Hearing.

**Main goals of the World Hearing Center**

- undertaking novel research
- coordinating international multi-center research projects
- actively developing new technologies, such as new cochlear implant systems
- introducing the latest technologies into Polish clinical praxis
- providing access to the latest treatments for Polish patients
- raising the profile of Polish science and medicine internationally.

Apart from the scientific and implementation issues the range of this new project will involve creation of new didactic and clinical facilities designed specially for educational needs and services for patients provided in the best possible conditions.

World Hearing Center
Kajetany, 17 Mokra Str.
05-830 Nadarzyn, Poland

www.ifps.org.pl

INNOWACYJNA GOSPODARKA
NARODOWA STRATEGIA SPÓJNOŚCI

UNIA EUROPEJSKA
EUROPEJSKI FUNDUSZ
ROZWOJU REGIONALNEGO